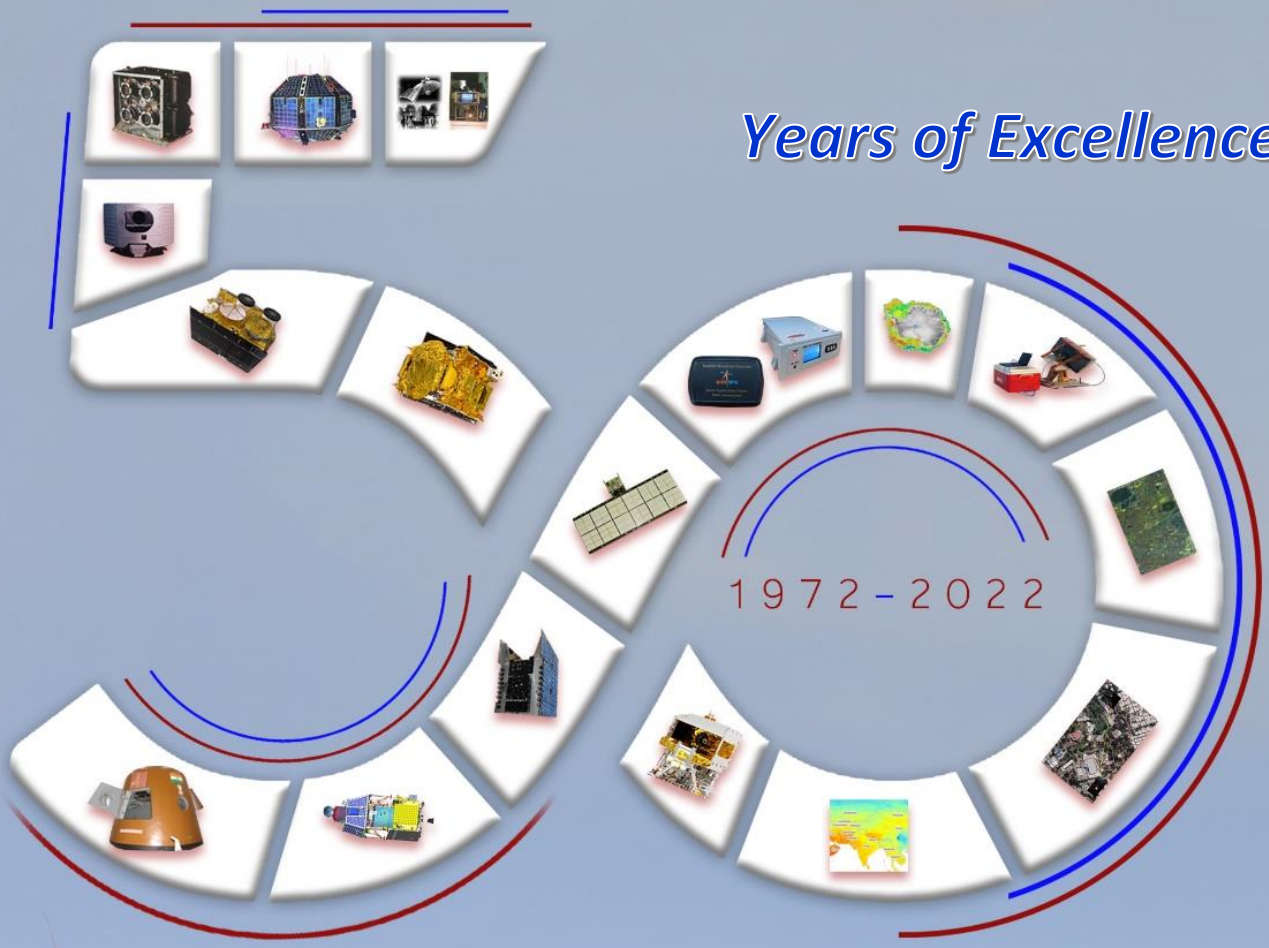
सैक के अनुसंधान क्षेत्र

-प्रायोजित अनुसंधान विषय सार-संग्रह

Research Areas of SAC

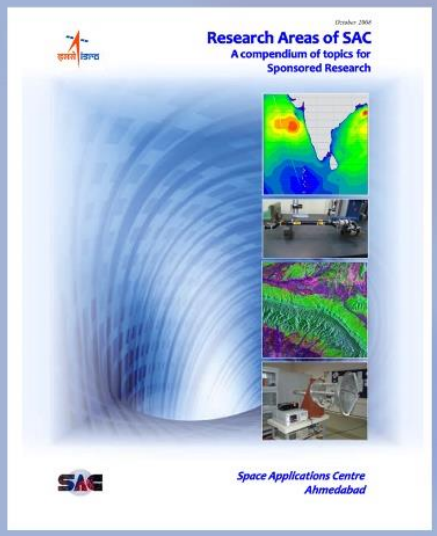
-A compendium of Topics for Sponsored Research

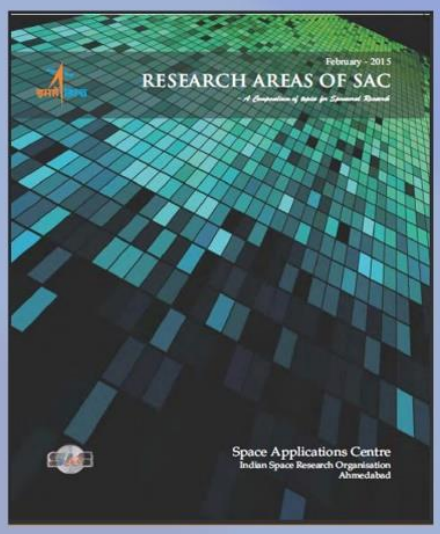


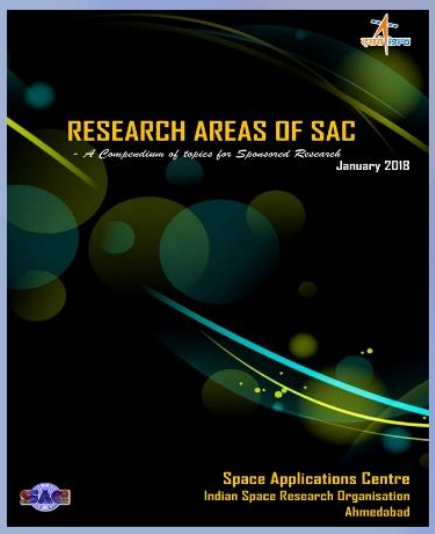
March 2023

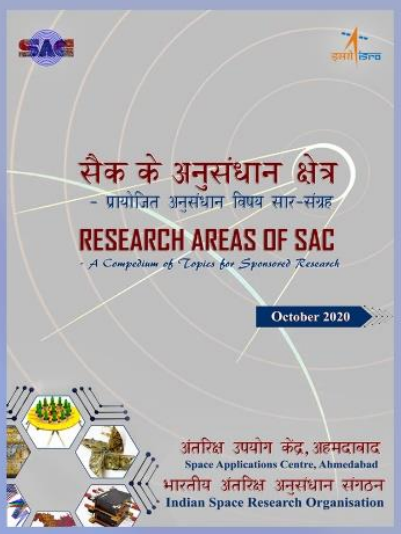
अंतरिक्ष उपयोग केंद्र, इसरो, अहमदाबाद
Space Applications Centre, ISRO, Ahmedabad

Proactive approach for Research Solicitation from Academia









सैक के अनुसंधान क्षेत्र

प्रायोजित अनुसंधान विषय सार-संग्रह

Research Areas of SAC

A compendium of Topics for Sponsored Research

Soliciting proposals from Academia

50 Years of Excellence

March 2023

अंतरिक्ष उपयोग केंद्र, इसरो, अहमदाबाद

Space Applications Centre, ISRO, Ahmedabad

(This page is intentionally left Blank)

जय हिन्द

एन एम देसाई / N M Desai
विशिष्ट वैज्ञानिक / Distinguished Scientist
निदेशक / Director

सत्यमेव जयते

भारत सरकार GOVERNMENT OF INDIA
अंतरिक्ष विभाग DEPARTMENT OF SPACE
अंतरिक्ष उपयोग केंद्र
SPACE APPLICATIONS CENTRE
अहमदाबाद AHMEDABAD - 380015
(भारत) / (INDIA)
दूरभाष / PHONE:+91-79-26913344, 26928401
फैक्स / FAX : +91-79-26915843
ई-मेल / E-mail: director@sac.isro.gov.in

FOREWORD

Space Applications Centre (SAC) is one of the major R&D Centres of ISRO; contributing to the organisation's Vision of *'Harnessing Space Technology for National development, while pursuing Space Science Research and Planetary Exploration'*. During its glorious 50 years of journey, SAC has proven its core competence in the development of space and air borne instruments/payloads ranging from remote sensing and satellite communication to meteorology, navigation and planetary exploration as well as country's first Human Spaceflight Programme *'Gaganyaan'*. In recent times, SAC has been a lead Centre of ISRO to contribute towards *'The Quantum Frontiers Mission'*, Prime Minister's Science, Technology and Innovation Advisory Council (PM-STIAC).

'Research Areas of SAC 2023: ***A Compendium of Topics for Sponsored Research''***, ninth document in the series aims to provide an overview of the current state of research being pursued at the Centre. It highlights some of the most promising areas of advanced and futuristic R&D and innovation in space applications and technology to meet the goals of national development and societal benefits. I believe the broad spectrum of research topics conceived by SAC Scientists/Engineers from diverse technical fields will ignite academia and researchers to contribute towards the various exciting facets of space applications, technology, payloads systems, ground segment technology, data processing etc. with the application of the state-of-the art tools, techniques, algorithms and methodologies.

I am confident that this well compiled document by our Research Management Team will serve its stated broader purpose of soliciting research proposals from Indian academia through varied avenues of ISRO's Sponsored Research viz. STC, RAC-S, S-TIC etc. resulting in the usage of tangible outcomes in SAC R&D and operational activities. The procedures and necessary guidelines for the same are also provided in the document. The scope of R&D is not limited by what is mentioned in the pages of this document and academia is encouraged to propose further research in related areas to strengthen Indian Space Programme. I cordially invite intellect and expertise spread across the research and academic institutions of the country to come forward and enthusiastically participate in *SAC's motto of Harnessing Space Technology for 'Atmanirbhar Bharat'*.

21/03/2023

(एन एम देसाई) / (N M Desai)
निदेशक / Director

(This page is intentionally left Blank)

Contact Details

This compilation is based on inputs from constituent entities of SAC who can be contacted for consultation related to their areas of research activities:

SAC:			
Director, SAC	Shri Nilesh M Desai	director@sac.isro.gov.in	3344*
Area Specific:			
SATCOM & Navigation Payload Area (SNPA)	Shri Sumitesh Sarkar	s_sarkar@sac.isro.gov.in	8346/8397
SATCOM & SATNAV Advanced Applications Area (SSAA)	Dr. Khagindra Kumar Sood	kksood@sac.isro.gov.in	3608
Antenna Systems Group (ASG)	Dr. M B Mahajan	mb_mahajan@sac.isro.gov.in	2114
Sensors Development Area (SEDA)	Shri Somya S Sarkar	sssarkar@sac.isro.gov.in	3853/54
Microwave Remote Sensors Area (MRSA)	Dr. Ch V N Rao	cvnrao@sac.isro.gov.in	5220/5221
Human Spaceflight & Advance Technology Area (HSTA)	Shri Dinesh Kumar Singh	dksingh@sac.isro.gov.in	2222 / 2220 / 2287
Earth, Ocean, Atmosphere, Planetary Sciences & Applications Area (EPSA)		dd-epsa@sac.isro.gov.in	4024
Signal & Image Processing Group (SIPG)	Shri Debajyoti Dhar	deb@sac.isro.gov.in	4148
Electronics Support Services Area (ESSA)	Shri A N Bhattacharya	apurba@sac.isro.gov.in	2334
Mechanical Engineering Systems Area (MESA)		xxxx@sac.isro.gov.in	3306/3305
Systems Reliability Area (SRA)		xxxx@sac.isro.gov.in	xxxx
Management & Information Systems Area (MISA)	Shri Vivek Singh	dd-misa@sac.isro.gov.in	3312
RESPOND @ SAC, Ahmedabad:			
Group Director, RTCG	Dr. Parul Patel		
Head, RESPOND & Research Management Division & Coordinator, RESPOND	Dr. Abha Chhabra	research_sac@sac.isro.gov.in	3339
Scientific Officer 'D'	Ankita Vishal Patel		
RESPOND @ ISRO HQ, Bangalore:			
Associate Director, RESPOND & AI	Dr. M A Paul	respond@isro.gov.in	080-23415269, 22172269

** Four digit Numbers xxxx at SAC, Ahmedabad can be reached by dialing 079-2691XXXX*

Acknowledgement

At the outset, we express sincere thanks to Director, Space Applications Centre for encouragement and guidance to Sponsored Research at the Centre.

SAC is a unique Centre of ISRO with variety of technical areas and R&D pursued in each of the technical areas by passionate Scientists/Engineers. This document is a compilation of valuable inputs generated from each of the technical areas with lot of brainstorming and reviews by senior management. We gratefully acknowledge the support, inputs received from all Deputy Directors, Group Directors, Group Heads, Division Heads, all Scientists/Engineers to bring out this document which would help academia to prepare focused research proposals. We are thankful to DD, MISA and GD, RTCG for their encouragement.

Document Control Sheet

1.	Report No.	SAC/MISA/RTCG/RRMD/2023/TR/01
2.	Title	***Research Areas of SAC 2023: A compendium of Topics for Sponsored Research***
3.	Type of Report	Technical Report
4.	No. of Pages	275
5.	Authors	SAC / ISRO Team. Compiled by Dr. Abha Chhabra and Smt. Ankita Patel.
6.	Originating Unit	RESPOND & Research Management Division (RRMD), Research, Outreach and Training Coordination Group (RTCG), Management and Information Systems Area (MISA) Space Applications Centre (ISRO), Ahmedabad.
7.	Abstract	This document highlights research areas relevant to the future activities of SAC. It helps in soliciting proposals from Academia for research relevant to important activities of SAC.
8.	Security Classification	Unrestricted
9.	Distribution	General

Contents

1. INTRODUCTION

Space Applications Centre (SAC), Ahmedabad is a major R&D Centre of the Indian Space Research Organisation (ISRO). Although, the genesis of this centre dates back to 1966 when first Experimental Satellite Communication Earth Station (ESCES) was established, it's formal existence came into being in 1972. The different units of ISRO in Ahmedabad pursuing research in applications of space technology were merged to form SAC and since then Centre has contributed to Indian Space Programme in various ways. During the illustrious Golden journey of 50 years, SAC has evolved its core competence in the development of space borne and air borne instruments/payloads and their applications for national development and societal benefits. These applications are in diverse areas and primarily meet the communication, navigation and remote sensing needs of the country. Besides, SAC has also remarkably contributed to ISRO's Space Science and Planetary missions like India's first dedicated astronomy mission 'AstroSat', first lunar probe '*Chandrayan-1',* first interplanetary Mars Orbiter Mission '*Mangalyaan*', 'Chandrayaan -2' etc. Recently, SAC has made pioneer efforts and significantly contributing to India's ambitious first solar mission '*Aditya-L1'*, third lunar exploration mission '*Chandrayaan-3'*, First Human Spaceflight Programme '*Gaganyaan*'. SAC is also a lead centre of ISRO's Advanced R&D towards Space Based Quantum Frontiers and Space Based Solar Power as well as futuristic R&D

Overview of SAC Activities

Currently, SAC is spread across three beautiful, green eco-friendly campuses having multi-disciplinary activities. The lush green main campus in satellite area is spread over 90 acres area has rich biodiversity and marked with legendary Ahmedabad Earth Station. The other two campuses ie. SAC Bopal Technical Campus and New Bopal Campus are spread over 14.7 and 39.9 acres, respectively. SAC also operates and maintain Delhi Earth Station at Delhi.

SAC focuses on the design of Space-borne instruments for ISRO missions and development and operationalisation of applications of space technology for societal and national development. The communication transponders developed at this centre for Indian National Satellite (INSAT) and Geo Synchronous Satellite (GSAT) series of satellites are used by government and private sector for VSAT, Direct To Home (DTH), internet, broadcasting, telephony etc. These satellites are instrumental in establishing communications in remote parts of the country as well. The payloads for major navigation systems of the country-Indian Regional Navigation Satellite System (IRNSS) and GPS Aided Geo Augmented Navigation (GAGAN) have been developed at SAC. This centre designs and develops the optical and microware sensors for the satellites, signal and image processing software, GIS software and many applications for Earth Observation (EO) programme of ISRO. These applications are in diverse areas of Geosciences, Agriculture, Environment and Climate Change, Physical Oceanography, Biological Oceanography, Atmosphere, Cryosphere, Hydrosphere etc. Visualization of Earth observation Data and Archival System (VEDAS) is a web platform developed for archival and dissemination of thematic data and data products generated by SAC or in collaboration with other participating agencies. The derived information is used to develop custom crafted geo-spatial applications which can feed into or support the

decision making system. Meteorological & Oceanographic Satellite Data Archival Centre (MOSDAC) is a data portal of SAC and has facility for satellite data reception, processing, analysis and dissemination. MOSDAC is operationally supplying earth observation data from Indian meteorological and oceanography satellites, to cater to national research requirements.

In recent years, Human Spaceflight & Advanced Technology Area has been created to give focused thrust towards development of advance futuristic technologies pertaining to Human Spaceflight, Communication, Navigation & Remote Sensing payloads missions. Human Spaceflight Technology Area (HSTA) is responsible for conceptualizing system configuration and integration activities related to Crew Cabin and Communication Systems for Gaganyaan and associated technology developments, simulators and ground segment elements. HSTA is also entrusted with the responsibility for streamlining futuristic advance technology developments in the field of free space Optical Communication, Atomic Clock, Microwave TWTA, Teraherlz technologies, Quantum Frontiers (Quantum Communication & Quantum Radar) & associated photonics technologies.

SAC also has state-of-the art laboratory facilities including highly sophisticated payload integration laboratories, electronic and mechanical fabrication facilities, environmental test facilities, GIS and image processing and analysis facilities. Systems Reliability Area provides formulation of quality systems, procedures and guidelines, ensuring their compliance for the realization of highly reliable systems used in satellite payloads for communication, optical & microwave remote sensing, planetary missions, as well as ground based systems.

The technical areas are supported by a well-structured Management and Information Systems Area. This newly carved area is responsible for streamlining the activities related to Project Planning, Budgeting, Human Resource Development, RESPOND & Research Management, Training and Outreach, Cyber Services, Capacity Building and Industry coordination. RESPOND & Research Management is responsible for coordination and management of various in-house as well as Sponsored Research programs. It includes in-house TDP/Advanced R&D as well as Sponsored Research with academia under RESPOND, Space Technology Cells, Regional Academic Centres of Space, Space Technology Incubation Centres etc. Centre has a well-stocked library with vast collection of knowledge resources and innovative information services. The centre also has state-of-art in-house Vikram Sarabhai Space Exhibition and mobile exhibition to propagate space technology and applications amongst students and public and outreach to rural and remote areas of the country. The Centre also conducts nine-month post graduate diploma courses for students from the Asia Pacific region under the aegis of the Centre for Space Science and Technology Education (CSSTEAP) in Satellite meteorology, Satellite communication and Global Navigation Satellite Systems. Specialised training programmes like SMART (Satellite Meteorology and OceAnography Research and Training) and TREES (Training and Research in Earth Eco-System) are also conducted to promote and encourage graduate and post graduate students, professionals from academia and researchers across the country to pursue research in the field of satellite meteorology & oceanography and Earth ecosystems, respectively. SAC has active collaborations with industry, academia, national and international institutes and space agencies for research and development. The industry portal provide opportunities for technology transfer/consultancy between SAC and private/public/MSME sector industries with the objective of faster industrial growth.

SAC main campus with legendry Ahmedabad Earth Station

New Bopal Campus

Delhi Earth Station

Bopal Technical Campus

2. SPONSORED RESEARCH PROGRAMME

Cutting-edge research and innovation are core ingredients for national development with science and technology. The world is witnessing an exponential growth of technology in every domain of life. Research and Development (R&D) activities form the engine for futuristic technical advancement. Indian Space Research Organisation (ISRO) started the Sponsored Research (RESPOND) programme in the 1970s, with the primary objective of encouraging academia to participate and contribute in various space related research activities. This is one of the flagship programme of ISRO with an aim to establish strong links with academic institutions to carry out quality R&D projects of relevance and derive useful deliverables to support ISRO's ongoing and future missions. It also facilitate enhancing academic base and capacity building through human resources and laboratory infrastructure at the academic institutions across the country to support the goals and objectives of Indian Space Programme.

Sponsored Research which was initiated as RESPOND program way back in 1970s, has grown manifold under several Capacity Building initiatives by ISRO. These include RESPOND, RESPOND Basket, Space Technology Cell (STC) at premier Indian Institutes of Technology (IITs), IISc Bengaluru and Savitribai Phule Pune University (SPPU), ISRO's Regional Academic Centre for Space (RAC-S), Space Technology Incubation Centres (S-TIC), Centre for Nanoscience and Engineering (CeNSE), IISc Bangalore, Advanced Space Group at Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram.

SPONSORED RESEARCH AT SAC

SAC is in forefront of ISRO's Sponsored Research programme. This year is momentous, as we are celebrating glorious Golden journey of 50 years of excellence (1972-2022) of SAC establishment. '*Sponsored Research at SAC'* with academia across the country is an integral part in it's journey. A large number of academic institutes and universities have been participating in Sponsored Research at SAC being carried out under RESPOND, RESPOND Basket, STC, RAC-S, S-TIC. In addition, SAC is also actively participating in R&D projects under national missions like IMPRINT (IMPacting Research INnovation and Technology) and UAY (Uutachar Avishakar Yojna) Programmes of Ministry of Education (MoE) and partially funded by ISRO.

SAC has a proactive approach for research solicitation from academia. So far, twenty six Interest Exploration Meetings (IEMs) have been organised across the various geographic regions of the country to encourage and promote academia towards space research activities. The IEMs were held at Ahmedabad (2005), Shillong/Patna (2006), Allahabad (2008), Dehradun (2009), Srinagar (2009), Jodhpur (2011), Bhopal (March 2012), Aizawl-Mizoram (July 2012), Bhaskaracharya National Institute of Space Application and Geoinformatics (BISAG-N), Gandhinagar (January 2014), (Gujarat Technological University) GTU, Ahmedabad (November 2014), Tamil Nadu (September 2016), Jharkhand (March 2017), Odisha (March 2017), Pune (2019), Nashik (2019), Amravati (2019), Ahmedabad University (2019) and Lucknow (2019), Smart India Hackathon (2022) and IIT Kharagpur (2023). Interest Exploration Webinars were also held at Kopargaon-Pune (2021), IIT Guwahati (2022), Ahmedabad (2022) and Mumbai (2022).

These IEMs & IEWs resulted in a well-distributed geographical spread of the ongoing Sponsored Research projects in East, North-East, North, North-West, West and Central regions of the country.

2.1. RESPOND BASKET

ISRO is embarking upon many new areas of Science and Technology by taking up challenging technological assignments incessantly. In this significant task of National Importance, ISRO is looking for wider participation and contributions from academia in a focused manner for timely accomplishment of its goals. RESPOND under Capacity Building Programme Office (CBPO), ISRO HQ bring out a "RESPOND BASKET" of Space comprising of urgent and most important research topics with a brief write up about the topic, scope and expected deliverables so that interested academia can prepare and submit detailed proposals in discussion with ISRO experts.

2.2. Space Technology Cells (STC)

ISRO has set up Space Technology Cells (STCs) at premier institutes of the country to carry out thematic research activities in the areas of space science, space technology and applications in support of Indian Space programme. Currently, Space Technology Cells are established at IIT Bombay, IIT Kanpur, IIT Kharagpur, IIT Madras, IIT Roorkee, IIT Guwahati, IIT Delhi, IISc Bangalore and Joint Research Programme with Savitribai Phule Pune University of Pune, Pune.

2.3. Regional Academic Centres for Space (RAC-S)

Regional Academic Centres for Space (RAC-S) is a regional level new initiative to pursue advanced research in the areas of relevance to the future technological and programmatic needs of the Indian Space Programme and act as a facilitator for the promotion of Space Technology activities in the region. Currently, four RAC-S have been established by ISRO at National Institute of Technology (NIT) Kurekshetra, Malaviya National Institute of Technology (MNIT) Jaipur, IIT (BHU), NIT Patna, Guwahati University, NIT Surathkal for Northern, Western, Central, East, North-East and Southern regions of the country, respectively.

2.4. Space Technology Incubation Centres (S-TICs)

Space Technology Incubation Centres (S-TIC) have been set up by ISRO to attract and nurture the students at graduation level with innovative ideas / research aptitude for carrying out research and developing the Academia-Industry ecosystem for space technology. ISRO has setup Space Technology Incubation Centres across six regions of the country viz. NIT Jalandhar (North), VNIT Nagpur (West), MANIT Bhopal (Central), NIT Rourkela (East), NIT Agartala (North-East) and NIT Trichy (South). The outcome of the research from these S-TICs will be transferred to the group of Indian industries within that region, capable of productionising them and utilising them into several spin-off products thereby identifying new business/job opportunities as 'start-ups' on Space technologies and related systems.

2.5. Centre for Nanoscience and Engineering (CeNSE), IISc

Considering the requirements of ISRO in nanotechnology and nanoscience, an MoU has been entered with CeNSE, IISc Bangalore on April 21, 2017. The scope of the MoU includes the utilization of the state-of-the-art nanofabrication and characterization facilities for the R & D activities by the various centres of ISRO, in addition to joint development and training/capacity building. A Programme Review and Advisory Committee (PRAC), Chaired by Scientific Secretary, ISRO and Co-Chaired by Chairman, CeNSE with senior scientists/faculty from ISRO and IISc has been constituted to review and monitor the ongoing research projects/ activities and to provide overall policy guidance and research directions to the CeNSE.

2.6. Advanced Space Research Group (ASRG)

Advanced Space Research Group (ASRG) at Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram has been established for all collaborative research activities of IIST with all R&D centres of ISRO. An Empowered Overseeing Committee (EOC) which comprises of members from all research centres of ISRO is the apex body to ASRG. IIST Link Unit at ISRO Centres is also established to have effective coordination of the joint research programmes.

A brief outline and possible set of topics for various research themes solicited from Academia under Sponsored Research is given in subsequent chapters. Research Areas of SAC is also available at www.sac.gov.in/respond/ .The website is updated regularly.

Annexure : *Kindly refer to Annexures of the document for guidelines and formats for new research proposal submission, terms and conditions of ISRO research grants, general rules for fellowships, etc. under various schemes of ISRO's Sponsored Research.*
For further details, please visit website: https://www.isro.gov.in/research-and-academia-interface/research-activities

The snapshots of previous '***Research Areas of SAC'*** document are provided in inner cover page of this document. This ***Research Areas of SAC-2023*** document is eighth in the series.

The geographic distribution of Sponsored Research at SAC with Academia is shown in Figure below.

Geographic distribution of Sponsored Research at SAC with Academia (*as on November, 2022*)

SAC's all Sponsored Research activities with academia under various avenues are reviewed annually at SAC. The glimpses of SAC Annual RESPOND Review (ARR), Annual STC Review (ASR), Annual Sponsored reseArch Review (ASAR) are provided in the back cover pages.

Glimpses of 22nd SAC Annual Sponsored Research Review (SAC-ASAR 2022) held in November 2022.

RESEARCH AREAS OF SAC

3. SATCOM & NAVIGATION PAYLOAD

One of ISRO's major tasks is to provide space-based assets, applications and services related to telecommunication, broadcasting and navigation. Satellite Communication (SATCOM) & Navigation Payload Area (SNPA) is responsible for the designing and development of the satellite payload.

SNPA deals with satellite communication and navigation system engineering, designing, fabrication and payload assembly and integration of the payload. Also, SNPA designs and develops various payload filters and amplifiers. There area of activity also includes digital signal processing.

Research Areas in the field of SATCOM and Navigation Payloads

3.1. Digital Systems in Advance Satellite Technology Research

Introduction: - The current success of satellites is primarily in the fixed satellite services, broadcast satellite services and broadband/internet-related satellite services. In the satellite communication business, the trend for ever-increasing capacity, flexibility and availability of service, as well as increasingly more affordable, more compact, lighter, and even more stylish and ergonomic ground and personal terminals, has become need of the present. It is also believed that satellites in future still play a key role in providing mobile services despite the setbacks that came with early market failures. Onboard digital signal processing has potential for offering innovative satellite services. Availability of space-qualified high-capacity high-speed Field Programmable Gate Array (FPGAs), availability of high-speed Analog to Digital Converters (ADCs) / Data Assimilation Converters DACs and development of specialized-function Application Specific Integrated Circuits (ASICs) have made advanced services a reality. Managing mass, power, complexity, functionality and reliability for such payload is of paramount importance for offering services at acceptable cost. The emphasis worldwide is on:

- Increasing the performance (i.e. service availability)
- Quality of experience (i.e. less delay)
- Reducing cost/bit of information
- Efficient use of spectrum
- Network integration with terrestrial system
- Flexibility (i.e. reconfigurable payloads)
- Integration with navigation and observational satellite systems
- Security of communication
- Resistance to interference and jamming

The accomplishment of above tasks would require developing techniques for:

- Innovative and efficient spectrum processing and sensing algorithms
- Innovative techniques, protocols and architecture
- Innovative business models

The satellite technology is divided in to two major category

1. Communication satellite related technology
2. Navigation satellite related technology.

3.2. Communication Satellite Related Technology

3.2.1. Advanced Coding and Modulation for Satellite Communication

Recently the terrestrial communication system of fiber optical cables has grown tremendously. In order to develop a harmonious infrastructure with terrestrial communications systems, the speed of satellite communications must be increased to meet the speed of terrestrial communications system. It is useful to consider a so-called Internet satellite and its development. Then, the communication satellite R&D for the next 30 years has been proposed as shown in the Table (ll The generation change of a unit for ten years, as shown in Table seems to be too long in the recent times called "Dog year".

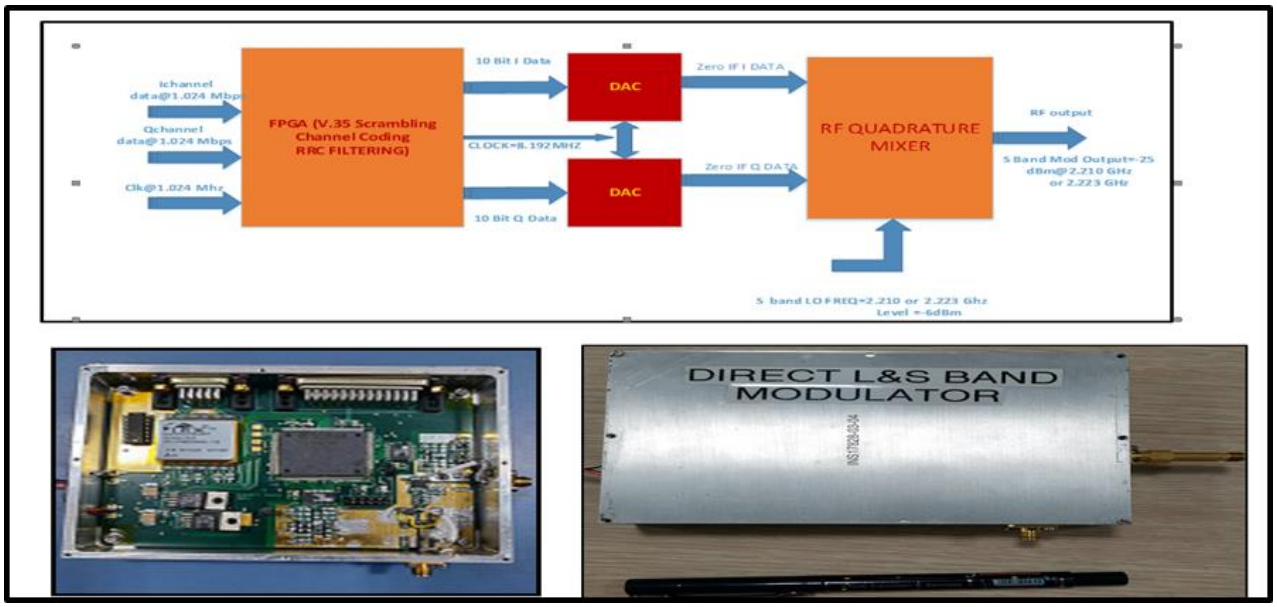
One generation of 10 years may be long, but it must be reasonable because it may be about a generation of infra structure. An Internet satellite is meant one that provides fixed, broadcast and mobile satellite communications

Time frame	Generation of satellite	Capacity	Characteristic
2000–2010	The first generation communications satellite (1G-satellite)	5–50 Gbps	WINDS, iPSTAR
2010–2020	The second generation communications satellite (2G-satellite)	50–500 Gbps	More capacity, global capability
2020–2030	The third generation communications satellite (3G-satellite)	0.5–5 Tbps	GEO platform

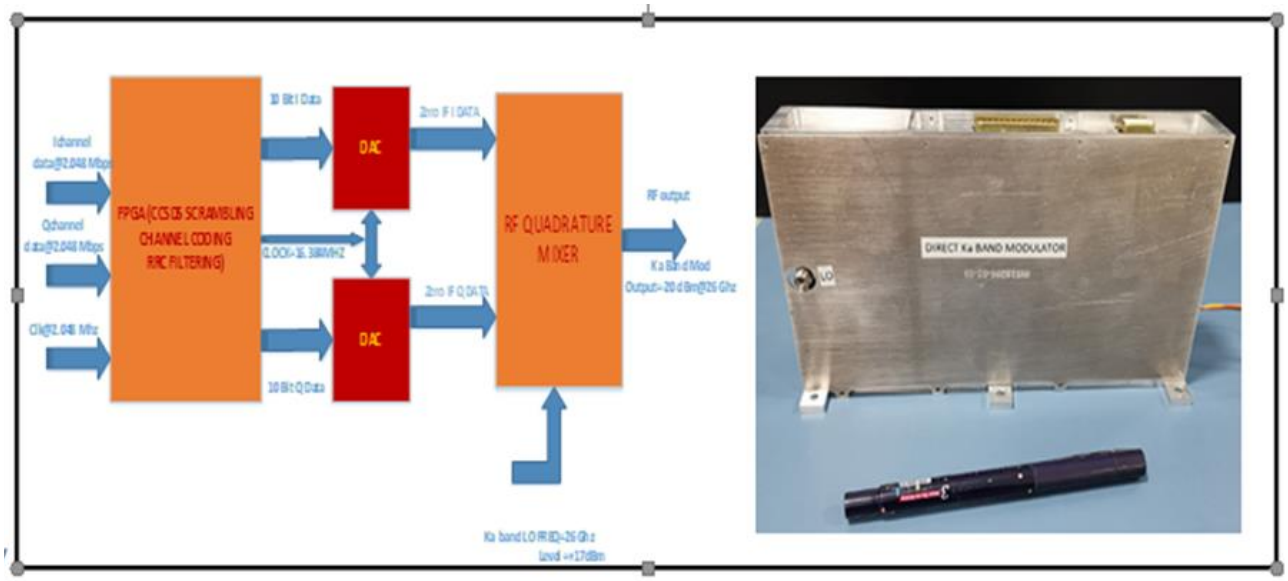
Table Communication Satellite throughput predication

Current Situation and challenges

Most of the communication satellite in ISRO like Indian National Satellite (INSAT) and Geosynchronous Satellite System (GSAT) class of series satellites used mostly Quadrature Phase Shift Keying (QPSK) and Binary Phase Shift Keying (BPSK) modulation system. The reason of using these modulation systems, because of their simplicity and better performance compare to other modulation systems in satellite communication scenario. They are still the popular choice, even in worldwide satellite communication scenario. There are two major approaches for modulator design heterodyne and homodyne. Heterodyne approach basically involves two level of up conversion i.e. the first modulation at Instruction Fetch (IF) label and then up conversion to desire Radio Frequency (RF) frequency. In homodyne approach involves direct conversion from zero IF to desired RF frequency. Till now mostly all major modulator design is based upon heterodyne based approach. But now current state of art design is based upon homodyne approach. Following figures shows direct S and Ka band modulator design for Gaganyaan project. The challenges are left in these modulation are to handle high data rate, where the hardware or component used earlier design will not be useful. The other challenges are reduction of size and power consumption of such system. So, high data rate system using our current modulation scheme with reduces size and power is the current challenges.



Block Diagram and DVM model of S Band Modulator



Block Diagram and DVM model of Ka Band Modulator

3.2.2. Channel coding for satellite communication

The large distance between the transmitting spacecraft and the receiving earth station and the limited transmitting power result in a very poor signal- to-noise ratio at the receiver side. The consequence is a large amount of transmission errors. At the same time, the data bits are highly compressed before transmission to allow as large as possible a number of images to be transmitted in the limited data rate. But especially compressed data bits are very sensitive to transmission errors. Therefore, channel coding method is also one of the most important technologies.

Current Situation and challenges

Currently most of the satellite made by ISRO used convolutional code with different code rate 1/2, 3/4, 7/8 in concatenation with Reed-Solomon (RS) code in some of the satellite. This type of channel codec works well since last 20 years in satellite communication world. However due to increasing in demand of quality of service and several upcoming deep space explorations, it is now essential that change channel codec for future mission. The Consultative Committee for Space Data Systems has suggested few of the channel code for future satellites and deep space explorations. The current state of the art channel codec is

- Turbo convolutional codes(TCC)
- Turbo product code(TPC)
- Low density Parity check code(LDPC)

New channel coding Scheme

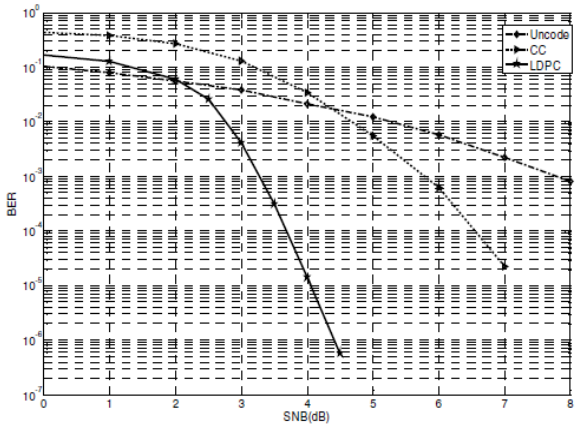
For our satellites and deep space mission Turbo convolutional code and LDPC code are the two main area of thrust for future mission.

- **Turbo Convolution Code**

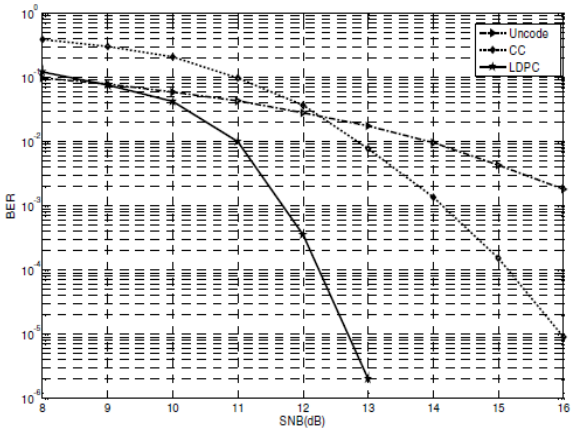
Parallel-Concatenated Convolutional Codes (PCCC), known as turbo codes, allows structure through concatenation and randomness through interleaving. The Consultative Committee for Space Data Systems (CCSDS) Telemetry Channel Coding Recommendation establishes a common framework and provides a standardized basis for the coding schemes used by CCSDS Agencies for space telemetry data communications. This standard traditionally provides the benchmark for new and emerging coding technologies Turbo codes have an astonishing performance of bit error rate (BER) at relatively low Eb/No. Turbo codes were chosen as a new option for this standard in 1999, only 6 years since their official presentation to the international community: this was the first international standard including turbo codes. The reason was the significant improvement in terms of power efficiency assured by turbo codes over the old codes of the standard. In Chandrayan-1 mission of ISRO, we have used Turbo convolutional code as per CCSDS standard 131.0-B-1 for low data rate telemetry application. We have also planning to use this turbo code for human space program.

- **Low density parity checks code (LDPC)**

The another important error correcting code, whose performance close to Shannon limit know as low density parity check code. The LDPC code is also a close contender of turbo code. LDPC codes have a remarkable performance with iterative decoding that is very close to the Shannon limit. When compared to the decoding algorithm of convolution code, LDPC decoding algorithm has more parallelization, low implementation complexity, low decoding latency, as well as no error-floors at high Signal-to-Noise Ratio (SNR) as turbo code. The next generation satellite communication systems e.g. digital video broadcast satellite/terrestrial (DVB-S2/T2) have readily adopted LDPC code for Forward Error Correction (FEC), mostly due to its near Shannon performance at very low signal to noise ratio. However, the channel code performance also depends upon the modulation scheme, figures shows the performance of LDPC codec and convolutional code with respect to BPSK and 16 Quadrature Amplitude Modulation (QAM) modulations.



BER comparison under BPSK modulation



BER comparison under 16 QAM modulation

The use of advanced channel coding techniques (e.g. TC and LDPC codes) is the state-of-the-art technology used in current satellite systems to provide broadcasting services to fixed terminals in the Ku/Ka frequency bands into two-ways (i.e. Digital Video Broadcasting – Second Generation (DVB-S2) in the forward link and Digital Video Broadcasting – Return Channel via Satellite (DVB-RCS) in the return link, respectively), in which the Additive white Gaussian noise (AWGN) channel is usually assumed. In particular, DVB-S2 considers irregular LDPC codes of either 16200 or 64800 bit code words and 11 coding rates (i.e. ranging from 1/4 to 9/10). With respect to DVB-RCS, double-binary turbo codes are assumed with 12 frame sizes (i.e. ranging from 48 to 752 bit couples) and 7 coding rates (i.e. ranging from 1/3 to 6/7).

Sync word less Concatenated RS and convolutional code encoder and decoder development

The recommended concatenated coding system in satellite communication consists of a Reed-Solomon outer code and a convolutional inner code (which is Viterbi decoded). In typical scenario there is requirement of sync word for synchronization for RS decoder, which lead to reduce the overall efficiency of data transmission and also the overall throughput. The proposed activity will remove the requirement of sync word in each data packet which will improve the overall data efficiency. The proposed activity will be useful for future payload like Gaganyaan etc.

Digital Processors for High Throughput Satellites.

Conventional high throughput satellites employ limited, RF based processing due to unavailability of wideband signal processing hardware. For future high throughput satellites, it will be necessary to employ processing techniques to distribute the on-board resources in an optimal fashion and extract the maximum possible throughput. The relevant research areas would be:

1. Development of integrated wideband, direct sampling data converters and RF transceivers.
2. Development of on-board partially or fully reconfigurable, failure tolerant, ultra-scale FPGA based signal processing system

3. Development of multi-channel wideband signal processing system for digital beamforming and channelization in broadband multibeam communication payloads.

Precoding for V/High Throughput Satellites

Precoding is to counteract the multibeam interface when high/full frequency reuse is employed in V/HTS so that noncomplex UTs can maintain a high Signal to Interference plus Noise Ratio (SINR), even the same carrier frequency is used by adjacent beam. To achieve this precoding employs the channel state information (CSI) toward each UT to mitigate the interference. Signal processing for optimization of precoding matrix and implementation of Precoding function in next generation V/HTS. Some research areas are calculation of Precoding Matrix, and Efficient Implementation of Precoding Matrix in satellite.

3.3. Navigation Satellite Related Technology

3.3.1. Modulators for Navigation Satellites

This Satellite Navigation has revolutionized the navigation world, opening new opportunities in an increasing number of sectors that require high precision. ISRO has taken up the project for the implementation of an independent regional navigation system currently known as Navigation with Indian Constellation (NavIC). The project Indian Regional Navigation Satellite System (IRNSS) envisages establishment of regional navigation system using a combination of Geostationary Orbit (GEO) and Geosynchronous Orbit (GSO) spacecraft's. NavIC is already providing two types of services restricted and unrestricted services or public domain services in L5 and S Band. Binary offset carrier (BOC) and Binary phase shift keying (BPSK) is use for these services. In NavIC, we are using different method for combining these two modulation scheme in order to get constant modulation envelope i.e., the total transmitted power does not vary over time. So that the transmitted information is not contained in the signal amplitude and the transmitted signal amplitude becomes less critical. However, in future NavIC satellite we are going to transmit L1 band signal also for better interoperability and compatibility. In L1 band, we need comply the power spectral density of Multiplexed binary offset carrier (MBOC) modulation. There are other navigation players, who are transmitting their own custom modulation scheme in L1 band. These are mention below.

- **CBOC:** The Composite BOC is the solution adopted by Galileo for the Open Service in E1/L1.
- **TMBOC:** The Time-Multiplexed BOC is the solution adopted by GPS for L1C.
- **Quadrature Multiplexed BOC**: Adopted by compass.

  A suitable modulation scheme, which comply MBOC power spectral density may design and develop to complete the future requirement.

3.3.2. Coding Scheme

Like other wireless communication signals, navigation signals are subject to noise, multipath and shadowing effects which may induce errors in the received data. Modern navigation signals employ some techniques to detect and correct these errors.

Galileo, modernized GPS as well as space-based augmentation systems (SBAS) (e.g. Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS)) messages make use of FEC. In the following the various error protection techniques used by these systems are described and some details are given for the encoding and decoding processes. The fundamental principle of channel coding is to add redundancy to the navigation message, which is used by a receiver to detect or correct possible errors in the received symbols. The redundant bits added by the encoder are a function of the original information. The original bits may or may not be directly visible in the encoded message. In the first case the encoding is called systematic while in the second case it is called non-systematic.
Channel coding techniques can be further divided into block codes and convolutional codes. Block codes operate on fixed sized blocks of data, each of which are encoded separately, while convolution codes operate on a continuous stream of input data. Both kinds of codes are employed in Global Navigation Satellite System (GNSS), a few of which are detailed in following Table.

Table
CODING SCHEMES USED IN GNSS SIGNALS

System	Signal	Message	Coding
GPS	L1 C/A	LNAV	none
	L1C	CNAV-2	block: BCH & LDPC
	L2C	CNAV	½-rate convolutional
	L5	CNAV	½-rate convolutional
Galileo	E1-B	INAV	½-rate convolutional
	E6-B	CNAV	½-rate convolutional
	E5a	FNAV	½-rate convolutional
	E5b	INAV	½-rate convolutional
SBAS	L1	SBAS	½-rate convolutional

Recently china (Compass) is also transmitting signal in L1 band having own custom Bose-Chaudhuri-Hocquenghem (BCH) and LDPC codes. In NavIC signal, we are also planning to transmit L1 band signal for better interoperability and compatibility. So there will be a need to develop custom channel coding of navigation signals.

3.3.3. Optical Interconnects for High Speed Signal and LO distribution

There is a need for High bandwidth (BW) serial data transmissions. Optical Interconnects are required to minimize power consumption, mass and volume. They are practically lossless propagation in an optical fiber within a Digital sub-systems module. The other significant advantages are Immunity to Electromagnetic Interference (EMI) and Electro Magnetic Compatibility(EMC), are mechanically flexible and galvanic ally isolated and provides low phase noise degradation.

3.3.4. High-Performance DSP for Software Defined Payloads

To meet the requirement of high speed and reconfigure software defined payloads, a high performance Digital Signal Processors (DSP) processor which can meet space electronics quality guidelines are required. Their performance should be benchmarked for following applications

1. DVB-S2 modem: 2 Gb/s transmit, 1 Gb/s receive
2. Fast Fourier Transform FFT (complex 16 bit fixed-point): 150 GOPS (Giga Operations per Second)

3.3.5. Digital Cancellation Scheme for High-Order Passive Intermodulation Interference

Passive intermodulation (PIM) is a phenomenon that additional signals at new frequencies (not only the harmonic frequencies) are generated when signals containing two or more different frequencies are processed at the passive devices, such as duplexes, cable connectors, waveguides and antennas. PIM would worsen the antenna gain-to-noise-temperature (G/ T) value, thereby further disrupting the whole system. A full-digital PIM canceling adaptive scheme can be explored based on Least Mean Square LMS algorithm.

3.3.6. Onboard Clock Ensemble for clock anomaly handling

To improve the clock accuracy in future navigation payloads it is required to generate the output frequency signal based on an ensemble of input clocks with optimized performance and improved robustness by clock anomalies handling. Following three algorithms can be developed: Measurement Filtering (MF), based on a cascade of low-pass recursive filters with exponential window functions. Clock Fault Detection and Correction (CFDC), with associated logic based on MF outputs, onboard Clock Ensemble (ONCLE), based on weighted averaging according to filtered frequency information covering clock anomaly handling

3.3.7. On-board Autonomous Orbit Determination of Navigation Satellites using inter-satellite ranging

Autonomous orbit determination of a navigation constellation is the process by which the orbit parameters of navigation satellites are autonomously calibrated onboard the satellites without the need for external aids. It commonly uses a satellite onboard data processing unit and a filtering method to process the measurements of inter-satellite ranges. The onboard data processing unit is the main module of autonomous navigation systems.

3.3.8. FPGA/ASIC Design Methodology

Following areas for research in FPGA/ASIC Design for onboard signal processing:

- 65 nm, 28 nm Fully Depleted Silicon On Insulator (FD SOI) to be evaluate for low power Application-Specific Integrated Circuit (ASIC) development for future high speed Digital Subsystems
- Formal Verification to Verify Single Event Upset (SEU) Mitigation Techniques for increasing design reliability
- High Level Design Methodology for faster design rollout

3.4. Development of Ferrite Material for Space Use

Microwave circulators and isolators are used in communication payloads to improve impedance matching and to avoid multiple reflections. Ferrite material is used in the waveguide junctions because of its non-reciprocal properties, resulting in circulation when magnetized.

Understanding the structure of the ferrite material requires knowledge of chemistry, theory of magnetism in ferrites, the non-reciprocal characteristic of ferrite junction at microwave frequencies due to gyromagnetic effect, which involves physics and advanced mathematics.

The important properties of a ferrite are:

Saturation Magnetization, Ms: This property is related to the spontaneous alignment of electron spins parallel to the applied magnetic field.

Gyromagnetic Line width, ΔH: It is a measure of ferrite magnetic losses in the vicinity of ferromagnetic resonance.

Effective line width, ΔHeff: It is a measure of ferrite magnetic losses for off-resonance operating points (below and above resonance).

Spin wave line width, ΔHk: It is a measure of attenuation factor of spin waves excited above a power level.

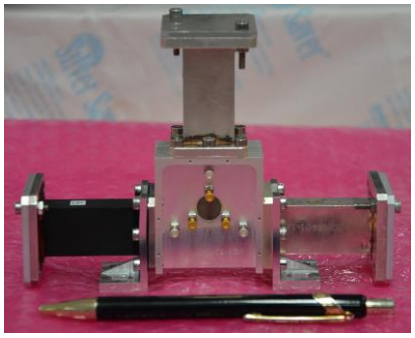
Magnetization temperature coefficient, **α**: It is a measure of relative change in magnetization with respect to temperature.

Curie Temperature, Tc: Temperature above which ferrite material has no magnetic properties.

The table below shows the ferrite material properties sought for to be used in circulators for space use:

Application	Requirement	Material Property
Low Power Circulator/Switch	Low Insertion loss, Wide Bandwidth, Compact	Minimum **ΔHeff, α** Maximum **ε** **Ms** as per the frequency
High Power Circulator/Switch	Low Insertion Loss, High average and peak power handling	Minimum **ΔHeff, ΔHk, α** **Ms** as per the frequency High **Tc**

a) Ku Band Stripline Isolator



b) Ku Band HP WG Circulator

c) S Band HP WG Circulator

Developed Isolator/Circulators at SAC

Research undertaken/to be taken up in Ferrite Devices at SAC

1. Low power and High power Wideband Coaxial circulator
2. High power waveguide circulator at Q-V band and millimeter wave
3. Ferrite Phase shifter
4. High power and low power Ferrite switches

3.5. Amplifier Technology

Amplifier Technology

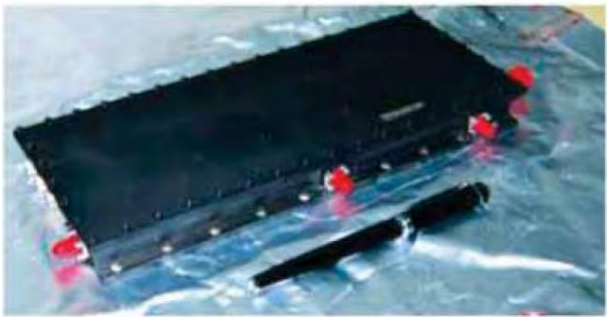
The microwave and RF amplifiers present in various communication and navigation payloads includes low, medium and high power amplifiers over different frequencies ranging from UHF

to Q/V-bands. III-V group (Gallium Arsenide (GaAs) and Gallium Nitride (GaN))based semiconductor technology in the form of discrete RF transistors and Monolithic Microwave Integrated Circuits (MMICs, packaged & unpackaged) are being utilized for the design and realization of high performance solid state amplifier circuits and subsystems.

The next generation satellite communication systems require high output power amplifiers with high efficiency and linearity in small size, low weight having better reliability. To meet the desired performance from amplifier subsystems, control circuits like digital attenuators, phase shifters, voltage variable attenuators, switches etc. are also designed, realized and successfully used in various payloads in the development of channel amplifiers and Solid State Power Amplifier SSPAs. At the lower end of frequency spectrum, at UHF to C-band, availability of GaN technology is offering newer breakthrough in realizing the power amplifiers which may even be replacing Travelling Wave Tube Amplifier (TWTA) in future satellites.

The Indian Regional Navigational Satellite System (IRNSS) provides regional navigation satellite system using a combination of GEO and GSO spacecraft over the Indian region. GaN based SSPA are emerging as a viable alternative to TWT amplifiers especially at L and S-band used in these navigation satellites.

150 Watt L5-band GaN Power Amplifier

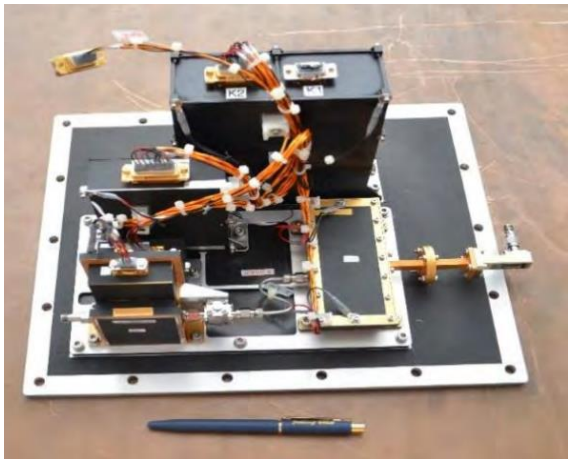


250 Watt S-band GaN Power Amplifier

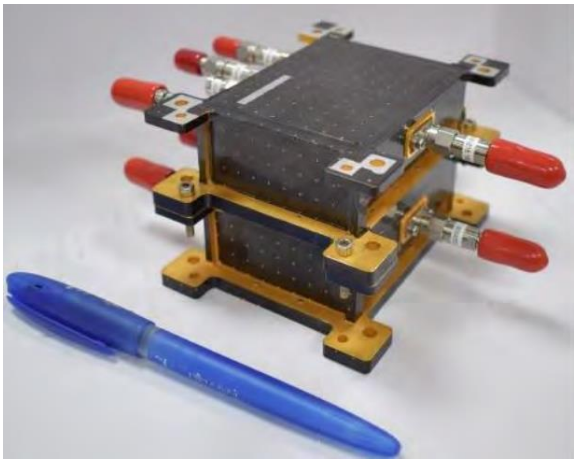
Scope of the work exists in the area of simulation and design of medium to high power compact SSPA with size comparable to TWTA or even smaller. ISRO had already designed, developed and successfully demonstrated communication at Q/V-band in one of its mission. High throughput satellites are being proposed at millimeter wave band in future, requiring further technology development utilizing state-of-the-art techniques in the development of miniaturized driver amplifiers and high power SSPAs with highly efficient RF power combining techniques. There is a requirement of wideband, high power MMIC power amplifier designs upto V-band. To achieve higher power, low loss combining techniques and development of planar or 3D miniaturised RF power dividers and combiners are required at these frequencies.

ISRO had also designed and developed a 2-channel Switch Matrix at Ka-band utilizing high isolation Single Pole, Double Throw (SPDT) switch MMICs and split block assembly. There is research scope in developing state of the art packaging technique for preserving high isolation from such RF switches. There is also research scope in development of thermal modelling and thermal management techniques for high power amplifier MMIC. Multi-function MMIC design

& development for driver amplifiers and multi-channel transmit modules are also new areas of research.



Q/V band SSPA



Ka-band Switch Matrix (stacked)

L1-band Driver Amplifier

Ku-band 4-channel Transmit Module

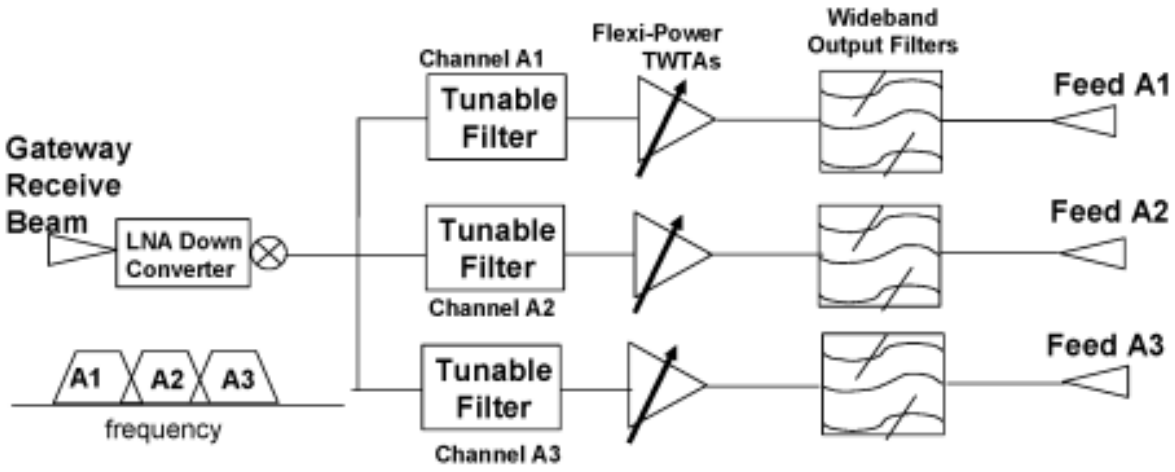
Areas of research are:

- Wideband, high power SSPA & Channel amplifiers in UHF, L, S, C, Ku, Ka and Q/V-band.
- GaN based high power compact SSPAs at UHF, L and S-Band.
- High power amplifier GaAs and GaN MMIC designs.
- State-of-the-art technology for design & development of compact SSPA at Q/V-band with waveguide RF interfaces.
- Spatial power combining techniques at millimeter wave frequencies.
- High efficiency Continuous Waves (CW) SSPAs with associated thermal & power management.
- Implementing Efficiency enhancement techniques in S, C, Ku-band Power amplifier.
- Thermal modelling & thermal simulations of MMIC power amplifiers.
- Modelling & simulation of entire amplifier module consisting of MMICs for the effects of bondwires, package cavity etc. on RF performance at Ku-band & beyond.
- Design & development of ASIC for the tele-command interface control circuit for channel amplifier & SSPAs.
- Design & development of high isolation switches and voltage variable attenuators at Ku & Ka-band.

3.6. Reconfigurable Filters for Satellite Communication

Introduction:

The use of reconfigurable payloads in satellite provides significant advantage over current state-of-art satellite configurations. Re-configurability of payload allows for multimode and multifunctional operation. Agility opens the way for reconfigurable payloads that can be tuned during mission time while in orbit. The ability to reconfigure the operating frequency band offers key advantage to adapt long-lifetime satellites to rapidly evolving user requirements.



Flexible Payload Configuration

A switchable filter bank can act as alternative solution to a tunable filter where discrete flexibility is required. One such approach, used in the past, employs multiple IMUX and OMUX units, addressing different frequency plans, with extra RF switching functionality to change between them. This solution, however, is costly both in terms of added component costs and the increased mass and volume of the satellite.

Reconfigurable Filters:

Microwave Filters used in the communication payload have very stringent in-band and out-of-band requirements. If Tunable/Reconfigurable filters are used to replace these filters in payloads, they must meet these stringent requirements. In particular, they must have High Q, maintain required bandwidth, must have reasonable return loss and should provide required rejections at specified frequency points. These filters should also be able to meet average and peak high power requirements. High Q filters presently used in the satellites are primarily made from 3-Dimenssional Waveguide Cavity Resonators, Dielectric Resonators or Coaxial Resonators. Filters made from these resonators meet all the stringent requirements of the payload including high power handling. Depending upon the application, frequency of operation and power handling requirement, one of the above resonator technology is chosen for realizing payload filters. Tunable/Reconfigurable filters required for the satellites will also be required to be realized using these 3D resonator technologies to meet payload requirements. Most of the present day research has been focused on micostrip based tunable filters or SIW based tunable filters. The important

constraints related to High power, High Q applications makes these reconfigurable technologies unsuitable for payload applications.

Recently, some progress has also been made in the tunable 3D high Q filters using mechanical motors, piezoelectric actuators and micromechanical switches for aching desired tenability. Some of the major challenges involved in the development of such 3D high Q tunable filters are:

a) Maintaining required bandwidth and reasonable Return Loss over wide tuning range. Non-uniform variation in resonant frequency of various resonators of the filter and variation in coupling values (External & Internal) of the filter with frequency could lead to degradation in Return loss of the tunable filter.
b) Maintaining High Q over wide tuning range. Tuning of resonator over wide tuning range could lead to significant reduction in its Q-factor.
c) Ensuring High average power handling capability and required Multipaction margin of 6dB. Implementation of tuning mechanism should not lead to degradation in power handling capability of the filter.
d) Qualification of Tunable filter for Space Application. Tunable Filter along with its tuning mechanism, should endure QM level environmental tests.
e) Ensuring required Reliability of the tunable filter and its tuning mechanism over its operating life. Reliability of the tunable filter could be impacted due to wear and tear of moving parts or due to increase in the number of parts.
f) Minimizing the power consumption and complexity for the tunable filter.

Recent Advances in Reconfigurable Filters:

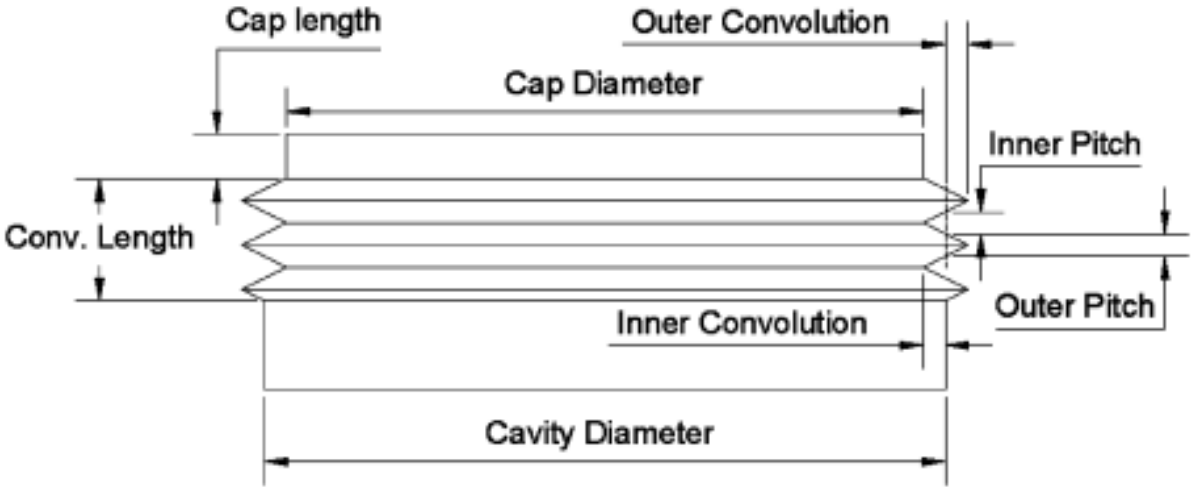
Though, the optimal design of Tunable/Reconfigurable microwave filter suitable for payload application is yet to be developed, many researchers around the world are at work with this goal in mind. To obtain a tunable cavity filter and thus a tunable mux, the resonant frequencies of the resonators that comprise the filters must be reconfigured. Depending on the resonant mode and its electromagnetic field distribution used in the cavities, this can be achieved by different approaches. These approaches have led to various results in terms of achievable unloaded Q factor, spurious-free tuning range, or mechanical simplicity. Tuning can be performed using mechanical, magnetic, or electrical commands. Some of the recent advances in the field of 3D tunable filter are given below:

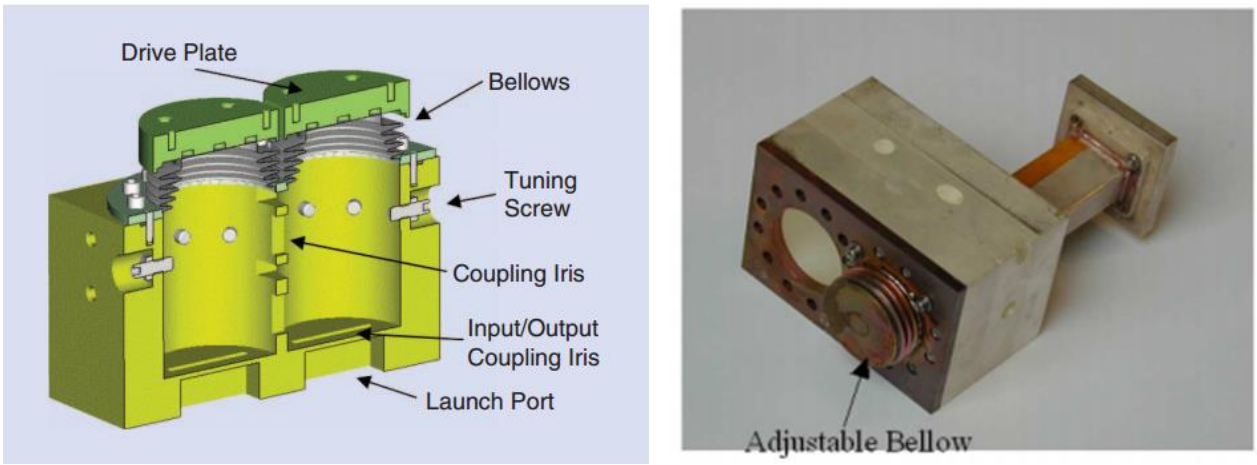
3.6.1. Mechanically Tunable waveguide cavity filters:

a) Bellow-Mounted Tunable Filters:

Waveguide cavity filters have been widely used in satellites, due to the high-Q and high-power handling capability. In addition, cross-coupled circular-waveguide dual-mode filters, typically operating in TE113 mode, offer mass and size reduction and excellent RF performance. Mechanically tunable waveguide cavity filter maintains both High-Q and high-power-handling capabilities. A mechanically tunable waveguide filter can be implemented using bellows. The bellows is a flexible electroformed copper structure which acts as a tuning element. It is a thin-walled (nominally 0.002-in thick) metallic closed-

end piston with a designed profile and specific number of convolutions. The bellows-mounted tunable filter offers a very low loss performance over a wide tuning range. A very stable transmission response over a very wide tuning range is also a distinctive feature of this technique. However, there is a tradeoff between RF and mechanical performance when designing a bellows profile. Mechanical operating characteristics are maximized by increasing the number and amplitude of convolutions, whereas RF performance relies on bellows with fewer convolutions.



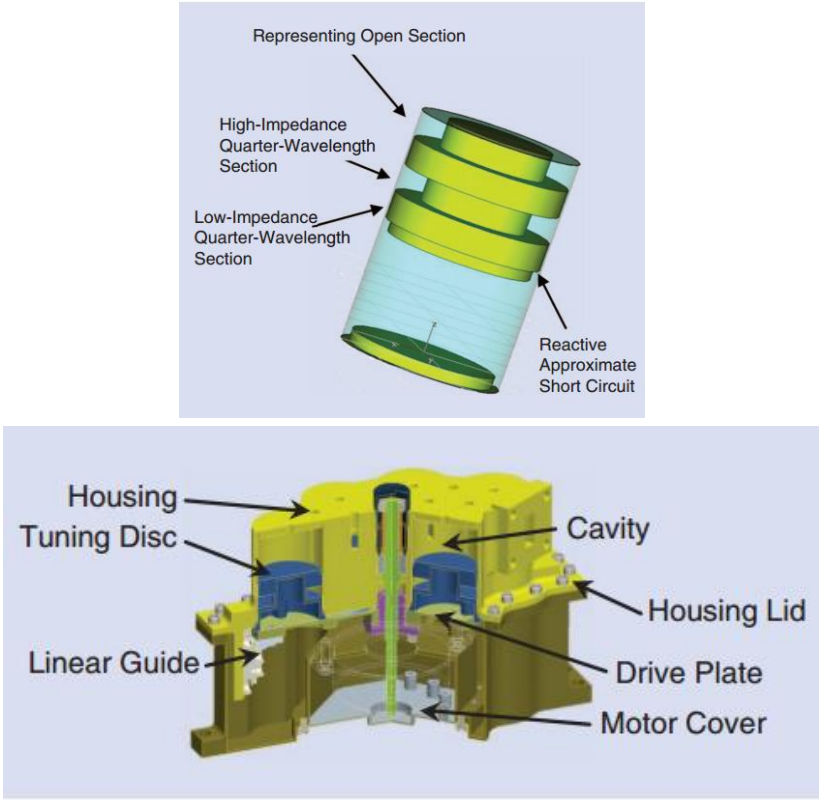


Bellow mounted tunable cavity filter

b) Fully Tunable TE011 Cavity Filters

A fully tunable filter for a completely flexible transponder requires tunability of both the bandwidth and center frequency of the filter. RF performance of the filter should be maintained over wide tuning range. In cylindrical cavity filter operating in TE011 mode, electric field strength and current distribution approach zero at the edge of the cavity end walls making it possible to use tuning discs without Q degradation, which in turn leads to the potential for incorporating small and low power consumption motors due to the contactless tuning feature. A movable plunger with diameter smaller than or equal to that of the cavity is used for filter tuning. The A contactless plunger is used to provide a reactive short-circuit condition at the back of the metal disc ensuring good electrical contact, creating a near shortcircuit condition. This type of plungers consists of quarter-wavelength transformers. The three-section plunger

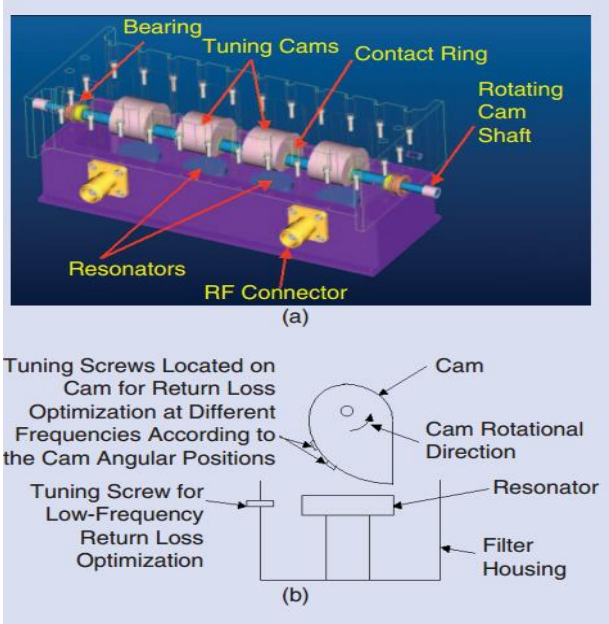
incorporates two low-impedance sections and one high-impedance section. Providing an RF enclosure to the resonator prevents unwanted modes from interfering and degrading the operating TE011 mode. The achieved Q of approximately 10,000 for a Ku band filter is reported in the literature. This design, however, has narrow spurious free window due to presence of low-Q TM111 mode.

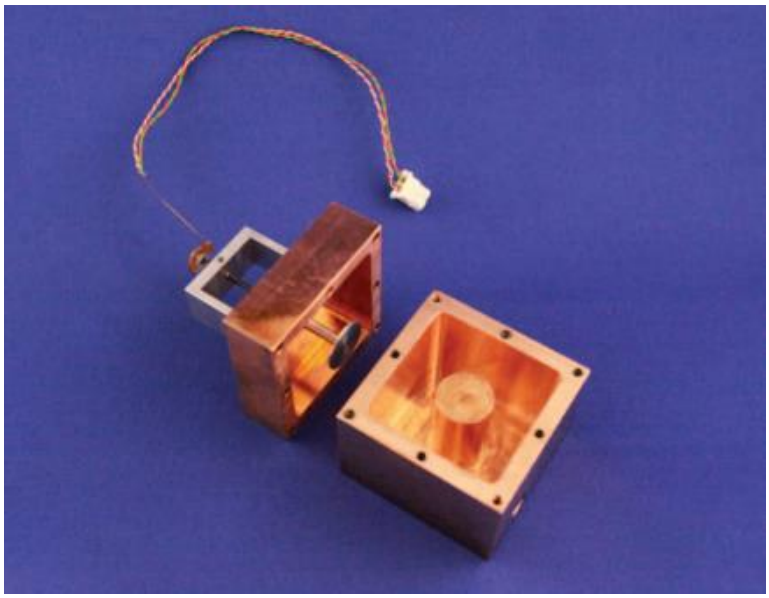


Fully tunable TE011 cavity Filter

3.6.2. Coaxial Tunable Filters

Coaxial resonators offer moderate-Q and have been implemented for satellite channel-filtering applications. Coaxial technology is suitable for tunable filter applications because of the ease of tuning, which is a well-known characteristic of coaxial resonators. A design of a manually tunable coaxial filter is shown in following figure. In this design, Tuning is achieved by rotating a shaped cam above the resonator post which in turn changes the capacitive loading of the resonator. Variation in capacitive loading required for tuning resonant frequency of coaxial resonator can also be achieved by varying the height of tuning disk used at the top of the resonator.





Tunable Coaxial Filter

3.7. Synthesis and Analysis of Microwave Filters Based on Available Computational Methods

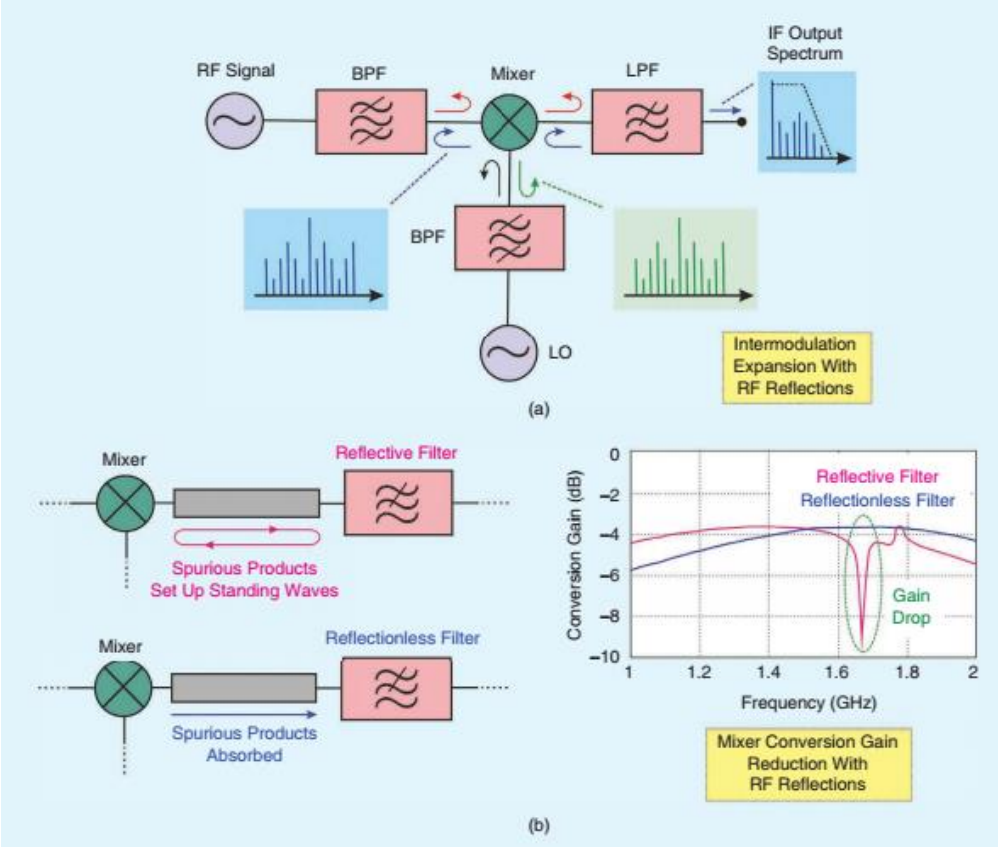
To design a microwave filter, synthesis of electrical circuit is required. Synthesis generates complex polynomial for filter transfer function. Coupling matrix synthesis is a popular approach for extraction of the electrical parameters from the complex polynomials. The extracted parameters of coupling matrix are the circuit building blocks for a required filter response realization.

The coupling matrix can be configured/modified for any desired topology of the filter and its corresponding (transmission/Reflection) response. Methods for direct optimization of the coupling matrix for desired transmission/reflection response are also available in literature. Prospective and retrospective

use of the coupling matrix for any desired RF response for adaptive resonator topology can be very helpful for time efficient and better electrical performance designs.

Software development for numerical electromagnetic analysis and optimization of standard geometries like rectangular, circular, coaxial resonator based microwave filters with GUI will initiate efforts towards indigenization of Electro-Magnetic (EM) solvers. The scope of software development can be further expanded to more complex geometries. Numerical electromagnetic techniques like Mode matching, Finite Element Method (FEM), Finite-difference Time Domain (FDTD) can be used depending the nature of geometry. The existing Commercial EM tools are highly expensive and hence good amount of foreign exchange can be saved after successful completion of this activity.

Reflectionless Microwave filter



The problems of (a) intermodulation expansion in a receiver's low-conversion stage due to multiple out-of-band RF signal power reflections produced by reflective-type filters and (b) mixer conversion gain reduction resulting from generated standing waves in interconnection transmission lines. LPF: low-pass filter; IF: intermediate frequency.

A long-overlooked opportunity to enhance the signal-to-noise ratio (SNR) and dynamic range within a signal chain and to reduce harmonics/spurious content within these circuits is to address a seemingly innate property of filters: their out-of-band reflective behaviour. Reflectionless filters utilize a novel

circuit topology to effectively eliminate the standing waves created by traditional filters without additional components (such as pads). This unique property gives designers a new way to improve the system performance of a wide array of broadband circuits, or any circuits suffering from out-of-band impedance mismatch. The typical performance of conventional filters (reflective filters) only exhibited a matched impedance at its ports within the filter's pass-band. The stop-band regions of these filters are intentionally designed to have very poor impedance match. As a result, undesired stop-band signals, including harmonics, interference, and noise, are all reflected from the filter ports back through the signal chain. If these unwanted signals are reflected back to another reflective device, a standing wave effect emerges. This standing wave will persist and build on itself until the attenuation of the transmission path between the two reflective components dampens and absorbs the unwanted signal energy. The reflectionless filter is a set of filter topologies and designs that inherently exhibit a broadband matched impedance. The major advantage of reflectionless filter topology is that these filters are readily cascadable, so sharper roll-off and greater stop-band rejection may be achieved by adding filters as modular building blocks. The figure above shows the improvement of the receiver chain with the introduction of reflectionless filter.

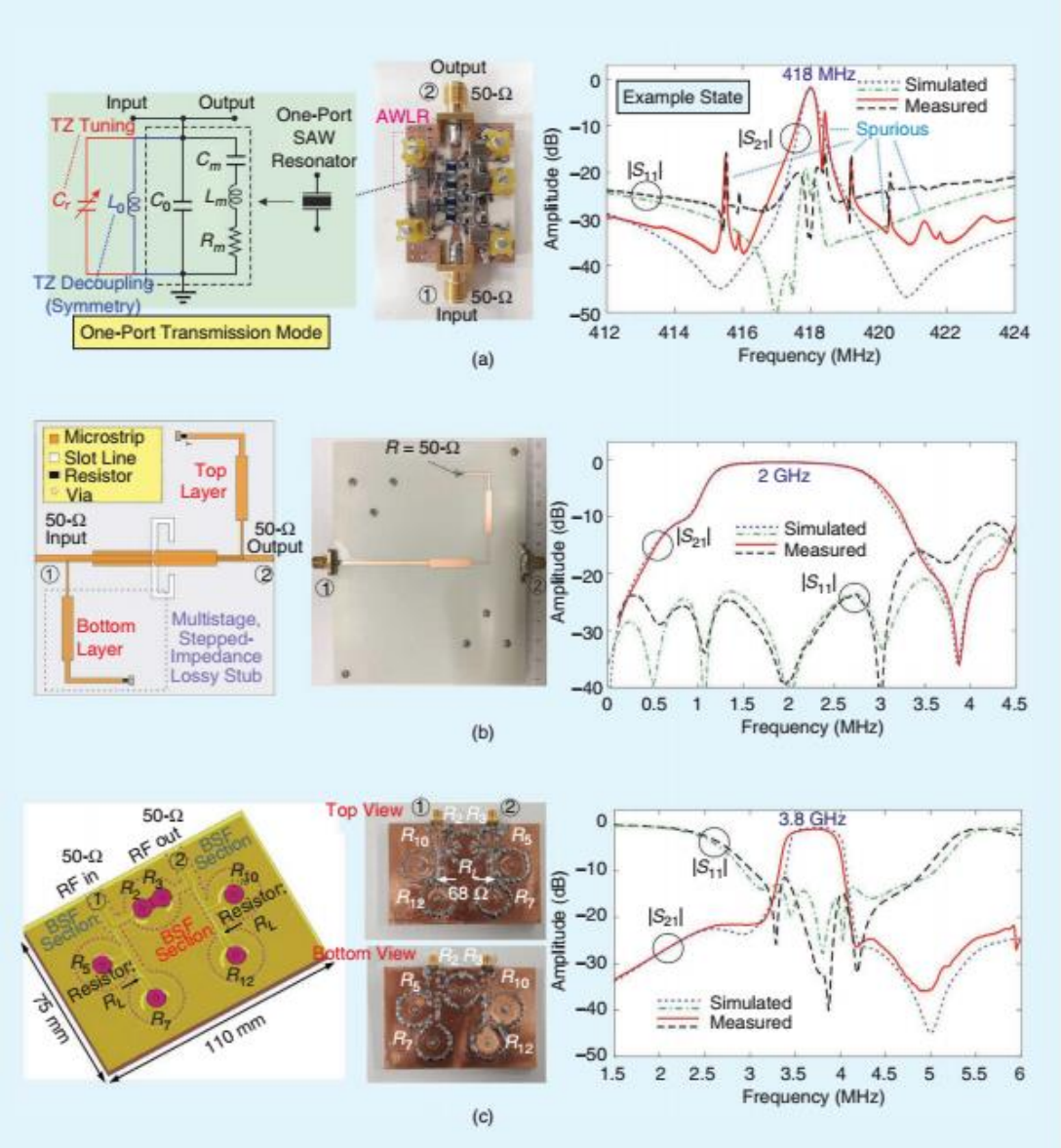
Recent Advancements

Reflectionless Bronchopleural Fistula (BPF) devices developed mostly in planar realizations. However, to much lesser extent they are also have been demonstrated in other technologies. Below are the technologies where nonplanar reflectionless BPF components have been demonstrated are shown in figure:

1. **MMIC and low-frequency technologies**: Reflectionless BPFs in MMIC technologies are demanded for modern, energy-efficient, compact RF front-end chains .A theoretically perfectly matched symmetrical BPF network with even- and odd-mode subcircuit compensation, an integrated, passive, two-port absorptive BPF is developed. This prototype exhibits a quasi-elliptic-type bandpass filtering response centered at 2.5 GHz with return loss levels above 15 dB from dc to 10 GHz for a chip area of 1 mm^2. It should be noted that commercial counterparts of this solution are already available showing promise for deployment in future RF transceiver modules. On the other hand, although, thus far, they are used only in low-pass filtering components (which can be easily extended to BPF ones after appropriate lowpass-to-bandpass frequency transformations), the novel classes of reflectionless filters for very low-frequency applications. The future need is to demonstrate and extend this concept for Ku and Ka-band.

2. **Acoustic wave technology**: BPFs in acoustic wave realizations are leading frequency-selective devices in mobile communications systems, due to their high quality factor (Q) and compact footprint However, most show some major limitations in terms of their very narrow operational bandwidth and frequency-static filtering transfer function being mostly of the reflective type and because of their spurious mode creation. By efficiently combining the acoustic-wave lumped, element resonator (AWLR) concept presented in for enhanced-bandwidth, quasi-elliptic-type BPF realization with the complementary diplexer approach. AWLR-based BPFs with reconfigurable out-of-band TZs are shown in figure 1.2.
3. **Multilayer technology**: The exploitation of microstrip-to-microstrip vertical transitions with slot line resonators in multilayer schemes has proven its potential in the development of

ultra-wideband BPFs aimed at broadband and RF receivers. Using this concept and the lossy-stub-loading philosophy for reflectionless BPF design, new ultrawideband BPFs that simultaneously exhibit a very broad, symmetrical, reflectionless behaviour can be developed shown in figure 1.2.



Examples of reflectionless BPFs in nonplanar technologies. (a) An input reflectionless AWLR- based BPF using a complementary diplexer approach for TZ tuning. (b) A symmetrical, reflectionless, wideband BPF on multilayer technology using input/output multistage lossy stubs. (c) A symmetrical reflectionless BPF with substrate-integrated coaxial resonators using a two-port complementary diplexer approach.

Ceramic filters

As the name implies, RF & IF ceramic bandpass filters are manufactured from ceramics that exhibit the piezo-electric effect. One of the most common ceramics used is known as Lead Zirconate Titanate (PZT), lead zirconium titanate. The ceramic element uses its very high Q mechanical resonances to provide the

resonant feature. They have bandwidths that are typically measured between 0.05 and 20% of the operating frequency. Often the Q levels range between around 500 up to 10 000

Ceramic filters are electronic components that are widely used in IF and RF bandpass filter applications for RF circuit design in radio receivers and transmitters and the like. They may also be used as resonant elements in a variety of electronic circuit designs

3.8. Channelized Power Output Configuration Design and Analysis of Electronic Power Conditioner (EPC) for Synthesizers

The next generation of digital subsystems require very high current channelized power, high reliability protection mechanisms, stringent load regulation, fast dynamic response over wide range of load variations, good power efficiency and compact size. This requires an optimized power converter design along with a suitable channelization network.

Power converter design has challenges of handling very high output currents with help of synchronous rectifiers, high bandwidth closed loop response with type-2 compensation network, tight regulations over line-load-temperature variations, Minimal PARD and high efficiency. Whereas, Channelization network has challenges of handling high power switch operations and designing sophisticated protection mechanisms.

Scope of research proposal

These advanced requirements certainly require dedicated research and analysis on following areas:

- End-to-end simulation of power converter with detailed close loop stability analysis.
- Power loss optimization techniques for high current outputs.
- Isolated feedback network design with minimal stability implications.
- Low noise cascaded filter designs for attenuation of switching ripples.
- Reverse voltage protected high power switch design, with load current sense and fold back protection circuits.
- ASIC/ Hybrid Microcircuits (HMC) based solutions for single high power output DC-DC converter.

3.9. Theoretical Analysis & Realization of Singular Electronic Power Conditioner (EPC) Approach for Integrated Payloads in Communication Satellites

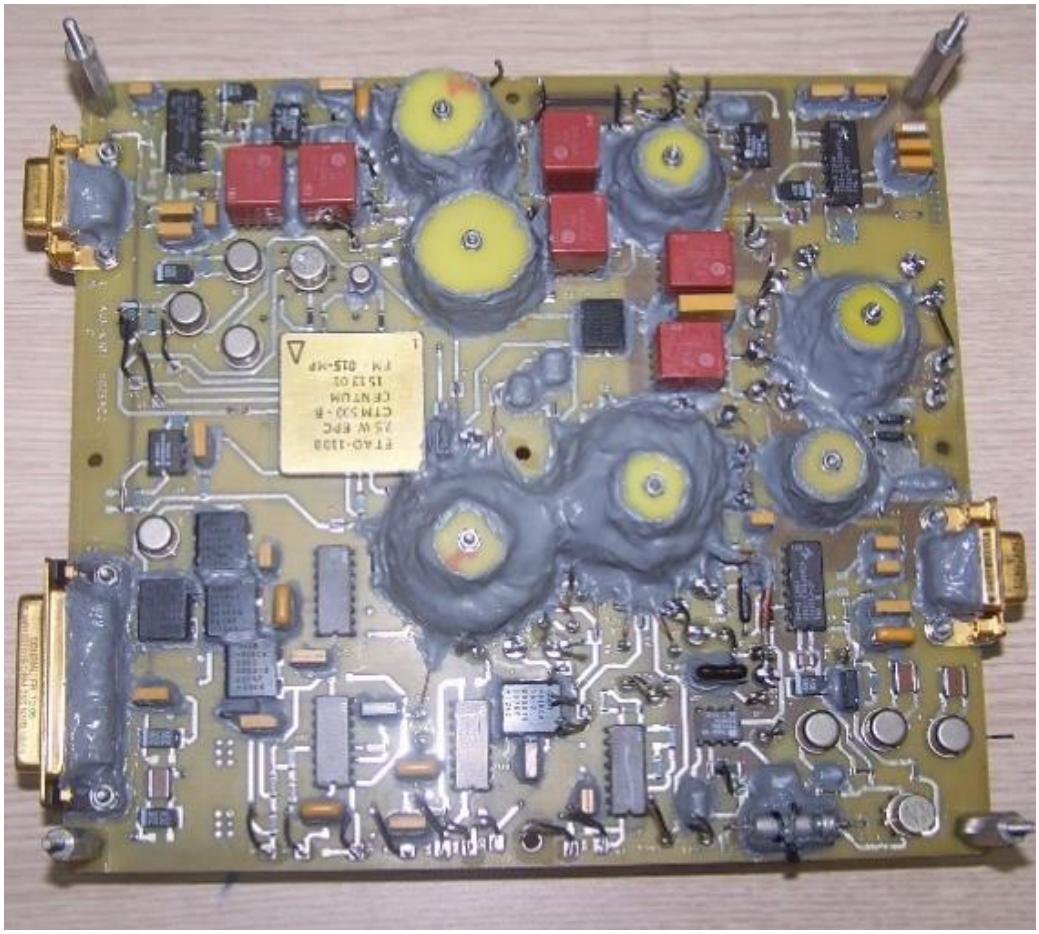
With the advent of advanced high-throughput communication satellites, miniaturized integrated payloads have now become a current trend in order to save conspicuous mechanical budget while meeting their respective functional requirements.

Where, earlier a transponder would have its separate electrical power supply in the form of an EPC, the upcoming mission profiles require a single EPC to cater to the power supply requirements of an entire regenerative transponder. This chain would comprise of Low Noise Amplifier, Filters, Digital Processor and Transmitter.

An integrated EPC has to be miniaturized and, at the same time, should feature high efficiency, compliance to each subsystem's electrical specifications. It should also maintain galvanic isolation and apt signal and power integrity to prevent exchange of noise among different output lines, for example between high voltage (+50V) based SSPA line and low voltage (+1.2V) FPGA line.

Scope of research proposal

- Complete theoretical analysis of EPC including modelling and simulation with suitable topology selected
- Incorporation of advanced techniques to miniaturize the size and increase the efficiency of the EPC like soft switching etc.
- Designing of efficient Printed Circuit Board (PCB) layout maintaining signal integrity and minimum noise in sensitive low voltage high current lines like those of an FPGA
- Design and implementation of turn-on and turn-off delay circuits between various output voltage lines which are within a subsystem like FPGA and between two or more subsystems
- Design and implementation of separate telecommand circuit to enable switching of transmission supply of EPC on-board
- Realization and delivery of EPC with compliance of electrical specifications of all of the subsystems



30W EPC for Integrated Payload

3.10. Integrated EPC for Multiple Subsystem Stacks: Individual Control of Commanding, Over Current Protection and Other Protection Mechanisms for EPC and Intended Subsystems

Single EPC that can cater requirements of multiple subsystems of payload with individual On/Off control and individual protection mechanisms for each subsystem has high potential for new generation High Throughput Satellites by saving sufficient mass and foot print.

Scope of research proposal

Theoretical study and analysis of advanced EPCs, which can supply power to multiple subsystem stacks, which involve several challenges viz.

- Electrical circuit modelling and simulation of circuit.
- Supplying power to multiple subsystems and meeting output voltage sequencing requirement of each individual.
- Dynamic switching load with fast transient response and converter stability.
- Selectable RF load at spacecraft through Telecommand.
- Protection of EPC in case of single/ multiple subsystem failures such that there is no impact on remaining subsystems if one or multiple subsystems fail to which EPC is supplying power.
- Thermal effects of subsystem failures on EPC.

3.11. Switching GaN based EPC for High Power SSPA

Recent advancement in radiation hardened Switching GaN devices paved the way for highly efficient and miniaturized converter realization. High Figure Of Merit of GaN switching devices in contrast Si switching devices help in achieving high switching frequencies without much trade off in the efficiency. This device technology significantly improves size and mass of the next generation high power converter and helps in high density payloads realization for SSPA.

Scope of research proposal

- Study of Gate drive circuit of GaN High-Electron-Mobility Transistor (HEMT) devices
- Spice based modeling and simulation of GaN HEMT driver circuit.
- Power circuit topology for efficient use of GaN HEMT devices.
- High output power EPC of 300-500W working at high Switching frequency.
- Use of Hybrid planer magnetics for miniaturization.
- Thick film hybrid HMC for realization of control circuit for further miniaturization of package.

3.12. Receiver & Frequency Sources Technologies

Compact, low power consumption and small volume are the system requirements of all times. In this direction a major emphasis and thrust has been provided over the years for development of miniature Low-Noise Amplifier LNAs, Receivers and Frequency converters over frequencies ranging from UHF to Q/V band. MMIC technologies combined with advance packaging techniques are being utilized for various communication and navigation payloads. Higher operating bandwidths and gain requirements combined with stringent spurious performance poses a challenge for development of compact systems as stringent filters are also to be incorporated.

Areas of Research are:

1) Beam Forming Receiver
2) Receiver Design for Doppler Shift
3) Flexible Receivers in terms of frequency and bandwidth
4) Design and development of RF switches, Variable Valve Actuation (VVA) and Video Graphics Array (VGA) upto Q/V band
5) Fully integrated Receiver (RF, Local Oscillator (LO) & DC/DC in single package)
6) Medium Power Beacon Sources
7) Design of Synthesizer Integrated Circuit (IC)s

3.13. System Engineering

3.13.1. LEO Constellation for Regional Coverage:

Advance technological changes in satellite communication has led to reduced payload manufacturing cost & launch cost per kg to Low Earth Orbit (LEO) orbit which has made LEO orbit a popular choice for broadband connectivity from space. LEO orbit has major advantage of lower latency and ability to cater smaller user terminals. Broadband LEO constellation can complement the terrestrial networks by serving unserved and improving Quality of Service (QoS) in underserved region. Such networks can be integrated with future technologies like 5G, 6G & Internet of Things (IoT) where connectivity between the devices is a prime requirement, which is major concern for devices located in extreme topography with no terrestrial connectivity.

The research areas in this field include:

- Development of algorithm for inter-satellite link dynamic routing/handover for data downlink/uplink to/from gateways
- System studies on integration of LEO broadband constellation & future terrestrial 6G technologies
- Development of on-board resource management algorithm based on user demand
- System study and algorithm development for LEO-GEO & LEO- Medium Earth Orbit (MEO)-GEO multilayer constellation routing
- Development of single aperture multi-beam , compact and light weight antenna integrated with compact lightweight trans-receiver module
- Development of compact ISL terminals for LEO-LEO and LEO-GEO communication
- Compact ISL terminals for LEO-LEO, LEO-GEO communication: compact optics, pointing and tracking system, optical modulators etc.
- Development of translucent/transparent on-board processing digital system based on commercial processor/FPGA technology

3.13.2. Software Defined radio based Satellite architectures for Future Satcom systems

In present scenario, low cost small satellites (Micro or Nano Satellites) are being launched or planned for launch on LEO orbit to provide communication services over the Globe. Small satellites provide an efficient and cost effective solution to different communication services as compared to bigger satellite platforms targeted for GEO orbit. Due to their low mass, power and volume envelope, the payload also

has to be designed considering these constraints. Software defined radio (SDR) based payload architectures can provide solution for compact/miniaturized design which requires low mass, low DC power consumption & less volume. Present SDR systems can receive/transmit signals directly at RF level up to C-band. This will eliminate the requirements of the complex frontend hardware which in turn provides savings in mass, volume and DC power consumption. SDR based communication payload architecture is well suitable for Indian Nano Satellite Bus (INS) and Indian Micro Satellite Bus (IMS). SDRs will also be useful for future communication payloads for GEO/LEO satellite.

- Common RF transceiver (single chip/module) having RF front end and Digital subsystems (direct sampling based ADC and DAC modules) to operate from UHF to Ku band frequencies.
- Studies and implementation of different signal processing algorithms for regenerative processing and flexibility in terms of channelization and bandwidth.
- Development of integrated wideband RF front end with LNA, Bandpass Filters & Precautionary and Liquidity Line (PLL) on RF Transceiver module
- Development of Direct Sampling based ADC and DAC modules which can be integrated with wide band RF front end.

3.13.3. Hybrid Satellite/Terrestrial networks and their compatibility with 5G cellular system

As the spectrum resources are becoming limited and trend is towards delivering high speed data rates in both satellite and terrestrial mobile communication. Hybrid network of terrestrial and satellite systems complementing each other shall be developed for ubiquitous coverage, seamless connectivity and high data rates.

Research areas in this direction are:

- Studies on Satellite – Terrestrial system architecture compatible with 5G Networks
- Channel modelling considering both land-mobile and earth-to-space channels
- Investigation of Multiple-Input Multiple-Output (MIMO), precoding and other signal processing techniques for enhancing capacity of mobile satellite systems and ensuring coexistence of terrestrial and satellite systems.
- Protocol level integration of satellite and terrestrial system and development of satellite-5G testbed.
- Investigations on satellite platforms and terminal architectures complementing terrestrial 5G networks.

3.13.4. Development of signal processing and resource allocation algorithms for multi gigahertz on-board processors

With the advancement in signal processing capabilities, the trend is towards channelization and processing of wideband signals covering gigahertz bandwidth. Similarly, the necessity to dynamically and efficiently allocate a communication payload's on-board resources such as power and bandwidth over the desired coverage requires the development of algorithms for beamforming-precoding, beam-hopping etc. Research areas in this direction are:

- Development of signal analysis algorithms for wideband signals (multi-gigahertz bandwidth). Sparse signal analysis/compressed sensing based algorithms can be targeted.
- Development of translucent processing algorithms which bridge transparent and regenerative payloads through partially decoding packets on satellite.

- Development of algorithms for beam-hopping, digital beamforming, and precoding for efficient spatial allocation of on-board resources.
- Satellite system design and architecture for multi-gigahertz signal processing payload.

3.13.5. Studies on Advanced Navigation systems

Satellite navigation has become a key infrastructure element worldwide, enabling numerous applications along with great economic activity. These systems have been conceived as cornerstone of the national security and playing that role effectively. The significance of these systems is evident from the fact that currently there are six global navigation satellite systems (GNSS) which are either operational, under deployment or modernization. The system capability is evolving in both civil and defence domains. Indian Regional Navigation Satellite System(IRNSS) system is now a full-fledged operational system which is providing navigation services over Indian region. The evolving user requirements and global scenario will certainly require continuous research and development to acquire and utilize newer technology in this field. Few such potential areas are enlisted below:

- Use of IRNSS signals for navigation with "signals of opportunity" of terrestrial networks.
- Systems studies for autonomous satellite navigation for MEO constellation.
- Development of simulation tools for situation awareness for navigation end users supporting their mission planning. Such tools will consider the complete navigation systems and provide the information about the system accuracy, availability, integrity and reliability for any operational situation.
- System studies on provision of standalone Positioning, Navigation and Timing (PNT) services for the missions on extra-terrestrial bodies like Moon/Mars.
- End-to-end performance analysis of IRNSS signals in LMS channels using software/hardware simulation platform.
- Research on security features of navigation signals such as anti-spoof and message authentication.
- Studies on navigation signal generation, multi-level signal/sub-carrier design and multiplexing using multicarrier constant envelope modulation schemes.
- Studies of various signal modulation schemes like Minimum Shift Keying (MSK), Gaussian Minimum Shift Keying (GMSK), Orthogonal Frequency-Division Multiplexing (OFDM), etc. as potential candidates for the future navigation signals. Studies should also include overall receiver performance analysis for such signals.
- Studies of interference mitigation techniques like wavelet based de-noising or other compressive sensing methods on receiver performance.
- Research in utilizing space service volume capability of GNSS signals.
- Clock ensemble algorithm development for improvement of on-board timing system performance.

3.13.6. Space based Automatic Dependent Surveillance-Broadcast (ADS-B) and Automatic Identification System (AIS)

Automatic Identification System（AIS） is a universal ship–borne terrestrial system used to improve the maritime safety and efficiency of navigation by enabling ship to ship and ship to shore communication. Automatic Dependent Surveillance-Broadcast (ADS-B) is the aircraft surveillance technology in which aircraft provide data such as position, velocity, and identification from on-board aircraft systems.

AIS and ADS-B both rely on message transmitted by users regarding their navigation status/location. Space based AIS and ADS-B augment the surveillance capability beyond the terrestrial system range with global coverage (remote, polar and oceanic areas), unrestricted by location. AIS & ADS-B payloads, hosted on low earth orbit (LEO) platforms receive AIS/ADS-B messages, process them and relay them back to ground for usage by service provider to end user.

Satellite receives the message from multiple AIS and ADS-B terminal at a same time which causes on-board message collision or messages may get garbled. Since, this is an upcoming area, there are several challenges:

- Development of On-board algorithm for detect, de-collision and decode of AIS and ADS-B message in low SNR (<9 dB).
- Development of low-size, weight and power (SWaP) digital processor.
- Development of low noise sensitivity (<-105 dBm) AIS and ADS-B RF front end.

3.14. RF characterization of communication and navigation payloads

Communication payloads include bent pipe, SDR based and spectrum processing configuration. Navigation payloads have data transmitter type configuration, which provide Position, Velocity and time solution to user. These payloads are characterized for different parameters such as IO transfer curve, frequency response, group delay, noise figure frequency conversion error, 3rd order intermodulation, spurious etc. for communication payloads & Error Vector magnitude (EVM), BER, phase noise, carrier suppression, magnitude/phase imbalance (IQ imbalance), absolute delay, code/carrier coherency etc. for navigation payloads. These parameters are characterized using an Automated Test System (ATS). The ATS is an interconnection of stimulus and measurement equipment to test a transponder (communication/navigation) in an automated fashion. The data is processed on a controller to provide the parametric results, which needs to be complied with the payload specifications. The processed data is displayed and stored in variety of formats such as excel, pdf, text, database etc. The ATS is generally developed on platforms such as LabVIEW, Matrix Laboratory (MATLAB), and Python etc.

ISRO is actively involved in development of payloads for variety of user applications for which high speed ATS development is required to test payloads in production mode as well as applying suitable DSP algorithms for estimation of various parameters.

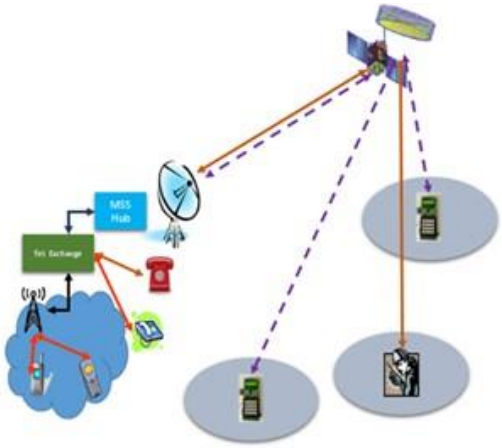
Payload testing also requires design and development of various ground components (low power and high power) such as Switching & Interconnect Network, switch matrix, waveguide/coaxial adaptors, couplers, dividers, high power waveguide terminations etc. to enable realization of ground test setup for communication and navigation payloads. Future research scope exists in ongoing activities:

- Development of web based Miniaturized ATS to characterize payloads from UHF to Q/V band and above, having very narrow to very wide bandwidths (5 KHz to 500MHz), using DSP techniques.
- Development of fast phase array antenna (PAA) measurement technique (in near/far field conditions) for LEO payloads
- Design of PAA test setup as well as qualification in thermovac & compact antenna test range (CATR) chamber.
- Characterization of multiple transponders in parallel using DSP techniques.

- Mismatch Fault isolation analysis using time domain techniques.
- Design and development of very high power waveguide terminations (> 2KW) at Ku and Ka band
- Design and development of high power pressure windows at S, C, Ku and Ka bands (quartz or alumina based).
- Design and validation of stimulus for various scenarios for communication, navigation, ADS-B, AIS, Radar, spectrum processing.
- Development of efficient technique for ground setup RF calibration setup for wideband multibeam/communication payloads.
- Feasibility analysis of Artificial Intelligence and Machine Learning (AI/ML) concepts application in analysis of payload test data generated during multiple phases of testing
- Query based trend analysis on centrally stored payload test data, generated at different geographical locations.

4. SATCOM AND SATNAV APPLICATIONS & ASSOCIATED TECHNOLOGIES

Satcom & Satnav Applications Area (SSAA) of SAC is entrusted with the development of technologies and devices that leverage the installed capabilities of two major categories of ISRO satellites *viz.* communication and navigation satellites. Various applications for both commercial and special usage are developed as per requirements of user agencies and / or vendors who are then enabled for further commercial or operational roll-out through a combination of transfer of technology (ToT) and build-to-print or -spec models with handholding provided. SSAA also builds and operates satcom networks through provision of hub / gateway stations along with associated baseband technologies to route and manage the traffic. Navigation-related developments comprise three major segments of GAGAN / NavIC utilization. These are development of GNSS receivers, GNSS application devices that provide value-added services based on positioning information and GNSS simulators to aid in development of these as well as performance validation of both NavIC payloads & developed receiver / application hardware.



SPS (IRNSS + GPS + GAGAN) Receiver

In House IRNSS Simulator

SSAA comprises of two Groups based on the above broad domains of applications activities.

The Communication Technology and Applications Group (CTAG) is focused towards development of various state-of-the-art baseband technologies, establishment of ground segments and applications development towards the effective utilization of space-based resources. The Group has its primary focus towards building satcom networks / ground infrastructure (Technology Development, Terminal & Hub Station etc.) to support different mobile satellite service (MSS) applications, fixed satellite services (FSS)Broadband Communication using up-coming High Throughput Satellite (HTS) and synergistic applications using a combined 'Com-Nav' approach for commercial / special user group.

Of late, the Group has successfully developed and demonstrated four types of MSS services namely Reporting Service for one-way small message & position reporting, low bit-rate two-way voice communication service (Satellite Phone), two-way multimedia communication *viz.* video conferencing and broadcast service using personalized gadgets. The Group has also established Ka-band interconnected gateways to support broadband HTS applications using the country's first high throughput satellite. CTAG also supports the communication network for national disaster management to cater to emergency

communications. Also, we are entrusted the propagation studies experiments for higher frequency bands like Ka, Q and V-bands.

The Navigation Technology and Applications Group (NTAG) within SSAA is responsible for developing various critical technologies related to ISRO's satellite navigation programme in general and Navigation with Indian Constellation (NavIC), in particular. Various types of receivers *viz.* IRNSS Payload-Test receiver, IRNSS SPS-User receiver, IRNSS RS-User receiver, GNSS Receiver, SBAS Receiver, Messaging Receiver and IRNSS Simulator have been successfully developed. Also, Reference receiver, Software-based receiver and ASIC chipset-based solutions for NavIC are currently being developed.

The Navigation Group has provided IRNSS encryption scheme and its implementation in payload besides PRN codes and its analysis for the NavIC programme. Data analysis of Ka-band propagation experiment and GAGAN-TEC network as well as IRNSS Secret Intelligence Service (SIS) performance analysis is also carried out. Other activities include development of applications related to IRNSS/GNSS/Augmentation systems and simulation studies related to digital signal processing for baseband applications relevant for ground-based applications systems. NTAG is shouldering the major responsibility to conduct the prestigious Centre for Space Science and Technology Education in Asia Pacific (CSSTEAP) programme under the aegis of the United Nations. A nine-month course on GNSS is offered to meritorious nominees from developing nations in the Asia-Pacific region under this.

In the following; a list a major areas of research respectively in satellite-based communication and navigation are provided wherein the Indian academic institutions can potentially contribute through RESPOND programmes.

4.1. SATCOM Applications and Technology Development

Space Applications Centre, ISRO, Ahmedabad is responsible for SATCOM Applications and Technology development for eventual use of Societal and Strategic users of the country. Besides meeting the application needs, the Centre continues to work on development of state-of-the-art technologies for SATCOM with an intent to indigenise technology and product development.

In the last two years, the Centre has been into the establishment of more than 25 SATCOM Gateway stations in Ku/Ka band to meet national enterprise VSAT communication demand using upcoming HTS class of satellite. In the Mobile Satellite Service domain, the Centre has developed applications like Real-time Train-tracking Information System (RTIS), MSS Network for Tracking of Sub-20m boats, Real-Time Aircraft Tracking System etc. to meet the custom requirements of user ministries. Besides these efforts, the centre also focuses on development of technologies like SATCOM baseband ASIC development, MMIC development for RF Sub-systems, Signal Processing algorithms for SATCOM baseband technologies to enable communication on the move (COTM) for Airline, Maritime and Land Applications. The Centre specializes on baseband technology development pertaining to FSS and MSS. The Centre is working on development of advance technologies for miniaturization (Satcom Baseband ASIC), cost and

power efficient battery operated MSS terminal development to support voice communication, IoT and M2M communication using MSS satellites. The Centre is also exploring the opportunity to promote development of RF and baseband sub-system technologies indigenously by collaborative efforts.

While efforts are ongoing to achieve self-reliance, there are many new technologies still that need development in the domain of Satellite Communication Ground Systems like more powerful processors/ASICs, new source/channel encoding-decoding capabilities, user terminal miniaturization and baseband algorithms that can enhance user mobility, versatility, performance in a cost effective manner.

This document incorporates research areas relevant to the satellite communications ground segment and application development to meet the near future requirements.

4.1.1. Baseband Technology Development

4.1.1.1. Non Orthogonal Multiple Access)NOMA (based Multi-beam High Throughput Satellite /Ultra High Throughput Satellite System

Recent research contributions have shown the way to use NOMA in SATCOM systems. Researchers are encouraged to submit their proposal for NOMA-based multi-beam satellite systems including mathematical analysis and the applicability of integrating NOMA to satellite systems from a system-level point of view. The researchers are requested to provide general approaches for cooperating NOMA with pre-coding techniques and their implementation plan. NOMA technique is also claimed to work under low C/I conditions in multi-beam HTS networks. Researchers are encouraged to submit their NOMA based receiver algorithm design, simulation, performance analysis and implementation plan for multi-beam SATCOM ground network.

Additionally, NOMA breaks the orthogonality in conventional orthogonal multiple access (OMA) such that multiple terminals can access the same time-frequency resource simultaneously, which improves the efficiency of spectrum utilization. The resulted co-channel interference can be alleviated by performing multi-user detection and successive interference cancellation (SIC) at the receiver side. Researchers are encouraged to submit their research proposals on how to improve spectral utilization in SATCOM networks using NOMA technologies for different application scenarios.

4.1.1.2. Algorithm and Implementation of real-time Wideband Spectrum Sensing)WSS (and Automatic Modulation Recognition)AMR (system for Blind Signal Detection

Blind Signal Detection needs highly efficient algorithms for wideband spectrum sensing and automatic modulation recognition system to facilitate its real-time implementation. These systems are also enabled to make identification of communication streams and their demodulations that uses advance technologies like carrier-in-carrier (CIC) or Professional Convention Management Association (PCMA). Researchers are encouraged to submit their proposal for efficient spectrum sensing coupled with automatic modulation recognition system. The proposal should or may also include interference monitoring system, signal

demodulation plan together with its implementation. Another problem of interest includes blind scrambler identification and channel coding technique identification.

4.1.1.3. Advance Baseband Technologies for Mobile Satellite Service

GEO-Mobile Radio Interface, better known as Grandhi Mallikarjuna Rao (GMR), is an European Telecommunications Standards Institute (ETSI) standard for satellite phones. GMR standard derived from the 3rd Generation Partnership Project (3GPP)-family terrestrial digital cellular standards and supports access to Global System for Mobile Communication (GSM)/ Universal Mobile Telecommunications System (UMTS) core networks. Adaptive Communication Environment (ACeS), Initial Coin Offering ICO, Inmarsat, SkyTerra, TerreStar and Thuraya for high-speed internet as well as audio and video services use it.

ISRO is coming up with its next generation of MSS satellite with 6/9/12m antenna in space. Researchers are encouraged to look at the protocol stack development opportunity (GMR like) for seamless voice communication between terrestrial (Logistics Task Force (LTE)/4G) and ISRO's MSS networks. It is expected from researchers to analyse the different channel models and "propose, develop & implement" efficient protocol stack for voice communication between terrestrial and MSS network. Researchers may look at opportunity to propose technologies to use upcoming 5G technologies and ISRO MSS network for IoT and Machine to Machine (M2M) communication applications.

4.1.1.4. Baseband Technology for Search And Rescue (SAR) systems of ISRO

ISRO operates INSAT satellite(s) equipped with a 402-MHz Search and Rescue payload as well as 406 MHz Data Relay Transponders that are being used for SAR operations using different types of distress beacons of maritime, aviation and land users.

- Researchers are encouraged to submit their proposal for development of MEO-SAR emergency locator transmitters with requisite Letter of Undertaking (LUT) processing algorithm.
- Data Relay Transponders are usually of 200 to 350 kHz bandwidth and being non-regulated band suffer from interference from users .The nature of interference being non-time dependent and sweeping nature causes the communication loss .Researchers are encouraged to submit development proposal in interference resistant waveform for sensor data reporting in burst mode of transmission that can offer better quality of service.
- Proposal on development of Mixed signal ASICs for SAR user terminals are encouraged.

4.1.1.5. MSS/DRT Network for data collection from Oceanic Platform

ISRO has already established a network with multiple GSAT satellites carrying MSS transponders & INSAT satellites carrying Data Relay Transponders (DRT) transponders. Also more next generation satellites with advanced MSS/DRT transponders & larger antenna will be coming up in future. This network can be potentially utilized for data collection & relaying applications from oceanic platforms. This network can facilitate the data collected by different oceanic sensors deployed at different locations

to be communicated to control centre in near real-time. The network can have hybrid reconfigurable terminals which can communicate in both MSS & DRT bands & provide unified interface with sensors.

Researchers are encouraged to innovate and propose design of ASICs, low-profile planar antenna system with beam-forming capability and suitable waveform for robust communication and leading to low power miniaturized system realization. A very low bit-rate (25-300 bps), fast acquisition, spectrally efficient spread spectrum burst demodulator design will add value to the proposal.

4.1.1.6. Baseband Sub-systems of Ground Network with multi-homing capabilities for Gaganyaan

ISRO has been working on the Gaganyaan Project, which will also include development of audio/video processing system for ground segment. All ground stations are connected to Master Control Centre (MCC) through multiple ground links to achieve failsafe transmission reliability and service quality. For real-time multiplexed streams comprising audio, video and data, the reliability requirement is different for each type of data stream. So there is a need of an efficient transmission technique for such multiplexed streams with different reliability parameter settings for each stream over a multi-homed networking environment. It is also required to have a suitable handoff mechanism in case of link failover with minimum handoff latency.

Researchers are encouraged to propose a custom protocol stack for seamless multimedia communication over multi-homing network.

4.1.1.7. Design and Simulation of digital beam-forming /electronic beam steering-techniques for high frequency COTM/SOTM)Communication on the Move / Satcom on the Move (applications .

ISRO has been allocated S-band for Mobile Satellite Service and Ku/Ka band is being used to offer aeromobile broadband services. In order to make the terminal efficient and support COTM/SOTM, electron beam steering technology is needed.

Research proposals are invited on design and development of efficient electronic beam steering system with interference protection features for S/Ku/Ka band of operations. Researchers are also encouraged to submit their proposal for mechanically steerable antenna system of small size as well as hybrid system for aeromobile applications.

4.1.1.8. Design and Development of Header Compression and QoS Mechanism for IP data communication services over satellite network.

Header compression is a mechanism that compresses the IP header in a packet before the packet is transmitted. Header compression reduces network overhead and speeds up the transmission of either Real-Time Transport Protocol (RTP) or Transmission Control Protocol (TCP) packets.

The RTP Header Compression over Satellite Links feature allows to use RTP header compression over an asymmetric link (such as a satellite link), where the uplink and downlink connections are on separate

interfaces. This feature provides improved system performance by reducing network overhead and speeding up transmission of RTP packets.
Quality of Service (QoS) is the collective effect of service performance, which impacts the degree of satisfaction of a user of the service. QoS is to the ability of a network element (e.g. an application, host or router) to have some level of assurance that its traffic and service requirements can be satisfied. To enable QoS requires the cooperation of all protocol layers from top-to-bottom, as well as every network element from end-to-end. Proposals are solicited for various techniques to enhance QoS and an enriched user experience.

4.1.1.9. Development of baseband signal processing elements for aero-mobile terminals

Broadband connectivity 'at 35,000 feet' i.e. in-flight is growing in several dimensions. More aircraft are installing on-board broadband systems, more data is being consumed while in-flight, and the expectation for service network performance is increasing.The service is offered using high-throughput Ka-band satellites and ISRO's common ground equipment comprised of multiple satellite gateways and user terminals. The network is a multi-beam network and offering efficient broadband services with high throughput using low cost terminal is a challenge.

Researchers are encouraged to offer their innovative design of UHTS class of Modem Technology (wide and faster acquisition with capability to support large drifts) supporting state of the art access schemes, Mobility management techniques for aero-mobile broadband and other signal processing techniques for low cost terminal realization.

4.1.1.10. Design & Simulation of physical-layer waveform for high mobility wireless channel (high Doppler-delay channel)

Providing reliable wireless communications for high mobility terminals remains one of the main challenges faced by satellite high-mobility communication systems. because the high Doppler frequency offset, Doppler rate & delay caused by the high-mobility nature of the mobile terminal, and low signal-to-noise ratio (SNR) circumstances caused by limited satellites' link budgets degrade the system performance seriously. This is a very challenging aspect in LEO broadband communication. Most of algorithms mainly focused on the estimation and compensation of Doppler frequency rate and Doppler frequency offset, rather than reducing the influence of Doppler effect in the communication system. To solve such a problem in high-mobility satellite communications advance physical layer waveform may be proposed which is insensitive to Doppler & delay.

Researchers are encouraged to offer innovative solution in form of algorithm, simulation model as part of their proposal.

4.1.1.11. Design & Simulation of baseband technologies for LEO Broadband communication

The LEO Broadband Communication Network consist of Ka/Ku band user terminal, Space segment & Ka-band Satellite Gateway. Satellite Orbit propagation & Scheduling, automatic antenna pointing/beam

steering, beam acquisition/ switching, Space resource management, Satellite handover & security are the major technology challenges.
Researchers are encouraged to propose innovative efficient solutions/algorithms for above challenges.
Researchers may also propose detailed hardware & software architectures of various baseband systems in User Terminals & satellite gateways.

4.1.1.12. Design & Simulation of waveforms for Extremly Low SNR Satellite communication

Recently, the satellite communication sector is witnessing rapidly increasing demand in the field of mobile broadband & IoT applications. Such applications require development of miniaturized, low-cost & low power user terminals which can operate at extremely low SNR (<-30dB) with minimal compromise on bandwidth efficiency.
Researchers are encouraged to propose innovative efficient waveforms along with advanced signal processing algorithms for robust acquisition, synchronization & reliable operation of receiver under dynamic channel conditions (extremely low SNR & high Doppler). Additionally, researchers are encouraged to propose efficient multiple access schemes & signal processing technologies for achieving maximum capacity in the satcom networks employing proposed waveforms.

4.1.1.13. Enhanced Spread Spectrum Aloha Technology Development

Enhanced Spread Spectrum Aloha (E-SSA) is an asynchronous access protocol especially conceived to provide messaging services over the satellite return link. Protocol is slightly modified version of the robust 3GPP Wideband Code Division Multiple Access (W-CDMA) random access waveform (asynchronous burst transmission). The absence of synchronization mechanisms simplifies deployment and activation of the terminals. A wide range of applications based on burst transmissions not significantly capacity-demanding have been envisaged, such as telemetry, environment and traffic monitoring, emergency alerts, fleet management, highway tolling, forecast predictions.

Researchers are encouraged to submit their proposal for ESSA system simulation and Receiver design and implementation plan.

4.1.1.14. IoT enabled terminal development

Implementation of IoT/M2M via satellite deals with mainly two issues: First, the physical layer level: terminal related constraints (limited in power, energy, and antenna size), channel (potentially with masking and multipath) and the space segment to ensure proper link budget allowing the communication. On the other hand, the need to provide access to the resource to a large number of terminals. The access layer should also be able to interface with larger networks architectures.

There are two possible ways of realizing IoT/M2M via satellite. The first scenario involves the use of a satellite relay terminal that interfaces with terrestrial access technology sensors (backhaul communication link). The second scenario is based on direct communication with sensors / objects via satellite constellation.

Research proposals are invited for implementation of low power, low cost terminals, waveforms and other sub-system technology to support IoT over Satellite & Terrestrial networks.

4.1.2. Ground Segment Network and Hardware Technology Development

4.1.2.1. Indigenous VSAT sub-systems technology development

In current scenario, there is another requirement of indigenization of various baseband subsystems of VSAT terminals. VSAT remote terminals have stringent power/size & operational requirements which results in miniaturization of RF & baseband subsystems.

Researchers are encouraged to innovate and submit proposal for indigenous design and development of following sub-system of VSAT technology:

- Mass-manufactural, efficient low cost design solutions of RF Sub-systems (Battery Disconnect Unit (BDC), Block upconverter (BUC), Supplier Security and Privacy Assurance SSPA etc.)
- Rapid Deployable VSATs :Rapidly deployable VSAT terminals is another important technology for quick emergency disaster communication .These design of such terminals involves advanced antenna & RF technology including supported by state-of-the-art baseband technology for quick antenna pointing & establishing reliable communication link from a mobile platform having limited power/space availability .These terminals should also extend interface to terrestrial devices for providing backhaul connectivity through satellite.

4.1.2.2. Development of Low Profile Ku/Ka band terminal for Mobile Satellite Service

ISRO is aiming at realizing the mobile satellite service in Ka-band .Researchers are encouraged to submit their proposal for Ka-band Mobile Satellite Service system solutions with their feasibility and recommendations; Proposals for terminal design, Proposal for protocol stack development for seamless overlay with existing MSS services, in case needed .Innovative ideas are encouraged from researchers towards providing reliable MSS services in Ka-band along with sub-system design proposals .

4.1.2.3. Portable HUB baseband system development (ESIM)

Earth stations in motion (ESIM) address a complex challenge – how to provide reliable and high-bandwidth Internet services to what are – literally – moving targets. They provide broadband communications, including Internet connectivity, on platforms in motion. There are currently three types of ESIM: ESIM on aircraft (aeronautical ESIM), ESIM on ships (maritime ESIM) and ESIM on land vehicles (land ESIM). Earth Stations in Motion (ESIMs) are the result of the most modern satellite technological developments and are designed to be used on aircraft, ships and land vehicles. They are small size terminals, with high-precision tracking capabilities, associated with state-of-the-art Ka-band satellites providing high-power multiple spot beam coverage, allowing transmission rates in the order of 10-50 Mbits/s.

Recognizing that there is a need for global broadband mobile-satellite communications and that part of this need could be met by allowing ESIMs to communicate with fixed-satellite services (FSS). The advances in satellite and earth station technology make ESIMs the best solution for users on the move and bring the benefits of high performance FSS networks to communities that have yet to benefit from true broadband offerings.

Researchers are encouraged to submit their proposal for design, development and implementation of different ESIMs.

4.1.2.4. Internet Protocol for Satellite Network

In recent years, many routing algorithms have been proposed for LEO satellite networks. Routing Internet traffic over satellites can be addressed using two alternative approaches. We can simply consider each satellite as a node in the Internet and use a traditional protocol stack. However due to the long round trip time (RTT) delay between the satellites and the terrestrial infrastructure, problems such as routing instability and slow convergence will be even worse than only using the terrestrial Internet. On the other hand, we can consider the satellite network a separate autonomous system (AS), with its own protocols. In this case, an IP packet will be encapsulated in a suitable way when entering the constellation, and rebuilt when inserted back in the terrestrial network at destination. The routing problem is divided into two sub problems: Up-and-Downlink (UDL) routing and Inter satellite link (ISL) routing.
Again, to ensure quality of services, research in this field is growing and there are various open issues and research areas in the field of Satellite Networks like –

- Reducing the routing overhead of a dynamic QoS routing in a different traffic is a challenge
- GEO satellites have advantage of technological maturity and good coverage but due to high delay and attenuation limits, transmitting real time information becomes a problem .A single layer LEO satellite network has poor performance on transmitting long distance .How to combine advantage of both the satellite to improve network performance

Multicasting datagram in the satellite networks to achieve larger coverage area on the terrestrial infrastructure is also a potential research area.

4.1.2.5. Adaptive protocol

To cope with the highly dynamic behaviour associated with the wireless environment and mobility, it is widely recognized that protocols should be able to adapt to a wide variety of situations. While protocols in the wired network also adapt to different conditions in a very limited way, usually at connection-setup time. Once a connection in a wired network is established, the underlying conditions will remain relatively stable, other than occasional congestion. This is often not so in wireless mobile networks. The wireless link experiences a range of conditions e.g., fading, transient service outage, high error rates, burst error patterns, and highly unpredictable traffic on shared links. Furthermore, mobility exacerbates the situation by introducing handovers, motion-induced effects, rerouting actions, and limited battery life.

Adaptive protocols provide productive ground for advanced protocol research. As nearly all protocol research has been done on relatively static protocol architectures, there is much to learn about how to select a different protocol on the fly when the original one no longer provides the required level of service. Protocol adaptation may be realized in several ways. Active networking, in which packets may contain executable instructions (in addition to headers and data), provides one approach to implementation. The efficient implementation of adaptive protocols in both hardware and software present interesting research problems. Some of the challenges are listed below:

- End-to-end protocol design that dynamically switches from one interface to the other, transparently to the application and its user
- Protocol stack development to support adaptiveness
- Development of principles to allow on-the-fly protocol selection in wireless mobile networks . Identify techniques for deciding when to select a new protocol, for switching protocols, and for efficiently implementing this feature in software and hardware .

4.1.2.6. SATCOM in Non-Terrestrial Network (NTN)of 5G

With the advent of 5G terrestrial network, Satellites are being proposed as an integral NTN component. ISRO is keen on extending its reach to be a part of next generation 5G communication, especially in the light of new satcom policy of the Govt of India.

Researchers are encouraged to submit their research proposal for system and sub-system design for facilitating NTN component in 5G using SATCOM.

4.1.2.7. Q/V Band Propagation Study

Presently Alphasat is the only satellite operating in Q/V band for European region available for such studies. Recently with GSAT-29, ISRO had established a limited capacity communication system for experimental purpose between Ahmedabad & Delhi. Due to congestion in higher band and bandwidth availability & demand, a very strong push for Q/V band is expected in future. Very high signal impairments and no availability of validated models for the Indian Region indicate a need to investigate this hereunto neglected area. These will serve as vital input for future satellite designs and deciding QoS and availability figures. Modelling and associated mathematical studies, development or realization of RF subsystems, beacon from satellite, pan-India study; Academia & Foreign Collaboration may be explored.

4.1.3. ASIC Technology Development

4.1.3.1. Design and Development of miniaturized, multiband S, L, UHF band / (S-band Low Power Wideband Transceiver Mixed Signal ASIC for SATCOM terminal

- The mixed signal ASIC will comprise of comprise of front-end LNA, filter, transceiver with built-in LO for full duplex operations, gain& filter blocks, ADC-DAC etc. The selected architecture should have all imbalance measurement and compensation techniques built into it. The device calibration feature will be an added advantage.

- The research proposal should address the development of low power, low cost custom RF wideband transceiver ASIC in S/L/UHF-band to support communication using miniaturized handheld and battery operated SATCOM terminals. The proposal should include all specifications of each sub-block, the reconfiguration parameters etc.

4.1.3.2. Design and Development of RF-ASIC to support implementation of low-power, cost-effective electronic beam steering capabilities for aero- mobile communication in Ka/Ku band.

Aero-Mobile terminal in Ku-Band/Ka-Band with beam steering capability could be miniaturized using RF-ASIC .

Researchers of this domain are encouraged to submit their proposal for design and implementation of RFIC for miniaturized, power and cost efficient terminal implementation.

4.1.3.3. Development of low cost terminal with Commercial-off-the-shelf (COTS) ASICs for RF front-end (MMIC and LTCC based RF Frontend for miniaturization)

The important aspect of any terminal is it being hand held and light weight this trend we have observed in terrestrial mobile phones as day by day they are becoming light and small. If we consider the Satcom terminals, the miniaturization is current necessity of the situation as to be better usable and appealing for the consumers. The miniaturization is happening on the baseband front by the development of Application Specific IC's and single board setup where whole baseband is being included. Hence, the miniaturization on the RF part needs to be done in order to decrease the weight and the size so that the whole terminal can be small and light.

There are a few techniques to reduce size & weight of the RF section. One of the most-utilized techniques is MMIC design in place of discrete microwave circuits where discrete active and passive components are integrated using either transmission lines on different substrates chosen according to frequencies. Monolithic Microwave Integrated Circuits (MMICs) contain active, passive, and interconnect components all on single wafer and can operate at frequencies from hundreds of MHz to hundreds of GHz. The size advantage obtained is very drastic as MMIC are of size of um to mm whereas the Microphone MIC circuits are in range of cm. Most of today's MMICs are fabricated on III-V compound substrates such as GaAs, InP, and GaN. This new technique enables us to make the circuits like LNA, Mixer, Power amplifier etc on a single Silicon doped chip, which are instead made using discrete components.

Another miniaturizing technique lies in a type of packaging technology named Low Temperate Co-fired Ceramics (LTCC) where the technology is used for robust assembly and packaging of electronic components

It also offers may features like embedded components like capacitors resistors and inductors, as the passive components are available they can be utilized to make filters. The technology also allows us to make Substrate Integrated Waveguide filters. Further as the MMICs are bare dies, they need packaging, and interconnection LTCC proves to be the best option, which results in an integrated on a single RF module, which is very space efficient, and light weight. Furthermore, Antennas can also be made in order to make

a more integrated space efficient and lightweight RF module which contains everything from Antenna to the IF signal.

The utilization of all these techniques can yields us miniaturized RF frontend, which can be of similar size of that of a compact baseband card thereby yielding us a small, and light weight hand-held terminal, which can be comparable to modern day mobile phones.

- **Modem ASIC development for Ultra High Data Rate System)100 Mbps -2 Gbps(**

- **Mixed Signal ASIC development with built-in low cost SATCOM transceiver for various low-power IoT applications.**

4.1.3.4. Power Saving technique)Backend ASIC design(of ultra-low power Software Defined Modem (SDM) ASIC

Satcom baseband modem ASIC is being developed for various Satcom ground applications. Typical application of Modem ASIC, which are battery, operated & demands low power consumption. The Modem ASIC supports multiple mod-code & wide range of data rate. Based on application ASIC is configured by Serial Peripheral Interface (SPI)/ Universal Asynchronous Receiver-Transmitter (UART) interface. Currently even when a simple configuration is running, the power of entire core is ON and the clock is active.

Idea is to implement various power saving technique in frontend/backend ASIC design to suspend functionality of partial design or full design based on applications. Following power saving modes can be thought of considering nature of applications:

a. **Fully sleep mode** :This mode is very useful in case of burst transmission & reception .Device will consume minimal power when not active .In this case, only configuration core is always active . Modem core is enabled whenever required & kept shut for rest of the time.
   Typical applications :Reporting Terminal,
b. **Partial sleep mode:** This will be useful in almost all applications .This mode will disable the non-functional block for a particular configuration .In only Viterbi is used is active then other decoder should be shutdown .Entire receiver chain can be turn off in case of transmit only terminal & vice-versa .
   Typical applications :Two way MSS Vessel tracking terminal

Sleep mode can be implemented using following methods

i.Clock gating
ii.Power gating
iii.Multi-Voltage level

4.1.4. Applications and Tools Development

4.1.4.1. Development of Hybrid Network for Real-time Person or Asset Tracking using Machine to Machine Communication Technology and Indian Navigation System.

Currently, ISRO has developed satellite-based solution for tracking of personnel and assets like vehicles and fishing boats. Although this solution is extremely useful in remote locations where terrestrial, network coverage is sparse or not existing at all, there is similar need for such solutions in areas, which are widely covered by terrestrial networks. A hybrid solution is proposed which can enable communication of mobile terminals using both SATCOM and terrestrial networks. This will greatly save the satellite resources and enable us to serve more number of users.

The network will consist of terminals having the ability to communicate their location and other significant information with the hub via satellite and terrestrial networks. The terminal will be equipped with NavIC receiver to detect its location. It should have the intelligence to detect the availability each of this network and switch between them as and when required.

As an extension of this functionality, the terminal should be intelligent enough to detect the presence of similar neighbours (terminals) around it. This may be achieved via point-to-point communication using Bluetooth/Wi-Fi. The Hub can also assist in finding neighbours. The terminal can find its neighbours and can directly contact them in emergency. A smartphone may interface with the terminal for visual representation of location and other information. Mobility management and interface for interaction between terminals also needs to be developed.

- **Development of Spectrum and Waveform Analysis tool using low cost SDR platforms.**
- **Hub No Man's Sky (NMS), Network Control Program (NCP) and Web-based tools for effective Decision Support System**
- **Propagation studies, Advance Fecal Microbiota Transplantation (FMT) development and inclusion for improved QoS**
- **SATCOM System definition, Unified protocol stack and Test Bed development of 5G with Non-Terrestrial Networks (NTN) element**
- **NTN standardization efforts and Capacity Development Activities**
- **Development of mobility management algorithm and Hub Network Management System for different application**

4.1.4.2. Satellite Communication On The Move (SOTM)

Satellite communications-On-The-Move (SOTM) is a communication capability used for high speed satellite connectivity in moving vehicle. SOTM terminal with vehicle mounted automatic tracking antenna will provide two-way, high-speed communications on the move under various operational conditions using HTS (High Throughput Satellite). Using SOTM terminal, it is possible to provide high

speed satcom connectivity for aero-mobile, land or marine applications. ISRO has developed prototype Ku band SOTM receive terminal with 0.6m antenna using 2 axis (Az and El) stabilized servo based system and demonstrated it for live DTH reception in moving vehicle.

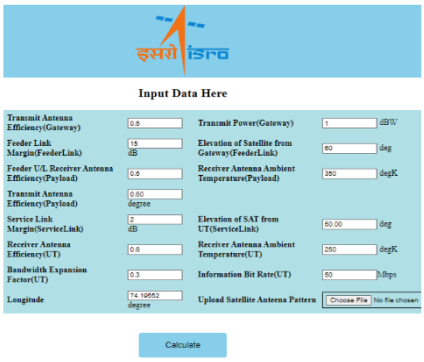
Research proposals are invited for

- Mechanism and Control system design for 3 axis/4 axis automatic antenna steering and tracking of targeted satellite within +/- 0.1 degree accuracy for Ku band transmission.
- Solutions for estimating highly accurate heading information by INS (Inertial Navigation System)/ Sensor in dynamic magnetic environment. Magnetometer is not providing proper heading under dynamic magnetic field condition.
- Technology for Low cost INS with GNSS without compromising performance
- Compact and light weight Ku/Ka band flat panel/planner array antenna/ Carbon Fiber Reinforced Polymer (CFRP) reflector for mechanically steered transmit-receive SOTM system
- Design and development of efficient electronic beam steering system for Ku/Ka band operations as well as hybrid scanning system (electronic + mechanical)
- Design and development of system to test pointing accuracy of SOTM in lab environment and algorithms to find out misalignment.

4.1.4.3. Satellite Network Simulator (SNS)

The project's main objective is to develop a Satellite Network Simulator, which is used to generate and collect data-driven insights into the satellite network-level planning and design activities. The simulator will allow an estimation of bandwidth and power requirements to attain a target system-level capacity. The simulator will model the Variable Coding and Modulation (VCM), Adaptive Coding and Modulation (ACM), and Uplink Power Control (ULPC) systems that will be executed in an operational satellite network. Using the simulator, the system engineer will determine the attainable data rates attained in the clear sky and the rainy conditions and gather insights into the potential avenues of removing or reducing the bottlenecks so that the overall system capacity is improved.

Home Page of Simulator



Link budget Page

SNS is being developed in Python language with features viz. to carry out the forward and return link budget calculations, rain fade modelling, capability of providing DR site suitability recommendation, ULPC/ACM simulations, selectable DVB-S2 and S2X modcods in both forward and return link and evaluation of system availability. It will be useful for System engineering, network planning, throughput evaluation at different fading levels of existing & future High throughput satellites in higher frequency bands.

4.1.5. New Frontiers in SATCOM

4.1.5.1. Development of High Data Rate (HDR)/ Ultra High Data Rate (UHDR) modems for Home broadband service

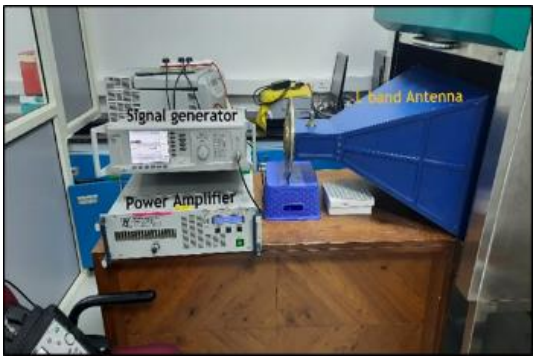
SATCOM based Home broadband service is one of the emerging field .Ultra High Data Rate Modems will be essential component of this technology .These modems should be capable of supporting upto 1Gbps receptions capability for offering broadband services equivalent to terrestrial broadband, to remote users . The major design challenges for such UHDR modems include reconfigurable hardware platform & high-speed data processing subsystems including demodulation loops, high throughput advanced FEC Encoder/Decoders & multi-core baseband data processing engines.

4.1.5.2. Indigenization of Future HTS Gateways

ISRO is inclined towards providing Direct to Home Broadway connectivity using HTS Satellites. This will require Gateways & antenna system in large quantities. Aim is to bring down the overall cost with indigenization efforts. Today, across the globe three major market players are operating and have maximum market share. The trend is to implement gateways in frequency band of Ka or higher band.
Researchers and Industry partners are encouraged to innovate and propose efficient design of 9/11m antenna system, RF-sub-systems, NavIC based TFGU, Hub Monitoring and Control System, Antenna Tracking System etc. which can reduce design and production lead time, be cost effective and mass producible design.

4.1.5.3. Device and method for fragmenting virus/microbe using RF radiation

A non-thermal method of virus inactivation (in-vitro) especially SARS-CoV-2 by physically fracturing the viral outer envelope using microwave radiation at its precise natural frequency has been developed at SAC. A generic theoretical approach has been identified to calculate the natural frequency of any spherical virus. Nanoparticle Tracking Analysis (NTA) & real time Real Time Polymerase Chain Reaction (RT-PCR) analysis was performed to test the efficacy of the developed prototype on Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). On detailed analysis of test results it was found that the device was efficient enough to eliminate up to 99% of SARS-CoV-2 upon one minute of exposure. Antiviral efficacy of developed prototype is successfully tested for various virus contaminated surfaces such as glass, metal, ceramic and laminate and achieved up to 99.99 % SARS-CoV-2 viral elimination within five minutes of radiation exposure time.



Experimental test setup using Satcom subsystems to validate the concept of viral fragmentation upon microwave exposure at its natural frequency.

Miniaturized device prototype developed by SAC/ISRO for corona virus fragmentation using microwave radiation.

Research Areas include:

- Design and development of miniaturized decontamination system which removes airborne contaminants -- such as biological (virus/microbes) and chemical impurities.
- Implementation of the technology for destruction of mosquito larvae at an early stage.
- Sanitization of spacecraft using resonance frequency technique to avoid spread of microorganism during interplanetary travel.

4.2. Satellite-Based Navigation (SATNAV) Technology & Applications

India has developed its own navigation system named NavIC (Navigation with Indian Constellation). The NavIC constellation is a combination of GEO and GSO satellites which are presently transmitting L5 (1176.45 MHz) & S (2492.028 MHz) band signals that are received by the user devices equipped with NavIC receivers. In receiver segment, various types such as User Receiver, Reference receiver, Timing Receiver and messaging receivers are being developed by SAC and through transfer-of-technology (ToT) and other collaboration modes, by private companies. These receivers are capable of providing pseudo-range (Code phase) and carrier phase measurements which can be processed to provide metre- to cm-level position accuracies. Real Time Kinematic (RTK) solutions based on differential positioning concept and Precise Point Positioning (PPP) are techniques used to provide very high accuracy positioning upto cm-level accuracy. Receivers equipped with these capabilities are usually dual frequency equipment and use very precise carrier phase measurements. These receivers have very wide applications in the field of survey & land records, geodesy, 5G, testing driverless / autonomous cars and precision agriculture. Also, NavIC chips as well as NavIC-in-mobile platforms are coming up and may be used for ubiquitous location-based services etc.

Furthermore, there are various scientific and technical applications which can be addressed by using NavIC and other GNSS receivers, Inertial Navigation System (INS), ground-based navigation system such as Pseudolite system developed at SAC etc. Different algorithms are required to process these multi-constellation receivers equipped with INS and other navigation aids. Therefore, new algorithms, software

and solutions are required to be developed. This document highlights various research areas in Satellite Navigation to cater applications in various fields. Use of GNSS measurements has also been very promising in meteorological applications such as estimation of Integrated Water Vapour (IWV) which is ingested in Numerical Weather Prediction (NWP) models etc. Space weather is also one of the very important aspect which is being addressed using GNSS signals.

This section relevant to applications deriving from ISRO's navigation satellites constellations is broadly divided into two major segments of technology development and GNSS applications which largely include scientific applications also.

4.2.1. Technology Development

NavIC signals in general may be prone to interference with other GNSS satellite signals such as GPS, Galileo and Beidou. The NavIC S-band signal in particular may experience interference from commercially used S band spectrum by Wi-Fi and WiMax services. Therefore, interference/jamming detection and mitigation algorithms and techniques need to be vitally developed.

4.2.1.1. Interference/Jamming Detection & Mitigation

1. Pulse Blanking
2. Adaptive Notch Filtering
3. Control Radiation Pattern Antenna (CRPA)
4. Spectral filtering using FFT/ Inverse Fast Fourier Transform (IFFT)
5. Short time Fourier Transform
6. Wavelet Transform
7. Robust Statics

4.2.1.2. Spoofing Detection/Mitigation

Spoofing of GNSS signals has drawn a lot of attention due to increased risk among GNSS users especially by defense and strategic users. Spoofing is the intentional transmission of fake GNSS signals to divert users from their true position. This may fool a receiver to output wrong position. This may prove hazardous, even fatal in a strategic scenario. Following are the activities which may be taken up for development:

1) Automatic Gain Control AGC gain monitoring
2) Spoofing Detection using Receiver Autonomous Integrity Monitor (RAIM) with/without INS coupling
3) Angle of Arrival Discrimination
4) Signal Spatial Correlation
5) Correlation of Propagation-Dependent observables
6) Polarization Discrimination or Dual Polarization Antenna (DPA)
7) Sum of Squares (SOS) Detector
8) Cross-checks between code & carrier-phase measurements from different frequency bands

4.2.1.3. Configurable GNSS Universal Correlator Architecture ASIC

New GNSS Baseband ASICs process maximum civilian GNSS signals due to multiple advantages such as increased PVT accuracy, availability etc. A universal configurable correlator architecture comprising of acquisition and tracking channels is therefore required to process civilian GNSS signals which have:

1) Various modulations (BPSK, MBOC, TMBOC, Quadrature Multiplexed binary offset carrier (QMBOC), AltBOC)
2) Permanent Registration Number PRN code length,
3) Chip rate

4.2.1.4. GNSS-INS Integration

GNSS signals are highly vulnerable to jamming but provide very accurate position. However, INS cannot be jammed but position accuracy degrades after some time, primarily due to drift. Therefore, GNSS-INS integration is one of the most robust solutions to be offered to navigation users. Such kind of receivers are very useful where GNSS signals are obstructed such as inside long tunnels, indoors, under foliage, hilly terrain, urban canyon scenario, etc. Following are the techniques which could be addressed:

1) Loosely-coupled GNSS and INS integration
2) Tightly-coupled GNSS and INS integration.
3) Deep-Coupled integration

4.2.1.5. GNSS Weak Signal Acquisition & Tracking

[A] High Sensitivity Receiver

The sensitivity of a baseband signal processing (acquisition & tracking), is critical for a GNSS receiver to function in weak signal environments. Typical Line of Sight (LOS) GNSS signals power is around -130 dBm. Attenuation due to foliage, tall buildings results in signal power level upto -160 dBm or lower. Very efficient FPGA hardware implementation is required.

High Sensitivity Navigation Receiver for Commercial Applications
GNSS Receiver Algorithms for Space Service volume/Lunar mission type applications

[B] Open Loop Navigation Signal Processing

4.2.1.6. Development of CMOS /BiCMOS RFIC

SAC is involved for design and development of NavIC based receiver for broad range of applications, like Civil, Military and Space applications. It is required to develop Complementary Metal-Oxide Semiconductor (CMOS)/BiCMOS Bipolar Complementary Metal-Oxide Semiconductor, Radio Frequency Integrated Circuit (RFIC) to have multi-chip module solution along-with indigenous baseband ASIC and to have miniaturized NavIC Rx. for various applications.

Commercial and space grade RFIC is required with the following blocks:

1) Tri band integer PLL/ Fractional PLL.
2) Triband / wideband LNA
3) Image reject Mixer Narrow band and wideband
4) Variable gain amplifier
5) Low drop out regulator
6) Complex filter for IF range
7) SPI interface to control the overall receiver block
8) Multibit ADC: Multibit low power ADC is required to meet high Anti-jamming capability.

ADC specifications:

a. Bit resolution: 16 bit
b. SFDR: 86dB
c. Sampling clock: 50MHz
d. ENOB: >14 bits

9) MEMs based Temperature Compensated Crystal Oscillator (TCXO):

Satellite application of space-grade NavIC receiver required high acceleration sensitive TCXO. MEMs based TCXO can meet the 0.5 ppb/g acceleration sensitivity. MEMs based capacitive resonator is suitable choice for space application and piezo resistive resonator can meet ground application.

4.2.1.7. Construction and selection of balanced and near balanced Pseudorandom Sequences with lower correlation values and large linear complexity

Spreading PRN codes are utilized in satellite navigation for ranging, spectrum spreading and satellite identification in Code Division Multiple Access (CDMA) based GNSS systems. Considering future navigation signals, there is an increasing demand of spreading codes families of various Length, family size, and correlation properties PRN sequences to be used in communication and satellite navigation should have certain statistical and correlation properties. While designing a sequence for satellite navigation, it is desirable for sequence to be balanced, have low value of out of phase auto-correlation and cross-correlation, have well behaved distribution of one and zeros and should be easily implementable in hardware. Since the sequences in sequences in the field of satellite navigation are also modulated by data or overlay codes thus, it is also desirable the sequences have low values of out-of-phase odd auto-correlation and odd cross-correlation as well. Sequences with longer length or time-period greater than few milliseconds are often partially cross-correlated in a navigation receiver. Large linear complexity sequences are a potential candidate for signals with anti-spoofing capability. This work involves designing of a PRN code family where each PRN sequence of the code family should have the properties of randomness. The code family set should have sufficient number of codes to satisfy a global constellation of satellites and enough for supporting the augmentation system, if any. It also involves selection criteria determination and to compare the performance of a set of codes against the performance parameter matrix to find optimum codes. Performance parameters for code selection include sequence balance; run length, orthogonality, auto- and cross-correlation histograms at various Doppler offsets, excess line weight and values for the low auto-correlation functions.

4.2.1.8. Design and Development of True Random Number Generators

Random numbers are of paramount importance in field such as cryptography, Monte Carlo simulations, randomized algorithms etc. In contrast to Pseudo Random Number Generator, physical (true, hardware) random number generators extract randomness form physical processes that behave in a fundamentally nondeterministic way, which makes them better candidates for true random number generation. TRNG are useful for key generation in field of encryption and authentication of satellite navigation signals. This work objective is to develop a true random number generator, which produces random numbers that passes through the criteria of randomness, which is given by a series of statistical tests of National Institute

of Standards and Technology NIST Test suit, Diehard battery of randomness tests etc. In general, TRNG suffers with unequal probability of occurrences of one and zero which is known as bias. Thus, the developed TRNG should also include the post processing mechanism of bias removal. Some of the RNG constructions are as follows-

- Noise-based RNGs
- free running oscillator RNGs
- chaos RNGs
- quantum RNGs
- The resources utilized by TRNG, its throughput and frequency of operation are some of the design criteria which needs to be considered while choosing an architecture. The generated random numbers should pass through randomness property measured using statistical tests.

4.2.1.9. Multi constellation and multi frequency GNSS positioning algorithms

Owing to the complementary nature of the various GNSS signals / services, there is a worldwide trend for deriving position solutions of more than one GNSS signal. Known as multi-GNSS, this has the potential of providing an accuracy superior than any of the GNSS signals when used singly; complementing the number of satellites in case of lower availability and / or blockage and extension to the space service volume (SSV). Employing more than one frequency (multi-frequency) to obtain the positioning solution offers the advantages of enhanced accuracy, resolution of ionospheric effects, etc.

Potential research areas in these two domains may be satellite selection, triple-frequency for ambiguity resolution, inter-system/signal/frequency bias estimation, etc.

4.2.1.10. GNSS Security, Vulnerability, Encryption, Authentication

1) Key exchange Algorithms: IRNSS RS service for authorized users involves encryption and to improve security, encryption keys are changed regularly to avoid brute force attack and cryptanalysis from unauthorized users. IRNSS RS receivers deployed in field will have to be communicated with changed keys.
2) Key Distribution/Key management for GNSS strategic applications
3) RAIM, Advanced RAIM and TRAIM Algorithms
4) Spreading Code Encryption for very long code using stream/block ciphers
5) Block-chain technology for authentication/security of GNSS services
6) Geo-encryption
7) Message Authentication Techniques for NavIC

4.2.1.11. Precise Satellite Relative Location Estimation System for Tandem Satellites operation

Design & development of “precise Baseline/Orbit determination system” for Tandem Satellites operation. Following are important research area in this topic:

1) High-precision GNSS receiver
2) Precise orbit & Baseline determination
3) Implementation Dynamic Force Models
4) High-precision orbit propagation

4.2.1.12. Navigation Simulators

The design and development cycle of GNSS Receivers is highly dependent on the signals provided by GNSS Simulators right from conceptualization to product development cycle. Following are important research areas in Navigation Signal Simulation:

5) Low-cost NavIC Simulator
6) Handheld GNSS Simulator
7) Interference Simulator for GNSS bands
8) Low-cost Navigation Educational Kit
9) Seamless indoor/outdoor navigation with NavIC and other Signals of Opportunity/Technologies
10) LEO GNSS and NavIC + LEO GNSS Simulators

4.2.1.13. Software Defined Radio (SDR) based NavIC system Development

SDR is a popular trend that allows the configuration of generic receivers that may be customized based on specific user requirements. Potential domains for research proposals in this area may be:

1) NavIC-GNSS receiver
2) NavIC-GNSS simulator
3) SDR for RTK and PPP
4) SDR for Pseudolite-based navigation System.
5) SDR for GNSS + Pseudolite System

4.2.1.14. Pseudolite-NavIC-GNSS receiver algorithm Development

Pseudolite System is ground-based navigation system which may provide very accurate position within a localized area. These are low-cost systems and can be easily integrated with other GNSS systems. Following topics may be taken for development of new algorithms:

1) Successive Interference Cancellation to mitigate near-far problem in Pseudolite
2) Pseudolite-NavIC-GNSS hybrid user position algorithm/ Extended Kalman Filter (EKF)/ Unscented Kalman Filter (UKF) based algorithms
3) Time synchronization algorithms with GNSS
4) Signal acquisition & tracking in pulse-CDMA mode
5) Pseudolite indoor-positioning algorithms
6) Multipath mitigation algorithm
7) Algorithms for bi-directional Pseudolite based system for interplanetary scenario like Mars, Moon etc.
8) Pseudolites for landing application at Indian airports

4.2.1.15. LEO GNSS:

Position, Navigation and Time (PNT) services can be provided by mega-constellations in LEO orbits, which are otherwise primarily meant for providing communication and broadband internet services across the globe. Following are the research areas in this domain:

1) System engineering aspects
2) Doppler Positioning and Velocity Algorithms
3) New navigation processing algorithms for acquisition and tracking
4) GNSS+LEO constellation designs and algorithms

4.2.1.16. Differential Positioning & RTK Receiver Algorithm Development for NavIC

Differential positioning is a technique which provide cm-level accurate position and transmits corrections from a base or reference receiver at accurately known location to a rover receiver through UHF/VHF link. This technique assumes that both base and rover receivers are observing common set of satellites. Differential positioning is performed using both pseudo-range and carrier-range measurements. Following algorithms may be developed:

1) Integer Ambiguity (AI) resolution in carrier-phase measurements
2) Carrier Phase-Based Positioning
3) Low-cost single frequency RTK receiver algorithms
4) RTK correction generation & dissemination module in RTCM format
5) GNSS Corrections: RTK, RTK-PPP, PPP
6) Network RTK for India
7) NTRIP based interface for NavIC
8) High-accuracy Post-processed RTK positioning algorithms

4.2.1.17. Precise Point Positioning (PPP) Receiver Algorithms

Precise point positioning (PPP) is a technique using Global Navigation Satellite System (GNSS) satellites to achieve decimetre level or better position accuracy using a single receiver. This technique relies on the availability of highly precise ephemeris and clock products from a network of reference receivers without using a base station. PPP also requires a dual-frequency receiver with precise carrier range measurements. However, nowadays single frequency-PPP is also being attempted by researchers. Precision usually in this case means a horizontal position accuracy of 10 cm or better.

1) Precise ephemeris & clock product generation & dissemination
2) EKF-based PPP algorithms
3) Low-cost single-frequency PPP algorithms
4) Multi-constellation PPP
5) PPP-AR (Ambiguity Resolution) algorithms
6) High accuracy Post-processed PPP algorithms
7) PPP-INS positioning algorithms
8) PPP-RTK positioning algorithms
9) PPP with Pseudolite or GNSS + Pseudolite system

4.2.1.18. Atmospheric Studies

NavIC L5 and S Band signals along with other GNSS signals can be used for estimation of better ionospheric TEC and relevant model development. These signals are useful for ionospheric scintillation studies and also for tropospheric model development.

- Ionospheric studies over the Indian Region
  a. Real-time ionospheric Total Electron Content (TEC) & scintillation map generation
  b. Ionospheric tomography model development
- Tropospheric Studies
  a. Tropospheric model development for Indian region
  b. Tropospheric mapping function development
- Weather Monitoring and forecast through NavIC S-Band
  a. Thunderstorm detection using Machine Learning/Deep Learning Techniques
  b. Multipath and Soil Moisture model development using AI/ML/DL

4.2.1.19. Other Topics

1) Short delay Multipath Mitigation Techniques in GNSS Receivers
2) S band interference in Satcom and Satnav applications
3) Spoofing Detection: Using Multiple antennas, Signal time of arrival
4) NavIC data processing in RTKLIB
5) Robust positioning with Civilian GNSS signals.
6) Ground Testing of Rubidium Atomic Clocks.
7) Navigation Solution with Multi-Constellation.
8) Ground Characterization of On-board Atomic Clock performance.
9) Effect of Wi-Fi, 3G/4G/5G on NavIC/GNSS Signals.
10) Design of Global Indian Navigation constellation.
11) Cooperative & peer to peer positioning
12) Positioning for Autonomous systems (robot, drones, marine vehicles)
13) Time to First Fix (TTFF) reduction in GNSS receivers
14) Assisted NavIC
15) Design and development of NavIC Data Post-processing Tools (GAMIT, Berneze, RTKLIB like s/w)
16) Design of NavIC Advisory generation and dissemination (like GPS's NanU)

4.2.2. GNSS Applications

4.2.2.1. Precision Agriculture:

India is an agricultural country. Produce of agricultural products can be optimized using GNSS techniques such as RTK and PPP. This entails significant savings of equipment usage, fuel consumption, potential for manual error, etc. and can significantly enhance productivity. Following algorithms/solutions may be developed:

1) RTK-based precision agriculture solutions
2) PPP-based precision agriculture solutions
3) Low-cost or community-based solutions (e.g. village-level)

4.2.2.2. Mobile Application Development

- The availability of NavIC-enabled mobile phones will provide improved accuracy and availability as these mobile phones use all-in-view (multi-constellation) based processing. Besides GNSS, other sensors in the mobile phones can aid in improving accuracy as well as availability of position solution in the places with weak or blocked GNSS signals. Mobile applications can be developed for fusion of GNSS and sensor data for location-based services.
- NavIC-GNSS mobile App for location based services using GIS map
- Mobile-based train tracking App for Railways including paperless ticketing
- NavIC/GNSS based Navigation App for blind/physically impaired person
- Android Studio based positioning using raw NavIC/GNSS observables
- NavIC/GNSS anomaly reporting

4.2.2.3. Scientific Applications

The following research activities may be suggested for scientific applications of GNSS. One may extend this work in future for finding the cloud dynamics and even for hydrology. This, however, is possible when the measured data is highly dense in nature. With more precision in measured data, it may also be utilized for finding the cyclonic condition and movements. Especially, NavIC S-band signals may be very useful for weather studies. Also, networked GNSS data may be utilized for earthquake research and hazard mitigation. Data from available network over India, may be collated, in one hand to find the crustal movements, while the post-earthquake signatures on ionosphere may be studied, on the other hand, to identify and index the strength of the earthquake and its extent.

1) Modelling Equatorial TEC perturbation
2) Forecasting of ionospheric scintillation
3) Integrated Water Vapour (IWV) estimation using GNSS
4) Cyclone tracking & Precipitation prediction
5) Seismic studies using TEC

4.2.2.4. Other Applications

1) Marine Applications
2) Disaster Management using GNSS & GAGAN
3) NavIC/GNSS-based navigation for UAV
4) GIS application involving NavIC/GAGAN and ISRO's geospatial database Bhuvan
5) GNSS based spacecraft attitude determination
6) Application/software for vehicle parking system including automatic toll collection
7) NavIC based biometric bracelet
8) Low-Cost Surveying and Land Record Mapping using NavIC & GAGAN Receivers
9) GNSS for Smart City applications
10) IRNSS Messaging based Applications
11) Timing Applications of NavIC

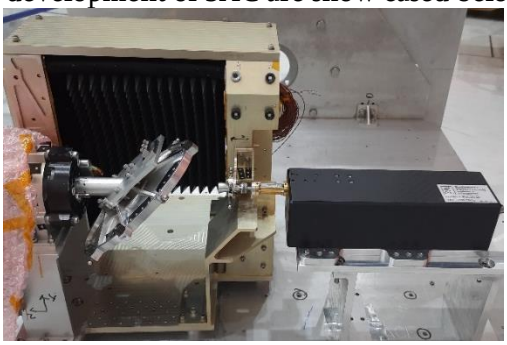
5. ANTENNA SYSTEMS

Antenna Systems Group (ASG) is involved in the design and development of antenna systems for satellite (communication, navigations and microwave remote sensing) and ground applications.
Few of the antenna technologies recently developed and used in different missions of ISRO are listed below,

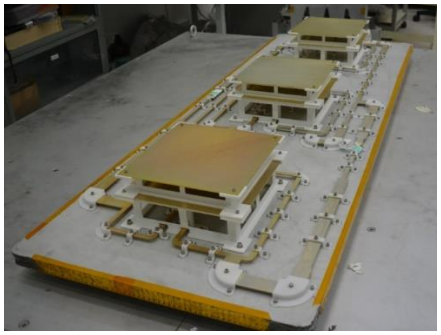
i) Shared Aperture Tri-band Antenna (L1/L5/S-bands) for navigation payload,
ii) Active phased array antennas at Ku-band, X-band and C-band etc for communication and earth observation programs,
iii) mm wave scanning reflector antenna for humidity sounder,
iv) Altimeter antenna for chandrayaan-3 and Gaganyaan misions,
v) Cassegrain multiple beam unfurlable antenna for radar imaging payload,
vi) Ka-band Multiple beam antennas with different size beam from common antenna for HTS
vii) Frequency selective surface (FSS) based S/Ka band Cassegrain antenna for data relay communication payload,
viii) THz Quasi optical Beam Waveguide (BWG) antennafor 3m /6m telescope,
ix) Active integrated GNSS band antennas for Geodetic applications.
x) Antenna for SOTM applications,

Apart from these antenna technologies, ASG has also developed various advanced technologies under R&D activities. Some of these antenna technologies viz. flat panel liquid crystal based reconfigurable antenna, metasurface antenna, multifeed per beam antenna for HTS using single reflector, shared aperture S/Ka band feed, quad band active radar calibrator antenna, GNSS reflectometry antenna, P-band SAR antenna, Q-V band Gap waveguide based array antenna etc. are developed. Currently few other technologies still under development are ultra wideband antenna (2-14 GHz) for Very-long-baseline Interferometry (VLBI) applications, digital beam forming based antenna at S-band for interference mitigation, SDR payload multibeam antenna, multilayer board based active integrated phased array antenna, planar man pack terminal antenna etc. ASG has developed few technologies for antenna measurements like planar near field test range, antenna diagnostic tool and quiet-zone scanner, antenna phase-centre measurement tool, Technique of time domain based antenna pattern measurement, Microwave Holography technique for reflector profile measurement etc.

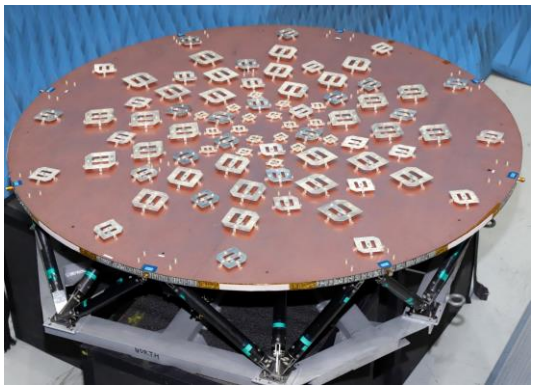
Some of the development of SAC are show cased below.



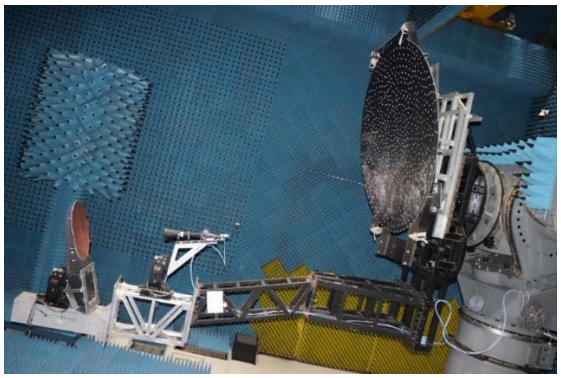
183 GHz Scanning Reflector antenna



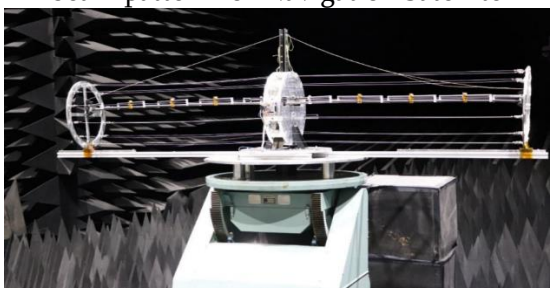
P-band SAR Antenna



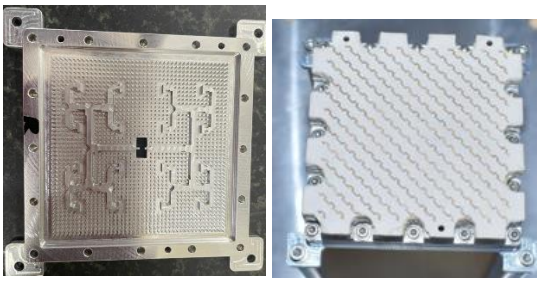
Tri-band Shared Aperture Antenna with shaped beam pattern for Navigation Satellite



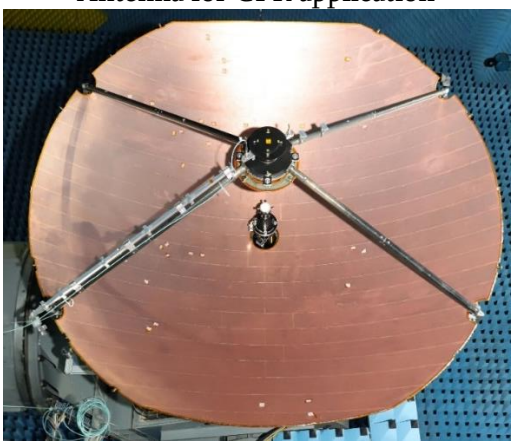
Ku-band Contoured Beam Gregorian Reflector antenna of Communication Satellite



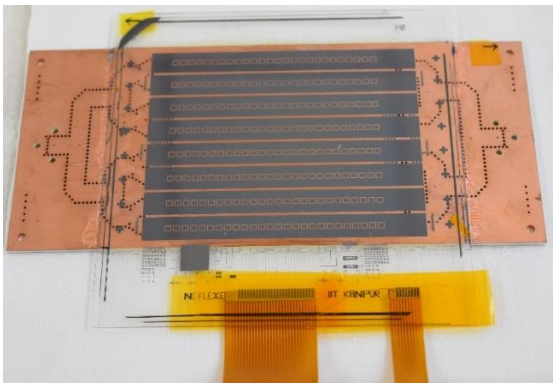
3.2m deployable , low frequency, UWB Antenna for GPR application



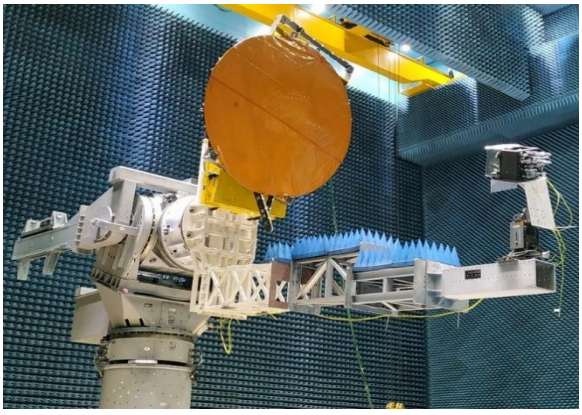
Gap Waveguide based Array Antenna



Frequency Selective Surface (FSS) based S/Ka band Antenna



Flat Panel Liquid Crystal Based Metasurface Reconfigurable Antenna



Ka-band Multiple Beam Antenna with different size beams
(communication cum RF Tracking Feed)

There are few technologies in which SAC is interested to invite research proposals from Indian academia.
They are mentioned as follows:

Research Areas in the field of Antenna

5.1. Parallel Plate Waveguide Slotted Array

Recent global trend of constellation of Small SAR satellites for remote sensing provides the opportunity for development of lightweight SAR antenna. One of the options for this can be parallel plate waveguide slotted array, which has inherent advantage of being lightweight, planar and suitable for easier deployment. The requirement is to develop a small sub-array tile and a deployable feeding network, to develop a large array antenna for lightweight SAR application.

5.2. GRIN Lens based Beam Steering Antenna

Lens based beam-forming antennas offer a low-power, low cost alternative to hybrid beamforming antenna arrays. Graded refractive index (GRIN) lens are the metastructures with a continuously spatially graded index of refraction which allows for some control of the EM radiation passing through the structure. The major advantage of use of graded index type lens (GRIN) is their capability to enhance the field of view using beam steering. Once the lens is designed with base radiator, it can be mechanically rotated to conically steer the beam. Such technology offers low profile and light weight beam steerable antenna best suited for various Ku and Ka band ground terminals being developed at SAC.

5.3. Ultrawideband Dual Polarized Vivaldi Antenna Arrays for High Resolution SAR

High-resolution SAR systems usually requires wide signal bandwidth, to achieve the fine resolution in elevation direction. Such system requires high gain Ultra wideband (UWB) type array antenna to cater such need, for both polarizations. Vivaldi array antenna inherently offers wide bandwidth performance and one of the most suitable candidate for such SAR system. Vivaldi array antennas made with PCB technology allows reducing the height and overall mass of the array as well as improved feed network losses. Vivaldi antenna being the end-fire radiator, poses the main challenge in making it dual polarized and developing it using PCB technology. The preferred operating frequency range for the required UWB array antenna is 9-10GHz with ~33dBi gain.

5.4. High gain beam scanning antenna using near-field rotatable phase correcting plates

Beam-scanning high-gain antennas are widely anticipated for future satellite based communication system and spaceborne synthetic aperture radar (SAR). The requirement of agile, slim and lightweight beam steering antenna is always preferable for the said systems. The use of nearfield rotatable phased

correcting plates to conically steer the beam is one of the state-of-art technologies, being explored world wide in different forms. Such antenna system requires the base radiator, with nearly symmetric aperture field distribution. The two phasing disc offering progressive phase shifts in the two orthogonal directions are placed in the nearfield to offer the resultant progressive phase shift to the radiating field. Such beam steering concept is based on Risley prisms in optics. Such beam steerable antenna has major advantage in term of profile and mass. SAC has requirement to develop such antenna at Ka-band.

5.5. Mechanical Beam-Steering multi panel Array Antenna

Low cost moderate gain beam steerable antenna are in urgent demand for MSS type ground terminals at S-band. Such antenna is to be designed with simple, stable, robust structure offering low production cost in commercial markets. Mechanical Beam-Steering Array Antenna (MBSA) is one of the technologies falling the similar category. Here, the phase shift is achieved by physically displacing the antenna element using motors on backside. The major advantage of MBSA is high aperture efficiency (>90%) as compared to the available competitive beam steering technologies.

5.6. Design & development of High Power Ferrite Phase shifters for RF beamforming Antennas

The proposed research work will be catering to development of high power re-configurable beam antenna systems. Design and development of Ferrite based phase shifter involves selection of different types of phase shift mechanisms. Ferrite material selection. Ferrite biasing mechanism selection. Characterization of ferrite for a given bias and computing the hysteresis loop. The design can be of analog or digital type phase shifter. High power handling design and multipaction margins to be-analyzed. Size and compactness also play a vital role as these phase shifters will be accommodated between a cluster of feeds.

5.7. Plasma antenna

The plasma antenna is an emerging technology that partially or fully utilizes ionized gas as the conducting medium instead of metal to create an antenna. The key advantages of plasma antennae are that they are highly reconfigurable and can be turned on and off, which is good for stealth and resistance to electronic warfare and cyber attacks. The plasma can be freely moved to the desired geometry of the reflector by plasma diode which enables the beam to be steered quickly without the need for mechanical motion. When the gas is not ionized, it allows other antennas to transmit and receive without any interference which is a very useful feature.

5.8. Design & Development of Terahertz Planar Array Antennas

The proposed research work will be catering THz communications and imaging systems. Developing antenna systems at terahertz frequencies will investigate many problems related to antenna realization, integration and characterization

Design and development of terahertz array antennas will involve selection of suitable radiating elements (Horn, slots, patch etc.) and design of appropriate feeding mechanism (waveguide, Substrate-Integrated Waveguide (SIW), Gap WG etc.). Emphasis should be on the antenna realization technology (silicon micro machining, metallization, Computer Numerical Control (CNC) fabrication etc.). The RF design should take care of all the limitations arising out of realization methods. The design should also address the scalability of antenna architecture to achieve higher antenna Gain. Suitability of material selection for space missions to be addressed.

5.9. Reconfigurable reflector antenna for Flexible payload

In the life span of a satellite it might be required to change the service area and for that beam reconfigurability is the prime requirement. Reflector antennas are of paramount importance for satellite communication. While unshaped parabolic reflectors are useful for generating circular pencil beams, shaped surface are useful for generating contoured beams. Conventional reflector antennas are generally made of rigid materials and beams cannot be reconfigured while in orbit. Reflectors with phased array antenna as feed with a large number of active elements can be reconfigured in orbit, but they have a number of disadvantages in terms of complexity, mass, high power requirements and cost. Hence, it is required to develop reconfigurable reflector antenna made of some flexible material (electrically conductive) like membrane or mesh. The surface shape of the reflector to be modified using a matrix of linear actuators. Expected deliverables are complete research report with guide lines for development of reconfigurable reflectors, Realization of Reconfigurable reflector antenna operating at Ku Tx & Rx band – preferably dual reflector system with Gregorian optics and Performance demonstration at SAC CATF

6. ELECTRO-OPTICAL SENSOR TECHNOLOGY

Electro-optical (EO) imaging systems for Earth and planetary observations have significantly evolved in the recent years. More than eighty state-of-the art EO sensors have been designed and developed by Sensors Development Area (SEDA) at Space Applications Centre (SAC), Ahmedabad for various high resolution, multispectral, and hyperspectral imaging missions. SEDA is engaged in EO sensor system design and engineering, design and development of focal plane detection system, electronics systems, assembly, integration, testing (AIT) and performance characterization of integrated imaging systems.

The system design and engineering discipline focuses on system configuration studies, EO sensor modelling and simulation studies, proto type development, spectral and radiometric characterization of subsystems and integrated imaging system, design and development of precision calibration sources encompassing visible to IR spectrum, in-orbit performance assessment, design and development of optical communication systems, data analysis and trouble-shooting during the development phase.

SEDA is actively engaged in design and development of exotic focal plane detection systems for various ISRO missions comprising long array Charge Coupled Device (CCD) detectors, area array detectors, multi-array Time Delay and Integration detectors, Active Pixel Service (APS) CMOS detectors, low noise scientific detectors, etc. In addition, many IR detection focal planes (IDDCA) have also been designed and developed for various ISRO missions. The research in this field involves studying device physics, designing various pixel architectures leading to custom design of detectors, electronics circuit designs to meet operational requirements of detectors, design and development of detector test benches, performing extensive EO characterization of detectors, design and development of flight model focal plane systems and testing, etc. There is major thrust on indigenous design and development of detectors for upcoming ISRO missions with involvement of academia, national and global foundries.

The EO sensor image quality is primarily determined by the performance of optical system. The optical system of EO payloads have significantly evolved in recent years. SEDA has designed and developed high performance optical systems with primary apertures as high as 1.2 meters. SEDA is also engaged in indigenous design and development of metal mirrors, convex gratings, filters, opto-mechanical structures, etc. Tremendous research opportunities exist in the field of design and development of optical systems for spaceborne that include sparse aperture systems, high performance imaging interferometers, thin film development, volume holographic grating, aspheric and freeform optics, computer generated holograms, liquid mirrors, etc.

Electronics systems play a pivotal role in any spaceborne optical imaging chain. They cater to the requirements of detector drive, video processing, data handling, image compression, on-board control and bus management, active thermal management, power conditioning, interfacing with spacecraft mainframe elements etc. Robust design, miniaturization, usage of state-of-the components, programmability, on-board intelligence are some of the approaches adapted in the realization of sensor electronics systems. This field offers tremendous research opportunities in terms of design and

development of generic electronics systems, system on chip based on-board computers, embedded processors, soft IP cores, standardized interfaces and Logic, memory, high speed data handling systems, on-board compression, soft IP core development, FPGA, ASICs, hybrid components, low noise, high efficiency power systems etc.

Assembly, integration and testing (AIT) of EO sensor is a very complex and involved process. AIT ensures a zero-defect imaging system hardware with high image quality performance. AIT calls for development of various systems and methods for performance estimation, optimization, characterization, in-orbit performance assessment, analysis of huge amount of data generated during various test phases, fault detection and prediction, test setups, interface characterization etc.

AIT requires sophisticated test setups for simulation of spacecraft mainframe elements, high speed data acquisition and analysis, support variety of interfaces such as Controller Area Network (CAN) bus, Camera link etc. , SEDA is engaged in design and development of precision ground checkout instrumentation for payload testing. Various research opportunities in this field to design and develop high end data acquisition systems, command and control systems, test protocols, generic setups, data analytics tools, etc.

SEDA looks forward to a very fruitful association with academia to work on many potential research and development opportunities in the field of EO sensor design, focal plane detection systems, optical systems, electronics, AIT and ground checkout instrumentation. Some of the research opportunities are discussed below: -

6.1. EO Sensor System Design, Simulation and Characterization

6.1.1. Development of physics-based models for simulation of Electro-Optical Sensors

Design and development of EO sensors is a very complex process and requires a thorough understanding of the system behaviour and assessment of its possible outcomes before one embarks on the development of physical system. A physics-based model of EO sensors can significantly help in understanding and visualizing performance aspects and also extensive trade-off studies. The model shall capture the functional/behavioural characteristics of various subsystems such as optics, detectors, electronics and also shall account for various instrument effects arising due to their complex interplay at highest abstraction level. The model shall help in simulating final data/images for a proposed EO sensor configuration to enable visualization and quantitative assessment of instrument sensitivity to the design parameters/system, environment/on-board processing/viewing geometry, etc. Based on the model a software tool needs to be developed that should interface with COTS design software systems in Optical/Mechanical/Electrical domain and available RT models for atmospheric effect simulations. In other words, an end-to-end model shall be developed starting from simulation of ground targets, illumination conditions, observation geometry, intervening medium/atmosphere, at-sensor radiance, sensor characteristics, boundary conditions (under which the sensor is performing) leading to digital counts. The input scene to the sensor model can be typical laboratory targets, actual ground 3D targets or

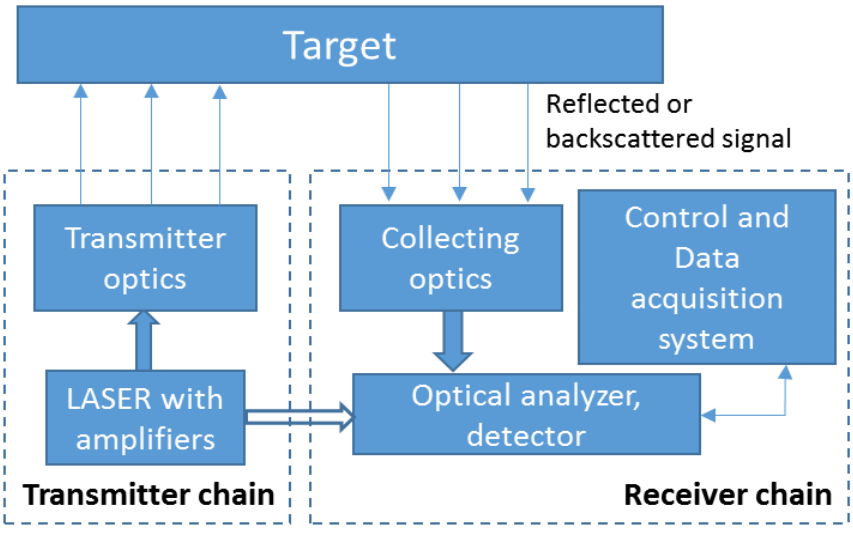
images acquired from the other sensors. This is an exciting research field and will help in the development of a comprehensive model and simulation tool for upcoming ISRO missions.

6.1.2. Design and development of on-board calibration system for absolute calibration of EO sensors

Extensive pre-flight absolute calibration of EO sensors are carried out in laboratory for establishing the transfer function of the EO sensors. However, due to launch loads, in-orbit operating environment, and natural aging process of its components, the sensor characteristics tend to change. This has significant impact on accuracy of Digital Number (DN) to radiance conversion process, which in turn affects the remote sensing parameter retrieval accuracies. Hence, it is important to design and develop appropriate on-board calibration system(s) for periodic calibration and updation of the sensor response function to ensure desired accuracy in DN to radiance conversion. The calibration system should ensure both radiometric and spectral calibration from visible to Infrared Radiation (IR) spectral region. These sources can be passive or active. Research is invited in the areas of design and development of on-board calibration sources e.g. Blackbody for IR calibration (high emissive nano-particle coating), diffuser plate for Visible/Near-Infrared (VIS/NIR) calibration, doped diffusers or active sources for spectral calibration. These systems are required to be compact and stable over long period of time. This can significantly help in improving the accuracy of payload data.

6.1.3. Design and development of a proto-type LIDAR system

Light Detection and ranging (LIDAR) measures distance or characteristics of the target by illuminating that target with a laser light. A narrow laser-beam can map physical features with very high resolutions. Typically, light is reflected via backscattering. LIDAR can be used for ranging, surface profiling and atmospheric studies (clouds, aerosol and wind). Suitable combinations of wavelengths can allow for remote mapping of atmospheric contents by identifying wavelength dependent changes in the intensity of the returned signal.



Typical LIDAR system

A LIDAR typically comprises of a transmitter chain, receiver chain and associated electronics. Critical components of LIDAR system are high power laser system (100mJ or more with pulse duration of ~10ns), large aperture collecting optics (>1m aperture size), detection system (time gated photon counting,

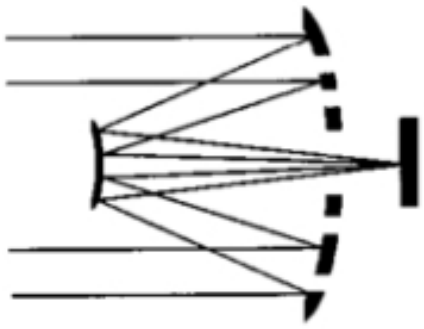
interferometry, etc.). Research opportunity exists in design and development of high power continuous and pulsed lasers, large optical apertures, focal plane based on time gated detectors and interferometry systems leading to proto-type development of LIDAR system.

6.1.4. Image Simulators and Algorithms for Characterization of Imaging Sensors

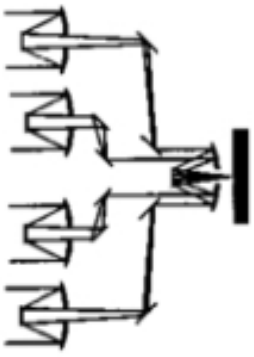
EO sensors undergo extensive pre-flight testing and performance characterization to ascertain sensor behaviour and demonstrate performance compliance against specifications. Currently, static targets such as bar targets, slits, and flat field targets are used as input scenes for the EO sensor testing and characterization. However, this limits test capability in terms of temporal, spatial, and spectral variations in the scenes that an EO sensor sees in the actual remote sensing scenes. Research opportunity exists for design and development of synthetic scene simulators to generate dynamic scenes for EO sensor testing and characterization. Digital Mirror Device and Digital Light Processing can be potentially used for generating Multi-spectral and Hyper spectral scenes. The research in this field involves design and development of hardware and software system for generating suitable synthetic scenes having required dynamic variations, development of methods/algorithms for EO sensor performance estimation using the sensor output and evaluation in terms of image quality metrics, etc.

6.1.5. System configuration and simulation studies for Sparse Aperture telescope

The angular resolution of a traditional telescope is diffraction-limited and is given by $1.22\lambda/D$, where λ is the wavelength and D is the size of the optical system aperture. However, the optical system aperture is limited by the current glass-making technology and the cost involved. In order to overcome this limit, the technique of optical synthetic aperture have been reported in the literature. The optical synthetic aperture consists of several telescopes (as shown in figure below) with smaller apertures, phased in a manner to generate an equivalent large aperture.



Common Secondary Mirror



Multi Telescopes

This emerging field offers significant research opportunities in terms of studying feasible system configuration, perform extensive simulation studies, develop advanced processing techniques for generating improved resolution imagery from the acquired data, etc. The research will lead to development of a small-scale prototype for demonstration and validation of design and processing techniques.

6.1.6. System design, simulation studies and control system development for Segmented mirrors based EO sensor

A segmented mirror is an array of smaller mirrors designed to act as segments of a single large curved mirror. The segments can be either spherical or asymmetric. They are used as objectives for large reflecting telescopes. To function, all the mirror segments have to be polished to a precise shape and actively aligned by an active optics system using actuators built into the mirror support cell. In this research field opportunity exist to study feasible system configuration, develop simulation model, design and develop metering, actuation and control systems to maintain the segments in required shape and orientation to get the desired performance. This research aims to develop a small-scale prototype for demonstration and validation of the involved technology elements, and processing techniques.

6.1.7. Extending Super Resolution concept to Spectral Domain

Extraction of finer spectral resolution information from Hyper-spectral Imagery, given a large number of relatively coarser resolution images with overlapping spectrums. Similar to super-resolution imagery, if data is collected with a given spectral bandwidth, but with finer spectral sampling compared to the bandwidth, then it should be possible to generate images having narrower spectral bandwidth. The scope of the work includes development of models and simulation studies to demonstrate the concept and also develop a proto-type system to study hardware implementation aspects.

6.1.8. Design and development of Active cavity radiometers

Active cavity radiometers (ACRs) is one type of pyrheliometer used for measurement of direct beam solar irradiance. It is an electrically self-calibrating, cavity pyrheliometer used to measure total and spectral solar irradiance. They can be suitably tuned for measuring radiation from UV to IR spectral region. These radiometers remain stable over long duration and thus can be used as a calibration standard for relative calibration of uniform illumination sources or spectro-radiometers. Various research opportunities in the field includes studying active cavity radiometers, define feasible system configuration, perform extensive simulation studies and develop a proto-type model for demonstration.

6.1.9. Long range 3D imaging using flash LIDARs

3D Flash LIDARs have emerged as a potential imaging sensors for real time terrain mapping, 3-D measurements, guidance and navigation to support in rendezvous and soft landing missions, etc. A 3D flash LIDAR provides depth information of objects in the scene in addition to their 2D spatial distribution. The technological elements in 3D flash LIDARs involve Laser head, receiver optics, focal plane unit and electronics system with embedded image processing techniques for 3D measurements etc. This research envisages design and development of a proto-type 3D flash LIDAR imaging systems that involves system configuration studies, simulation studies, realization of small scale proto-type with COTS components, development of electronics system with embedded processing capabilities, performance characterization and field studies.

6.1.10. Design and development of high-resolution imaging system with active optics correction elements

High resolution imaging system generally employ large aperture optical systems and are generally affected by launch loads and orbital environmental conditions, which induces large amount of aberrations effects leading to loss of MTF in the acquired images. Active optics correction systems enable corrections of these deformations using an actively controlled optical surface in the telescope chain. The proposed study aims to design and develop an active optics correction based EO sensors for future missions.

6.2. Focal Plane Detection Systems

6.2.1. CCD and CMOS sensor fabrication process modelling and simulation studies

CCD and CMOS image sensors are mainstay sensor technology employed in spaceborne imaging systems. State-of-the-art imaging systems require custom development of these sensors. Sensor fabrication process and device modelling and simulation studies are very important milestone in the development of these sensors. SEDA has developed a dedicated modelling and simulation lab for design of these sensors as it allows more leverage to meet custom requirements. The lab is equipped with various simulation tool kits such as Technology Computer-Aided Design (TCAD) and MATLAB etc. The research opportunities include modelling of CMOS and CCD based optical image sensor fabrication process to estimate key performance parameters such as quantum efficiency, cross talk, sensitivity, dynamic range, charge handling capacity, etc.

6.2.2. Modelling and simulation studies on Superlattice structure-based SWIR and MWIR sensors

Infrared imaging detectors are increasingly being used in the focal plane of spaceborne imaging systems as it offers unique opportunities for variety of remote sensing applications. SEDA has taken up modelling and simulation activities for design of exotic sensors operating in Short-Wave IR (SWIR), Medium-Wave IR (MWIR) and Low-Wave IR (LWIR) spectral range. Research opportunities in this field includes TCAD and MATLAB modelling of Type-II superlattice structure for sensitivity in IR ranges, development of methodologies for higher temperature operation by suitably modifying stack to reduce dark current and development of techniques for enhancement of Quantum efficiency beyond 50%.

6.2.3. Design and development of high power NIR and SWIR LASER modules

Spaceborne LIDAR systems are gaining attention of the remote sensing community as it offers variety of applications in surveying, geodesy, geomatics, geomorphology, seismology, forestry, atmospheric physics, laser guidance, and laser altimetry etc. One of the important elements in the LIDAR system is high power Light Amplification by Stimulated Emission of Radiation (LASER) system. Currently SEDA is exploring design and development of the of high-power NIR & SWIR laser modules. The research opportunities include design and development of laser head, amplifier circuits, pump sources, drivers, diffractive optical elements, cooling system etc for long distance 3D measurement and flash LIDAR applications.

6.2.4. Thermal Background modelling for integrated IR detector cooler assembly (IDDCA)

Thermal background is one of the major sources of noise and offset in the IR detector system. Hence, it is important to estimate thermal background flux in the IDDCA to implement effective thermal control system. The research opportunities include development of physics-based model for estimation of thermal background in a given IDDCA configuration using various software tools such ray-tracing tool, thermal analysis tool, result visualization and quantitative estimation in Labview/Matlab etc. These modelling

efforts will help in understanding the source of thermal background and enable improved design of IDDCA and the imaging system.

6.2.5. Design and development of drive circuits for CCD sensors

The research opportunity exists in design and development of CCD based image sensor drive circuitry for minimization of noise floor and clock induced charges. The design shall adopt different circuit design techniques for shaping CCD clocks (-10V to +15V, drive capacitance: 500pF, frequency: 10MHz) for maximization of stable video and reference sampling zones.

6.2.6. Design and development of Photonics Integrated circuits (PIC) based system on chip

System-on-chip significantly helps in integrating various image sensor circuit function in a very small footprint, thereby saving resources on payload/spacecraft. The research focuses on design and development of integrated circuits for clock and data multiplexing / demultiplexing, modulation/ demodulation, laser driver, laser and photodetector, packaging of imaging detector with PIC based chipset to miniaturize focal plane detector proximity electronics.

6.2.7. Design and development of High speed Event detector

The research focuses on design and development of CMOS image sensor pixels for automatic thresholding, target detection and tracking applications. Fast occurring events could be observed by identifying them within the pixel at analog level by using programmable thresholding circuitry. The pixel level circuitry initiates readout by raising appropriate flag. Such flags help row – column circuitry to readout events of interest at high frame rate, up to 50kHz. Once of the possible application could be automatic detection and radiometry of lighting events.

6.2.8. Development of process flow for CMOS chip debug

The research opportunities exist in the de-processing, micro-surgery, hot electron imaging active micro-probing, and IR microscopy, etc for debugging of CMOS chips. After we fabricate any chip, it is quite challenging to debug possible problems areas (design, fabrication, assembly, integration, packaging and testing) if it does not meet the desired performance. We have to develop some of the chip debug tools to be able to debug complex chips. These sort of tools and technologies would also help to identify possible reasons for yield reduction.

6.2.9. CMOS pixel process development at 180nm

The research opportunities exist in Pinned photodiode-based pixel (7 to 50micron pitch) development to meet charge handling requirement from 30ke to 3Me. This research will lead to development of pixel process for TDI CMOS focal plane arrays.

6.2.10. Packaging of Infrared detector arrays for multispectral application

This research focuses on development of techniques using industry for butting of smaller arrays to form large arrays, integration of filter / cold shield / lens, assembly of detector onto cold table mounted with flexible thermal link for cooling down to 50K and minimization of thermal load by utilizing new interconnect materials.

6.2.11. Design and development of Ultraviolet detectors based on wideband gap semiconductors

Photon detectors based on wide band gap semiconductors have recently garnered considerable attention due to its suitability in development of highly sensitive ultraviolet detectors. The scope of research includes comprehensive review of literature in the field, understand the mechanism of these sensors, inherent advantages and disadvantages of those detectors, explore suitable materials for producing these detectors, etc.

6.2.12. Development of curved sensors

Curved image sensors have emerged as novel technology that can decouple the traditional constraints between field-of-view (FOV), resolution and image quality. Usage of curved sensors relaxes the stringent imaging performance requirements on the optical systems at extreme fields. Many research groups are working on the device fabrication technologies. The scope of the research in this field is to explore various fabrication process technologies, carry out design and simulation studies for pixel architecture for curved sensors, address issues/challenges in the field and attempt to develop proto-type curved sensor for characterization studies. This research will lead to adaption of such curved sensors in the future spaceborne missions.

6.2.13. Metamaterial based absorber surfaces for image sensors applications

Metamaterial structures have attracted substantial attention due to their ability to obtain desired effective permittivity and permeability by carefully designing its structure. It has resulted in the discovery of exotic phenomena such as negative refraction, cloaking, perfect absorption etc., which are not possible with ordinary materials. Broadband metamaterial absorber shows a promising prospect in applications such as controlled reflectors, solar cell, infrared detection. Junyu Li, Haoran Zhou et al have developed deep subwavelength plasmonic metamaterial absorbers for infrared detection (Conference on Laser and Electro-Optics (CLEO) 2019 © OSA 2019). In this study, a metal-insulator-metal based infrared plasmonic metamaterial absorber consisting of deep subwavelength meander line nano-antennas(MLAs) based array was fabricated and experimentally demonstrated the absorption from 11 μm to 14 μm with a pixel pitch of 1.47 μm. Plasmonic metamaterial absorbers (PMAs) are arrays of subwavelength-spaced metallic nano-objects (also termed as optical antennas) whose primary function is to concentrate the propagating light into regions much smaller than the wavelength and efficiently dissipate the optical energy into heat via localized surface plasmon resonances (LSPRs). The proposed research aims to explore CMOS compatible metamaterial absorber structure, simulation of absorption characteristics of these materials, explore fabrication feasibility, etc.

6.2.14. Dilute Magnetic Semiconductor (DMS) material synthesis for spintronics applications

A new class of materials known as dilute magnetic semiconductor (DMS) are semiconductor materials that exhibit both ferromagnetism (and a similar response) and useful semiconductor properties. If implemented in devices, these materials could provide a new type of control of conduction. Whereas traditional electronics are based on control of charge carriers (n- or p-type), but magnetic semiconductors would also allow control of quantum spin state (up or down). DMS have been a major focus of magnetic semiconductor research. These are based on traditional semiconductors, but are doped with transition metals instead of, or in addition to, electronically active elements. Due to their novel properties of change and spin control, they have generated huge interest among the scientific community as a strong candidate for the fabrication of spin transistors and spin-polarized light-emitting diodes.

6.2.15. Optical Beam Steering Photonic Chip for Lidar

In a Lidar, a laser beam is formed to concentrate the optical power within single pixel instead of the whole scene, which makes it a point-wise measurement system. To form an image, the beam is scanned through the FOV Namely, a beam scanner. Scanning LiDAR achieves higher signal-to-noise ratio (SNR) at the cost of lower points per second (i.e. point throughput) and slower frame rate, and more importantly, at the cost of having a beam scanner. Beam scanner is often realized through mechanical actuation of either the source itself or the discrete optics around the source. While mechanical optical beam scanner design is already an established domain of engineering, there is a fundamental challenge associated with achieving good control precision and reliability goals for automotive vehicles using a low-cost mechanical system. To reduce the unit cost of a scanner module and make it feasible for consumer electronics, various solid-state beam scanning solutions are the preferred option. There are many approaches to realize a photonic chip for Optical beam steering like MEMS Switch based array of grating coupler, Optical phased array, true time delay based beam steering, etc. The beam steering chip shall define the beam width of less than 0.2 degree and shall steer the beam within 20 degrees in both axes.

6.2.16. On-chip nano wire grid fabrication for polarization sensing

Traditional imaging systems have focused on capturing and replicating the imaged environment in terms of colour and intensity. One important property of light, which the human eye is blind to and it is ignored by traditional imaging systems, is polarization. Polarization of light caused by reflection from materials contains information about the surface roughness, geometry and other properties of the imaged environment. Polarization-contrast imaging has proven to be very useful in gaining additional visual information in optically scattering environments, such as target contrast enhancement in hazy/foggy conditions, depth map of the scene in underwater imaging, presence of ice in clouds or non-spherically shaped dust particles and in normal environmental conditions, such as classifications of chemical isomers, classifications of pollutants in the atmosphere, and non-contact fingerprint detection among others. In addition, polarization of light has found a niche in many biomedical applications, such as imaging for early skin cancer detection, cell classification and retinal surgery.

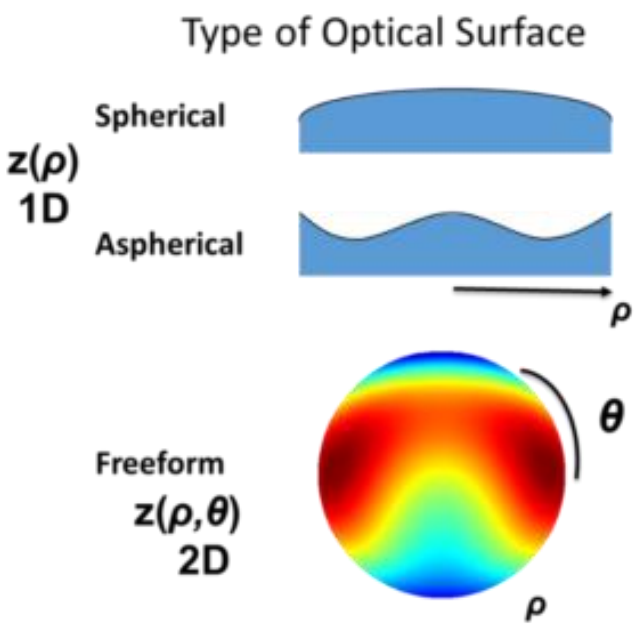
Wire grid polarizer is compatible with complementary metal-oxide-semiconductor (CMOS) technology, and it can be fabricated monolithically by using metal layers for wiring. Using deep-submicron CMOS technologies, which allow the design of metal patterns finer than 100 nm. The angle (0, 45, 90 and 135 degree) of the polarizer on each pixel can be designed.

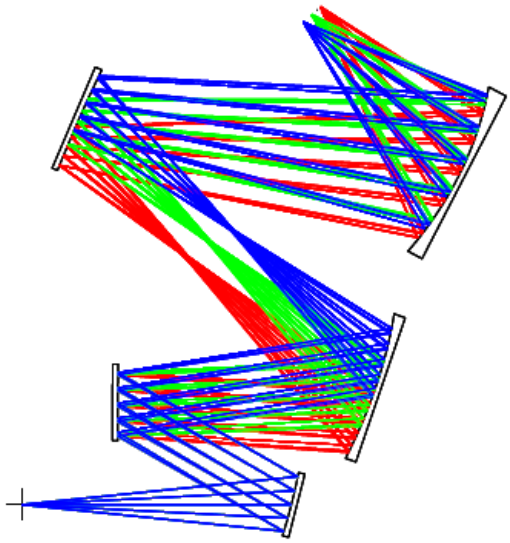
6.3. Design and Development of Optical Systems

6.3.1. Optical systems using freeform surfaces

Freeform optics offers more degrees of freedom to optical design that can benefit from a compact package size and a large field of view for imaging systems. The introduction of freefrom optical surfaces in a space instrument offers the possibility to improve its performance, its volume and weight or a combination of both. Motivated by the advances in modern optical fabrication and metrology, freeform optics has found place in many applications. The freeform mirrors are manufactured by diamond turning based on a feedback modification strategy.

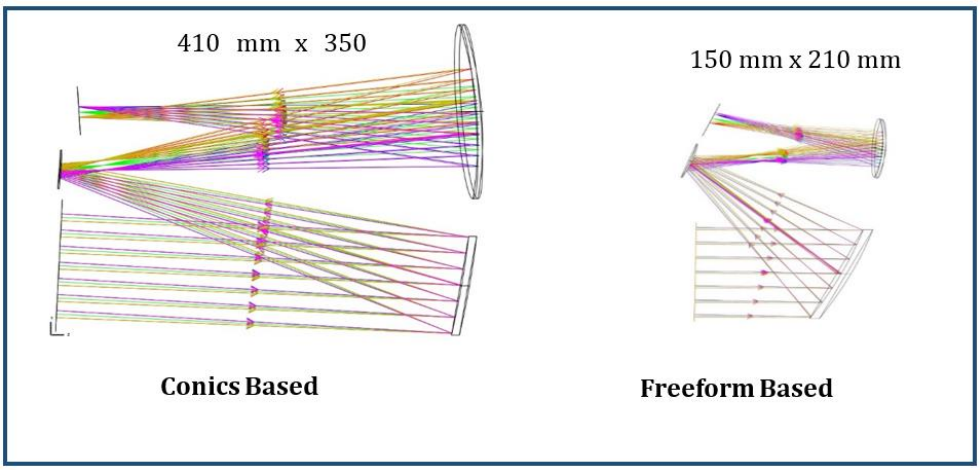
Freeform optics involve optical designs with at least one freeform surface which, according to the International Organization for Standardization (ISO) standard 17450-1:2011, has no translational or rotational symmetry about axes normal to the mean plane. Integration of freeform optics and surfaces into imaging systems remains a major challenge. However, the new degrees of freedom introduced by freeform optics designs are the driver to overcoming these challenges. These additional degrees of freedom enable many potential advantages, including system miniaturization, reduced component count and even entirely new optical functionality that will have a profound effect on the optics industry.





Example of optical system using freeform optics

Research activity that can be taken up is to utilize freeform surfaces to design future telescopes with wide field of view. One particular study can be carried out to show how the freeform optics can be used to miniaturize/improve the performance of an optical system. Another interesting research activity is the fabrication and testing of free form surfaces (IR/ Visible range). One such example of miniaturization using freeform optics (XY polynomial) is shown in the following figure.



6.3.2. Chalcogenide optics in dual-band IR Applications

The development of dual-band IR sensors that image both MWIR and LWIR on the same image plane challenges the optical designer to create refractive lens systems with one aperture. In the past, classic materials such as Ge and ZnSe have been combined with more exotic materials such as barium fluoride (BaF2) and gallium arsenide (GaAs) to focus light across a wide range of IR wavelengths. Material limitations create unique challenges for wideband chromatic correction. Existing and new formulations of chalcogenide glasses provide additional indices of refraction and dispersion characteristics for chromatic correction as well as thermo-optic properties for athermalization. Chalcogenide glass is an increasingly important tool for the optical designer, providing a versatile material for many applications—from thermal imaging to hyperspectral imaging. The properties of these amorphous glasses are useful over a broad spectral range, from the near-infrared (NIR) at 700 nm well into the LWIR spectrum.

Chalcogenide glasses consist of mixtures of the Group 16 elements selenium (Se), sulphur (S), and tellurium (Te), and various Group 14 and 15 elements such as arsenic (As), germanium (Ge), tin (Sn), and others. These glasses are well suited for imaging in the IR regime because of their high transmission, low dispersion, and low refractive-index change with temperature. By changing concentration ratios, glass properties can be tailored for index of refraction, dispersion, glass transition temperature, and other properties. This gives the optical designer or the lens manufacturer more freedom than traditional IR materials. As traditional IR materials such as Ge and zinc selenide (ZnSe) rise in cost, the use of chalcogenide glasses is becoming more widespread. Chalcogenide materials offer substantial savings today in both the raw material cost and in fabrication methods such as molding technology. They also provide numerous benefits to systems with stringent specifications. There are many sources for chalcogenide glasses, including Vitron GmbH (Jena, Germany), SCHOTT North America (Duryea, PA), and IRradiance Glass (Orlando, FL), which produces a number of glass types along with custom melts.

Rochester Precision Optics developed moulded micro- and nanostructures in chalcogenide glasses. The optical properties of chalcogenide optics can be altered by nanoscale surface textures. Antireflective structures that reduce reflectance significantly reduce glare and improve transmission.

Unlike a thin-film coating that creates interference effects, nanostructures are not bandwidth-limited. Hybrid structures have demonstrated performance over dual-band regions (3–12 μm), showing promise for future applications such as high damage threshold for lasers, super hydrophobicity, and antifogging. While these functionalities have been shown on the development scale, there are still great challenges in developing industrial fabrication methods that can reduce the cost of such nanostructured materials.

This rapidly evolving world of high-volume, low-cost IR optics, along with the expansion of extremely demanding dual-band IR applications, has created a requisite for use of chalcogenide glasses. Chalcogenide materials have the ability to be altered and provide optical and systems designers many more options than historic IR material offerings without compromise.

The scope of the proposal is as follows:

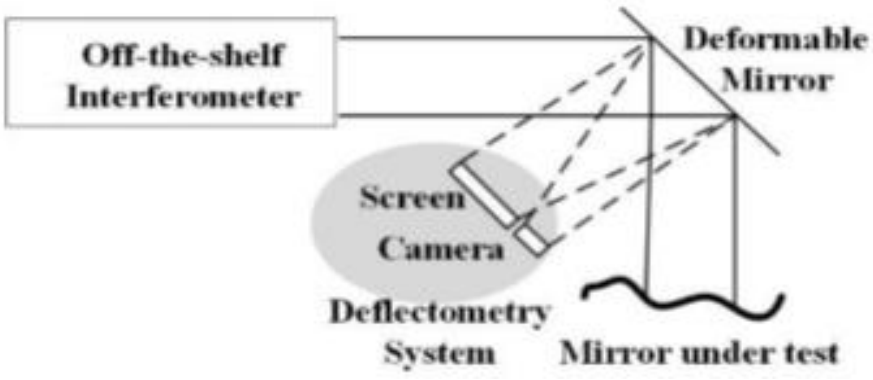
- Study of feasibility for use of chalcogenide glasses for spaceborne remote sensing application.
- Design of dual band IR common optics using chalcogenide glasses that will image both MWIR and LWIR on the same or different imaging sensors.
- Collaboration with indigenous industry and universities for realization of Chalcogenide optics via. Fabrication, assembly and testing for achieving the desired performance goals.

6.3.3. Adaptive test techniques for Aspherics and Freeform surfaces

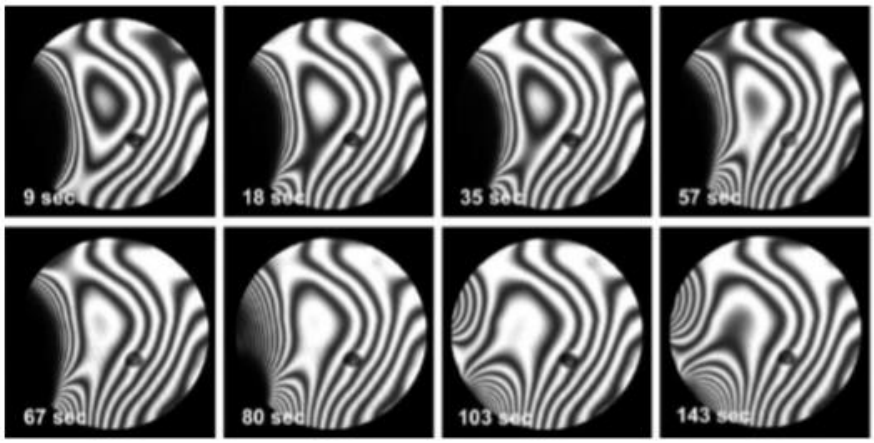
During the manufacturing of optics, the in-process (i.e., not-yet-completed) optical surface must be accurately measured to correctly guide the iterative fabrication process. The customized null element makes the process time taking and costly.

Also, for interferometric surface form measurement of final freeform surfaces the measurement is limited by the Nyquist criteria, which is often encountered due to large slope of freeform surfaces.
To overcome this, one of the current techniques is Adaptive interferometric null testing method
The adaptable null component may be a Spatial Light Modulator or Deformable Mirror.

1) **Test set-up using deformable mirror**



When an unknown test optic is first inserted into the metrology system, non-ideal (e.g., partial) interference fringes could be observed.



Next, the DM is driven based on the results from the algorithm recovering near-null interference fringes. This creates an online null condition for the freeform surface. The interferometer measurements, along with the results from the Deflectometry System are combined to produce the final surface shape data.

The algorithm, that is used for fringe restoration will be heavily influenced by the merit function which is provided as the required target. A smart choice of this merit function will result in a quicker and more efficient convergence (to the ideal or threshold value).

Limitation of the method: DM has limited range of stroke of actuators and can only compensate mild free form departures.

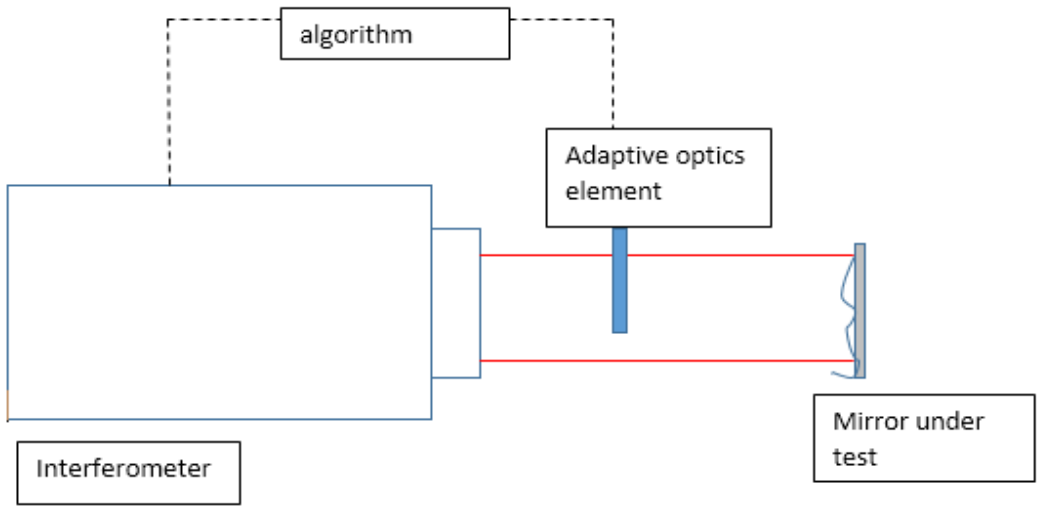
The DM will be developed and characterised by industry/academia, which can further be integrated in to the test set up at SAC. The other important part of the test set up i.e. Deflectometry system used to monitor the DM surface can be developed jointly by SAC & academia.

6.3.4. Test set up using Spatial Light Modulator

The DM-based null test is adaptive and economical compared to CGH; however, DM has limited range of stroke of actuators and can only compensate mild free form departures.

A high-definition (i.e., >1080 pixels, <5 μm pitch) spatial light modulator (SLM) circumvents the limitation of the DM.

The phase conjugation algorithm is additionally utilized for turning resolvable fringes into null ones. Finally, local severe surface figure error is extracted from the SLM phase and the null test result by reverse optimization based on ray trace model.



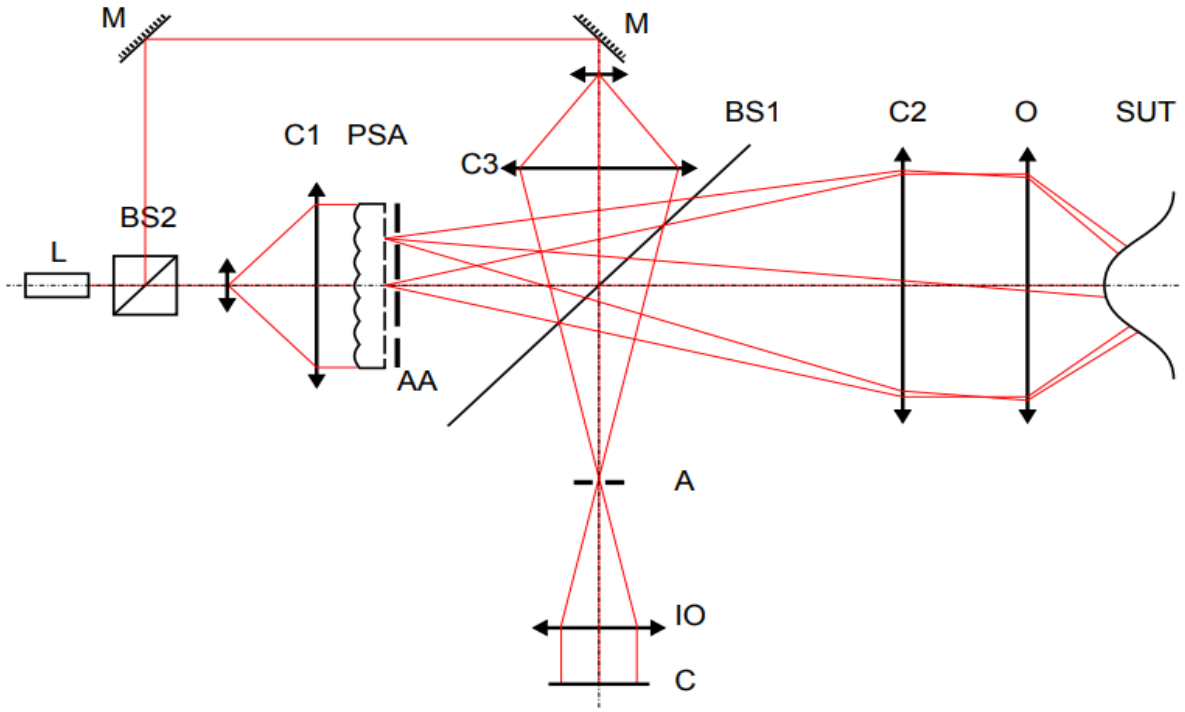
TDP is already going on. Collaboration may be sought on development of algorithm. The commonly used algorithms for such applications are widely used in Machine Learning applications. Some of the algorithms are

- Stochastic Parallel Gradient Descent
- Simplex Optimization
- Genetic Algorithm
- Simulated Annealing

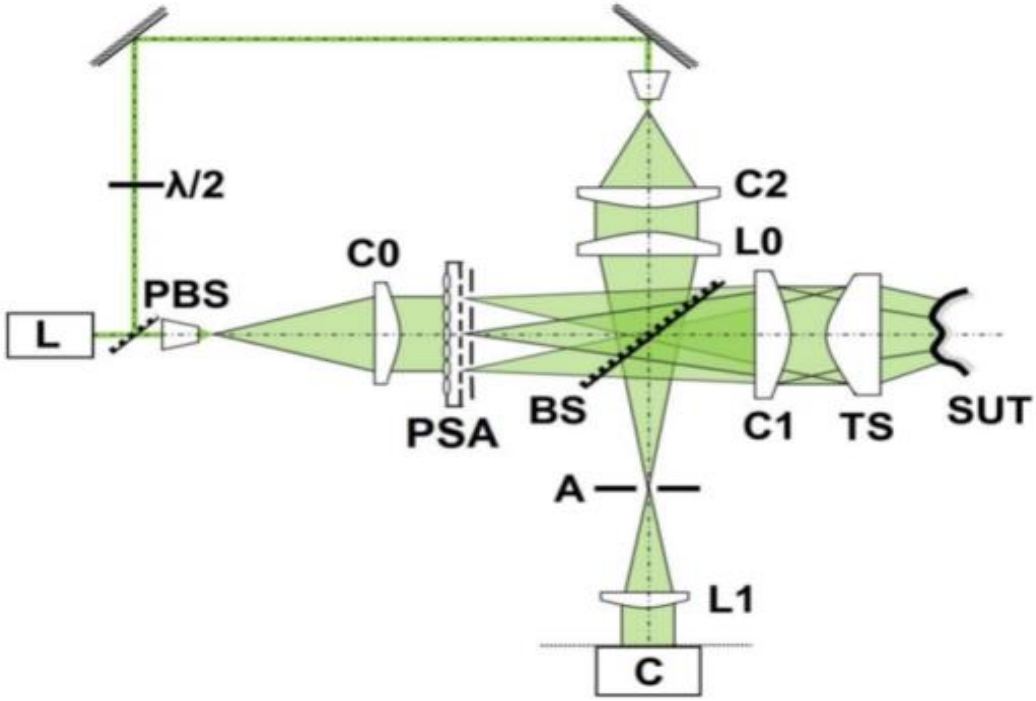
Simulation can be carried on supplied data and later verified experimentally at SAC.

6.3.5. Tilted Wave Interferometer

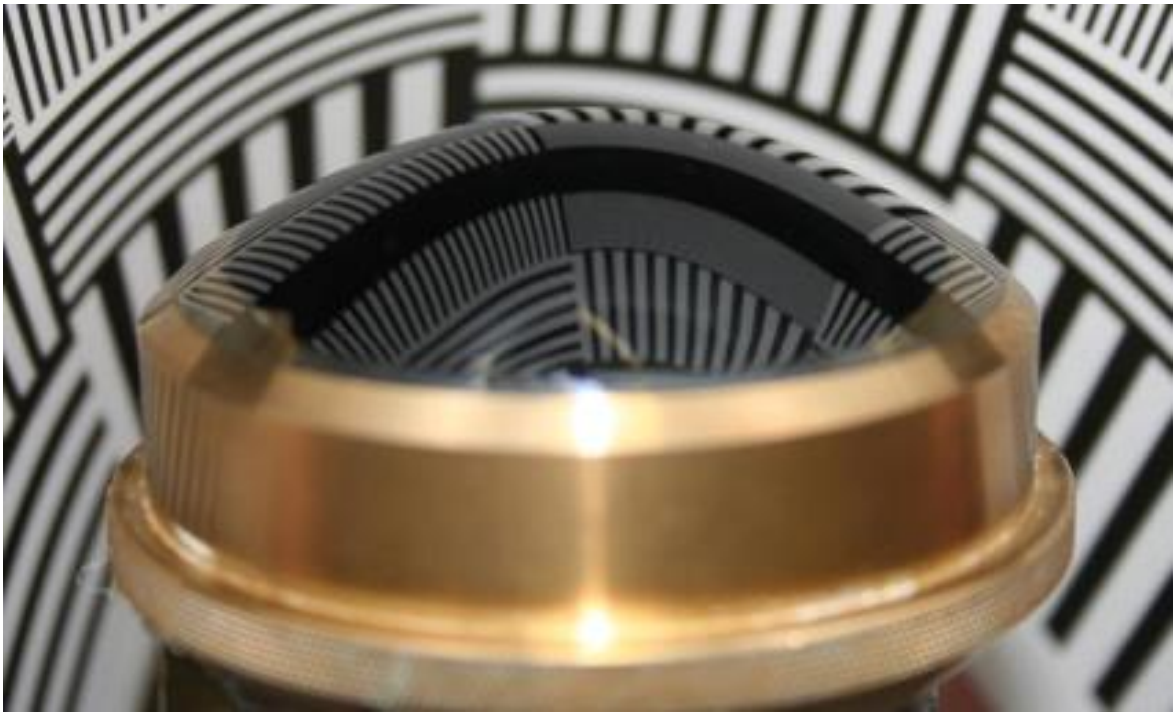
The use of aspheric and freeform surfaces becomes more and more important in the design of modern optical systems. These surfaces offer additional degrees of freedom to the optical design, allowing to improve the optical imaging as well as to reduce the number of surfaces needed for an optical design. However, testing of such surfaces is still a difficult task. This issue can be addressed using the technique of Tilted Wave interferometer. TWI is non-null, full-field interferometric measuring technique for aspheric and free-form surfaces with a new degree of flexibility. The interferometer uses a set of tilted wave fronts to locally compensate the deviation of the surface under test from its spherical form. Also since its non-null technique, hence the costly optics is not required for testing. The main difference of this approach to the scanning type interferometers is that the acquisition of the data is highly parallelized, since all test wavefronts are applied to the surface in only four steps. Further, the surface under test (SUT) does not have to be moved during the measurement process. Both these advantages lead to a very short measurement time of far under a minute.



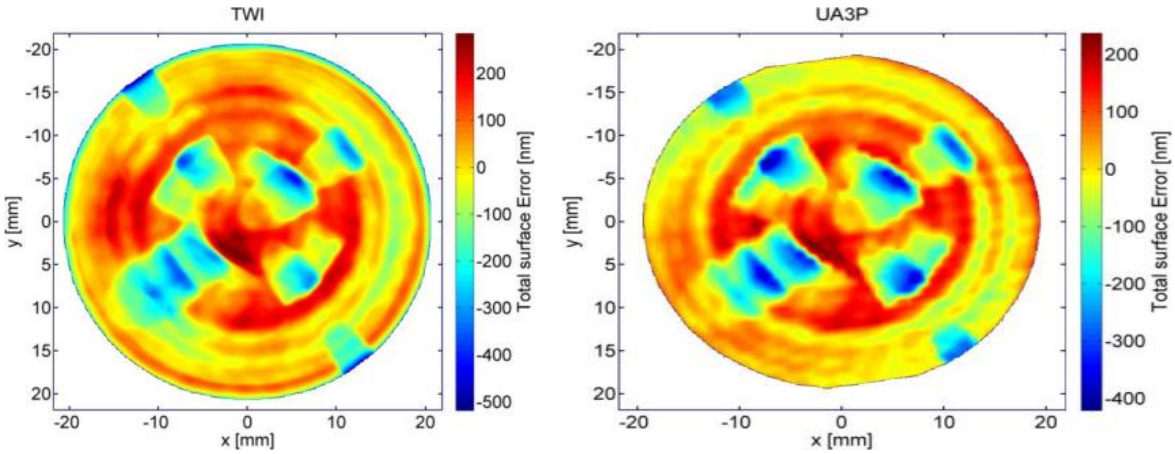
Schematic setup of the interferometer. L: Laser source; BS1, BS2: Beam splitter; C1, C2, C3, Lens; PSA: Point source array; AA: Aperture array; M: Mirror; O: Objective; SUT: Surfaces under test; A: Aperture; IO: Imaging optics; C: Camera.



Tilted Wave Interferometry



Aspheric surface with clear aperture of 40mm and 800µm / 5° deviation of the best fit sphere.



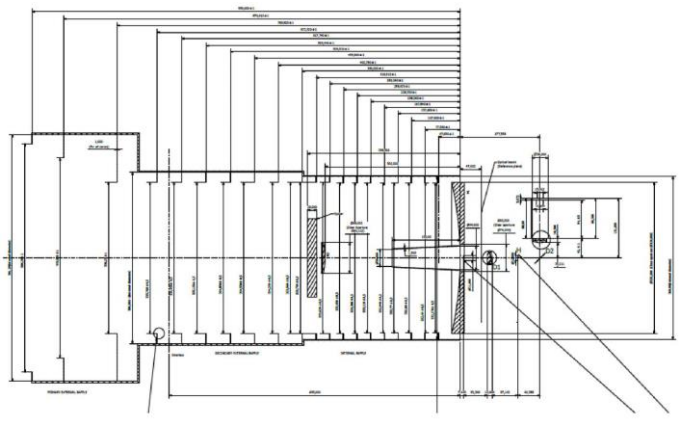
Measurement of aspheric surface by TWI (left) and comparison measurement by CMM (right)

The surface has a strong astigmatic shape of about 1mm deviation from the spherical form. The marks from the diamond-turning tool are clearly visible in the measurement.

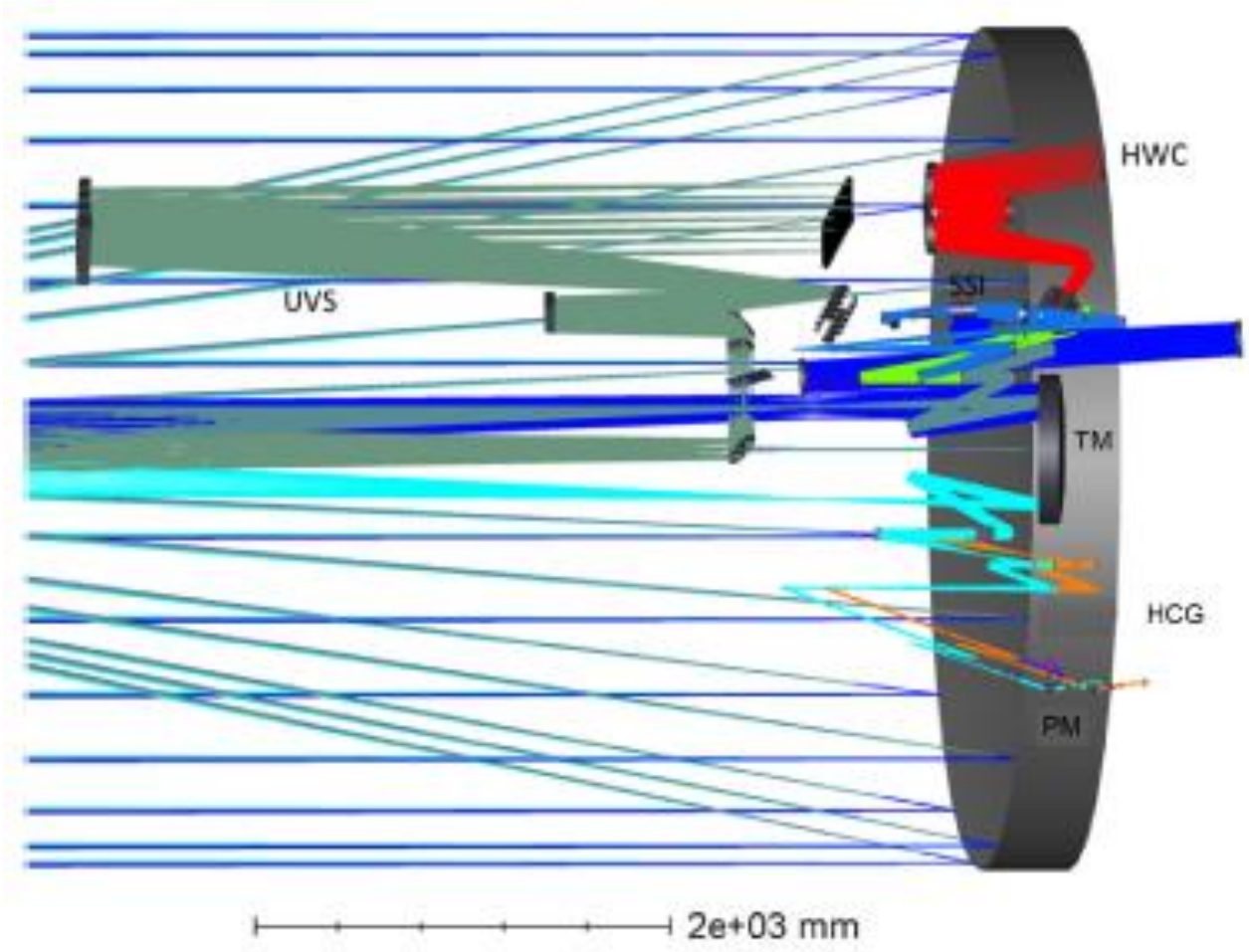
6.3.6. Optical Design of telescope for space observatory for study of Exoplanets

Planets that orbit around other stars are known as Exoplanets. Exoplanets are very hard to see directly with telescopes. They are hidden by the bright glare of the stars they orbit. Therefore, indirect methods such as radial velocity, transit photometry/spectroscopy and timing variation methods are used to detect exoplanets. In some cases, direct imaging method is also used to find exoplanets.

The telescope to study exoplanets can consist of a single instrument (eg. Characterising ExOPlanets Satellite (CHEOPS) of European Space Agency (ESA)) or a cluster of instuments (eg. Habitable Exoplanet (HabEx) of National Aeronautics and Space Administration (NASA)). The design options include Ritchey-Chritien (RC) or a three mirror anastigmat (TMA) design followed by science instruments. The spectral range of these telescopes generally include ultraviolet (UV), visible and near-infrared (near-IR), shortwave infrared (SWIR) and sometimes midwave infrared (MWIR) regions. The telescopes include both imaging and spectroscopic capabilities. Stray light suppression using effective baffling is very important as the faint light from exoplanets should not be suppressed by any other light coming from earth or stars. Research in this field is invited for the development of optical systems for upcoming exoplanet missions.



Comprehensive baffling system to suppress straylight (CHEOPS)



Optical schematic of telescope assembly with instruments (proposed in HabEx)

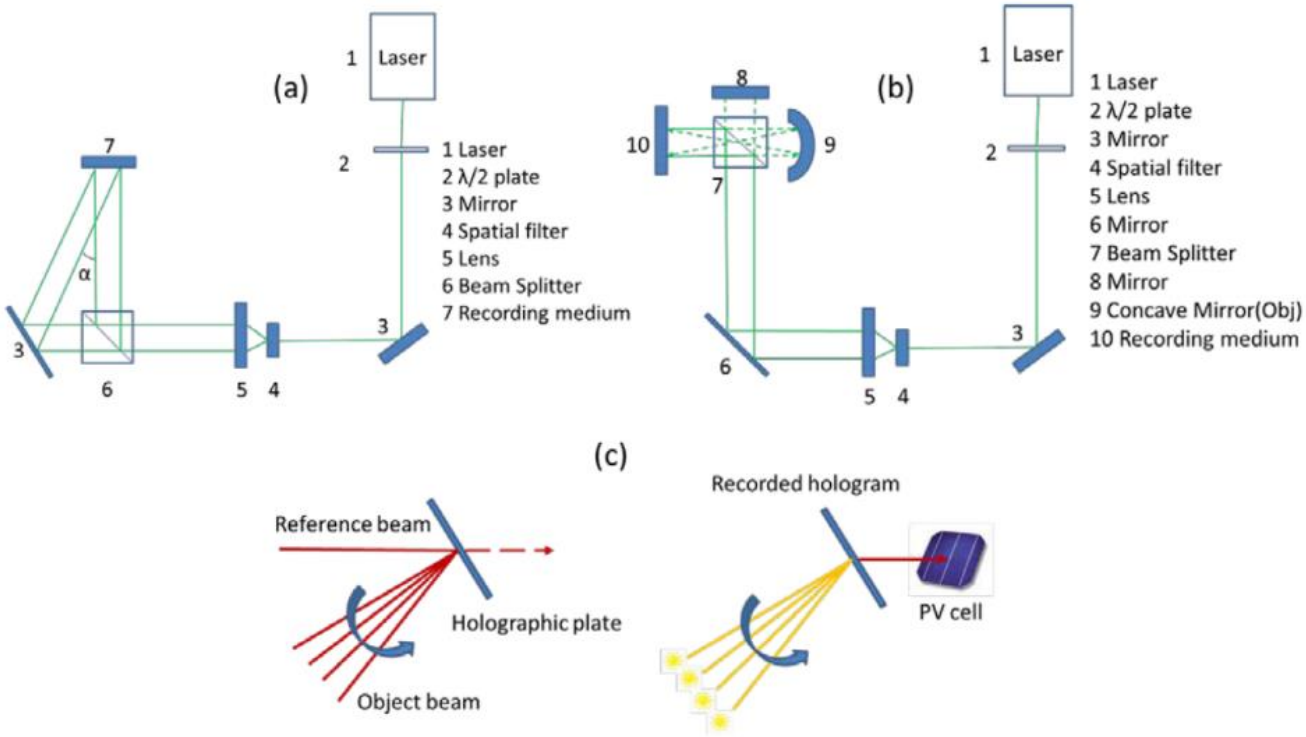
6.3.7. Design and development of Volume Holographic Grating (VHG)

VHGs are widely used in ground based astronomical spectrometers with moderate to large diameter telescopes ranging anywhere between 8 meters to 10 meters. These have also been extensively used in gas sensors where spectral peaks with very narrow bandwidths are required to match with gas absorption spectra. They are suitable for both ground and spaceborne applications. Considering the major advantage of higher number of grooves/mm and consequently finer spectral bandwidth of few picometer, the VHG have been used in multiple global space missions like Sentinel 3A and Rosetta etc. This research proposes design, fabrication and characterization of a plane/curved VHG for spaceborne imaging spectrometers for astronomical observations and environmental monitoring.

The fabrication of VHG basically involves writing of a typical pattern by optical interference between two coherent laser beams (reference and object beams) superposing in a photosensitive material making fringes in the material by means of a periodical variation of the refractive index (i.e. a sinusoidal profile) throughout the volume of the photosensitive material. The technique enables writing 600 to 6000 grooves/mm on a substrate diameter upto 850 mm.

Scope of the research

a. Modelling of the grating with peak efficiency at required wavelength mainly catering to VNIR and SWIR, fabrication and characterization.
b. Indigenous/ in-house development of the holographic exposure system to record fringe pattern of desired frequency and orientation using photo-polymer coated plane/curved glass substrate.
c. Indigenous / in-house development of photo-polymer or gelatin like films.
d. Development of a suitable processing technique so that modulation pattern is accurately reproduced after a wet-dry processing cycle.
e. Exploring feasibility for space usage and carrying out related testing.



The interferometric techniques, c) recording material

6.3.8. Computer Generated Holograms (CGH)

Aspheric and freeform optical surfaces are frequently used in spaceborne/airborne sensing instruments as they help in reducing the number of optical components in the system, thereby reducing the size and weight of the sensing instruments. Aspheric surfaces are usually tested using null interferometric testing methods: either refractive (null lens) or diffractive (Computer generated Holograms). A Computer Generated Hologram (CGH) is produced via computer synthesis, where the object does not exist physically but it is expressed in mathematical terms. CGH's can generate any shape of wavefront including freeform. Two types of CGH's are used: Amplitude CGH (chrome pattern on glass) and Phase CGH (Pattern etched on glass). High precision and high resolution CGH's can be fabricated using microlithography technologies like electron beam lithography and laser beam lithography. These

microlithographic techniques are common in semiconductor industry for integrated circuits (IC) fabrication.

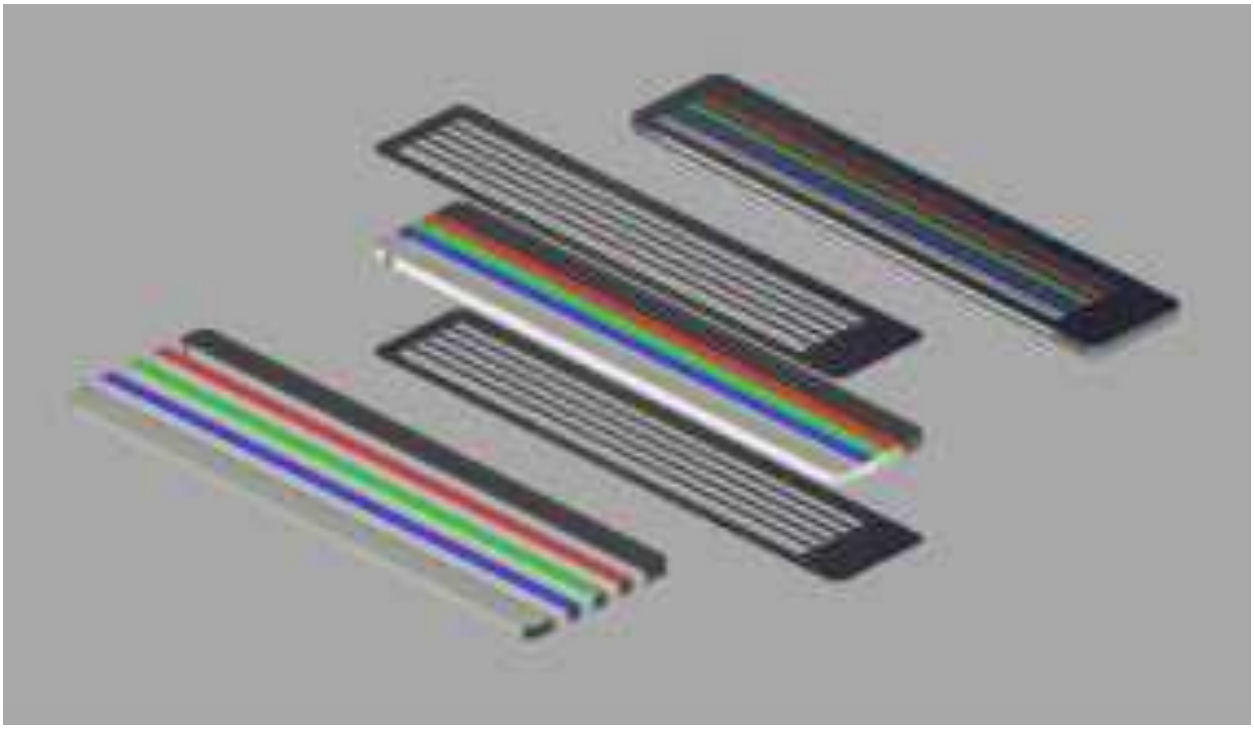
Scope of the Research:

a. Resist (e-beam or photo resist) coating,
b. Electron beam / Direct Write Laser (DWL) Lithography for resist patterning,
c. Resist development, Metallization (E-Beam evaporation),
d. Lift-off or Wet Chemical Etching for Amplitude CGH and Glass dry etching for Phase CGH.

6.3.9. Design and development of Strip Filters in VNIR spectral range.

Strip filters are interference filters. The strip filter assembly can be developed using butcher block technique. In this the filter strips catering to different spectral bands are glued together to form an array. Using the coating facility (SYRUSpro1110) at thin film lab SEDA, the required band pass filter (B1-B4) coatings will be developed. These filters are then diced into strips of required widths using the dicing facility in the lab. Four filter strips belonging to different bands (B1-B4) will then be glued together to form the filter arrays. These activities can be carried out at SAC.

In order to use it on board, one needs to block the stray radiations at the junction of the strips, for which masking coating needs to be applied, which also defines precisely the clear aperture of each filter strip. For this purpose, we need to use lithography followed by masking coating deposition followed by dry etching. At present these facilities are not available in the lab, hence the facilities available at other institutions can be utilized for this purpose.



6.3.10. Development of band pass filters with controlled thickness variation across the filter length.

The interference band pass filters are sensitive to angle of incidence. Not only the central wavelength shifts due to angle but also the shape and transmission changes at higher incidence angles. This becomes more significant in case of narrow band pass filters. In optical payloads with large field of view, it becomes almost mandatory to design the tele centric optics in order to minimize this effect. This in turn makes the design very complicated and may require aspheric components, which are difficult to fabricate. In order to reduce spectral shifts due to large angles, a band pass filter can be design to compensate for this shift by introducing controlled variability in the filter thickness. The variability can be introduced by designing the appropriate masks, which will be filter specific. By replacing conventional filters by these variable filters, the optical design can be made very simple. The design of these filters will be done in house. Development of the controlled thickness variation of the coating across the filter will be taken up in collaboration with Academic institutions.

6.3.11. Development of IR filters

For payloads, involving IR imaging we need filters catering to the spectral range from 3 – 15 microns. The proposal is to design the filters in house and get it coated with the help of institutions within India. At present, the thin film lab does not have the facilities to develop the coatings in the IR spectral range. These activities can be taken up with the help of other institutions within India.

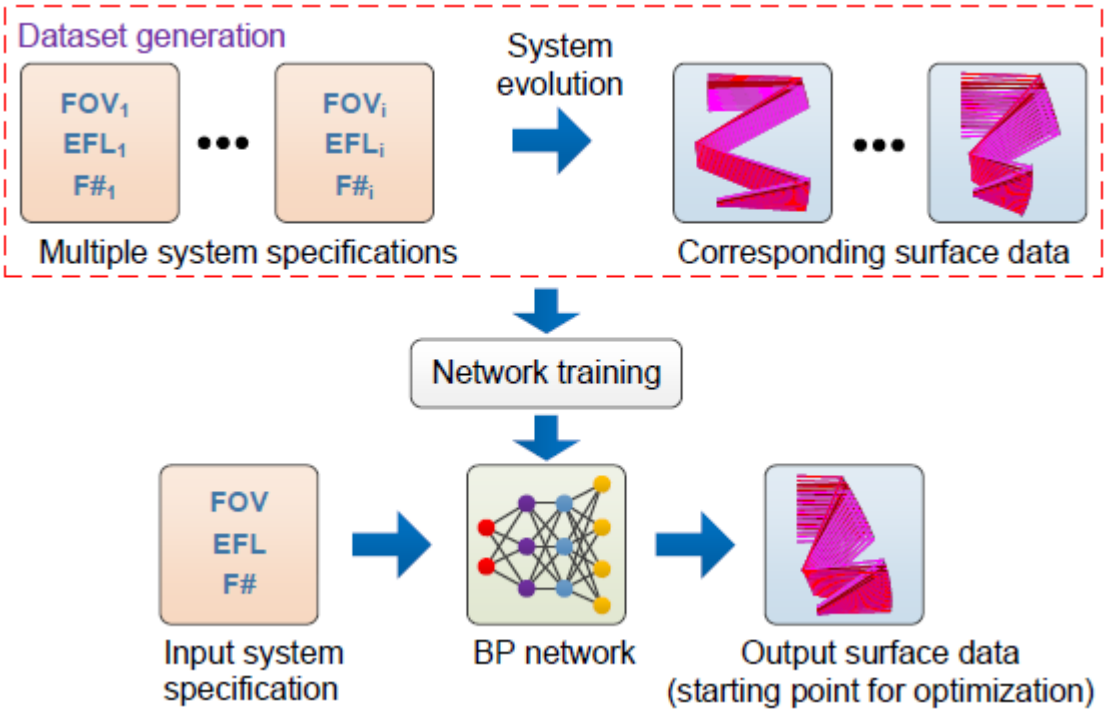
6.3.12. Development of Rugate Notch Filters

Notch filters are optical filters that selectively rejects a portion of the spectrum, while transmitting all the other wavelengths. Notch filters based on the principle of optical interference can be fabricated using Rugate dielectric stack, which provides high reflection in a narrow wavelength region and high transmission outside.

These filters act as mirrors for a narrow band of wavelengths. In the free space optical communication as well as in space based detect ability and identification of submersibles. In this high energy, LASER pulse is transmitted from ground based station towards a space based mirror that scans over a specific oceanic area looking for returns from underwater objects. These filters can replace the reflectors. This will reduce the background noise, as they will only reflect the narrow band of wavelengths around the LASER wavelength. They are also useful in the RAMAN spectroscopy and fluorescence based imaging.

6.3.13. AI enabled design of next generation optics/optical systems

The traditional design method for imaging optics is to first find a starting point, and then perform optimization. However, for freeform system design, proper starting points with similar system specifications and special nonsymmetrical configurations are very rare, which greatly increases the possibility of using extensive human effort.
Use of Deep learning algorithms (Artificial Neural Network (ANN) in particular) can significantly aid in finding optimized starting points for imaging system design. This research work envisages development of an intelligent framework where the entire design process need not be repeated again and will result in faster development of EO payloads. A typical AI enabled design framework is shown in Figure below:



This approach offers several advantages, particularly in the situation where there are limited existing designs and patents and knowledge is limited. The intelligent framework developed can be used to learn from the previous added designs. Moreover, designers do not have to manage the starting point exploration or analytical/numerical design process.

6.4. Electronics System Design and Development

6.4.1. Development of Integrated Circuits for Harsh Environment Operation

Harsh Environments are defined as environments, which are characterized by high/low temperatures, extreme vibration loads, harsh chemical environment, high radiation etc. The electronics or systems required to operate under such harsh/extreme conditions have application such as in aircraft engines, automotive, oil-well drilling and space exploration like near to Sun and planets like Venus where the surface temperature is appx. >400°C. Hence there is a requirement of development of electronics and sub-systems (both commercial and space) which can operate under extreme environments.

Present technology used in development of integrated circuits are mostly Silicon which is suitable for reliable operation when the temperature is <150°C. The other technology Silicon-On-Insulator (SOI) can operate upto temperatures <300°C. Hence, these ICs are susceptible to damage in high temperature and radiation environment and hence require additional distancing and shielding, thereby putting restrictions to where these circuits can be placed.

Recent developments have shown use of wide bandgap (WBG) semi-conductors like Silicon Carbide (SiC), Gallium Nitride (GaN), diamond etc. These materials have shown tremendous resistance to harsh temperature and radiation. Development of an integrated (like SiC-CMOS) circuit technology enables development of integrated circuits which are stable in harsh environments.

The benefits are improved reliability, reduction in size / weight and power for cooling systems (which are typically required when conventional electronics (Si or SOI) is used) and possibility of direct sensing and control systems in harsh environment.

6.4.2. System Modelling and Controller Development for IR Payloads

Various control systems are used in IR payload for controlling the temperature of various Opto-mechanical elements. IR detector requires temperature control of IDDCA cold tip, detector window, Blackbody and other elements within few mK accuracy and stability.

There is a need to develop an executable model of the system including the plant using first principle methods or other methods (using experimental data). MATLAB or other modelling tools can be used for developing the executable model.

Methodology:

1. In first principle method, equations governing the working principle of the plant are developed. Consideration to material properties and interfaces are given to develop accurate relationships between controlling variable and controlled variable.
   If information related to operation of some blocks are not available, field data (experimental data) can be used to model these blocks.
2. Above models are simulated and Controller is tuned and optimized for best performance in terms of overshoot, rise time, settling error and stability.
3. Additional logic e.g. safety logic can be included for protection against over current / voltage.
4. Controller architecture algorithm should be selectable / programmable.
5. This PID controller is to be implemented in Micro-controller/FPGA. To achieve this translation from the system level model to HDL or C language is required. This can be achieved using C Code or HDL coder toolboxes or similar tools/ methods.
6. Generated HDL/C Code are simulated and compared against the results from system level model.
7. Final validation is done by doing Hardware in loop tests with the actual FPGA/Micro-controller.

6.4.3. ASIC: Design, Simulation, Fabrication and Modelling

The scope the activity covers Analog, Digital and Mixed signal ASIC design, simulation, verification, layout, tape-out and fabrication. The main motivation is miniaturization and indigenization of electronics in the form of low power ASICs and Readout Integrated Circuits (ROICs) with objective of integrating multiple functionality in a single device. The ultimate goal is to integrate individual blocks to realize “System on Chip (SOC)”. Some of the ASICs, but not limited to, are multi-channel Analog Front end device for detector signal processing, High data rate Serializer-deserializer, High precision low noise multi-output voltage reference, programmable bias generator and regulators (negative and positive), Bipolar high speed high capacitive CCD clock drivers, IR detector ROICs, multi-channel temperature controller, switches etc. Design and development of radiation hardened library covering standard cells and devices is also covered under the scope. ASIC modelling either software or based on implementation

in FPGA/microcontroller of various ASICs to be part of various system level simulations and optimizations is also envisaged.

6.4.4. Modelling of Special Components, Interfaces, Hardware

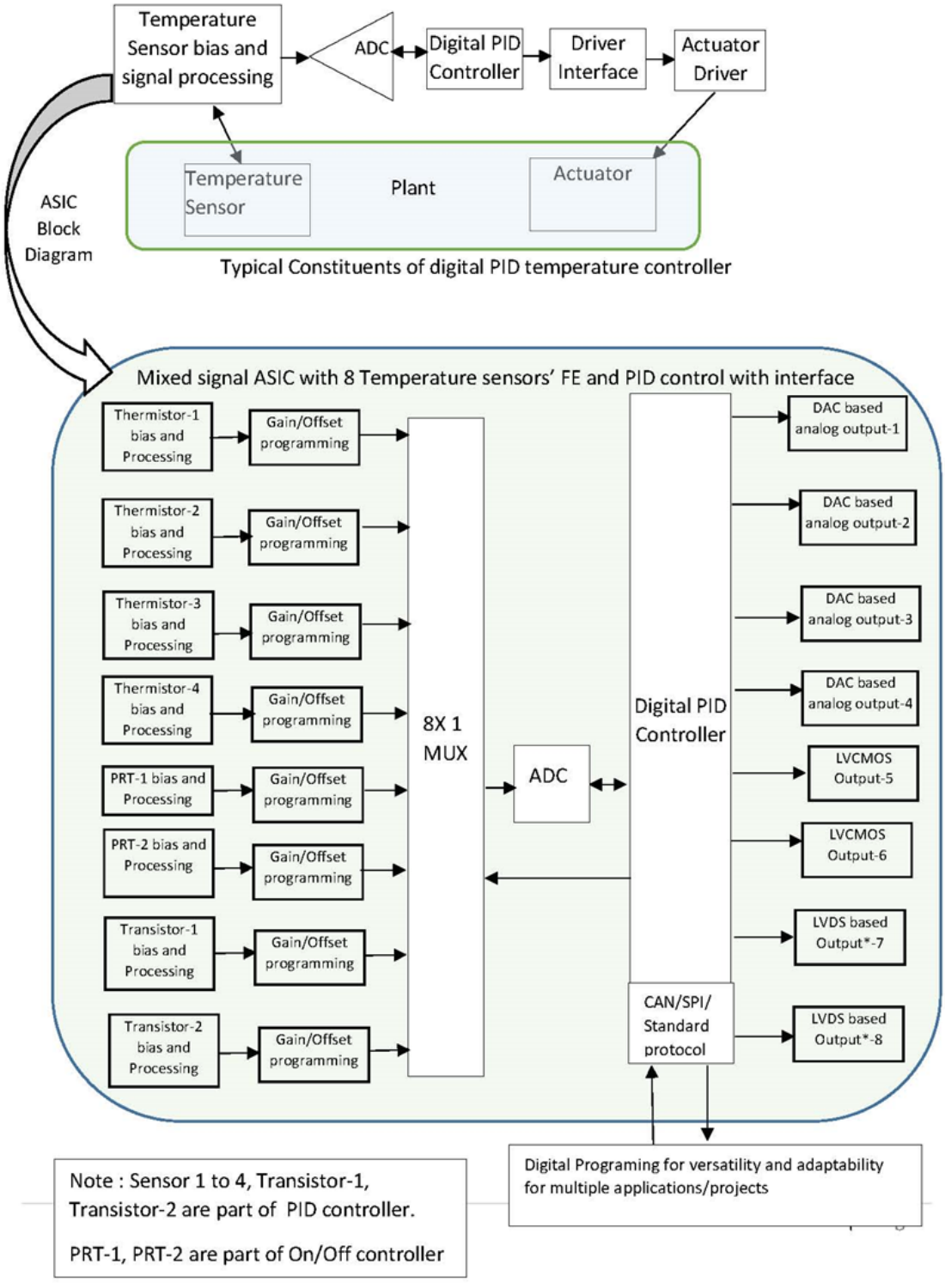
Modelling of various state of the art mixed signal devices, detectors, interfaces etc is envisaged. Font-End design (detector proximity electronics) of an electro-optical payload faces lot of constraints w.r.t system requirements, detector used, real estate availability, harness routing, mechanical design, optical ray diagram, thermal requirements, grounding scheme, hardware in the vicinity etc. Also almost all electro-optical payloads are unique for each mission w.r.t above constraints and it becomes impractical and non-optimal to use a common standardized design for front end electronics. Hence development of various models of components, detectors, interfaces taking into account mechanical constraints, layout, routing, signal integrity, thermal issues, pcb size, circuit topology, grounding scheme, hardware in the vicinity etc needs to be developed. The development of this kind of integrated model will help in better understanding of the system performance at early stage and faster realization of the hardware.

6.4.5. Generic Multi-Channel Front-End and Digital Proportional-Integral-Derivative (PID) Controller with actuator interface ASIC for Temperature Control

Electro-optical payload cameras have many elements like detector, calibration source, optical elements etc. which need stabilized temperature for proper functioning. Range of temperature depends on system engineering, physics involved in device working and overall mission performance specification. Passive cooling is popular and simpler method for temperature control. Cooled object (achieved through deep space radiative coupling) is heated using close loop system to maintain defined temperature. In this scheme, Thermistor or Platinum Resistance Thermometer (PRT) are used as temperature sensor. Foil heater of required capacity are used as actuator. Control is either based on On/Off method or PID method. Other type of temperature control uses active cooling where very low temperature (<200K, cryo-temperature) is to be achieved. This approach uses transistor Vbe to sense cryo-temperature. Linear or Brushless Direct Current (BLDC) motor is used to achieve cooling. Actuator drive signal is 50Hz AC sine wave or Two/Three phase pulses.

In general, any digital domain based temperature controller has (a) Temperature Sensor (b) Signal conditioner (c) Digitizer (d) PID or On/Off control logic (e) Interface control signals for actuator driver (f) Driver for actuator excitation. ASIC proposed for blocks (b), (c), (d) and (e) is multi-channel (typically eight) independent temperature signal conditioning channel ASIC, with versatile and generic design, planned to support multiple application of temperature control. Offset and gain control in signal conditioner blocks is required to allow temperature control using PRT and Thermistors. 3 PRT, 3 Thermistor and 2 Transistor based channels are planned. Digital interface (Low Voltage Complementary Metal Oxide Semiconductor (LVCMOS)/ Low-Voltage Differ-ential Signaling (LVDS)) is planned for actuator driver control. 2 On/Off actuators control, 4 PID actuator control and 2 motor actuator control are planned. Digital PID controller should be programmable using CAN or any other interface for adaptability to multiple applications.

Proposed for ASIC Development



6.4.6. ASIC development of Generic N-channel MOSFET drivers and PWM generator with integrated Current and Hall Effect sensing mechanism and sigma delta ADC

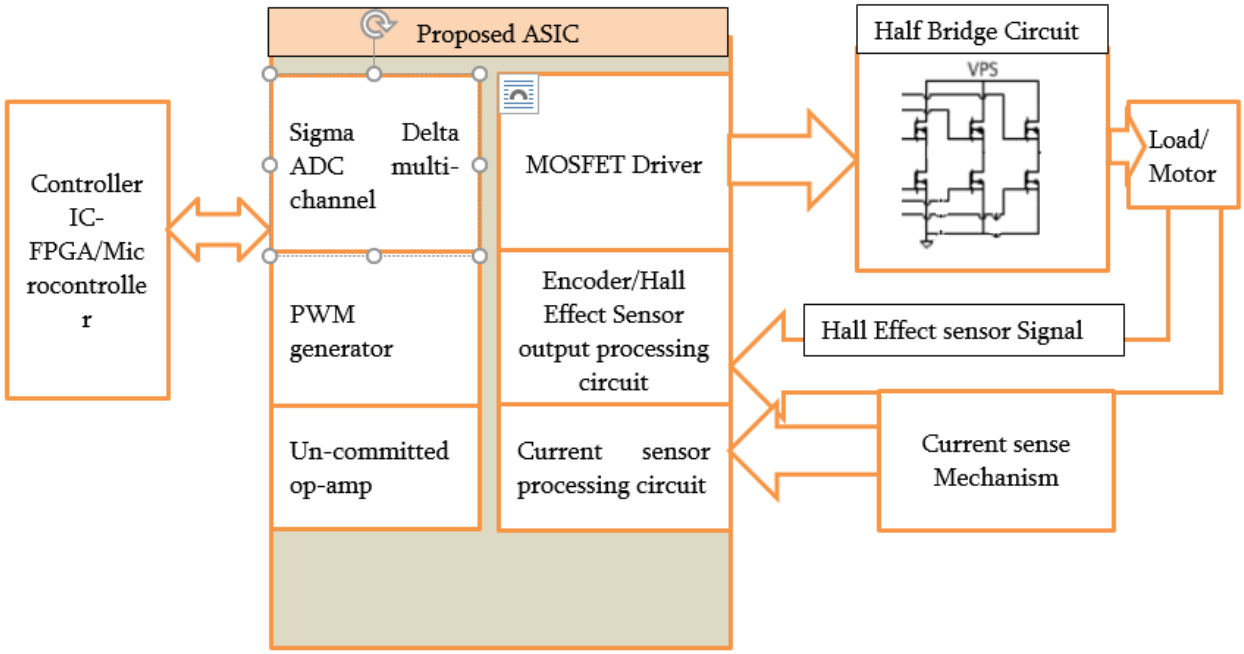
The main objective of development of this ASIC is complete indigenization of space grade motor drive electronics. Generic design of Metal-Oxide Semiconductor Field Effect Transistor (MOSFET) driver is aimed for half bridge control. The ASIC envisaged also has integrated current sense amplifier, hall effect sensing, Pulse-width modulation (PWM) generator and ADC. N-channel MOSFET drivers are mainly used in N-channel Metal-Oxide Semiconductor (NMOS) based drive circuits of stepper motors, BLDC motors, Cryo-coolers etc. A MOSFET driver is a type of power amplifier that accepts PWM signals and produces a high current (>1A) / high voltage (>10V) drive input for the gate of a high-power transistor (such as power MOSFET) with fast switching frequencies (>100KHz) and dead time (~500ns).

Current sensor amplifies a small differential input voltage developed by the current flowing in a sense resistor at the load side. The processing circuit processes the electrical signal generated by Hall Effect sensor or resolver output. Modern Sigma-delta converters offer high resolution, high integration, low power consumption, and low cost, making them a good ADC choice. Multi-channel delta sigma ADC is required for processing control parameters e.g. Load current, voltage etc. The Independent PWM Generator (switching frequency > 100KHz) block is required to generate pulses for carrier-based pulse width modulation converters. The block can be used to fire the MOSFETs of single-phase, two-phase, three-phase bridges. PWM resolution of >10 bit is preferred. PWM generator shall provide internal or external reference input for modulation and shall have a bypass option for providing input from external FPGA/uC. An uncommitted (low bandwidth, precision) op-amp is required, so they can be tuned based on the application. The gain resistor of op-amps should be external to allow the buffer and filtering of required signals. Typical specifications and block diagram of the ASIC is as below.

Typical Specifications:

- 4 High and 4 Low side outputs
- >1A drive per output
- High side voltage/bootstrap voltage > 50V
- Programmable dead time up-to 500ns
- 3 Current sensors
- 4/8 channel sigma delta ADC, >12 bits, >100ksps
- 6 bi-level inputs for Hall sensors
- Resolver interface (optional)
- Optional Buffered PWM inputs (3.3V or 5V)
- In-built PWM Generator with bypass option
- PWM resolution: better than 10 bits
- PWM frequency > 100KHz
- Duty cycle range: 5% to 95%
- Un-committed Op-amp (BW- 1MHz, typical)
- Serial programming

Block Diagram:



6.4.7. Reconfigurable System-On-Chip based solution for satellite on-board computing

High speed computing has always played an important role in on-board data processing and control. On-board computing has been represented mainly by the on-board computer (OBC), which is the kernel of the On-Board Data Handling (OBDH) system that is central to the overall satellite design and its operations. The OBDH system is an integral part of the satellite platform and in many missions extends to comprise various elements of payload electronics. In future missions, there is need for advance technologies that can be achieved via miniaturized multi- System-on-Chip (SoC) processor designs.

Now a day, the increasing requirements of on-board reconfiguration and on the fly programming capability, system-on-a-programmable-chip (SoPC) designs has emerged as a major enabling technology. It is envisaged that the application of the SoPC concept to on-board computing will result in radical improvements and unleash new capabilities. In addition to the benefits of SoC design, such as reduction of size, complexity and cost, it can provide the means to build flexible and modifiable on-board computing systems. The SoC platform can be configured to meet different mission requirements.

The SoC on-board computer (SoC-OBC) consists of mainly soft IP cores, programmable gate arrays including the LEON/ Advanced RISC Machine (ARM) processor and multiple peripheral devices. A purpose-built Direct Memory Access (DMA) controller handles the data transfers between the peripheral cores and the main memory. The AMBA AHB and AXi buses is for interfacing of high-performance system modules. The Advanced Microcontroller Bus Architecture (AMBA) Aadhaar Payment Bridge (APB) bus supports peripheral functions with minimal power consumption and reduced interface complexity. The CAN, High-level Data Link Control (HDLC), SpaceWire and space fibre network interface controllers and the EDAC block are typical components and interfaces for use in space.

Designing On-board Computer consisting of programmable system on chip hardware is really challenging and this will provide the common miniaturized hardware platform for multiple missions along with providing seamless solutions and flexibility of programming, controller, data processing and standard interfaces.

Scope of Research:

- Design and development of On-board computer hardware encompassing mainly Programmable System on chip(PSOC), Rad hard FPGA, high end memories and all standard interface CAN/Spacefibre/Serdes/LVDS interfaces along with SI and PI analysis with industry collaboration.
- Soft cores IP design for standard interfaces and Logic
- Standard Memory DDR2/3, ONFI controller designs.
- External peripheral interfaces design &development.
- Embedded processsor/LEON/ARM processor interface with FPGA.
- Onboard partial n selective configuration.
- Space fibre codec n network design and development.

6.4.8. Real time image processing in on-board Space systems:

Target detection and tracking has gained significant importance in many applications, including optical communication, inter-satellite communication, motion detection, reconnaissance and surveillance in which the major is to reveal trajectories of the targets. Considering the recent developments, many electro-optical systems are in need of full automation for achieving this task. Therefore, many multi-tracking algorithms include two fundamental stages as the automatic, time independent detection of targets; and association of the detections in the temporal space. Problems remains to be challenging mainly due to unknown and changing number of targets; noisy and missing observations; interaction of multiple targets. Moreover, all these challenges are needed to be solved in a time efficient manner for real-time applications in space systems.

Scope of Research:

a. Study and implementation of object detection algorithm for low SNR targets and its real time implementation in on-board FPGA hardware
b. Tracking algorithm development: Kalman for tracking and trajectory prediction.
c. Study/development of Optical Flow algorithm for planetary landing.
d. DSP based real /near real time data processing for signal analysis and image processing.
e. Real Time decision making for Landing System.
f. Machine learning techniques along with computer vision techniques need to be studied and implemented for the targets required for obstacle detection, landing site and surveillance.
g. Real Time Operating System (RTOS) optimisation for on board I

6.4.9. Power supply systems for Space missions

Payloads for Remote sensing and planetary exploration missions require state of art Power Supply electronics to cater to various requirements of Camera Electronics sub systems. These Power Supply Electronics requires to meet several stringent requirements such as multi-output voltage lines in range

3.8V to 24V, very low noise (≤20mV), high efficiency (>70%), EMI 461E complaint, inbuilt input power protection and output short circuit protection.

The following technologies are of particular interest in future Power Supply electronics development

a. Very Low noise (≤5mV), Low power (<10W), highly efficient (>80%) complying with EMI 461E standard, space grade isolated power supply /module.
b. Multi-output (3 to 4 voltage lines in range 3.8V to 24V), high efficiency (>80%), Medium Power (25W – 100W), Low noise (≤15mV) complying with EMI 461E standard isolated space grade power supply
c. Development of Hybrid Micro Circuit (HMC) based miniaturised dual output (+3.8V and +5.6 V) DC-DC converters with high efficiency (>75%), medium power (> 30 W), inbuilt EMI filter and having EMI/EMC compliance to MIL-STD-461E.
d. Development of housekeeping and protection circuitry in the form of HMC to monitor and protect power supply electronics from various fault conditions such as Overvoltage and under-voltage protection, Over temperature protection, Overcurrent protection and Output Short circuit protection
e. Development of Rad-hard non-isolated synchronous buck converters for wide input voltage (10-30VDC), adjustable output voltage (from 3V to 80% of Vin) and high output current (>10A).

6.4.10. Optical data transmission system for Nano/micro payloads

High resolution wide swath imaging typically requires payloads and satellites of large dimensions & weight. Huge amount of data requires to be transmitted to ground requiring multiple transmitters further increasing the mass and size. Cost of such satellites is too high. Development time is large and penalty associated with any component under performing/ malfunctioning is large. Alternative approach is to develop a constellation of Nano satellites to cater to above requirements. However traditional Nano satellites suffer from low data transmission capability and poor pointing accuracy. To overcome this problem it is proposed to develop a Nano satellite utilizing optical data transmission. However incorporating a traditional Optical Communication Terminal (OCT) is not feasible in the mass and power constraints of a Nano platform. It is therefore proposed to develop & demonstrate a miniaturized Optical data transmission system to enhance the capabilities of ISRO's small satellites.

6.4.11. Single Board Controller based Payload & Mainframe Electronics for High Resolution Nano Satellites

Traditional ISRO Nano satellites (~10Kg) are capable of providing ~20m resolution from LEO orbits. However higher resolution & lower mass is desirable for future Nano missions. A Nano Satellites consists of following subsystems:

- Payload sub-systems (Sensor, Electronics, Optics, Mechanical)
- Mainframe subsystems (Attitude Control system ,OBC, RF system)
- Electrical Harness
- Mechanical Frame/Housing for Payload and Mainframe
- DC-DC for payload
- DC-DC for Mainframe

Present approach has dedicated electronics for various functions of the payload and satellite mainframe e.g.

- Sensor Bias, Sensor Control, Sensor data processing, Compression , Data Formatting, Data Transmission is managed via 2-3 Boards.
- Payload DC-DC Electronics Board
- Satellite mainframe OBC Board, ADCS Board, RF Board.
- Mainframe DC-DC Electronics Board

For reducing the overall satellite mass (<5kg) while improving payload performance (resolution, swath, SNR), miniaturization & integration of various Electronics is proposed. A Single Board High Performance Controller along with a bus structure shall be developed carrying out functions of Sensor Bias, Sensor Control, Sensor data processing, Compression, Data Formatting, Satellite mainframe OBC, ADCS, RF Data Transmission.

6.4.12. Space qualified flexible EMI Shielding and Radiation resistant coatings and enclosures for Onboard Electronics

High speed electronics systems, miniaturization of PCBs, Electronics packages, small payloads and other such advanced capabilities, electronic sub systems requires highly populated PCBs / Packages / harnesses to support their functionality and performance requirements. Such compact/dense packaging causes EMI effects. Traditional metal EMI shields take too much space thereby reducing the overall competitive functionality of electronic devices and increases the size as well. Therefore, more recently, the research focus is on flexible coatings and enclosures developed from nanocomposites. Therefore, we feel the requirement of the development of MIL-STD-461E compliant flexible EMI shielding and radiation tolerant enclosure, which can be easily applied and adapted onto a PCB design and very sensitive signal lines. The required composites should suite the needs of ISRO especially like space-qualified material, high thermal stability, flame retardant and durable for mission life of more than 10 years. These composites can be explored for designing materials that can shield radiation and protect PCBs and harnesses without much overheads. The qualification of these composites, but not limited to, should include Thickness measurement test, thermal shock test, thermos vacuum test, humidity test, coating peel test, outgassing test etc. The design of enclosures should be in a way that they don't need to be electrically grounded to the PCB, thus simplifying or eliminating masking. This should also be able to address EMI issues on the PCB, in between tightly packed semiconductor devices and can be tuned to absorb EMI at specific required frequencies. The design must also take care that they could be applied at the end of a product design cycle. These enclosures should not affect the electrical performances and sub system functionality at ground and at onboard. The shielding performance also need to be brought out for frequency range up to 1GHz with respect to the material thickness.

6.5. EO sensor System AIT and Performance Characterization:

6.5.1. Design and development of smart test setups:

Test setups help in simulating spacecraft mainframe interfaces, control and command of the sensor, and data acquisition for performance evaluation. Currently, test setups are custom developed for each EO sensor considering its interface, functional and operational requirements. However, in view of the upcoming demand for variety of EO sensors, there is a potential scope of research and development for smart test setups for EO sensor testing. The smart setups are easily reconfigurable to cater to variety of sensors, they have fault tolerant designs, and are self-calibrating to enable faster turnaround time and ensure precision measurements of EO sensor performance parameters.

6.5.2. EMI analysis and mitigation techniques

During AIT, various electronics subsystems, test setups and associated harness assemblies exhibit complex interplay and results in a complex EMI environment. This causes various random and fixed pattern noises in the EO sensor data, which can significantly impact radiometric quality of the imaging sensor. Hence, it is very important to identify the potential noise sources and develop suitable mitigation techniques. This offers a research opportunity for design and development of EMI analysis tool, which accounts for various noise sources in the sensor chain including electronics component level noise, crosstalk, signal coupling effects, ground noise coupling, engineering noise coupling, etc. and helps to analyse complex EMI scenario, identify the noise sources and help in developing suitable mitigation techniques. Available COTS software modules can be suitably used in the proposed analysis tool.

6.5.3. Development of new methods for EO sensor performance evaluation

SNR and MTF are two key performance parameters that are used as performance markers for comparative studies. Many methods exist for performance evaluation in terms of MTF and SNR, however, considering the stringent requirements of EO sensor performance in upcoming future missions, many new methods are required to be developed. This offers significant research opportunity in this field. We need to develop efficient, simple and robust methods for SNR and MTF measurements. Also, study shall identify new performance markers and develop suitable methods for its implementations.

6.5.4. Thermal analysis model of harness assemblies

Thermal analysis of EO sensors and spacecraft systems are carried out to evolve suitable thermal design and implementation approaches. Generally, thermal analysis of all electronics subsystems are carried out to evolve suitable thermal implementation scheme. However, thermal modelling and analysis of harness assemblies are generally ignored, although they are passive dissipating element in every spacecraft system. Thermal modelling of harness assemblies is very critical as it helps derive rerating specifications, avoid potential arching conditions, helps in improving performance of thermal control system.

6.5.5. Design and development of machine/deep learning methods for payload test data analysis

Large amount of data is acquired during ground testing of EO sensors. These data sets help in analysing EO sensor performance under various operating and environmental conditions. However, analysing huge data sets to bring out minute but potential performance degradations is very difficult with traditional approaches. There is an opportunity to develop machine learning techniques to analyse large amount of data acquired for various EO sensors.

6.5.6. Machine Learning Techniques for Fault Diagnosis using TM data

Complex EO sensors employ large number of interconnected subsystems to perform imaging task. The performance of all subsystems are monitored through the large number of telemetry (TM) channels such as voltage, current, temperature, timing information, configuration details etc. TM data is acquired during ground testing and also during in-orbit phases resulting in huge amount of TM data. These TM parameters allow designers to monitor the health of the sensor. Machine learning techniques can be developed to

analyse the large amount of TM data to observe even subtle performance deviations that can help in diagnosing the faults in the operations of EO sensors.

6.5.7. Development of harness embedded panels for plug and play AIT

Interconnection harness constitute an integral and important part of the EO sensor and satellite system. Various electro-mechanical constraints in implementing the harness interconnection calls for significant efforts in the design and development of EO sensors. Literature survey shows innovative concept of harness embedded panels, which significantly helps in saving precious volume on resource constrained satellite systems. We envisage to develop such harness embedded panels for Indian remote sensing sensors. In this arrangement harness is run within the panel thickness and connectors are available on top and bottom surface of the panel as end points for package interconnection. The proposed research work involves exploring innovative design of harness embedded panels, structural analysis, usage of smart materials and proto-type development, etc.

6.5.8. Development of efficient algorithm for image reconstruction for compressive imaging sensor

Compressive imaging (Optical domain compression) is an emerging field that allows design and development of single pixel camera systems for imaging. Significant efforts have been reported in the literature for development of single pixel camera systems as an alternative to current commercial cameras. However, not much study has been carried out in exploring the feasibility of developing a spaceborne imaging system architecture based on optical domain compression. Currently, we are working on a single pixel camera architecture for spaceborne applications. The research opportunities exist in development of efficient algorithm for image reconstruction using the images acquired by a compressive imaging sensor and carry out extensive bench marking against available methods.

6.5.9. Development of robust image quality metric and suitable methods for its estimation using in-orbit images

In-orbit image quality evaluation of EO sensors is a continuous evolving research field. This research work envisages development of a robust image quality metrics and suitable methods for its estimation from in-orbit images.

6.5.10. Development of methods for accurate estimation of SNR and MTF from in-orbit images

EO sensors undergo extensive ground testing during development phase. However, post launch performance deviations are generally observed due to various instrument effects due to launch loads and orbital environmental conditions. On-board and vicarious calibration methods are employed to assess the in-orbit SNR and MTF performance of EO sensors. However, the achieved accuracies in deriving performance parameters always suffer from limitations either from measurements or the methods itself. The proposed research work will first study the available methods and suggest new approaches for accurate estimation of these performance parameters.

6.5.11. Development of techniques for quantitative estimation of MTF contributions from various elements in the EO imaging sensor chain

In-orbit images generally suffer from MTF degradations due to instrument behaviour in the orbital conditions, platform vibrations and jitter, and atmospheric conditions. Extensive characterization is carried out in laboratory using standard targets and also in-orbit using stellar and various calibration targets. It is important to quantitatively ascertain MTF contribution from each elements of the imaging instrument to understand anomalous behaviour (if any) of one or more elements using the laboratory data and in-orbit images. This research work envisages development of methods/techniques to quantitatively measure/derive MTF contribution from each element in the EO sensor chain. Also, extensive validation studies to be performed using available EO sensor data.

6.5.12. Design, development and characterization of Spacefiber interface-based data transmission board

Spacefiber interface is an emerging technology for transferring huge amount of data running up to 40 Gbps and can have multiple channels for increasing the data Tx rates. The interface protocol is based on Spacewire. The Spacefiber protocol has wires or fibres as physical layer for data transmission. This research work envisages comprehensive study of Spacefiber interface, design and development of a bread-board functional model and extensive characterization of the developed data transmission board.

6.6. Ground Checkout Systems for EO Payload Testing:

6.6.1. Computer based Multichannel High Speed Digital Data Acquisition System

High Resolution EO cameras generate high speed data (of the order few Gbps). Evaluation of these cameras during various phases of testing, calls for design & development of High Speed Digital Data Acquisition System. Data Acquisition System receives incoming digital data from payload and transfers it to the computer. Data Acquisition System comprises of Data Formatter, Data Acquisition Modules installed in the computer and Data Acquisition Application. Data Formatter receives the digital data from payload over multiple chains with required electrical interface (LVDS, serializer/deserializer (SERDES)), formats it and transfers packed data to Data Acquisition Modules. Acquisition application acquires data from Data Acquisition Modules.

Out of different options for transferring the high speed data to computer, Camera link interface based transfer is one suitable option. Camera link interface supports high data transmission rates (2.04 Gbps for BASE mode, 5.44 Gbps for FULL mode & even higher for extended FULL mode configuration) & can be used to transfer very high speed data from Data Formatter to computer. Camera link's transmission method requires fewer conductors to transfer data. Hence it reduces the hardware components, interconnecting cables and simplify the Data Acquisition System configuration.

Design & development of High Speed Data Acquisition System which involves Data formatter (Data Input – Multi channel, SerDes interface) along with the Data Acquisition Application can be taken up for data transfer rate upto 4.0 Gbps using camera link i/f in-house which will be very useful during the testing of High Resolution EO cameras.

6.6.2. Comprehensive Automation of Test Benches

Automation of Spectral Response Measurement (SRM) test bench using a Bentham mono-chromator has been very successful and because of the same, the spectral characterization for all payloads works smoothly and effortlessly.

Complexity of the payloads have increased which demands more and more testing and that too repeatedly in different conditions. The 1553 bus based TC and TM systems simplify the tasks and have been implemented and are successfully working. Integrated testing becomes a laborious process when carried out by the test engineers and has chances of errors.

A scheme is proposed which has a generic architecture to combine instrumentation, data acquisition, parametric evaluation and a final output generation. The 1553 bus based instrumentation provides both the TC and TM functions. Tele-commands issued can be verified thru the telemetry for the confirmation. Synchronized data acquisition request can be made, followed by data processing to compute a set of parameters. This process is repeated for all modes of operations of the payload under a given test condition. At the end of execution of all operations, post-processing can be carried out over the data-set. Such instructions can be combined as a macro and executed as and when required.

For Microsat-2A (LWIR and MIR) payload calibration, there was a requirement to acquire and record the data of all seven exposures for different temperature settings ranging from 180K to 340K. To cater to this requirement, automation feature was developed for payload commanding to change the exposure, acquire and record the data and generate the results simultaneously. With the automation, the task could be completed with about a factor of three improvements in timings as compared to manual task.

This shall be an in-house development with the participation of focal persons from integration team, software and instrumentation developer for one test case project.

6.6.3. Knowledgebase Creation and Information Extraction

A huge database of information is available for all E/O payloads developed so far by SEDA. This information contains automatically archived test results, TM data, raw data, logs and manually uploaded documents. The information is structured at sub-system level and project level under categories such as Results, Issues, Discussions and Solutions. This will provide contents for to create a knowledge base for future generation projects. An interface on top of this, using Natural Language Processing (NLP) techniques can be developed. This interface shall accept the queries in human-understandable natural language and provide answers by processing the information.

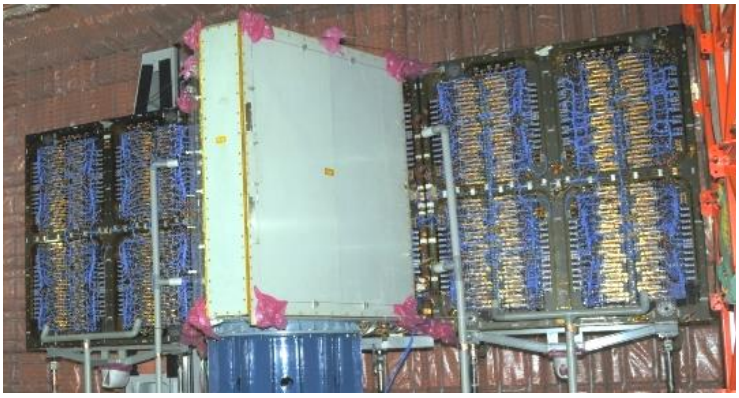
Academia has subjects related to Information Retrieval, Data Mining and alike under broad topic of Artificial Intelligence. Students from academia can be involved in the projects.

6.6.4. Development of learning algorithm for fault identification and recovery of EO payload by analyzing the video data, telemetry and commanding sequences

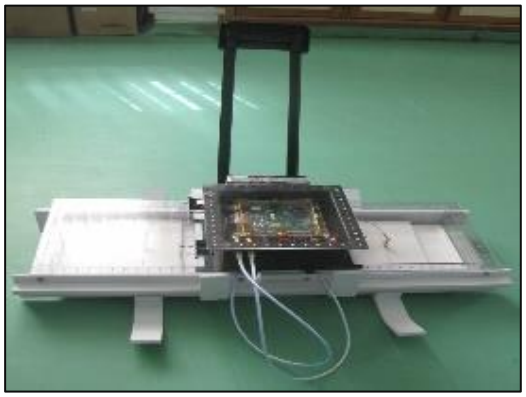
Electro Optical camera/payload consists of multiple subsystems i.e. Detector, Optics, Camera electronics and mechanical subsystems. To meet the performance specifications, it is required that all these subsystems operate to their best potential. During the course of integration and calibration of subsystems, lot of payload calibration data and payload telemetry is generated in response to the commanding sequences given to the payload. During this phase of payload integration, problems are observed which can be due to multiple reasons like faulty commanding sequence, improper cabling or faulty behavior of any subsystem. To diagnose these problems at the earliest, a learning algorithm needs to be developed which can continuously analyze the video data, telemetry and commanding sequences given to the payload and build a model of the payload over time. This algorithm will not only help during the payload integration phase but also during satellite integration and in-orbit operations of payload.

7. MICROWAVE SENSOR TECHNOLOGY

From a humble beginning in mid-1970s with the launch of Satellite Microwave Radiometers (SAMIR) onboard Bhaskar-I/II, in present day, microwave remote sensors developed by ISRO are at par excellence with its peer sensors of other space agencies. In the field of microwave remote sensors, ISRO has been growing consistently in the last three decades during which many major milestones have been achieved. During these years there has been multifold increase in microwave sensors applications which has resulted in increase in demand of various multiband radiometers, Radio Detection and Ranging (RADAR) imaging SAR payloads in various bands viz. P, L, S, C & X, single/dual band scatterometers, altimeters and sounders ranging from UHF band to terahertz. Apart from the conventional microwave sensors, the demand for sensors in emerging and more advance fields like microwave quantum sensing is also increasing. Accordingly, the efforts for design and realization of quantum radar also being taken up.



RISAT-1 C band SAR



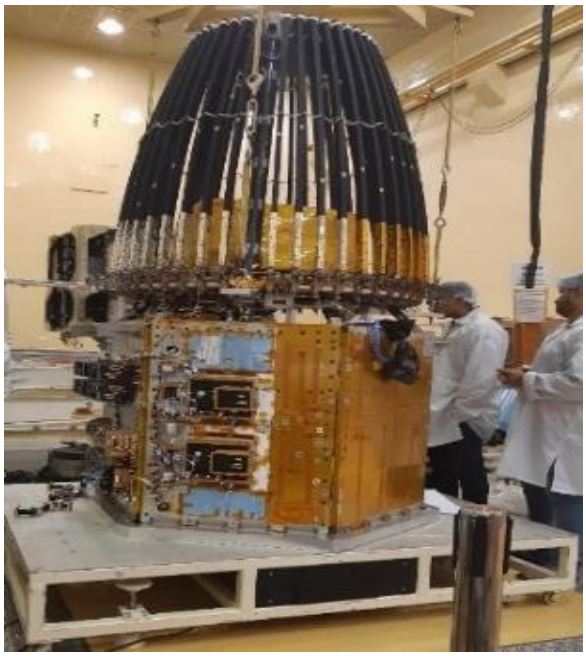
GPR

Airborne DMSAR

These microwave sensors are adding valuable scientific information particularly in the atmosphere, ocean and land application for both Earth observation and Scientific & Interplanetary Missions. To meet the user requirements of microwave payloads, it is essential to keep the pace of technological advancement in all sphere of building blocks including Transmitter, Receiver, Power electronics, Digital acquisition, Data processing & control, Fabrication technologies etc. Space Applications Centre has taken lead in developing technologies required for microwave sensors over last three decades. The first RADAR

imaging satellite RISAT-1 was launched with host of new technologies in 2012. Thereafter, the need was envisaged to develop more thematic based microwave payloads such as Occeansat-2 Ku band Scatterometer, Megha Tropiques MADARS, C band Air-borne sensor DMSAR were developed.

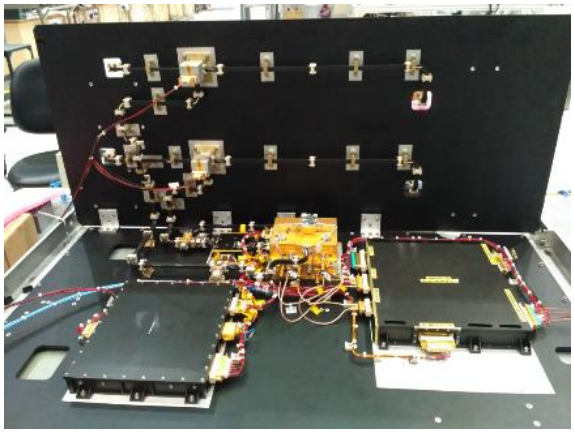
X band MiniSAR



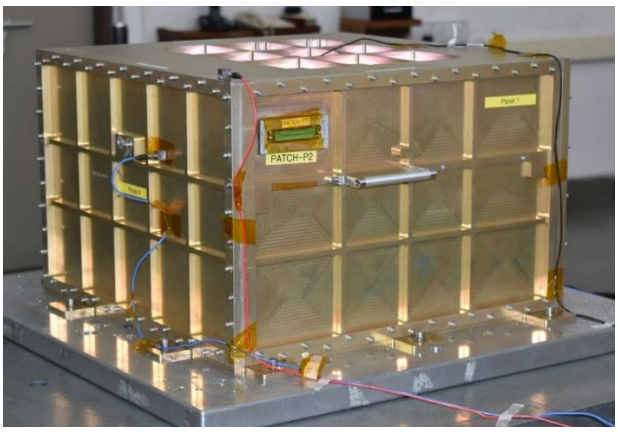
RISAT-2B X band SAR

Ku band Scatterometer

During last few years six new payloads were developed successfully meeting requirements of different users. These payloads include the development of constellation of three X band SAR (i.e. RISAT 2B, R1, R2), L& S band Polarimeteric SAR and Ka band RADAR (KaRa) altimeter for orbiter & lander of Chandaryaan II, Airborne dual band L & S SAR for joint air Campaign of ISRO-NASA, and SCATSAT-1 for deriving global ocean wind vectors. RISAT-2B satellite, first in the constellation of three Radar Imaging Satellites, proved excellence in radar imaging area with successful realization of various indigenous technologies like ferrite switches, Radial Rib Antenna system, high power GaN based pulsed switches and butler matrix, high speed digital acquisition and processor. RISAT-2BR1, the second Radar Imaging Satellite in the 3 Satellite constellation was realized in a short span of six months from the launch of RISAT-2B and its performance in orbit is commendable. Looking into excellent performance of Ka band Altimeter of Chandryaan II it has become technology marvel which has been inducted in both Reusable launch vehicle and Gaganyaan mission. The Altimeter is also a part of Chandrayaan-3 landing mission



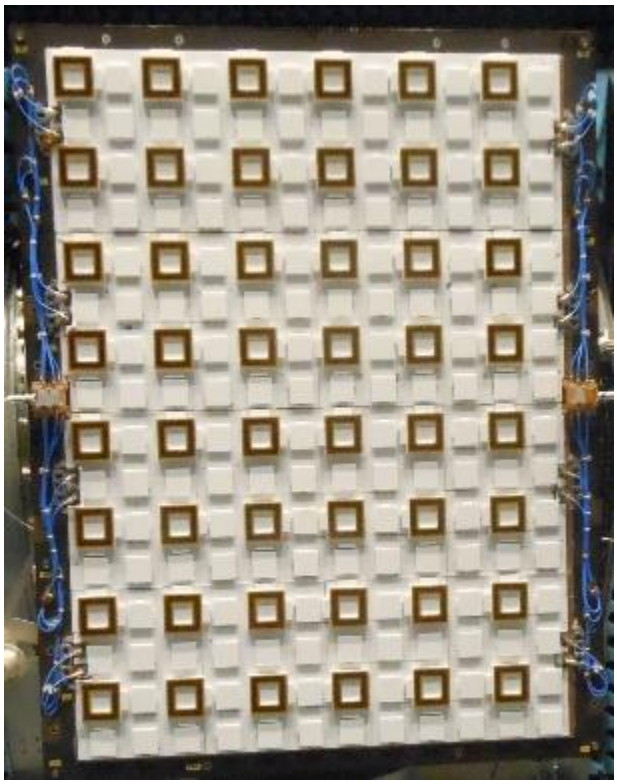
Ka band Radar Altimeter (CY2 & CY3)

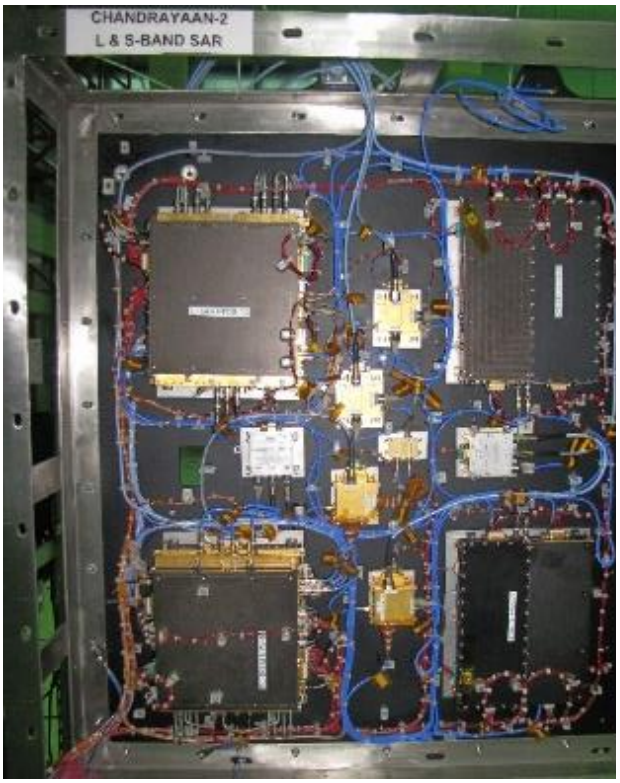


Ka band Radar Altimeter (IADT – Gaganyaan)

ARC

ARC deployed in Antarctica



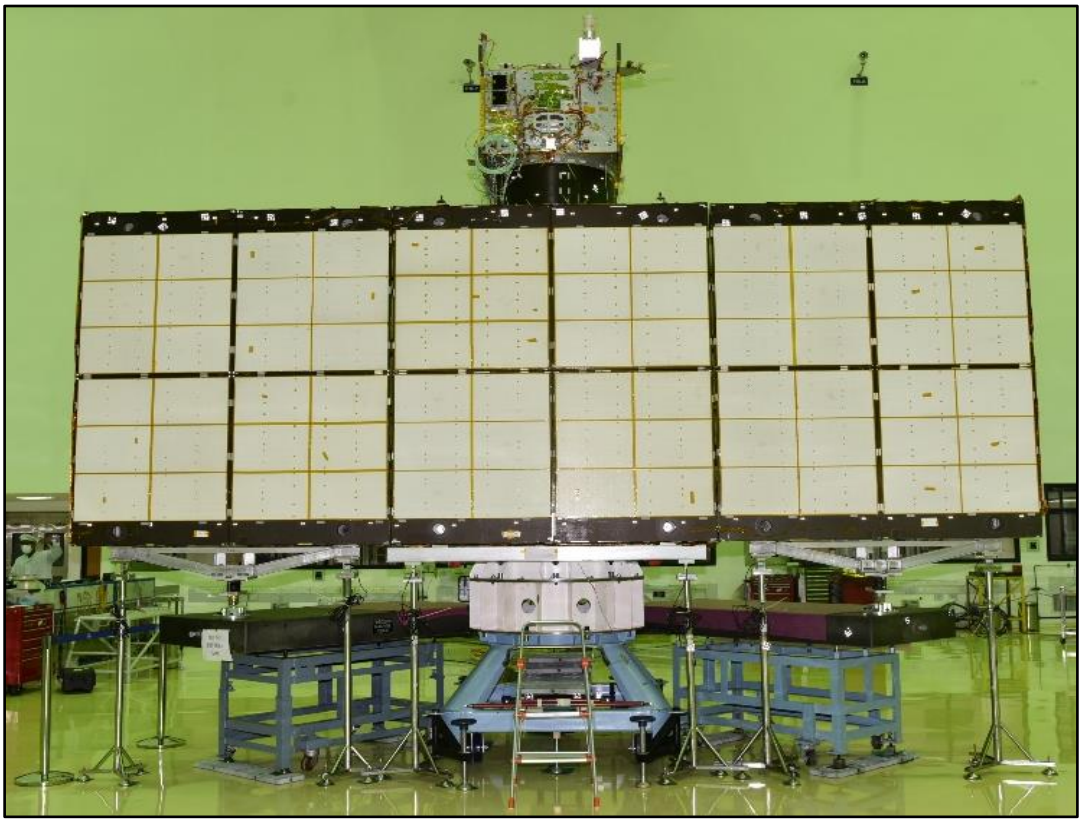


DFSAR for Chandrayaan-2 Orbiter

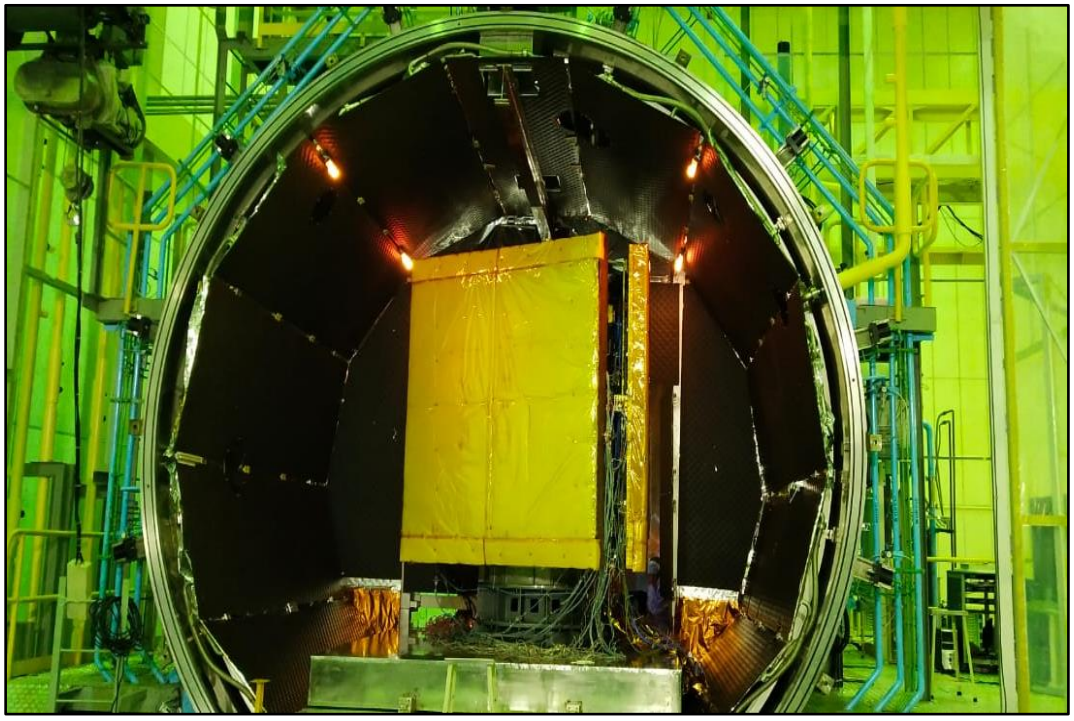
L & S band Airborne SAR

RISAT-1A is a follow on of RISAT-1 mission with almost similar configuration and improved technologies. RISAT-1 was launched on 24th April, 2012 with indigenously developed, first space-borne SAR of ISRO. The onboard C-band SAR payload provides valuable data to the user community for a gamut

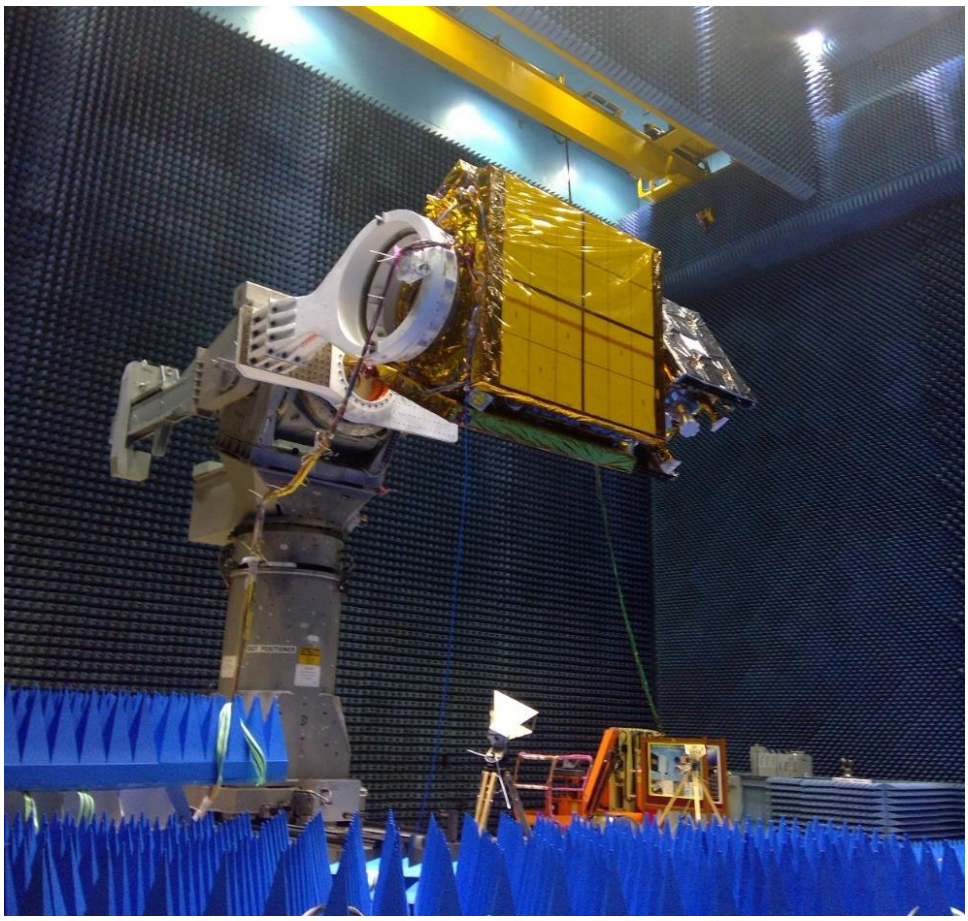
of applications -agriculture (crop forecasting and monitoring), disaster management, urban planning and many more. Though the overall configuration of the payload remains the same, RISAT-1A boasts of incorporating features, which target to keep up with the technological strides, and to improve on the present data quality. Two major requirements came when hardware is in advanced stage of development. First one is changing of orbit from previous 536km SSPO due to the requirement of frequent collision avoidance manoeuvers as proposed SpaceX's Starlink constellation at 550km orbit and suggested to avoid 550 +/- 25 km orbital range. Second one is changing of center frequency of the hardware to avoid interference from Wireless Local Area Network (WLAN) band due to the fact half of the RISAT-1A bandwidth overlapped with the frequency band allocated to WLAN. Both the requirements are addressed in a very short time owing to flexibilities in system configuration with minimum changes in hardware configuration, and all major imaging modes performance are retained without any change. Payload was flagged off after frequency modification on 26th March, 2021 and was launched on 14th February, 2022. Since launch, payload has been operating flawlessly and all major imaging modes are operated successfully. Magnetic Resonance Spectroscopy (MRS) systematic coverage started from 23rd March, 2022 and presently 16th cycle is in progress. Sharing of Payload data with Users initiated from September, 2022 for validation after successful completion of calibration activities. Formally RISAT-1A data is released for Users on 13th December, 2022.



RISAT-1A C band SAR Integrated with Satellite



RISAT-1A C band SAR inside Thermovac

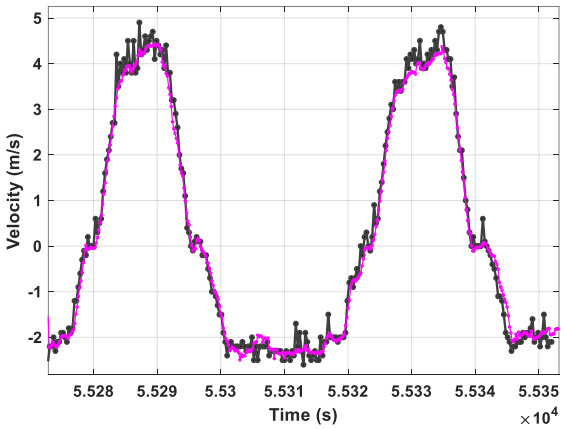


RISAT-1A C band SAR inside CATF Facility at URSC

EOS-4 Satellite inside Payload Adapter at SDSC SHAR Centre

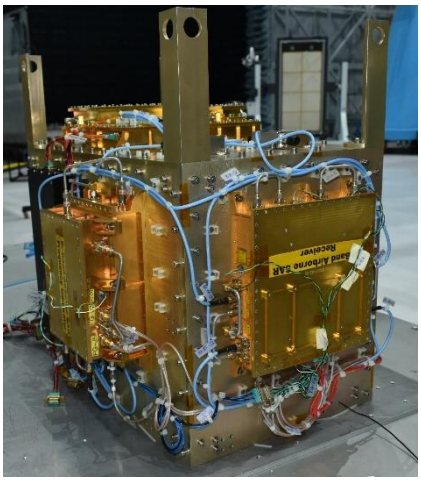
Velocity sensing is a critical part for any landing mission. The architecture of descent and landing system require autonomous ground-relative navigation to high level of accuracy. Looking at the futuristic planetary missions like LuPex and Mars Landing Mission (MLM) design of a radar-based velocity sensor is initiated in SAC. The radar will provide line-of-sight velocity along three independent direction to the navigation system. The measurement direction operates, and utilizes a memoryless design that provided a robust method of estimating velocity independent of previous measurements. Navigation Doppler radar will provide centimeter-per-second velocity on three unique beams. This sensor design uses a narrow beam antenna to achieve the required velocity precision. The system measures the Doppler shift by computing the frequency shift between transmitted signal and received echoes.

Preliminary field experiments to demonstrate the proof of concept were carried out at SAC campus as shown below.

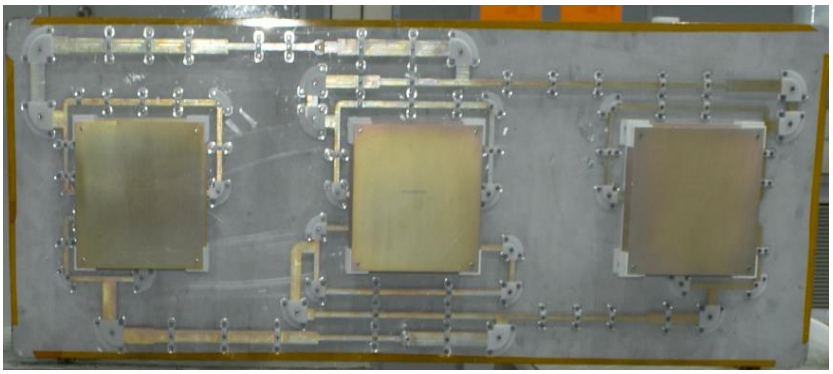


Field tests to demonstrate the principle of operation and velocity estimation using Doppler shift

Towards interplanetary program various sensors are being developed like Ka band Altimeter for Chandryaan 3, Radiometer, SAR and Ground penetrating RADAR (GPR) for VENUS, Lunar and MARs mission. Currently SAC is involved in the development of Ku band high resolution scatterometer (Oceansat III), S band SWEEP-SAR as part of joint mission of (NISAR) NASA ISRO Synthetic Aperture Radar (NASA-ISRO SAR) dual band SAR for cryosphere and ecosystem. An imaging radar capable of day/night and nearly all-weather operation at P-Band frequency (425- 475MHz) has been developed to cater to a wide spectrum of applications in forestry, disaster management, military reconnaissance & soil moisture and currently in demonstration of proof of concept.



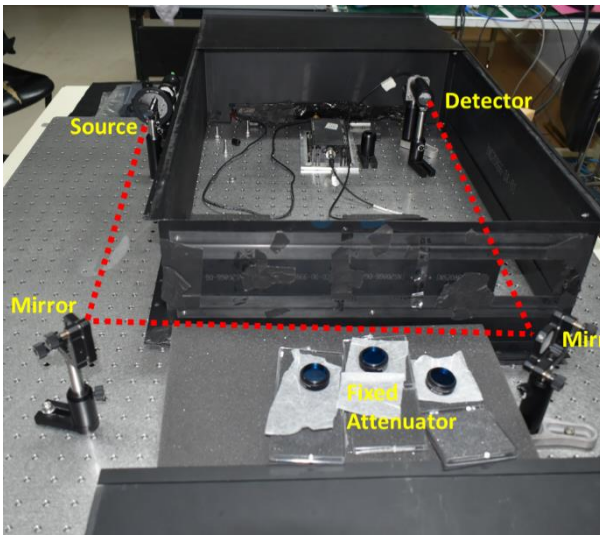
P-Band SAR Electronics Assembly



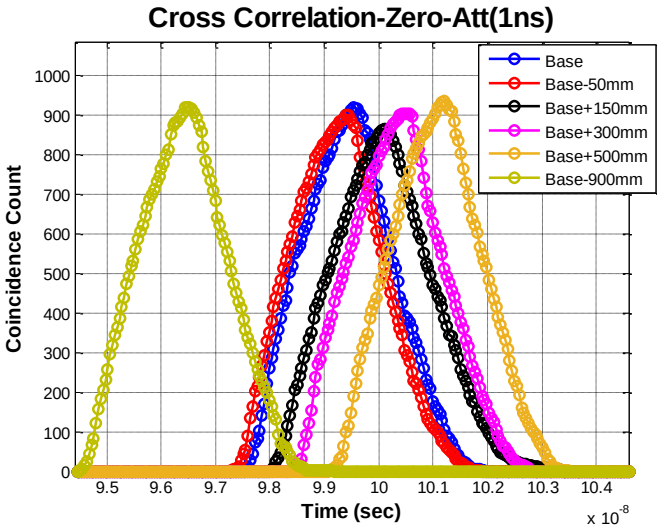
Antenna Assembly for Belly mount configuration

Apart from this effort are being carried out in the indigenous development of wide band ARC (Active RADAR Calibrator), ferrite switches, GaN and MMIC based transmit/receive core chips, frequency generators, onboard processors, Power ASIC, Digital and mixed signal ASIC, LTCC based compact T/R modules, etc. SAC is also venturing into development of complex technologies in the new area i.e. Terahertz Telescope and associated technologies required for the study of outer space and galaxy from space and ground based telescope.

Quantum sensing is an advanced sensor technology that utilize the quantum mechanical principle to enhance its capability to detect, identify and resolve targets of interest. Quantum sensing employs quantum entanglement as an extra resource to determine parameters by either using less resources or attaining a precision unachievable in classical protocols. Quantum radar is a detection and ranging system which uses quantum signal (Optical Photon /Microwave Photon) to probe/sense the target remotely. Microwave frequencies are more suitable for quantum sensing applications (Tan et al) due to natural high background noise. Quantum sensing activities are initiated at SAC as part of technology development program. Due to lack of single photon detectors in the microwave regime and cryogenic requirements, photon based ranging experiments are being carried out at optical frequencies as a pre-cursor to the development of the system in microwave domain and efforts for the microwave quantum source development are initiated.



Single Photon Based Ranging Experiments at SAC



Preliminary Single Photon Experiment Results

7.1. Research Areas in the field of Microwave Sensors

Different teams have developed various technologies/components/subsystems required for the development of RADARs, Altimeters, Scatterometers, Humidity Sounder, Temperature Sounder, Radiometer, etc. for past, current and future missions of earth observation and planetary program. This section will highlight them along with the proposed research areas under Respond in the following domains:

- **Microwave Transmitter & Receiver Technology**
- **Millimeter, Submillimeter & Terahertz sensor technology**
- **Digital Controls, Data Acquisition & Processing**
- **Power Electronics**

7.1.1. Microwave Transmitter & receiver Technology

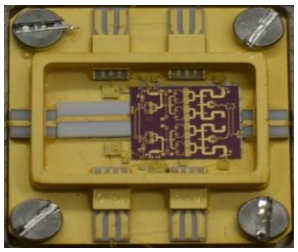
Brief Overview of the research done in SAC for the realization of transmitters and receivers for various microwave remote sensing payloads is as follows

High Power RF Subsystems

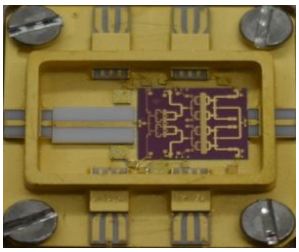
For the development of Transmitters for various Microwave remote sensing payloads, **many state of the art RF design and development activities, have been carried out in recent years, which have been successfully utilized in many of the delivered and ongoing payloads.** To mention a few, major successfully completed in-house developments are:

- GaN based Dual-Pol Pulsed Transmitters for Chandrayaan-2 SAR.
- GaAs High power MMIC power amplifier development at C and X-Band with an output power of more than 12W required for C-Band and X-Band SAR payloads.
- Ferrite based circulators and switches for various payloads.
- X-Band 8x8 Butler Matrix.
- X-Band 250W GaN Solid State Power Amplifiers.

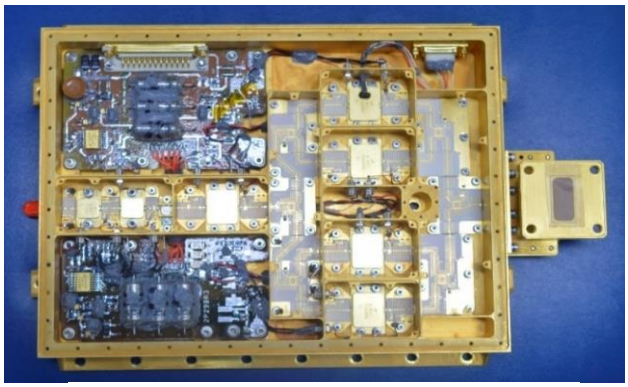
GaN based Dual Pol Pulsed Transmitter for Chandrayan-II



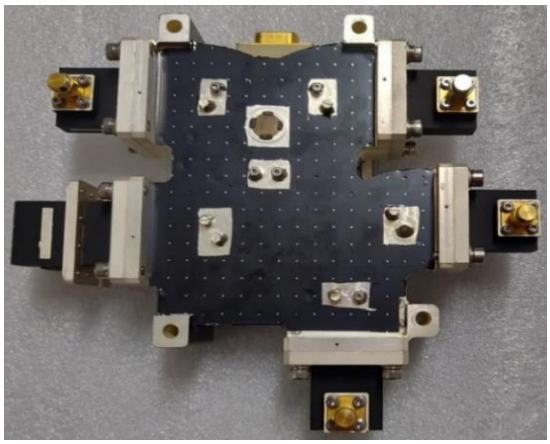
C-band 15W MMIC PA



X-band 12W MMIC PA



250W GaN based Pulsed SSPA

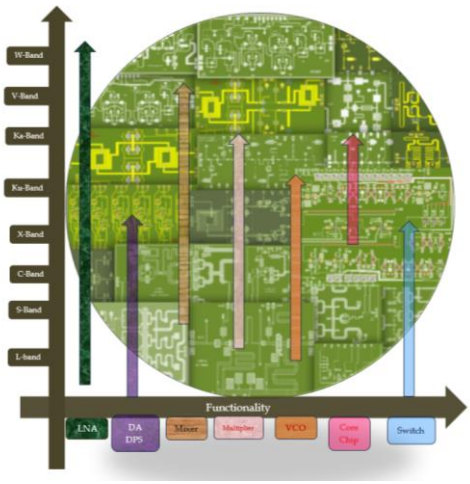


Ferrite based Circulator Switch Assembly

Apart from above GaN MMIC Power Amplifier design and development activities have also been taken up and state of art high power MMIC PAs delivering 60W at C-band, 50W at X-Band & 30W at Ku-band have been designed, developed and evaluated in on-wafer as well as packaged configuration. New RF power combining techniques like travelling wave combiner & radial combiners have been investigated and implemented to develop state of the art high power SSPAs with better combination efficiencies resulting in overall increase in DC efficiency of high power transmitters, particularly at higher frequency bands like X & Ku.

In-house developed MMICs:

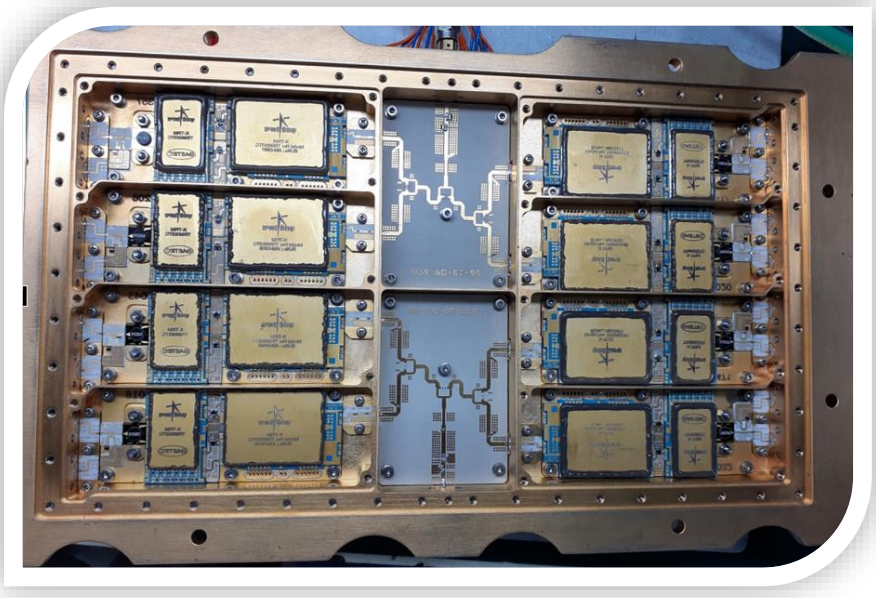
Wide spectrum Multi-function MMICs from DC to W-Band namely Low Noise Amplifier, True Time Delay Shifter, Digital Attenuator, Digital Phase Shifter, Sub-Harmonic Mixer, Voltage Controlled Oscillator, Multi Throw Switches, High Power Protection Switch, Multipliers, Driver Amplifier, Multifunction Core Chips



Indigenously developed X-Band Transmit Receive Integration Block (TRIB):

X-Band TRIB is a compact active phased array related hardware that integrates 8 X-Band 10 Watt Transmit Receive Modules (TRM) (effectively 80 Watt) and all the associated electronics in a single unit. The associated hardware activates the TRMs. These consist of (i) A single Power Supply Unit (PSU) for powering all the 8 TRMs (ii) A single Transmit Receive Controller for controlling the 8 TRMs individually (iii) A pair of Pulse Modulators for pulsing 4 TRMs each and (iv) RF power distribution network.

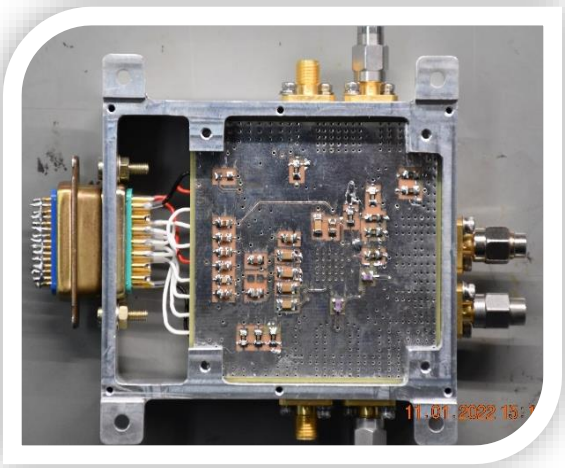
This product is an amalgamation of many high-tech technologies required for development of active phased array hardware including RF technologies like LTCC based packaging and assembly of MMICs for TRMs, Digital control electronics and pulsed power electronics.

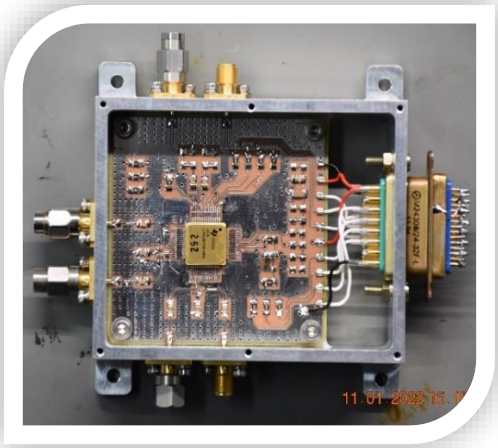


Reconfigurable Frequency Generator

Reconfigurable Frequency Generator module with multiple frequency outputs upto C-Band has been developed and the desired output frequency can be generated by the external commands. Multilayer RF board houses Phase Locked Loop (PLL) chip for Frequency Generation. All the spot Frequencies required for the payload are generated using PLL and Final LFM Transmit signal is generated by modulation / up-

conversion of baseband signals from Digital Chirp Generator followed by frequency multiplication for required bandwidth.





Multifunctional Broadband MMIC / High Power Switches

Capabilities developed in-house for broadband and high power applications are listed below:

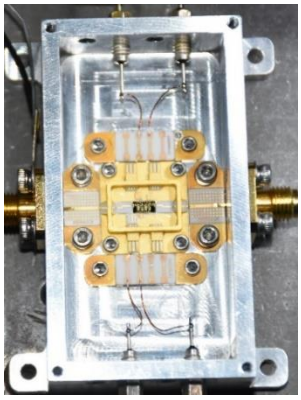
Broad band MMIC Low Noise Amplifiers

Broad band MMIC Low Amplifiers

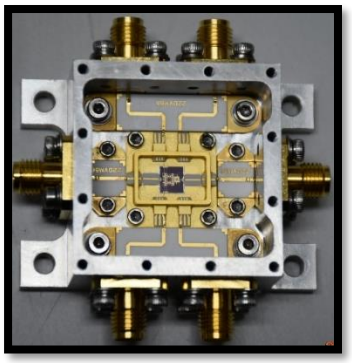
Broad Band IQ Modulators

Broadband Digital Attenuator

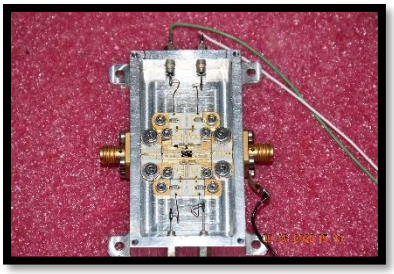
High Power P-Band Switch

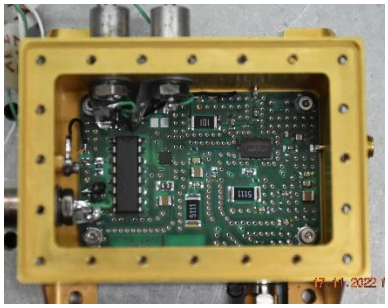


4 to 8GHz Amplifier

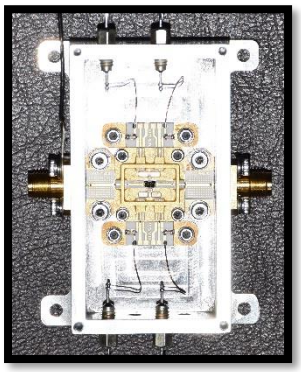


4 to 7 GHz IQ Modultaor

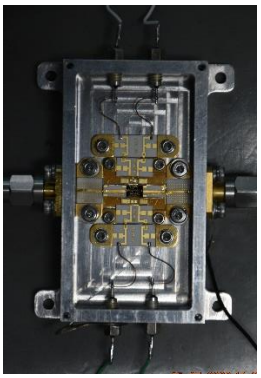




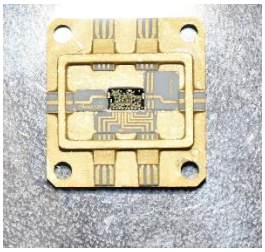
0.5-15 GHz Ultra wideband MMIC Amplifier



High Power P-Band Protection Switch



1-18 GHz Ultra wideband MMIC Amplifier



Broadband DA

8 to 12 GHz Amplifier MMIC

7 to 12.5 GHz Low Noise Amplifier MMIC

7.1.1.1. Proposed Research topics on Microwave Transmitter and Receivers sub-systems

Following research areas are identified which can be taken up currently for future use in upcoming microwave remote sensing payloads:

A. RFCMOS Based Frequency Synthesizer

Design of RFCMOS based Frequency Synthesizers is very much essential to cater to the requirement of mini satellites program of ISRO as these satellites demand very small payloads in turn single chip based RF sub-systems. These Synthesizers are based on mixed signal technology in which Low Frequency PLL and high frequency RF circuits viz. Amplifiers, Mixers etc are integrated in a single chip as single RFIC. Broadband Space Borne chips at L, S, C, X, Ku and Ka-band can be taken up for the development.

B. FMCW PLL Based Frequency Synthesizer

Sub-Sampling Phase Locked Loop Synthesizers with wideband Frequency Modulation are required for Frequency Modulated Continuous Wave (FMCW) RADAR applications. Linear Frequency Modulated Output can be generated directly from a single PLL chip using this approach with integrated DAC upto 1GHz bandwidth. Sawtooth / Triangular Baseband Chirp waveforms will be generated using DACs and this baseband chirp is fed to fractional PLL synthesizers as reference signal for generating the up-converted output directly from PLL synthesizer. Broadband Space Borne chips at X-band can be taken up for the design and development.

C. Stepped Frequency Continuous Wave Frequency Synthesizer chip

Stepped Frequency Output from 0.5GHz to 2 GHz in steps of 5MHz/2MHz over the sweep time of 7.5ms to 30ms is to be generated for Ground Penetrating RADAR applications. Dwell time for each step is programmable from 25us to 200us. PLL with broadband Voltage Controlled Oscillator (VCO) is to be used for the development.

D. Broadband Voltage Controlled Oscillators

The bandwidth of any Phase Locked Loop synthesizers is limited by the bandwidth of the VCO's that are being used. Broadband Voltage Controlled Oscillators are being realized with wide tuning range by using bank of varactor diodes and the required band is selectable by external command. Broadband (around 20-25% Bandwidth) Space Borne chips at L, S, C, X, Ku and Ka-band can be taken up for the development.

E. Wide band Analog Multipliers

When high output chirp bandwidth is required with limited bandwidth of base band chirp, we need to multiply the bandwidth using Frequency Multipliers. For high resolution SAR applications, requirement of output chirp bandwidth is very high. Hence Wideband Analog Multipliers are very much needed for high resolution SAR applications. Broadband (around 20-25% Bandwidth) Space Borne chips at L, S, C, X, Ku and Ka-band can be taken up for the development.

F. High Power Broadband MMIC Power Amplifier

Design using GaAs/GaN MMIC Processes: Collaborative work with academia for design of state of art broadband MMIC based high power amplifier using both GaAs and GaN MMIC processes

- Target Output Power: better than 10W (for GaAs process) & better than 40W (for GaN process)
- Target operating Bandwidth: 10% - 15%
- Target Frequency Band: L / S / C / X / Ku

G. Broadband High Power Front-end Duplexer using Ferrite devices:

Collaborative work with academia for design of state of art broadband & high power ferrite based duplexers in radar bands

- Target Products: Broadband High Power Circulator & Switches at X/Ku-band and Circulator-Isolator-Limiter assembly at S/C-Band
- Target bandwidth: better than 20%
- Power Handling: 250W peak with 10% Duty cycle (S/C-Band); 2KW peak with 25% Duty cycle (X-band); 150W peak with 30% Duty cycle (Ku-Band)

H. Development of discrete GaN devices for High Power Amplifiers:

Collaborative work with indigenous organizations and academia for the development of discrete GaN devices for High Power Amplifiers development could be extremely useful.
Development work involves the following:

- Development of discrete GaN high power devices up to Ku-Band.
- Development of non-linear models of these devices required for power amplifier design.

I. X-Band and Ka-Band Receiver RFICs:

This activity is to design and develop Receiver Core-chips using commercial RF CMOS technology at X and Ka-Band. Receiver core chip consists of low noise amplification, Manual/AGC and down conversion to IF/IQ signal of received input signal with the aid of LO as per the requirements. The tentative noise figure and gain of the X and Ka band receiver should be less than 3 dB and 5 dB respectively and better than 75 dB respectively with 30 dB dynamic range using the available commercial RFCMOS process. Core chip must also include all the necessary drivers, decoders, regulated power supply and LO amplification blocks as per the detailed specifications.

J. Design, modelling and technology development of wafer level packaged MMICs.

The proposal is for Design, modelling and development of suitable wafer level packaging technique for RF MMICs. Presently MMICs are packaged in LTCC and metal ceramic packages consuming more area, thus increasing the size and weight of the subsystems. This new proposal shall enable compact 0-level wafer level packaging.

K. RF Absorber sheets for use in RF discrete, LTCC and MMIC packages:

- Design and development of absorber sheets with specified rejection over broadband frequency range.
- Design and development of multiple absorber sheets with specified strong rejection over narrowband frequency ranges.

L. C-type and Pi-Type line filters/Feedthroughs for use in RF packages

This research area can be taken up to reduce dependence on foreign sources.

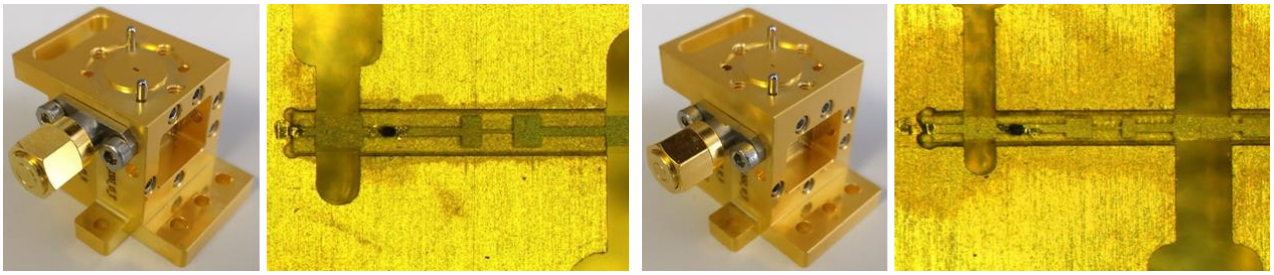
M. High power Waveguide Terminations at various frequency bands to provide matched termination for high RF power at termination ports of various subsystems.

7.2. Millimeter, Submillmeter & Terahertz Sensors Technology

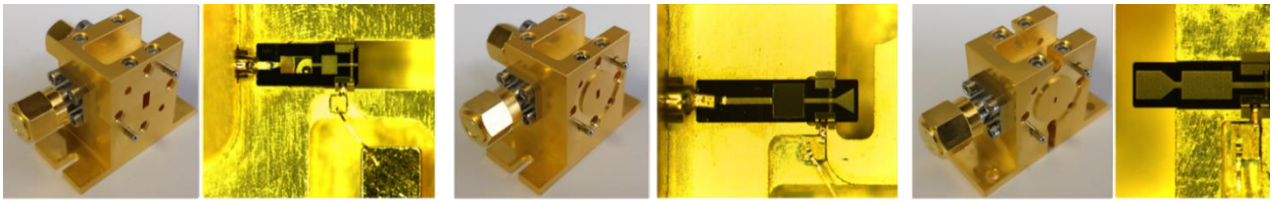
A major technology gap exists between radio/microwave and IR/optical wavelengths owing to lack of suitable technologies, particularly in India, to explore this electromagnetic spectrum region (millimeter, sub-millimeter and terahertz frequency). This electromagnetic spectrum has numerous applications in astronomy (to study evolutionary history of the universe, star-

formation processes), in quest for extra-terrestrial life (large bio-molecules have emission/absorption lines in sub-mm and THz frequencies) and trace gas monitoring of earth and other planets. Owing to these numerous applications, SAC has taken up the technology development activities in this unexplored frequency regime in a phased manner. Presently, design and development of high sensitivity Schottky Barrier Diode (SBD) based receivers at 230 and 345GHz for astronomical applications, primarily for mapping multiple CO transitions over entire galactic plane has been successfully completed. Technological accomplishments for this development are as follows:

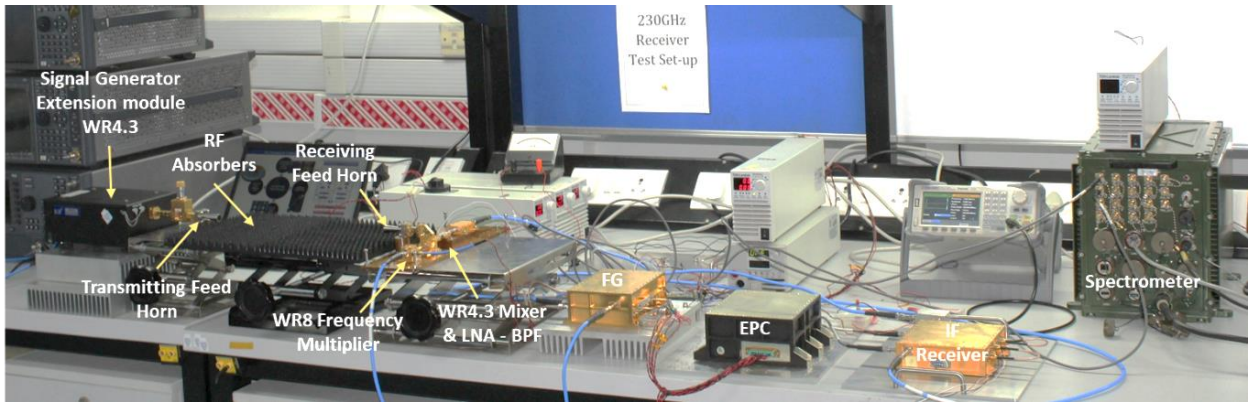
- *mm/sub-mm wave Receiver development at 230 and 345GHz using Schottky Barrier Diode based Sub-Harmonic Mixers as RF Front-End*
- *mm-wave LO development at 112GHz & 169GHz*
- *FFT Based High-speed (3GHz) Spectrometer*
- *Algorithm development for generating spectral and spatial CO maps over entire galactic plane*



230GHz sub-harmonic mixer *345GHz sub-harmonic mixer*



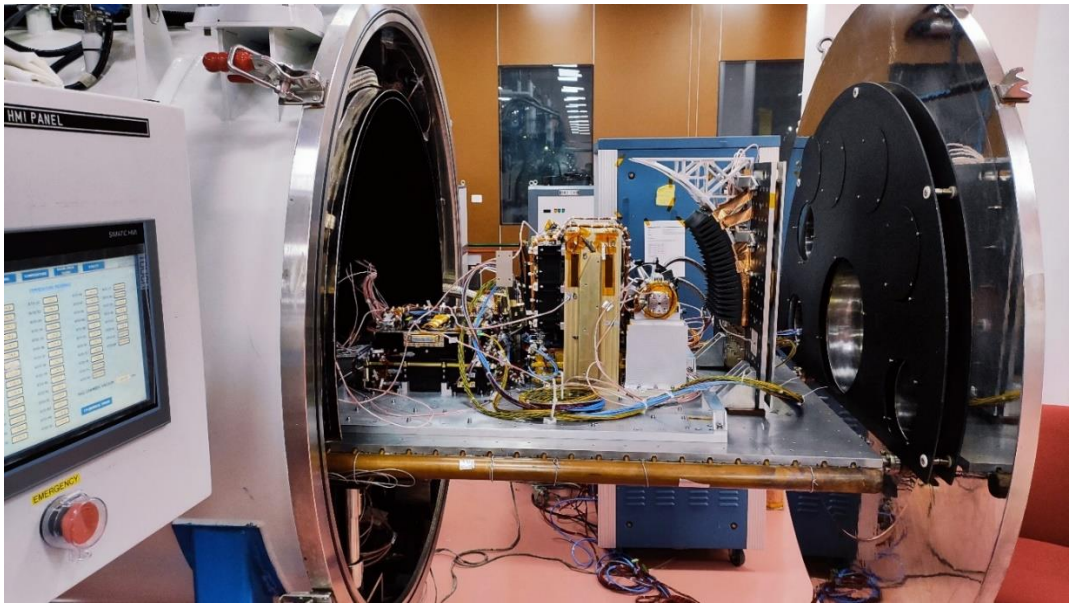
56.4GHz Doubler *112.8GHz Tripler* *169.2GHz Tripler*



Test set-up for characterization of 230GHz Receiver Chain

For study of earth's atmosphere, we have developed temperature and humidity sounder for temperature and humidity profiling of earth's atmosphere. Technologies for millimeter-wave radiometer payloads working in the frequency range of 50-60GHz and 165-200GHz for Temperature and Humidity Sounding have been successfully developed and demonstrated. The developed system for Temperature Sounding Unit (TSU) is a 17-channel, total power type radiometer at 50-60GHz, along with atmospheric window at 23.8 and 31.5GHz. The Humidity Sounding Unit (HSU) is a multi-frequency, 6-channel, total power type radiometer at 183.31±16.3 GHz, along with atmospheric window at 89GHz.

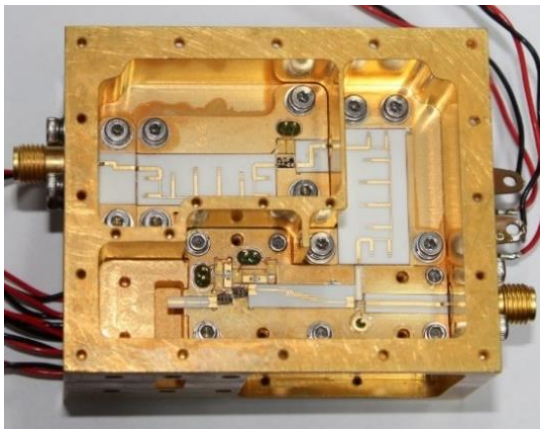
The successfully developed humidity sounder (HSU) is being flown as millimeter wave humidity sounder (MHS) payload on MicroSAT-2B bus for Small Satellite Launch Vehicle SSLV-D2 mission. MHS is configured as a multi-channel scanning Total Power Radiometer. MHS is a 6-channel cross-track scanning radiometer operating at 183.31± 15GHz band meant for atmospheric vertical humidity profiling from surface to 12km with vertical resolution < 2km and nadir spatial resolution of 10 km from 450km altitude. This will be ISRO's first in-house developed space-borne millimeter-wave instrument and a demonstration of the technology and its application as an advanced follow-on of the SAPHIR instrument (onboard MeghaTropiques). Various operational agencies have expressed their interest in utilizing the MHS data for assimilation in the Numerical Weather Prediction (NWP) models and other applications such as now-casting and cyclone applications. These include the Space Applications Centre (SAC), the Indian Meteorological Department (IMD/MoES), the National Centre for Medium Range Weather Forecasting (NCMRWF/MoES), the International NWP community (as recommended through International Technical Working Group (ITWG)/ Continuous Glucose Monitoring System (CGMS)), the European Centre for Medium Range Weather Forecasting (ECMWF), and the Bureau of Meteorology, Australia. MHS will serve as a very useful precursor to a full-fledged operational atmospheric sounder mission that may be extended to a constellation of at least two satellites, providing faster revisit time and thereby enhancing its utility for regional and global weather applications.



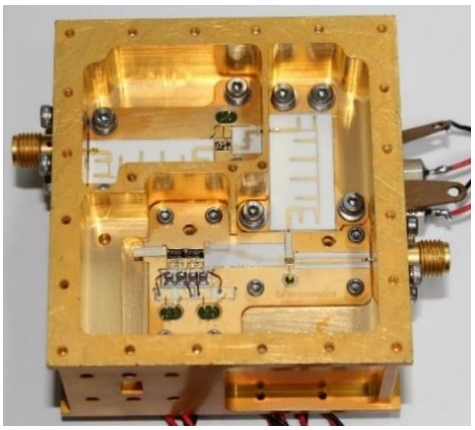
Millimeter wave humidity sounder (MHS) payload inside TVAC chamber

Another on-going technological development involves design and realization of a compact, field deployable, noise injection and self-calibrating mm-wave Ground based Atmospheric Sounder. Successful demonstration of this technology will pave the path for its technology transfer to industry for providing a low-cost solution to large-scale production of such sounders, which can be easily deployed at various establishments. Major technological developments for this compact atmospheric sounder include:

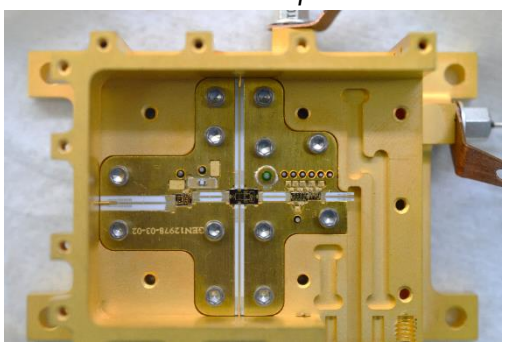
- *Miniaturized K, Ka and V Band Receivers, including RF Frontends, couplers and noise sources*
- *Wideband Tunable LO operating over 11-32GHz band*
- *Wideband antenna system, including Reflector, feed horns, wire grid polarizer and diplexer*
- *Miniaturized and modular IF backend, Digital system and EPC*
- *Scan Mechanism with provision for both elevation and azimuth scan*
- *Blackbody target for calibration*



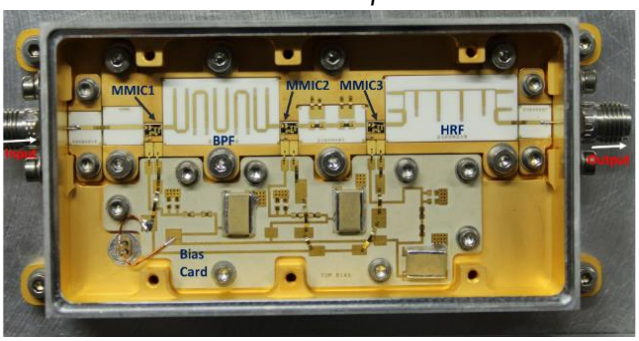
K-band receiver front-end



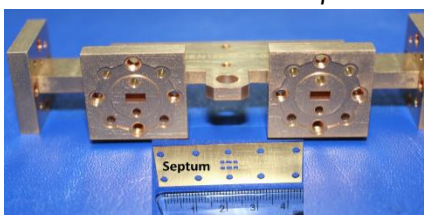
Ka-band receiver front-end



V-band receiver front-end

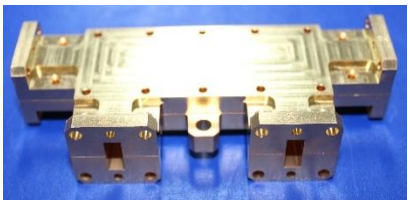


IF back-end



50-60GHz Coupler (WR-15)

26.5-32GHz Coupler (WR-28)



20-26GHz Coupler (WR-42)

7.2.1. Proposed Research topics on Millimeter, Sub-millimeter & Terahertz Sensors Technology sub-systems

Following research areas are identified which can be taken up in near future for upcoming microwave remote sensing payloads in mm-wave, sub-mm wave & Terahertz technology:

A. Design and development of Schottky Barrier Diode-based Sub-Harmonic Mixers up to 750GHz

At mm/sub-mm-wave frequencies, mixer is used as front-end element of receivers due to non-availability of LNAs at these frequencies, making it the most critical element to achieve high sensitivity receivers. At mm/sub-mm wave frequencies, sub-harmonic mixer topology is preferred owing to difficulties in generation of high power LO signals at fundamental frequencies. This work involves design and development of sub-harmonic mixers from 350GHz to 750GHz using Schottky barrier diode as non-linear element. The mixers shall be designed to offer minimum conversion loss and noise equivalent temperatures.

B. Design and development of SIS-tunnel junction based mixers up to 1.2THz

The superconductor–insulator–superconductor tunnel junction (SIS) is an electronic device consisting of two superconductors separated by a very thin layer of insulating material. SIS-based receivers, operating at ~ 4K temperature, can achieve state-of-the-art noise performance of the order of 2-5 times the quantum limit. The SIS based mixers are fundamental mixers, utilizing SIS junction as non-linear element for mixing operation. This research work involves design and development of cryogenically cooled (operating at ~ 4K) SIS based mixers operating up to 1.2THz.

C. Design and development of Schottky Barrier Diode-based frequency multipliers up to 1.2THz

At mm/sub-mm-wave/terahertz frequencies, GaAs Schottky diode based frequency multipliers are used for LO signal generation. This project deals with design and development of mm/sub-mm wave frequency multipliers till 1.2THz with operation at cryogenic temperatures of ~80K. The frequency multipliers should offer optimum efficiency and output power required for generating the required LO drive for Schottky diode/SIS junction based mixers.

D. Design and development of Electronically Tunable frequency synthesizers

Local oscillator sources use microwave oscillators followed by amplification and frequency multiplication stages with appropriate filtering to generate LO signals, required for down-conversion in heterodyne receivers. This project aims at design and development of electronically tunable frequency synthesizer with YIG-tuned oscillator (YTO) locked to a highly stable reference as the fundamental source to allow for electronic tunability.

E. Design and development of Gunn-diode oscillator based frequency synthesizers

Gunn diode oscillators based frequency synthesizers are widely used at mm-wave frequencies as they provide highly repeatable frequency tuning characteristics along with high output power. Gallium Arsenide (GaAs) and Gallium Nitride (GaN) are the most common diode materials for realizing Gunn diode based oscillators at mm-wave frequencies. This project deals with design

and development of Gunn diode based oscillators at W-Band for generation of mm-wave LO signals.

F. Design and development of InP-HEMT based LNA MMICs at mm/sub-mm wave frequencies using MMIC foundry services

Traditional LNA designed using GaAs process offers high noise figures at mm/sub-mm wave frequencies. LNA using InP HEMT MMIC technology offers superior noise figures at mm/sub-mm wave frequencies compared to other semiconductors. This project work targets design and development of InP-HEMT based LNA MMICs spanning from few GHz up to 750GHz using suitable MMIC foundry services.

G. Design and development of High-speed Digital board for high-end Spectrometers to be used for earth observation and astronomy

High-speed digital PCBs with wideband ADCs (6Gsps sampling requirement), FPGAs (Xilinx ultra-scale series or equivalent) and associated circuitry are required for design and development of digital FFT based spectrometer for heterodyne spectroscopy based systems. This research work involves design and development of a modular, scalable, multichannel spectrometer board with wideband high speed ADCs catering to 3GHz analog input bandwidth with an FPGA for spectrum generation.

H. Design of mm/sub-mm wave temperature and humidity sounder on CubeSat platform

The mm/sub-mm wave sounder from a CubeSat platform focuses on improved rapid-update capabilities provided by a low-earth-orbit satellite constellation for atmospheric observations. mm/sub-mm wave atmospheric sounder is a radiometer configured in noise injection mode of operation with a highly-integrated electronics to accommodate over a 6U CubeSat platform. The principle challenge of developing a radiometer payload for CubeSat platform is the high level of integration necessary to meet size, weight, and power (SWaP) requirements. The major technological elements in this research work are miniaturized receiver front-ends and associated LOs, hyper-spectral IF back-end system, antenna with its scan mechanism and radiometer calibration.

I. System configuration design of mm/Sub-mm wave Hyperspectral Atmospheric Sounder for earth's and other planetary atmospheres

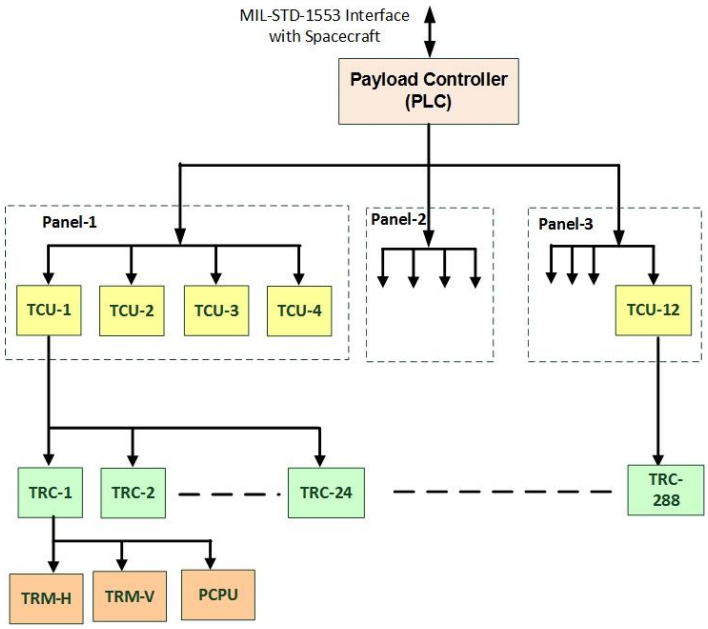
Sub-mm wave atmospheric sounders are passive radiometers making measurements of absorption lines of different molecules in sub-mm wave band like oxygen, water vapor, ozone, etc. which provides useful information regarding atmospheric conditions of the earth. Hyper-spectral mm/sub-mm wave Atmospheric Sounders is a new concept of achieving very high vertical resolution using a large no of channels in mm-wave bands. This project deals with system configuration design addressing detailed specifications for sub-systems; weighting functions for these molecules in different atmospheric conditions; Vertical resolution; channel placement on absorption profiles; Required bandwidth for each channel.

7.3. Digital Controls, Data Acquisition, Processing

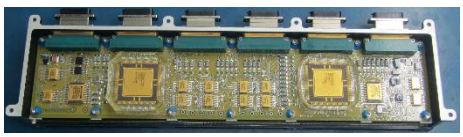
7.3.1. On board control Sub-systems of microwave remote sensing payloads

Payload Controller (PLC) is the central controller subsystem for a microwave remote sensing payload. PLC is responsible for control, coordination and status monitoring of all sub-systems of the payload. PLC has Mil-Std-1553 Interface with spacecraft On Board Computer, through which it accepts all tele-commands and provides telemetry. PLC generates timing signals and control signals for all other digital and RF sub-systems of the payload. PLC is implemented using On board Controller (OBC) ASIC and FPGA.

Microwave payloads with active phased array configuration (e.g. RISAT-1/1A, RISAT-2A, etc.) have three level hierarchy of distributed control sub-systems. Control sub-system hierarchy for RISAT-1/1A is as shown in following figure. PLC is the central beam controller. It controls 12 Tile Control Units (TCU) which is at 2nd level. Each TCU further controls 24 Transmit/Receive Controller (TRC) which is at 3rd level. Thus, the phased array active antenna has total 288 (12x24) TRCs. Communication among distributed controllers is done through RS-422/485 serial link. PLC sends beam selection data to TCU, which further transmits beam characterization data to TRC through serial commands.



Payload Controller (PLC)

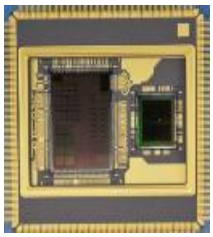


Tile Control Unit (TCU)

Transmit/Receive Controller (TRC)

In house designed OBC ASICs are used in TCU and TRC sub-system to get advantage of size, weight and power consumption. OBC-1 ASIC was the first Rad hard digital ASIC developed on 0.6u CMOS process for TRC & TCU of RISAT-1, subsecuently various versions of OBC ASIC have been developed. OBC-

2.1/2.2 are mixed signal ASIC developed with 180nm CMOS process of SCL. OBC-2.3 ASIC is indegenous rad hard ASIC developed on 180nm CMOS process for TRC of SAR payload of RISAT-1A and other similar missions. OBC-2.0 is a system on chip (SoC) having on chip Magnetoresistive Random Access Memory (MRAM) and mixed signal die for single chip implementation of TRC functionality. Following figure shows various versions of OBC ASICs.

OBC-1.0 ASIC	OBC-1.1 ASIC	OBC-2.1 ASIC	OBC-2.3 ASIC	OBC-2.0 SoC
				
▪ Digital ASIC ▪ 0.6um CMOS ▪ Rad hard ▪ uC & peripherals	▪ Digital ASIC ▪ 0.18um CMOS ▪ uC & peripherals	▪ Mixed Signal ASIC ▪ 0.18um CMOS ▪ uC, FPU, RS-422, ADC, MIL-1553	▪ Mixed Signal ASIC ▪ 0.18um CMOS ▪ Rad hard ▪ uC, FPU, RS422, ADC	▪ SoC (ASIC + MRAM) ▪ 0.35um CMOS ▪ Rad hard ▪ uC, FPU, RS422, ADC, Mil-553

7.3.2. Rad-Hard by Design (RHBD) Memories IP development

RHBD memories are used in various On Board Controller (OBC) ASICs for digital control sub-systems of radar payload. OBC ASICs contains on chip volatile memories like Single Port RAM (SPRAM) & Dual Port RAM (DPRAM), while external non-volatile memory Electrically Erasable Programmable Read Only Memory (EEPROM) is used in RISAT-1A and similar payloads. Following RHBD memory IPs for 180nm CMOS process are required for future ASICs:

- Design & Characterization of Radiation Hardening by Design (RHBD) volatile memories like Single Port SRAM, Dual port SRAM with size of 32KB to 1MB.
- Design & Characterization of RHBD non-volatile memories like EEPROM/Flash and OTP with size of 16KB to 256KB.

Area & Timing efficient memory cells should be signed, simulated and GDS-II layout should be generated. SAC will facilitate test chip fabrication and radiation testing for characterization of SEE & TID performance.

7.3.3. Real Time Operating System (RTOS) optimization for on board Payload Controller (PLC)

PLC is central control sub-system for control and status monitoring of whole microwave remote sensing payload. This proposal is to customize standard RTOS for PLC applications. Open-source RTOS may be customized in terms of optimization for resources (like memory, power, etc.) & performance (timing, accuracy, etc.) so that it fits in existing PLC hardware. Fault Tolerant (FT) features to be incorporated in design to enhance reliability for space borne applications

7.3.4. System on Chip for distributed controller

This proposal is to design System on Chip (SoC) with embedded processor, floating point coprocessor, differential I/Os, ADC, Oscillator, SRAM and Non-volatile memory, etc. This SoC should have fault tolerant features like EDAC, Watchdog timer, Lock-step processor so that it is usable in space environment. 180nm CMOS process or other suitable process technology may be chosen for design. This SoC is targeted for single chip implementation of T/R module controller for phased array SAR. Integration of digital SoC with RF chip for further miniaturization should be explored.

7.3.5. Multicore Digital Processing & Control SoC

Multicore processor based SoC with various peripheral module is planned to be developed for future microwave remote sensing payloads. This SoC will have dual/quad core of 32 bit RISC-V processors and various peripheral modules such as Mil-Std-1553, Space-wire, Timing Signal Generator, UART, SPI, etc. which will be connected through AMBA AXI bus. A dedicated Co-Processor/Accelerator for FFT/IFFT and signal processing for vision based navigation will also be available in it. This SoC will be useful for miniaturized implementation of Radar Altimeter with Hazard Detection and Avoidance functionality. The targeted SoC may be realized on 28 nm CMOS process with adequate radiation hardening by design (RHBD) features for usage in Space-borne applications.

7.3.6. On board Wireless data transfer tranceivers

This proposal is for design & development of wireless data transfer transceivers for space applications. Wireless transceivers should operate in Industrial, Scientific and Medical (ISM) (2.4GHz) band or other open frequency bands for data rate of 1Mbps with range of 10m. Applications of such transceiver is in intra-satellite data transfer between rotating to stationary sub-systems or Tile control sub-systems. The design should be done with target of fault tolerance so that it is suitable for space applications.

7.3.7. EDAC IP for FPGA of Solid State Recorder

This IP will be useful for design and development of a Solid State Recorder (SSR) based on Not AND (NAND) Flash memories for onboard usage. Flash memories are prone to random bit failures, error correction and detection algorithms needs to be employed to maintain data integrity and reliable operation of these solid state recorders. The main aim of the research would be to develop an efficient error detection/ correction algorithm for NAND flash based Solid State Recorders. Also the research must focus on real time optimal implementation of the ONFI (Open NAND Flash Interface), EDAC algorithm and efficient low overhead file system amenable for implementation on FPGA/ASIC.

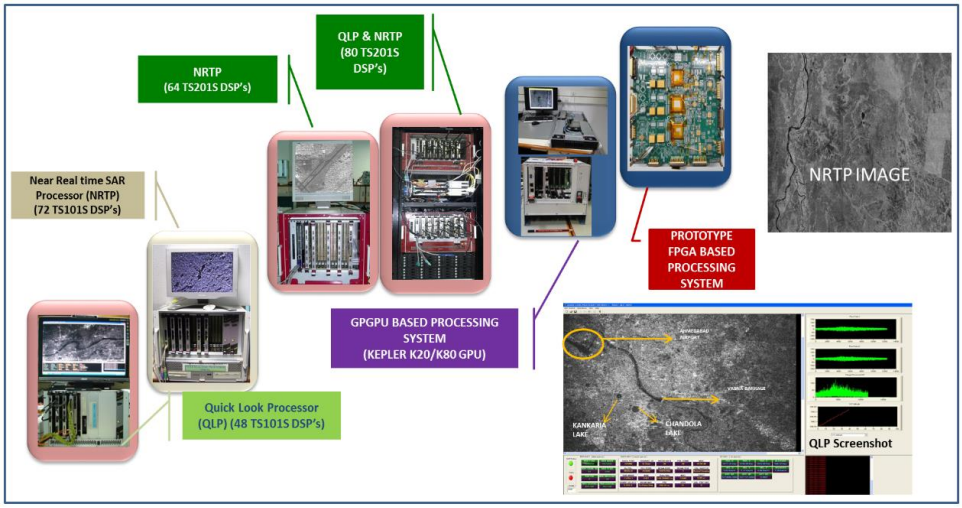
7.3.8. Advanced Synchronization techniques for distributed sub-systems

There is a need of clock and timing signal synchronization techniques for distributed sub-systems within a single satellite or across satellites. Both cases of single platform distributed system with wired connection and different platform distributed sub-systems without any connection should be addressed. GNSS disciplined oscillator based clock & timing signal synchronization techniques for space borne application is to be explored under this research area.

7.3.9. Onboard SAR processor (OBSP)

In order to leverage the benefits of onboard processing for SAR missions, the first and foremost requirement is the ability to generate precise SAR images onboard the spacecraft. One of the primary benefits of onboard SAR image generation apart from various onboard applications (like target detection, flood inundation map generation for Disaster management) is that, it substantially reduces the SAR sensor data rates for medium and low resolution modes. This capability is particularly essential for various planetary missions wherein downlink rates and earth visibility time are at a premium. Also, the Lossy BAQ compression is bypassed resulting in better image quality.

As a precursor to onboard SAR processor development, various real time SAR processing based on processing elements like multiple-DSP processors, GPGPU's and FPGA's have been developed in SAC.



Real time SAR Processor Development

Following are the potential research areas:

- **Processing Element and Hardware Configuration:**
  - FPGA configuration and architecture amenable for Real Time SAR processor implementation
  - Design of various ***SAR processing IP cores with radiation-tolerant features***
  - Design of ***fault tolerant SDRAM/DDR2/DDR3/DRR4/FLASH memory controllers*** for space use
  - Design and development of full ***ASIC based SAR processor***

- Configuration, Architecture, interfaces and data distribution scheme for multi-processor based system

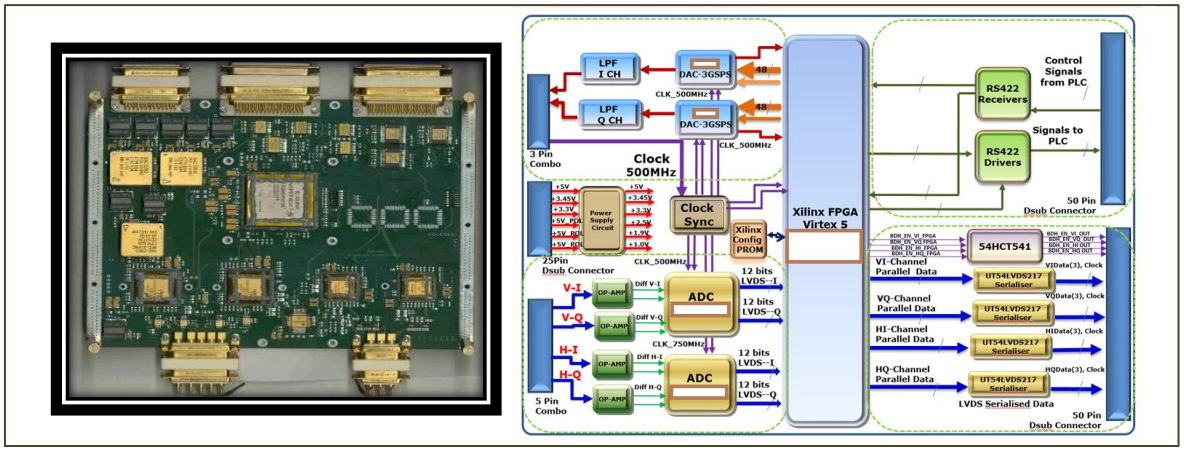
- **Onboard Signal Processor Algorithm:**
  - ***Efficient SAR processing algorithms*** amenable for onboard implementation catering to various SAR operating modes (Stripmap, ScanSAR, Mosaic etc.).
  - Low latency SAR image generation algorithm for spotlight & sliding spotlight modes with limited bit precision
  - Design of ***robust processing algorithms (with low precision arithmetic)*** for image generation in the absence of accurate spacecraft attitude/pointing/ velocity estimates
- Use of High Level Synthesis (HLS) tools for onboard SAR processor implementation on FPGA.
- Raw SAR Data simulator with the ability to simulate SAR data with motion and attitude errors.

7.3.10. Integrated RADAR Digital Receiver and Signal processor:

Typical functional requirements for any baseband digital subsystems of a RADAR payload include high bandwidth linear frequency modulated signal generation, high speed multi-channel digitization, real time signal processing and high speed data transmission. These functionalities are currently realized using multiple discrete devices/subsystems. The requirements for signal synthesis and acquisition are as follows:

- ADC Sampling Frequency: 750 MHz
- ADC Resolution: 8 bits or higher (Better than 7-bits Effective Number of Bits (ENOB))
- Number of ADC Channels: 2/4
- DAC Reconstruction Clock: 1 GHz
- DAC Resolution: 10 bits or higher
- Number of DAC Channels: 2
- Processing Functionality: Data Compression using BAQ (Block Adaptive Quantization) / Matched Filtering

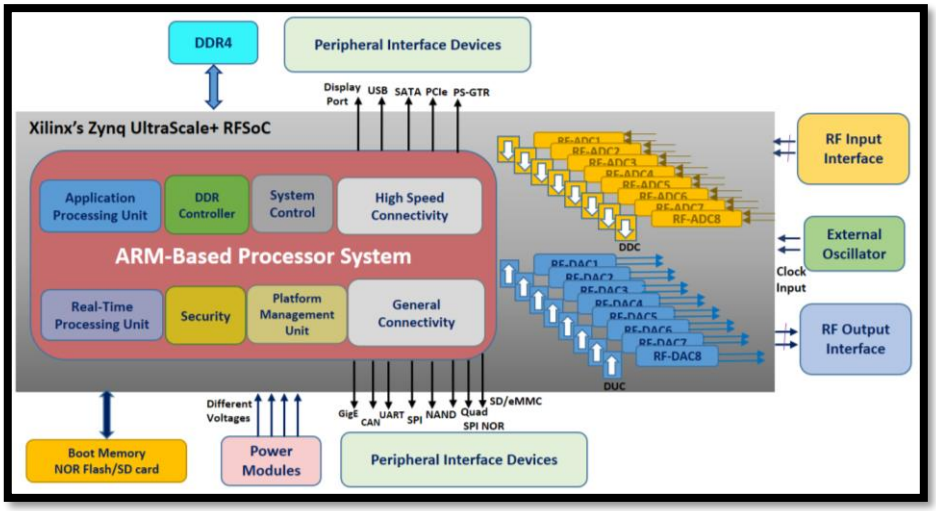
Data Acquisition and Signal Processor developed at MRSA/SAC



- Design and development of high speed mixed signal ASIC with multi-channel ADC, DAC and with high speed SERDES
- Design and development of a System in Package (SIP) module with integrated multi-channel ADC's, DAC's, high speed SERDES along with embedded programmable logic

7.3.11. Design & Development of miniaturized digital system for Airborne/UAV and LEO SAR missions

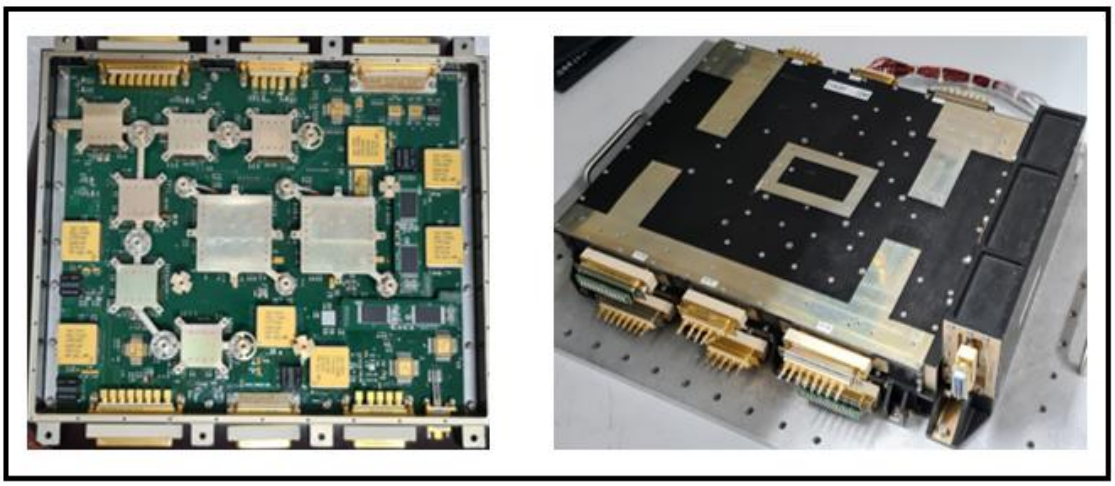
High resolution SAR system for a Unmanned Aerial Vehicle (UAV) platform/Cube-SAT pose severe SWaP constraints on the RADAR hardware. This calls for direct RF sampling/synthesis systems (eliminating RF down/ up conversion chains) integrated on a single chip. This research area involves design of digital systems based on RFSoC or similar devices for realization of miniaturized SAR systems capable of direct signal acquisition, synthesis and processing in L/S/ C- or X-band.



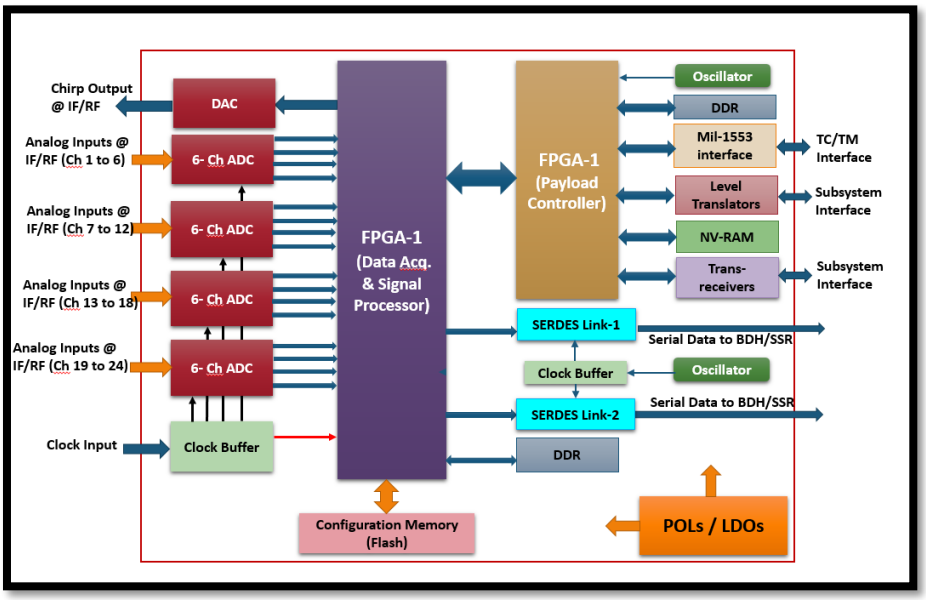
Miniaturized single chip digital system

7.3.12. Multi-Channel Digital Beam Forming & Autonomous Controller (mDBF-AC):

The current era of High Resolution Wide Swath (HRWS) SAR missions has replaced conventional Analog Beam forming technology with onboard digital Beam forming systems. This necessitates multiple Analog-to-Digital Converter (ADC) chains followed by digital signal processor and data formatter. One of the primary benefits of onboard digital beam forming system is that, it substantially reduces the SAR sensor data rates, while improving or balancing system performance. ISRO's first 24-channel Data Acquisition and Beam forming (DABF) system has been successfully designed and developed in SAC for Dual Frequency SweepSAR mission. In order to cater to future High Resolutions Wide Swath (HRWS) SAR missions, Development of next generation Digital Beam Forming system has been taken up with goals to realize miniaturized hardware with improved performance, very high data handling capability, value addition with features like wide bandwidth support, IF/RF sampling, autonomous payload control operations, provision of onboard re-programming, etc. This mDBF-AC system is proposed to be realized with state-of-the-art devices with equivalent footprint devices available in space-qualified categories.



24-Channel Data Acquisition & Beam forming System



Multi-Channel Digital Beam Former & Autonomous Controller

The following research areas are proposed towards realization of mDBF-AC system:

- FPGA based Digital Hardware design comprising of multiple-channel high-speed data acquisition, digital signal processor & data formatter, Radar wide band transmit waveform generation and Autonomous Payload control operations in single board
- Multi-Channel Data acquisition scheme @ IF/RF with very fine synchronization and channel alignment techniques
- High speed interfacing techniques between FPGA and data converters
- IP Core development for Efficient Phase synchronization & Digital Beam Forming techniques
- IP core development for fault tolerant Double Data Rate 3(DDR3)/DDR4 memory controller
- Wide band transmit waveform generation with inverse sync compensation followed by signal up conversion at IF or Radar RF frequency

- Enhancement in current payload controller operations including Autonomous control and onboard computation of programmable parameters
- On-the-fly software reprogramming techniques
- Scrubbing techniques for SEU mitigation

7.3.13. Onboard Signal Processor for GNSS Reflectometry

GNSS Reflectometry (GNSS-R) payload is a passive sensor used for sensing reflected Navigation signals over Earth's surface to measure key ocean and land parameters. The reflected signals after passing through amplification are digitized and processed for Delay Doppler Map (DDM) generation. This research area involves

- Design & development of a highly compact low power digital hardware consisting of quad channel medium speed ADC's, high density / high throughput FPGA, digital control processor and volatile memory for intermediate data storage.
- Design of Onboard Signal Processor algorithm for Precise Orbit Determination, Specular point calculation and DDM generation using direct and reflected signals
- Development of Hardware simulator which caters to modeling and generation/synthesis of the direct navigation signal and the corresponding reflected signal, received at LEO satellite in the operational scenario of a GNSS Remote Sensing spacecraft to be used for testing GNSS-R Signal Processor.

7.3.14. Signal Processing algorithms for RADAR Altimeter

MRSA/SAC has developed a RADAR altimeter based on FMCW technique. Presently design and development of Pulsed based Radar Altimeter is under progress in MRSA/SAC. These systems will be used in precise altitude and velocity measurements. Following are research areas

- Algorithms and schemes for precise velocity measurement techniques.
- Real time unambiguous velocity estimation from a FMCW RADAR Altimeter

7.3.15. Signal Processing Platform for Navigation and Hazard Detection and Avoidance (HDA) applications

Future generation of landing craft will autonomously map the surface, using vision, microwave and/or laser based sensors, during the terminal phase of powered descent and then, in real-time, choose and divert to a safe landing site in order to avoid hazards using Hazard Detection and Avoidance techniques. This will also require accurate position and velocity data during descent phase in order to ensure safe soft landing at the pre-designated sites. Following are the research areas

- Processing algorithms (for HDA, Position estimation, velocity estimation, image generation etc.) for real time microwave/optical based imaging sensors
- Development of suitable digital hardware platform having signal acquisition, control (for controlling sensors), processing (for sensor data processing s) and storage (for storing pre-known features of the landing sites) capabilities to cater to interplanetary landing missions

7.3.16. Audio Video Processing Unit (AVPU):

Targeted for Gaganyaan mission, Audio-Video Processing Unit provides two-way Audio and Video communication between crew members and ground segment, comprehensive information display and situational awareness to the crew about the status of all aspects of the spacecraft and mission. Following areas provide opportunities for research:

- **Hardware Configuration:**
  - Selection of heterogeneous radiation/fault tolerant hardware platform enabling Size, Weight and Power (SWaP) optimized configuration
  - Suitable for advanced high performance Multimedia applications like H.264/H.265 compression and decompression, high-speed data transfer over Display Port interface etc.
  - Support for high performance, low latency user applications with provision for interfacing with various peripheral subsystems.
- **Software Architecture:**
  - Development of application software for safety critical system
  - Hypervisor for heterogeneous processor configuration
  - Inbuilt fault tolerance, fault identification, isolation and recovery

7.4. Power Electronics

Electronic Power Conditioners (EPCs) required for the various RF and Digital subsystems of Microwave remote sensing payloads are being designed and developed in-house at SAC. These EPCs have shown excellent performance on-board ISRO's microwave payloads flown so far. To mention a few, major successfully completed in-house developments are:

- Power Conditioning and Processing Unit for TR Modules of C-band SAR payload.
- EPC for RF subsystem of MADRAS payload of Megha-Tropiques.
- EPCs for GaN based Dual-Pol Pulsed Transmitters of Chandrayaan-2 SAR.
- High power EPC for X-Band 250W GaN Solid State Power Amplifiers.

PCPU for C-band TR Module

EPC for MADRAS RF Subsystem

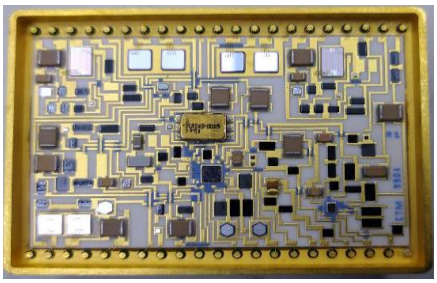
EPC for 250W GaN SSPA

EPC for Pulsed Transmitters of Chandrayan-II

- Multi-output pulsed EPC for TR integrated modules of X-band SAR.
- HMC based Point of Load (POL) converters.
- HMC based Controller for DC-DC converter and pulse Modulator
- 100W EPC for digital Subsystem of NISAR
- EPC for S-band TRiM (NISAR)

PCPU for C-band TR Module

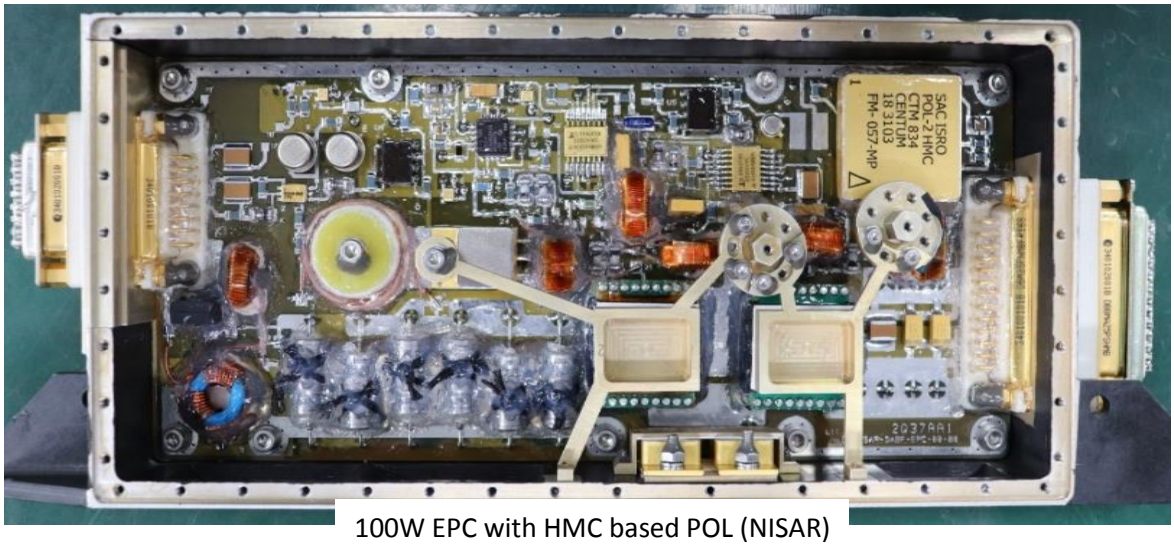
60W EPC for X-band TR modules for active antenna



Hybridized Micro Circuits (HMCs) for EPC

4 channel Pulse modulator using HMCs for active antenna

EPC for S-band TRiM (NISAR)



100W EPC with HMC based POL (NISAR)

Apart from above, High Voltage EPC for indigenous pulsed TWT have been demonstrated. Power ASIC design and development activities have also been taken up and are at advanced stage. Higher efficiency, smaller mass and volume, efficient thermal design and EMI/EMC compliance are the major driving parameters for any space-borne EPC design.

7.4.1. Proposed Research topics on Power Electronics sub-systems

Following research areas are identified which can be taken up currently for future use in upcoming microwave remote sensing payloads:

A. Miniaturized circuit protection module for DC-DC converters for Aerospace applications. The protection circuit comprises of Resettable eFuse, Input pug-in inrush current limiter and Under Voltage Lock-out (UVLO).

B. Work involves design, simulation and optimization of Generic front-end protection circuit for DC-DC converters. The final circuit may be implemented on a power ASIC or HMC.

C. Development of software tool for design, modelling and analysis of planar power transformer and power inductor. Digitally controlled energy efficient multi-output DC-DC converter with fast transient response. The work involves design, simulation and proto-type development of highly efficient multi-output EPC for high speed digital circuits with FPGAs. The EPC should have programmable output ON/OFF sequencing with fast transient response.

D. Study of design topologies and packaging aspects of GaN MOSFET based high voltage EPC for pulsed TWTA. The work involves study, simulation and comparison of various design topologies/configurations for high voltage EPC for multi collector pulsed TWT with Beam focus electrode for pulsed operation. The work also involves study and comparison of space grade high voltage potting materials and packaging aspects.

8. HUMAN SPACEFLIGHT AND ADVANCED TECHNOLOGY AREA

Human Spaceflight And Advanced Technology Area of ISRO has a well-defined roadmap for conducting space flights with humans and development of technologies to support the missions. Unlike other missions carried out by ISRO so far where mostly observation or service-oriented hardware was flown as payload, HSP will carry humans (as payloads). This creates bundle of opportunities for development of human centric technologies in a large spectrum of domains and disciplines. Some of the technologies fall under the category of 'must haves' while others can be innovative in nature, giving alternatives to existing technologies or enhancing certain aspects of mission.

SAC is developing various systems towards HSP where audio, video and text communication systems will enable end to end two-way communication between ground command and astronauts. The technologies involved in this service include following:

1. Compact, space qualified camera systems.
2. Baseband units to switch, encode, compress video and audio streams.
3. Noise cancellation based audio communication systems with versions, which can be wearable and can be panel mounted.
4. Modems for RF communications.
5. RF communication network elements like Solid state power amplifiers, switches, filters etc.
6. Antenna systems including phased array antenna.

ECLSS (Environmental Control and Life Support System) is system of systems which helps maintain earth like atmosphere inside habitat volume of crew module. This primarily includes maintaining optimal oxygen level, removing carbon dioxide and maintaining PTH (Pressure, Temperature, Humidity). SAC is engaged in developing EMS (Environmental Monitoring System) which measures the values of oxygen and carbon dioxide concentration in cabin environment along with PTH values. Methane and ammonia are by product of metabolism in human body. Carbon monoxide is emitted when something burns. EMS will also measure concentration of these trace gases to keep check on environmental quality and hazard prevention.

A portable version of EMS called, HEM (Handheld Environment Monitor) also is developed. Astronauts can use it to check presence of CO2 pockets, origin of trace gases, tracing source of fire, emergency backup of EMS etc.

Fire is one of the prominent hazard on board human spaceflight mission. Detection of fire is complex and many pronged approach is needed to evaluate a fire scenario. At the same time, one false alarm can cause unnecessary mission abort. An array of sensors and integration of data from all the sensors is necessary as part of fire detection architecture. UV flame sensors and optical smoke sensors are first line of detection supported by data from thermal cameras and temperature sensors. Change in gas concentration indices also are included in decision making before raising fire alarm. Dousing fire is manual and water mist based fire extinguishers will be used on board this mission.

First point of interaction for astronauts with their module is display system. As primary situational awareness instrumentation, display system receives data from mission computer in the form of parameter values like path, position, velocity and altitude of orbiter module and displays it as combination of graphs, bars and text. Another set of information is Environmental Control and Life-support Subsystem (ECLSS) parameters and medical parameters of astronauts that displays on separate pages. Mission status, date and time, list of tasks, warnings, alarms, text chat, video conferencing etc. are facilitated through display systems. Astronauts can navigate between pages using peripheral buttons on display. They can also command variety of actions using these peripheral buttons, which change its role based on current context or display page.

In addition to large LCD displays, a dot matrix display is developed which will show only critical parameters in alphanumerical formats.

Cabin lights are designed with white LEDs with intensity and color temperature control to automatically sync with time of the day. This feature would help maintain circadian rhythm of astronauts.

The most significant and critical phase of any human spaceflight mission is atmospheric re-entry and subsequent rescue of astronauts at rendezvous point of landing. Various systems are planned and being developed at SAC to support this phase of mission.

Radar Altimeter will be mounted beneath crew module to gauge exact altitude of crew module and pass it to mission computer so that parachutes can be deployed at right moment during descent phase. Location transmitter will read the precise location of landing after splash down through NavIC and GPS and relay the data to rescue team waiting at a safe distance in sea. An LED based high power VFB (Visible Flash Beacon) mounted on top of crew module will aid the rescue team in visibly locating the module in sea. Finally, a satellite phone in hands of astronauts with global coverage gives them ability to stay in touch with mission control even in last mile of mission.

Following areas are identified where academia can contribute directly. Driving factors of development shall be low mass, smaller volume, low power, environmental qualification for space and human rating aspects in design. Introduction of new technologies and improvement in existing technologies for HSP, both are seen as potential contribution from academia in this program. Indigenous development of these systems also adds value. The developed technique should also consider feasibility of implementation without affecting any of the existing functional requirements. Reliability aspects are of utmost importance in HSP. Hence, development should target reliability aspects right from concept formation stage and should be followed until building successful prototypes. Certification of every system for HSP is a significant aspect of development. Software used in such systems also undergo spell of certification. Certain design aspects in hardware and software must be built from beginning to aid certification process towards induction of hardware in an HSP mission.

8.1. Development of measurement systems and sensors for gas concentration

Human Spaceflight requires continuous measurement of concentration of major air constituents (O2, CO2, CH4, NH3 & CO) and more than 200 trace gases including trace volatile organic compounds (VOC) at ppm to ppb levels, which are relevant to astronaut's health. These are by-products of metabolism/combustion/chemical reactions in the cabin.

Measurement of these gases can be achieved by discrete sensors for each gas or by holistic techniques like spectrometry. Both approaches have their own advantages. Handheld measurement systems can use discrete sensors to build compact, light-weight and battery powered systems. Other techniques can be used to measure array of gases from the same sample. Indigenous development of compact and lightweight sensors and other systems using laser, chromatography, Fourier transform techniques etc have good potential for present and future applications in HSP.

8.2. Development of mitigation techniques for Communication blackout during re-entry

A spacecraft entering the Earth's atmosphere is enveloped by a plasma sheath which results in complete loss or a severe decrease in the strength of RF signals between the re-entry vehicle and the ground. This is referred as Communication Blackout. It results in loss of voice communications and data telemetry during the re-entry of manned space vehicles. The black-out duration can be up to 10-15 minutes and it occurs during the most crucial part of the vehicle's flight. It coincides with the maneuver phase and eliminates ground support during this vital portion of the re-entry phase. In case of an accident during re-entry, this phase is important for post accidental analysis. Due to its criticality, it is important to develop techniques to mitigate this problem. The theoretical study and the analysis should be validated through the practical experiments. Practical experiments may be conducted in the suitable plasma environment to validate the following:

- Dependence of EM wave attenuation on plasma profile.
- Dependence of EM wave attenuation on operating frequency w.r.t. plasma frequency.

In principle, the most obvious way in which the reentry communication blackout problem can be alleviated is by designing the communications system with a system margin greater than the plasma signal attenuation encountered during reentry. Typical plasma attenuation may exceed 100 dB, thus the required system margin is unrealistically large and cannot be achieved in practice. Hence, other alleviation techniques should be investigated which can be used in conjunction with the system margin. Worldwide many experiments have been done using following techniques to overcome communication blackout:

- By avoiding attenuation region in plasma sheath: Higher Frequency method.
- By reducing concentration of electrons in plasma sheath: Aerodynamic shaping, Injection of coolants.
- By altering the properties of plasma to minimize its interaction with the electromagnetic waves: Magnetic Field Method

Development of techniques to enable communication during this phase or to mitigate complete communication black-out can help existing and future missions of HSP. Experiments and finding that can aid to the understanding of phenomenon also can be seen as value addition.

8.3. Development of wireless communication systems

Introduction of wireless networking enhances communication in the vicinity of a spacecraft and also facilitates many aspects of communication within a spacecraft including mobile crew monitoring and communication, environmental monitoring and control, structural monitoring, and situational awareness. Wireless system designs should also consider conditions of operational space environment.

It is required to develop wireless systems that demonstrate reliable data transfer across avionics components, subsystems, and interfaces to simplify system integration, reconfiguration, and testing. Solutions that enable new avionic architectures and provide capabilities that expand mission performance while decreasing the Size, Weight, and Power consumption and cost of the resulting spacecraft are highly desirable.

Applications include sensors communication within habitat volume, communication during Extra Vehicular Activities, video capturing of separation events etc.

8.4. Study and simulations to identify and modify material flammability limits in low-g environment

The materials used in the habitable area of spacecraft carrying humans must be non-flammable. Flammability of some materials may not be by choice (e.g. food). It is of significance to identify flammability characteristic of materials used in spacecraft in low – g environment as gravity can affect these parameters. To determine if a material, when exposed to a standard ignition source, will self-extinguish and not transfer burning debris, which can ignite adjacent materials, the UPWARD FLAME PROPOGATION TEST should be performed. *(Reference: NASA-STD-6001)*

Development of instruments, setups and carrying out tests, generation of data related to material flammability, odour, outgassing and off gassing etc. on ground as well as in microgravity can be useful for present and future HSP missions.

8.5. Study of In-flight identification and quantification of species in water for long term space missions

Long Duration Human Spaceflight requires continuous monitoring of water quality to ensure crew health and safety. Water monitoring equipment like colorimetric water quality monitoring kit (CWQMK) are already a part of the ISS. For our future space station and interplanetary travel requirements, it is important to initiate the developments of these systems. These instruments would have immense applications in future space station, interplanetary travel and other long duration space missions.

Development of apparatus, test setups for experiments related to above subject, evaluation of data received from such experiments and development of mitigation techniques for observed ill effects can help in current and future missions of HSP.

8.6. Assessment of flame spread of large scale microgravity fire

Materials with high flammability must be assessed for the flame spread rate using HEAT AND SMOKE RELEASE RATE TEST (Reference: NASA-STD-6001)

Understanding nature of flame, process of combustion, rate of spread, mass consumption, quantity and rate of heat release etc can be taken up as study. Additionally, apparatus, test setups and identification of methodology, both on ground as well as in micro gravity also is needed to further the understanding of the subject.

8.7. Microbial monitoring in microgravity environment i.e Non- culture based in flight monitoring with species identification and quantification

Microgravity can affect the growth and survival of microbes. The research on this topic is essential to achieve safe and healthy long duration space habitation. Non-culture based in-flight monitoring with identification and quantification of microbial species is targeted for the development.

This research would help in understanding the relationship between humans and microbes, which may be affected hugely in microgravity. It will enable the understanding of how and where microbes proliferate in confined environment in space.

Test setups and instrumentation required for remote observations can be developed to achieve the above mentioned purpose followed by findings and conclusions that may become input or directive for future missions.

8.8. Disinfection technique and technologies for microbial control of water systems and environment in microgravity

Disinfection and de-contamination are highly essential to achieve safe and healthy long duration space habitation. ISS has a decontamination system which was designed with crew members' safety in mind by using high-power, ultraviolet, light-emitting diodes (UV LEDs) to sanitize surfaces. This cleaning process takes only a matter of minutes before and after the crew conducts the experiments. The sanitation process also removes airborne contaminants -- such as biological and chemical impurities -- and cleans up spills inside the glovebox, providing optimal accommodations for cell science and life science research. It also has an exchangeable glove system that was redesigned to be better suited for these types of studies.

These disinfection systems based various technologies like the Ultraviolet Germicidal Irradiation (UVGI) method etc. are essential for long duration space missions/Space Stations for disinfection/removal of microorganisms. Other alternate techniques also can be developed which are safer and more efficient.

8.9. Application of AI and ML in crewed missions.

Currently, System controls are based on ground based command or crew inputs through button/switch controls which require specific user action. Warning systems are based on predefined criteria and thresholds. AI and ML are relatively in nascent phase as far as space systems are concerned. However, the potential of technique and its application in future cannot be ignored. Hence, exploring possibilities of AI and ML in HSP is encouraged with all potential applications. Some are listed below.

1. Voice based system commanding mechanism without restricting/requiring use of any limb action.
2. An early warning system which learns from previous data to warn on possible occurrence of a hazard.

8.10. Compact fire suppression systems for crewed missions for micro gravity applications.

On board fire in HSP is one of the most serious on-board hazards. Every HSP mission carries fire suppression system. FSS should be safe for humans, should be quick and efficient in dousing fire, should

be clean and its application should be safe for onboard electronics. Fine water mist based FSS is in use onboard ISS now.

Indigenous development of compact, portable, easy to use and safe FSS is needed for current and future HSP missions.

8.11. Microgravity experiment platforms to simulate microgravity on earth

Research in microgravity is indispensable to disclose the impact of gravity on biological processes, organisms, materials, fire and functional systems. “True” weightlessness, for more than a few seconds at least, can only be achieved in space or zero-g flights in atmosphere. Drop towers, drone based agile platforms etc. have potential to bring out microgravity experiment platform.

Test setups, approaches, new ideas to carryout such tests can be used in existing and future missions of HSP.

8.12. Next generation fire detection systems

Fire is one of the most critical on-board hazard for any HSP mission. Detection fire is of paramount importance. Sensors must have very high sensitivity to variety of fire, flame and electric spark. At the same time, it should offer high immunity to false detection.

Most mission experiences have reported early detection by humans through smell, rather than on-board sensors. Development of “Electronic Nose” which can detect very low concentrations of combustion products can help in early detection of fire.

Fire is detected by measurement of concentration of specific gases, heat, temperature, flame etc. Novel approaches n detection, new parameters that can aid to detection of fire also is needed to enhance the fire detection scenario.

8.13. Display and other situational awareness technologies

Visual information (for situational awareness) is made available to the crew either through print pages or displays. A more effective method should allow crew to quickly access context based information.

Development can be focused on fixed and portable display devices with higher efficiency (lower size, mass and power) and better human centric aspects, taking advantage of advancement in display panel technology like flexible films displays etc.

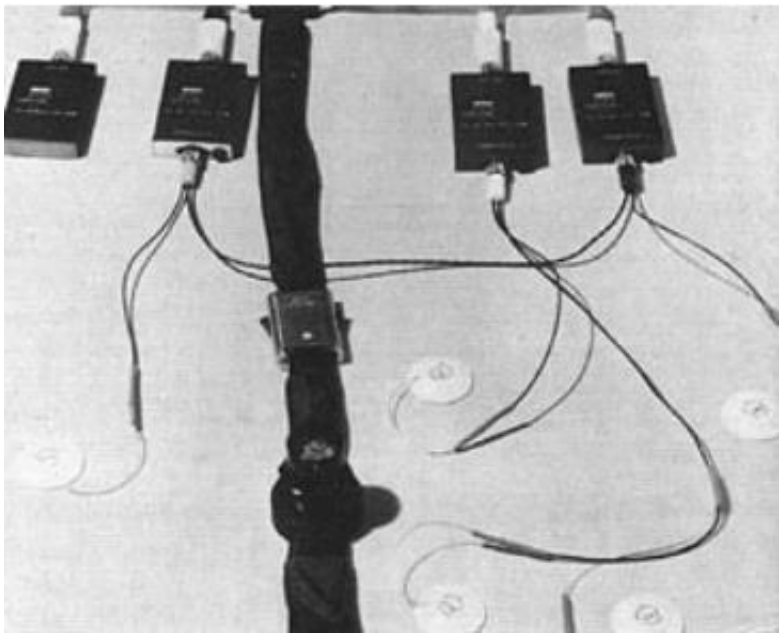
Augmented reality based devices can be used to provide context based information to the crew for information such as visual alert, holographic communication and object information. AI and ML can be included in such systems to make them more efficient and effective.

8.14. Personalized instrumentation for astronauts

Personalized instruments like wearable health monitors etc. are essential for all human spaceflight missions. Variety of sensors are flown with astronauts for monitoring of crew health parameters like Blood Pressure, Oxygen Saturation, Pulse Rate, Exhaled Breath Analysis etc. Wearable medical devices need to

be developed for continuous monitoring and transmission of these parameters to ground. This is essential for both long term and short term missions. Apart from its on-board application, they are equally useful during training and simulation studies.

These instruments would have immense applications in all kinds of human spaceflight missions for safe, reliable and continuous health monitoring of all crew.



Wearable Sensors

Breath Sensor System

8.15. Instrumentation for docking

Docking of spacecraft with space station or other manned modules for human or cargo transfer is an autonomous activity in most contemporary HSP missions. ISRO envisages development of these technologies to support automated or assisted docking while in orbit. Laser based or other types of ranging systems, camera based video systems, RF based systems are required for beacons, altimetry or distometry, velocimetry, optical flow techniques, close range photogrammetry and other parameters of situational awareness either in assist mode or in close loop mode for automated docking. Development of sensors, integrated systems and demonstration models can help in future docking missions of HSP.

8.16. Space suit related Instrumentation

Space suit is an integral element of any HSP mission. Variety of sensors including health parameter monitoring systems are part of an integrated spacesuit. Personal communication systems, integrated display systems, tools for articulations during EVA (Extra Vehicular Activity) and other accessories helpful to accomplish routine and specific tasks of astronauts are needed to be developed for all HSP missions.

8.17. Quantum Technology Group (QUTG)

Optical Communication

Optical and Photonics technologies have widespread applications in the field of high data rate communication, optical inter-satellite links, microwave photonics. SAC has a well-defined road map for optical communication development. Starting from sub systems realization for lab demonstrations to complete program for full-fledged implementation for satellite terminals has been planned with short and long term goals. System engineering activities for optical communication payloads are being envisaged for Intersatellite and ground to satellite optical communication links. End-to-end system design for realization and operation of onboard optical communication payloads are being done.

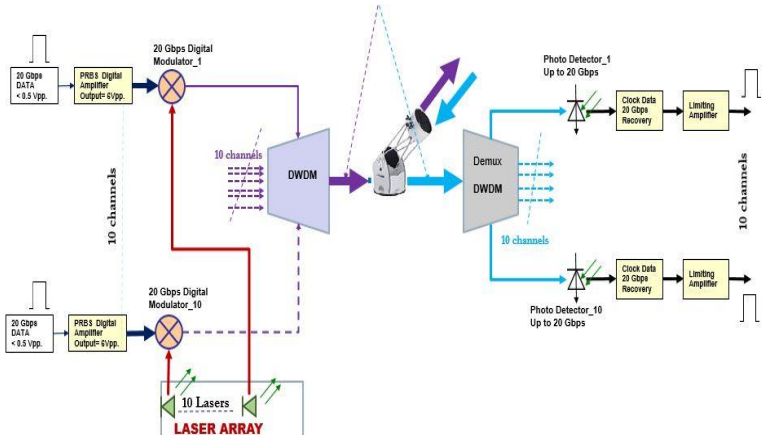
SAC is involved in design and development of advance optical communication subsystems like high data rate transmitters and receivers using different modulation/ demodulation techniques, EDFAs (high power and low noise) , filters etc. Various microwave payload subsystems like filters/switches, beam formers, frequency generators etc. are being realized using optical technologies to incorporate multi functionality, flexibility and miniaturization of RF payloads. Photonics integrated circuits based designs are also being envisaged for miniaturized optical subsystems.

High data rate communication for satellite applications are utilizing the enormous potential of photonic components. With the advent of advanced and miniaturized components like laser diodes, modulators, modulator drivers, filters amplifiers and Erbium Doped Fibre Amplifier (EDFAs), high data rate intersatellite links are possible using optical technologies. In today's data hungry environment, optical communication is providing 100s of Gbps of data rate using Dense Wavelength Division Multiplexing (DWDM) techniques. Microwave signals are being transported and processed using photonic techniques. This has paved the way for special areas of research called microwave photonics. Photonic technologies have the potential to replace conventional RF and microwave components use in the satellites to save space and power, which are very critical in satellite industry.

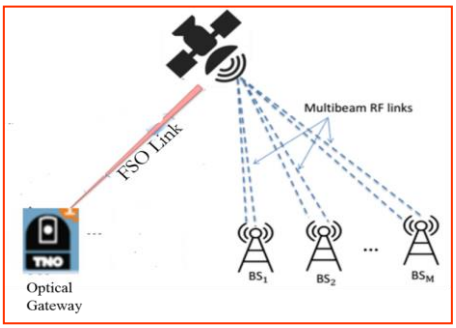
8.17.1. DWDM based 200 Gbps Floating Storage and Offloading Unit (FSO) link demonstration for future Terabit optical communication.

Terabits of data rate will be required for future high-speed links for LEO satellites and Intersatellite links for LEO constellations. Also high throughput satellites require 100s of Gbps data to be transmitted through multiple gateways. RF bands are facing saturation and limited to strict frequency regulation, leading to a requirement of large number ground stations for feeder links. Increasing frequency demand from terrestrial wireless communications also puts restriction RF frequencies and on feeder locations due to signal isolation requirement and practical operational issues. Multiple feeder stations call for multiple terrestrial links involving multiple operators and puts signal security at stake.

Technologies developed will be utilized for high data rate links for satellite-based links (LEO –ISL, LEO GEO, GEO-Ground) as well as for optical feeder links for high throughput satellites. A single optical feeder Station can cover vast geographical areas without number of RF feeder stations and their terrestrial links, which requires vast amount of ground infrastructure. These technologies can be extended to Terabits links for future Optical communication and HTS links.



Multichannel High data rate optical communication link @200Gbps



Feeder link for HTS

8.17.2. Multi wavelength Fiber Laser Generation Technique

Multi-wavelength laser generation from a single source of laser has attracted considerable attention among researchers over the last few decades. The Multiwavelength Fiber Laser Sources have potential Applications in dense wavelength-division-multiplexed (WDM) in High Throughput Satellite in optical communication, optical instrument testing and characterization.

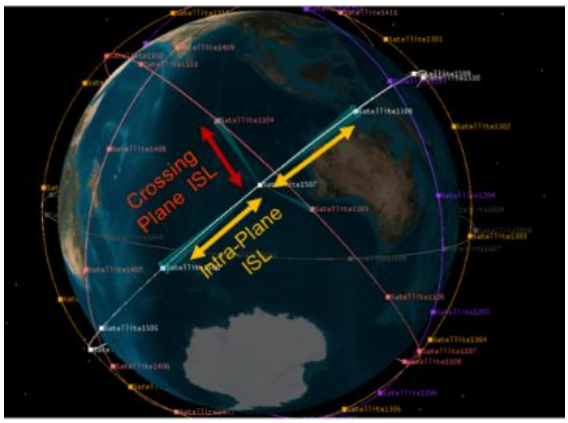
Such light sources are particularly in-demand because they provide an efficient and economical solution to increase the flexibility of WDM system. It has various advantage such as low cost and low insertion loss. The requirements for such optical sources are a high number of channels over large wavelength span, moderate output powers with good optical signal to noise ratio (OSNR) and spectral flatness, single longitudinal mode operation of each laser line, tunability and accurate positioning on the International Telecommunication Union (ITU) frequency grid. Technologies developed in this research will be utilized for optical feeder link for high throughput satellite

The scope of the work shall include to explore the several techniques used for multi wavelength generation namely comb filter, cascaded modulation, Brillouin scattering technique, and arrayed waveguide grating.

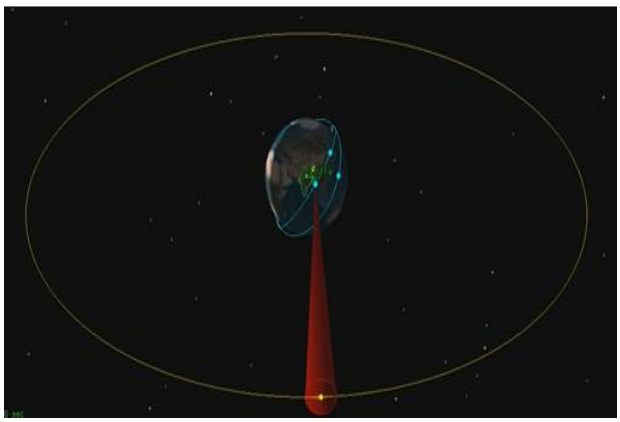
8.17.3. Compact Optical Terminal Development for Optical Inter-Satellite Link

The upcoming data rate requirement need a paradigm shift from conventional RF satellite link to free space optical link. RF link has some advantage over free space optical (FSO) link where atmosphere is involved. But for inter-satellite link, FSO link is the only viable solution in terms of size, weight and power. The added advantage of FSO link is high data rate, narrow beam width, low EMI/EMC etc.

ISRO has initiated the development for FSO inter-satellite link. The base band data will be modulated using optical carrier which has frequency in THz. Using a compact terminal consisting of optical telescope, optical communication subsystems and pointing acquisition and tracking (PAT) mechanism, ISL can be realized. This will also effective reduce the number of ground segment and will add space diversity.



Inter-plane and Intra-plane ISL



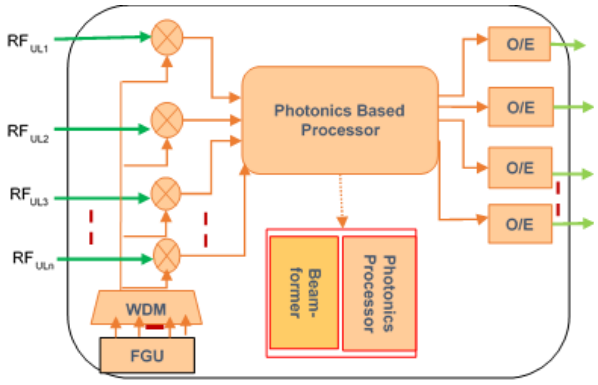
LEO-GEO ISL

8.17.4. Microwave Photonics for next generation broadband payload

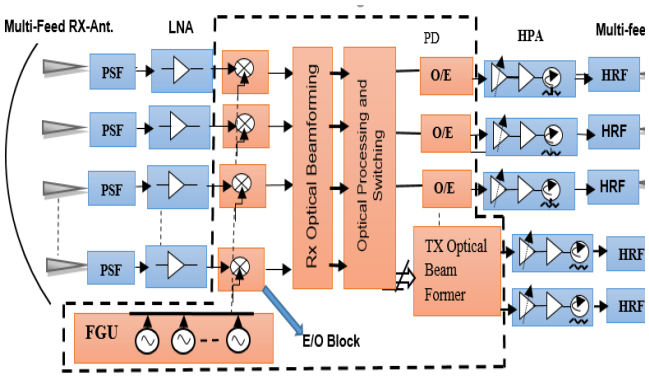
Broadband Satellite Communication in coming future shall have the capability of providing very high throughput (vHTS) 'Terabits/sec' with multi-beam coverage and with data rate >10Gsps on-board switching. It will be capable of providing flexible power, bandwidth and coverage depending on varying demand over the multi-beam coverage.

Microwave Photonic-based on-board processing will be a feasible solution to meet the high-speed processing demand of next-generation broadband satellite system with added advantage of lower mass, lower volume, less power consumption and better EMI performance.

The research areas in MWP are Microwave Photonic Filter, Photonic switching and Beam forming. PIC based approach for the above areas are also initiated.



General Architecture of Microwave Photonics based Processing



Photonics based Multi-beam Payload Architecture

8.17.5. High Power Er Doped Fiber Amplifier

High power optical amplifier (EDFA) is inevitable for the realization of free space optical communication link. This is the device, which amplify the 1550 nm optical signal directly without the need of any electrical conversion.

Er - doped fiber is popularly used as the gain medium for optical amplifier. The Pump laser will provide the required population inversion in Er fiber. Different pumping topologies e.g. forward pumping (co-propagation), Backward pumping (Counter propagation) and Bi-directional pumping (Co+ Counter propagation) is explored in the development to maximize the Gain, Saturated power and minimize the noise figure. Fiber fusion and thermal management of fiber plays the crucial role on the operation life EDFA.

For any type of optical communication payload, EDFA serves the purpose of power house to sustain the communication link. Though many commercial EDFAs are available, those are meant for ground applications. For space based EDFA, there are lots of design challenges in thermal design, optical fiber assembly, high power electronics aspects.

SAC have initiated the in-house development of EDFA in different phases with mid and high power output targets. This development is being carried out in phases. At present 5W output at ambient has been realized.

8.17.6. Higher order optical switch for low latency applications

The increasing user demands required high throughput microwave and optical payloads where onboard signal processing in photonics domain is the most viable option to meet the latency requirements of reconfigurable networks.

In photonic switching there are several techniques such as optical MEMS, Semiconductor optical amplifier, waveguide and thermal. In this technology, selection and hardware realization of the switch will be explored which has capability of high switching order (16*16 or higher), switching latency (few nano sec.) in optical C-band. The Cross talk (-40 dBc or better), polarization independent, transparent to data rate up to 10 Gbps with suitable tele command and telemetry provision are the key features of the hardware.

8.17.7. Digital Signal Processing for Optical Coherent Receiver in BPSK, QPSK or advanced modulation format

For advanced optical communication formats e.g. BPSK, QPSK, 8-PSK etc., the post processing of electrical signal is inevitable after detection through coherent receiver with single polarization (X

channel) or dual polarization (X and Y channel) multiplexing. Several impairments cause the optical signal distortion and those effects need to counter through algorithm. Main algorithm stage conventionally consists of Bessel filtering, Resampling, Quadrature imbalance, non-linearity and Chromatic dispersion compensation etc.
The data rate is typically more than 10 Gbps. In such high data rate, the DSP using FPGA is very challenging. There is a scope of code development for FPGA to mitigate the effects.

8.18. Quantum Key Distribution on a Moving Platform

The quantum transmitter transmits single photons which has very low power and narrow beam divergence, hence satellite to ground quantum key distribution demands very high accuracy pointing, acquisition and tracking (PAT) between satellite and ground station to have efficient and feasible quantum key rate. Moving towards the aim of achieving such technology, an indigenous compact PAT system is being designed and developed.

8.18.1. FPGA IP development

The real time key generation in QKD system requires processing and synchronization of the generated raw data between transmitter and receiver terminal in very short time. The development of all needed functional elements in one NavIC synchronized FPGA-IP for protocols BB84, BBM92 and Decoy state has already been successfully completed and demonstrated. Current IP for BB84 and BBM92 has been tested for up to 33MHz of repetition rate. Same IP is also capable of performing BBM92 protocol with a coincidence window of 20ns. Further, there is need of high-performance IPs for rate up to 200MHz pulse repetition rate and sub-nanosecond co-incidence window both for fiber and free space based QKD. This next generation IP is under development. Further, IPs for supporting new protocols are also being explored which can support fiber and free space QKD. New precision timing synchronization system using optical methods are also being explored to meet future high performance QKD links.

8.18.2. Quantum Network

SAC is working towards development of quantum network technology for last mile connectivity to users to communicate with unconditional security. A hybrid quantum network test bed is under development which includes both fiber and free space links within SAC for end user applications. A key management system is needed for routing and efficient distribution of keys between multiple nodes. Study and countermeasures of all possible eavesdropping attack on such network is also to be studied.

8.18.3. Single photon detector development:

Single photon detectors are used for quantum communication based applications include characterization of single & entangled photon sources, photon detection at QKD receivers etc. Various technologies like Single photon avalanche diodes (SPAD), Photo-gated phototransistors and Nanowire SNSPD are being used for the detection of photons with different photon detection efficiency and dark count rates and are being operated at room temperature or cryogenic temperatures. SAC has initiated the development of 1550 nm single photon detectors which can be operated at room temperature with Photon detection efficiency > 50%, Dark count rate <500 Hz, Dead time <10 microsecond which will give self-reliance to SAC in this technology. In this regard, SAC has initiated in-house & collaborative work with academia to develop the bare SPD chip and setup for its characterization and packaging.

8.18.4. Photonic Integrated circuit development (PIC):

Photonic Integrated circuit is the State of Art technology which brings all the bulk and discrete photonic components into a single miniaturized chip and thereby reduces the size & weight of bulky optical/photonic systems. PIC based chips requires less power and capable of providing much higher data rates in Tx-Rx based systems. SAC, has initiated PIC based design and development of Quantum Transmitter for Quantum key distribution. Various protocols are being explored in Indium Phosphide and silicon photonics platforms for the design implementations. Initiated design & simulations work for the implementation of BB84 based QKD Tx PIC. Various foundries are being explored for fabrication of in-house designed PICs. PIC based Quantum Random number generators, Entangled photon source and Single photon detectors are also being explored for future developments.

8.19. QUANTUM SYSTEMS AND TECHNOLOGIES

8.19.1. Software toolkit for simulation and analysis of polarization sensitive beam propagation system for Satellite based Quantum Communication

A user-friendly GUI based software toolkit is required for modelling the evolution of Gaussian beam of light and its polarization properties in near field and far field for any given optical system scenario including multiple components like lenses, mirrors, dichroic, beam—splitters etc. with the option of custom rotation/tilts. The software should support any input polarization state & DOP while having provision for defining the polarization properties of each surface through Muller formulism or input of birefringent material properties/measured data. It should further be able to simulate and analyse the transformation of beam profile and the polarization state of light for given orbital parameters (satellite trajectory, orientation etc.) and layout of on-board/ground optical system. Accordingly, it should generate required inverse transformation using any suitable birefringent optics system (like waveplates, liquid retarders etc.) for performing dynamic polarization compensation at the ground.

8.19.2. Development of High speed Polarization Modulator for Quantum transmitter

Several Quantum communications related protocols are developed on the basis polarization states / phase / time bin encoding of light. For polarization based protocols, Quantum Transmitter sends random polarized light sequences, with which secret shared key is created between Transmitter and Receiver. A typical setup for such communication consists of four laser transmitter units corresponding to four polarization states. However, a single laser transmitter unit with polarization modulator controlled through electrical bias can generate required polarization states, thus greatly reduce the setup size making it more appropriate for the satellite applications. Literature survey shows design of such polarization modulator can be done using a phase modulator. It is imperative that polarization controller should generate different polarization states at rate in few GHz range (20 MHz - 2 GHz) with desirable operating wavelength of 785 nm and 1550 nm.

8.19.3. Development of system engineering tool kit for simulation of Quantum Key Distribution (QKD) protocols for fiber based systems

A suitable software tool kit is required for extensive simulation and performance analysis of various QKD protocols. This toolkit can be used for end-to-end modelling, simulation and analysis of various fiber based QKD architecture to aid in system engineering. The software toolkit should support detailed modelling

architecture for analysis of a full system including link budget analysis, QBER, secure key rate etc. for fiber based prepare and measure as well as entanglement based QKD protocols like Decoy state BB84, BBM92, E91, DPS, COW, CV-QKD etc. This toolkit will consist provision of non-ideal/practical systems or components for realistic estimation of QKD system performance in various scenarios. It will also help to perform comparative analysis of various QKD protocols in a similar operating and environmental conditions.

8.19.4. Development of frequency up conversion based Single photon detector

Single photon event detection is done either by an avalanche photodiode (SPAD) or by super conducting nanowires (SNSPD) maintained in a cryo-cooled environment, operating in Geiger mode supported by output pulse shaping and avalanche quenching circuits. Visible-NIR (700-850nm) photon detectors have Si based technology while for optical telecom IR (1530-1575nm) it is InGaAs/InP. An alternative and effective method for single photon detection for IR wavelengths is through up conversion to the efficient Si detector technology. The development of such an up-conversion detector design requires sum frequency generation of IR single photon signal and a pump signal to generate an up converted single photon signal in visible domain (780-850nm) using non-linear crystals/waveguide. Research advancement in this technology will be a good development towards enabling QKD systems for both 800nm and 1500nm wavelength domains.

8.19.5. Design of single/entangled photonic source with high rate/dimensionality

The demand for faster key generation rates and better link margins in QKD systems is pushing photon source technology towards high generation rates (>100MHz typically). While attenuated pulsed lasers are simple solution to this, true-single/entangled photon sources are still considered a better option for making QKD systems truly secure against some of the eavesdropping attacks. It is desirable to have high rates, high dimension photon sources for increasing quantum channel efficiency (more bits per photon transmission). Hence, faster weak coherent pulsed sources and high fidelity-high rate single/ entangled photon source development in visible and IR operating wavelength domain is an ongoing research at SAC.

8.19.6. Study and analysis of suitable Optical ground station (OGS) locations across Indian mainland for free-space optical/quantum communication links

Optical ground stations (OGS) are required for carrying out satellite-to-ground (STG) and ground-to-satellite (GTS) based optical and quantum communication related experiments. This proposal deals with detailed study, analysis and identification of suitable OGS locations over Indian mainland considering various system engineering, atmospheric and orbital parameters in both STG and GTS scenarios. The research work must include comprehensive analysis of possible losses/distortion due to optical beam propagation through turbulent atmosphere single (weak coherent pulse) as well as entanglement based protocols in satellite based quantum communication scenarios at both 800 and 1550nm wavelength band. The operating conditions w.r.t sun light considering night time as well as day time operations with satellite in LEO/MEO/GEO orbit are to be considered. Multiple locations of ground stations should be identified along with their preference corresponding to five different zones of Indian mainland: north zone, east zone, west zone, south zone and central zone clearly highlighting over the year atmospheric loss profile, turbulence, cloud mapping, polarization/phase/entanglement perturbations, ambient noise,

solar irradiance etc. Comparative study should also be done on downlink and uplink configuration of optical/quantum communication. Suitable experiments, like radiosonde to characterize the atmospheric turbulence and atmospheric chemistry measurements should also be carried out for validation of the study & analysis. Development of a numerical model (software) to simulate end-to-end laser beam propagation through lossy and turbulent atmosphere.

8.20. ATOMIC CLOCK-Navigation Related Technology

Atomic frequency standards are the back-bone of the satellite navigation technology. SAC has developed indigenous atomic clocks for India's navigation programme – IRNSS (NavIC). The key concepts of atomic clocks involve atomic spectroscopy; RF & microwave electronics; microwave cavities; optics; low noise detection schemes and digital electronics. In view of supporting the in-house R&D activities, further detailed theoretical modelling can aid our practical work. Herewith, the following proposed research on theoretical and experimental studies can enhance our activities towards the optimisation of atomic clocks.

8.20.1. Rubidium atomic clock modelling and theoretical studies on fundamental limitations in detection schemes and stabilities of atomic frequency standards.

A detailed analytical modelling of rubidium atomic clock is to be performed. This should include the modelling of atomic signal and its features and the locking of crystal oscillator using the atomic signal. The signal-to-noise ratio in an atomic clock depends on the detection noise present in the system. Low noise detectors and low noise electronics have to be employed in order to reach better clock stabilities. Thorough studies on the best possible detection schemes is needed to employ the efficient methodology in compact space clocks.

8.20.2. Coherent Population Trapping based schemes for atomic clocks

In the Coherent Population Trapping scheme, the use of microwave cavities can be avoided to build atomic clocks. This can, in principle, bring down the size to a considerable extent. The recent advances in chip-scale atomic clocks has been possible due to CPT methods. Initial theoretical and experimental studies on this can be helpful for us to take it forward towards the space based atomic clocks.

8.20.3. Studies on light-shift effects in atomic clocks and analyses of onboard clock jumps.

Rubidium atomic clocks are the widely used clocks in GNSS for space based navigation. These Rb clocks are prone to onboard frequency jumps, which results in the error on the navigation signals. It is of utmost importance to understand the source of the jumps in the Rb clocks. The primafacie understanding has brought to notice that light-shift effect is the main cause of these jumps. However, a detailed study is needed to quantitatively understand the physics behind these jumps. Moreover, in this study the other potential parameters such as the radiation effect, magnetic effects etc need to be addressed which may result in giving rise to clock frequency jumps.

8.20.4. Trapped mercury-ion atomic clock

The trapped mercury-ion atomic clocks can reach stabilities and drifts, which are 1 and 2 orders (respectively) better than the rubidium lamp based RF clocks. These are strong potential candidates for the future deep space navigation missions alongside the current NavIC missions. The area of research

include study, design and demonstrate the trapped mercury-ion-clock physics package meeting state of the art specifications.

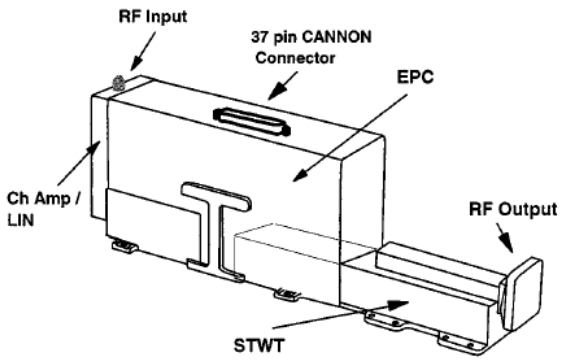
8.21.Travelling Wave Tube Amplifier (TWTA) is one of the critical technology elements used for efficient high power amplification in space borne payloads. Amongst all microwave amplifiers, TWTA offers unique combination of power, gain, efficiency and bandwidth.

Research opportunity in the field of TWTA is primarily oriented around

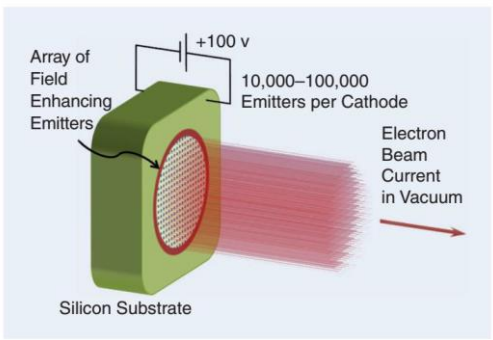
a) development of large signal simulation tools,
b) study & development of special UHV grade materials & special coating techniques on UHV material suitable for high temperature brazing,
c) characterization of Secondary Electron Emission (SEE) & work function of various metallic & non-metallic surfaces & methods for improving SEE characteristics
d) development of methods for coating and texturing on copper surface for reducing SEE,
e) techniques for measurement of high temperature stress & strain in complex shapes,
f) Design & development of long life high reliable space cathode.

Future research areas include development of

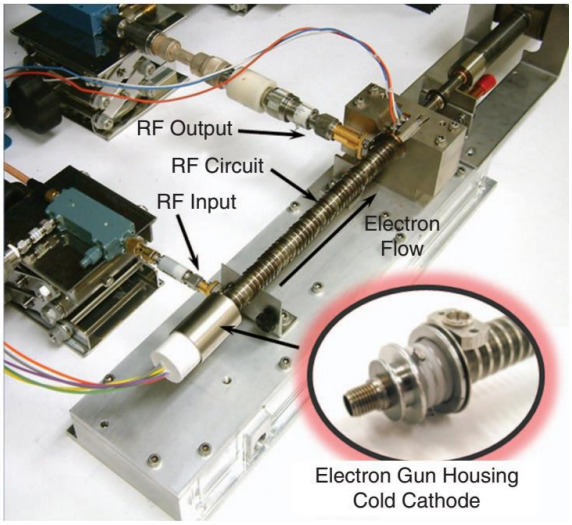
a) very high peak power Pulse TWTAs for radar applications,
b) Q/V band CW TWTAs,
c) folded waveguide TWTA and Coupled cavity TWTAs for higher frequency band power amplification,
d) brazed Helix technology useful for higher CW power,
e) Microwave Power Modules – combination of Solid state amplifier and TWT with advantages of both the technologies,
f) Flexible TWTAs for dynamic allocation of frequency, BW & power,
g) Filtered Helix TWT with improved harmonic suppression,
h) Cold cathodes,
i) Mini TWT that can be placed right at the back of phased-array antenna,
j) High power source that can be beamed to Microwave rockets.



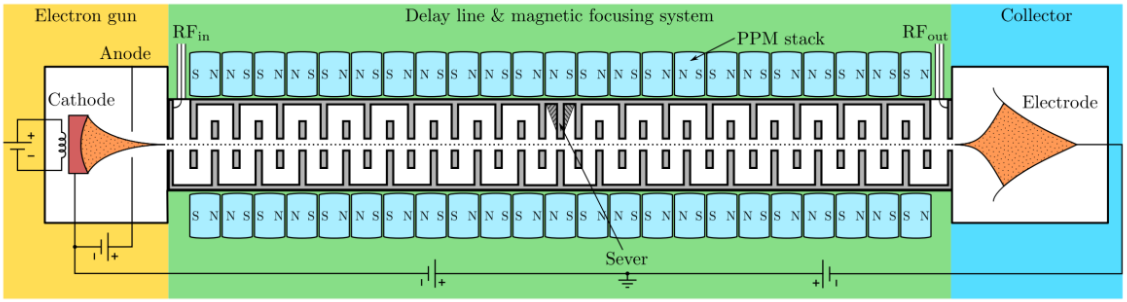
Microwave Power Module



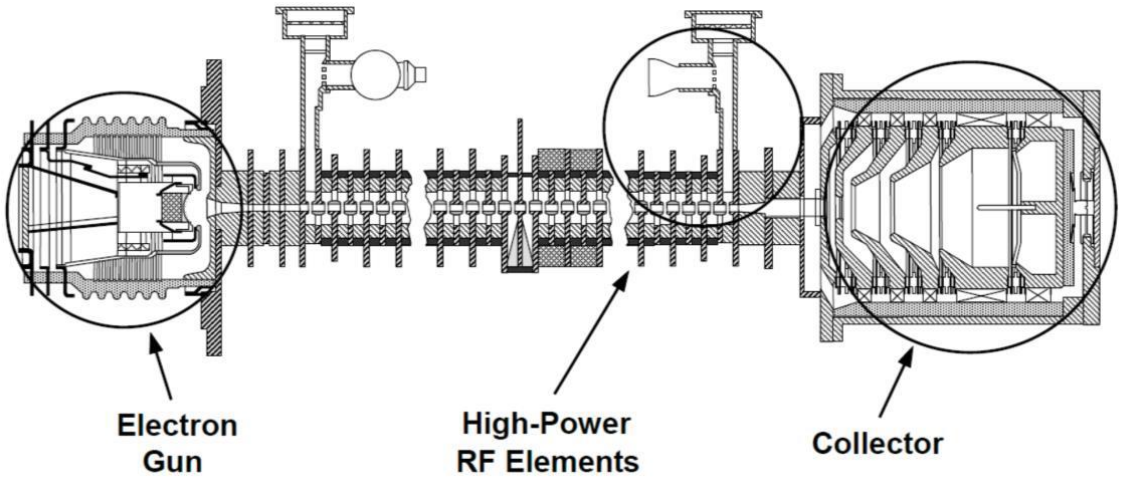
Embodiment of Cold Cathode Array



Cold Cathode TWT



Schematic of a generic folded-waveguide Travelling Wave Tube



Schematic of a generic Coupled Cavity Travelling Wave Tube

9. SIGNAL & IMAGE PROCESSING AND DATA PRODUCT

SIPG is responsible for the design, development, operationalization and maintenance of the software's for remote sensing data processing related to earth, planetary and astronomical observations for Indian as well as international user community. SIPG is also engaged in design & development of custom-made software for specific ISRO clients. The group specializes in design of algorithms for signal & image processing and geo-spatial techniques. Coupled with efficient computing for the development of Data Products and Data Quality Evaluation Software Systems and services, this group specializes also in machine learning, deep learning and artificial intelligence. SIPG is involved in processing data acquired from entire spectrum of ISRO's Earth Observation Missions - medium and coarse resolution space borne/air-borne optical multispectral, panchromatic and hyper-spectral sensors (viz. Resourcesat, Ocean Colour monitor, NEMO-AM, Microsat, Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)); optical radiometers on geostationary platform (viz. INSAT-3D/3DR/3DS, GISAT) ; high resolution and stereo data from optical sensors from earth and planetary missions, as well as for ultra-violet and X-ray sensors ; microwave sensors (Scatterometer, altimeters, SAR, radiometers, radio beacons, GPS-RO etc.) for airborne, space-borne and planetary missions ; calibration & validation methodologies and adoption of software engineering standards and practices.

Research Areas in the field of Signal & Image Processing and Data Product

9.1. Artificial Intelligence (AI), Machine Learning (ML), Deep Learning (DL)

9.1.1. Mutlispectral-to-Hyperspectral Reconstruction using Deep Learning

A wide variety of high resolution Mutlispectral images are acquired by satellites every day. However, the availability of high resolution hyper-spectral data is still limited due to hardware constraints. Deep learning and other AI methods have the potential to address this limitation by synthesizing hyperspectral images from the available mutlispectral images with minimal compromise in the spectral characteristics. Though such mapping is an ill-posed problem, setting proper prior knowledge in the model can help solve this problem. Recent works in AI such as diffusion models and Neural transformers have shown promising results in tackling such problems. The motivation of this research is to generate qualitative hyperspectral images from multispectral images for scientific utility.

9.1.2. Infrastructure mapping and monitoring using AI/ML techniques from Synthetic Aperture Radar (SAR) Data

Synthetic Aperture Radar (SAR) is an active microwave sensor that can take images of targets during day as well as night and can also penetrate cloud cover. The high resolution images acquired by SAR can be used to map and monitor various infra structure such as highways, airports, railway, bridges, buildings, vegetation etc. With availability of large amount of images from past, current and future SAR missions, a software for classification and temporal monitoring of government and non-government assets can be very useful for administrative purposes. The prime focus of this research is design and development of AI/ML based technique for classification of infrastructure in the readily available SAR image datasets. The infrastructures thus identified can be added to a library which can be referred for their temporal monitoring.

9.1.3. Artificial Intelligence (AI) Powered Rover Navigation

Low power (<5W) and less weight (<1kg) vision system for planetary rover navigation is the future demanding technology for exploring the permanently shadowed regions and deep craters. Additionally, Rover has to have intelligence build-in to navigate in hazardous terrain and should be able to plan its navigation path dynamically based on the self-health and environmental conditions. It is proposed to build on-board vision compute element as an integrated solution of having vision sensors and processing hardware with terrain generation capability

9.2. Image Processing

9.2.1. Digital Elevation Model (DEM) generation from Multispectral bands

Digital Elevation Model (DEM) generation from satellite imagery or other data sources constitutes an essential tool for a wide area of applications and disciplines, ranging from 3D flight planning and simulation, rectification of aerial photography or satellite imagery, creation of relief maps, 3D visualization, autonomous driving and satellite navigation, to modeling water flow, precision farming and forestry.

Conventional digital elevation models (DEM) are extracted from a pair of remotely sensed stereo images collected by satellites or aircrafts with a wide baseline. Typically, the B/H ratio of the stereo pair ranges from 0.6-1, which will provide a high elevation estimation accuracy. However, a wide baseline with large viewing angles will increase the likelihood of taller objects occluding nearby smaller features and will lead to more changes between image pairs, hence more difficulties in image matching process. In addition to this, stereo image acquisition is expensive as multi-view or dedicated sensors on-board satellite are required for capturing stereo images. To solve these problem, narrow baseline stereovision is one of the solutions. For most of multispectral sensors on board the satellite, the baselines between sensors of different bands are much smaller than traditional stereovision baseline. The images obtained from multiband sensors can avoid the occlusion problem and easier for matching process. With narrow baseline, the stereovision of multispectral images requires highly accurate sub-pixel disparity measurement.

The research element in this field is to develop and demonstrate a DEM generation algorithm for multispectral images with a very narrow baseline. In the traditional approach for DEM generation, one of the most important part is the development of a highly accurate sub-pixel matching algorithm for estimation of image shifts with an accuracy of the order of ~1/100-pixel. On the other hand, Artificial Intelligence and Machine Learning/ Deep Learning algorithms have experienced unprecedented growth in recent years as they can extrapolate rules in a data-driven manner and retrieve convoluted, nonlinear one-to-one mappings, such as an approximate mapping from satellite imagery to DEM's. Both conventional as well as Deep Learning-based methods need focused research in order to construct the mapping for DEM generation given a single RGB satellite image acquired from multispectral sensor. Also a technique needs to be developed to derive accurate absolute height values from the relative disparity map to generate DEM. This research will also help the generation of DEMs from relatively inexpensive platforms.

9.2.2. Multi-Modal Satellite Image Registration

Multi-modal remotely sensed satellite images generate a better representation of the target features and useful for diverse earth observation applications that includes resource assessment, vegetation profile mapping, snow/glacier studies and environment monitoring. Image registration is the crucial step in

multi-modal image analysis that should align multi-temporal images acquired by different sensors. The different modalities of imaging acquisitions such as optical and microwave remote sensing images considered to be a challenging pair for remote sensing image registration. It plays an important role in remote sensing image processing domain and applied in wide variety of tasks such as image fusion and change detection. The SAR/Optical image fusion results in generation of science quality data product only when multi-modal data are corrected or modelled for relative geometric error at sub-pixel level. Even Thermal Infrared and visible images acquired by different satellites and sensors provides useful complementary information. The multi-modal image pair need to be registered for any kind of next level of data analytics and image interpretation. The research should be focus on literature survey, data preparation, model design and development of multi-modal satellite image registration software using novel image processing techniques that can have amalgamation of recent machine learning techniques as well as powerful deep learning models. Even the research area can also focus on improving the already established feature and intensity based methods to achieve the spatial alignment of multi-modal remote sensing images. The experiments need to be evaluated with openly available remote sensing datasets in diverse landscape and showcase the results both qualitatively and quantitatively.
The scope of the proposed research cover survey, design and implementation of recent trends in computer vision, image processing, machine learning and deep learning models in remote sensing data processing domain.

9.2.3. Remote Sensing Data Change Detection Framework

Time-lapse remote sensing images provide vital information to study surface feature changes that happened gradually over decades. Monitoring gradual land cover change using earth observation satellites is required to identify urban sprawl, deforestation zones, new infrastructure's location, change in agricultural land areas, wetland distribution over inland water bodies and for various other space borne applications to make the planet earth habitable. The change information becomes a crucial input for land/urban planning and helps to take correct policy level decision for a large geographic area. The research work should focus on end-to-end remote sensing change detection framework design and implementation using latest machine learning techniques and deep learning models. The literature survey should be comprehensive and exhaustive enough before selection of change detection methodology adopted for the research work. Change detection software developed should be generic enough and not only focused on Earth but also possible to detect changes for planets of our solar system due to availability of large remote sensing image archives. Among them, Mars is a dynamic and active planet in our solar system, which attracts humans due to different geological events continuously reshaping its surface. The experimental results should showcase the visual assessment of the changes identified among bi-temporal remote sensing images in the form of change intensity detection map and colour composite image at different feature targets. The quantitative assessment of the change detection result should also be computed and compared with the state-of-the-art remote sensing change detection techniques.
The scope of the proposed research cover survey, design and implementation of recent trends in computer vision, image processing, machine learning and deep learning models in remote sensing data processing domain.

9.2.4. Aerosol Optical Depth Estimation from High Resolution Images

Atmospheric compensation or correction is an essential pre-processing step in scientific data analysis or interpretation of any satellite imagery and most importantly in applications that involve temporal studies. For this compensation or correction, a precise atmospheric model is very important which is quite sophisticated due to various inputs like aerosols, humidity, temperature, gaseous environment, surface properties, sun-target-sensor geometry etc. In atmospheric modeling, aerosols plays most important role and correct information about type and distribution is required to model the atmosphere. Therefore correction is ideal when scene-specific (in-situ) atmospheric data (aerosol content, water vapour, ozone, gaseous environment etc.) are available, which is rare and not possible in operational scenarios.
The most important parameter, Aerosol Optical Depth (AOD), can be accessed from various sources like Aeronet, Indian National Satellite System (INSAT), Moderate Resolution Imaging Spectrometer (MODIS) and Climatology (modeled using several years of data of a particular location). However it is not possible to get AOD for the date and time (except In-situ) for which the atmospheric correction has to be done but it can be derived from the multi-spectral (MX) bands, essentially having blue or near blue band. We are trying to estimate AOD using signature like water, vegetation and man-made constructions (e.g. tar and cemented structures) by considering them as standard reflecting targets and using spectral library as reference. Also in another approach, we are trying to use top of the atmosphere reflectance (TOAR) from above targets to estimate AOD by modeling TOAR vs AOD for a sensor of a particular satellite.

9.3. Computer Vision

9.3.1. Flash LiDAR based Terrain Relative Navigation

Landing on unknown territory is always a challenging task and navigating Lander to a safe location often require absolution sensor update. The active area of research in Terrain Relative Navigation is to use Flash LiDAR data as input for determining the absolute position and also for navigation relative to hazards. It is proposed to build on-board system of processing algorithms and hardware for Flash LiDAR based Navigation. This includes matching LiDAR intensity image with DEM or optical images on space qualified FPGA platform at a minimum update rate of 1fps. It should be able to provide hazard identification and absolute position (latitude and longitude) with an accuracy of <10m.

9.3.2. Lunar Surface Image Generation for Testing Image processing algorithms in closed loop

This research focuses on design and development of algorithms and software for generation of Lunar Surface Image using sensor geometry, sun geometry, platform attitude, local terrain data and surface properties. The surface image thus generated will be validated using actual planetary images. The methodology for Lunar surface Image generation can be used in closed loop for testing Lunar data Image processing algorithms.

9.3.3. Illumination, Scale, Translation and Rotation invariant image matching

For Interplanetary, Comets and Asteroid Landing Missions with precise position requirements, on-board Algorithm has to be developed for illumination, scale, translation and rotation invariant image matching on space qualified FPGA platform. This image matching should operate at a minimum update rate of 1fps and should be able to provide absolute position (latitude and longitude) with an accuracy <10m.

9.4. Processing and Analysis Frameworks

9.4.1. Block Chain enabled system for Geospatial data sharing

Blockchain is a revolutionary disruptive technology which has brought ripples in multiple fields ranging from finance to medical sciences. Originally designed to solve the double spending problem in a distributed ledger, several innovative applications have emerged and new ones are being discovered every day. At the heart of Blockchain, lies an immutable distributed ledger which contains a record of all transactions performed on the blockchain. The ledger is immutable in that once records are added into it, they cannot be edited or manipulated thus facilitating tamper-resistance. In a typical blockchain-based system, trust and management responsibilities are distributed among the operators. Unlike traditional systems, blockchain based systems require nodes to perform consensus operations to be able to verify and validate incoming transactions and add the blocks to the blockchain. Many revolutionary full-fledged applications, concepts as well prototype solutions have been developed in different fields such as Finance, Gaming, Banking, Supply chain management, etc. have been developed and working. Concepts such as DeFi, Smart contracts, DApps, as well Distributed Autonomous Organizations (DAOs) are currently being used to transform the way traditional organizations work. We believe that space applications can also benefit immensely from the power of this technology.

Research in this field is currently focusing on building a decentralized and secure Geospatial data sharing system which can support a wide variety of users autonomously. The system will enable seamless sharing of Geospatial data availability records over a public or permissioned blockchain and will enable better synchronization amongst users in the emerging scenario of the Geospatial landscape in the country. Towards this, research needs to be done to develop algorithms which can autonomously validate the data being shared on the network through efficient consensus mechanisms. Also, techniques for scalable and efficient wide-spread usage need to be developed so that it can be adopted in real scenarios.

9.4.2. Data Cube Infrastructure for Optical and Microwave IRS data

Number of Earth observation(EO) data users and developers are growing and a number of challenges need to be solved to fill the gap of acquisition and use of ever-increasing satellite data acquired by ISRO. The majority of EO data still remain underutilized mainly because of their complexity, increasing volume and lack of efficient processing capabilities. However, the full information potential of EO data can be utilized by directly providing Analysis-Ready-Data(ARD) to the user community. The ARD has all pre-applied corrections for radiometry and geometry. EO Data Cube (DC) is a new paradigm aiming to realize full potential of satellite data by lowering barriers caused by these Big data challenges and providing access to large spatio-temporal data in a user and developer friendly form thereby fulfilling both visualization and analysis needs. Systematic and regular availability of Analysis Ready Data for Optical and Microwave IRS missions, will significantly reduce the post processing burden on ISRO's IRS data users The aim of this research is to enable rapid data access and pre-processing to generate ARD using interoperable services chains

9.4.3. Clifford Algebra (also known as Geometric algebra) based processing and analysis framework for multispectral and Hyperspectral Images (high dimensional data manifold)

Geometric algebra (GA) provide a unified and concise homogeneous algebra framework based on advanced geometric invariants, projection geometry, affine geometry, etc. It can efficiently solve the geospatial data processing problems due to its advanced geometrical vector-based data processing.

GA is important in image processing and computer vision due to its application in handling color/channel by using vector and its ability to solve AI classification problems. Feature extraction of a given image is a key step in many computer vision and image analysis tasks, such as satellite image denoising, remote sensing image object identification, image fusion, super-resolution reconstruction, and target recognition. At present, there are many solutions, but due to mathematical limitations, these methods

mostly deal with grayscale images, and the matching of color images is rarely studied. The common method used for color image matching is to convert the images into a grayscale images and then use the gray image method to match them. Converting a color image into a grayscale image leads to the vector attributes of the color and some important color information being lost, however, which can cause matching failures. GA can provide a solution for this via its sub-algebra quaternions.
The scope of the proposed research development of GA models, Correction, denoising, feature detection, matching and analysis of large volume of multi & hyper spectral datasets for Earth Observation applications.

9.5. Synthetic Aperture Radar Data (SAR) Processing

9.5.1. Baseline refinement and Phase Noise reduction in SAR Interferograms

SAR Interferometry has a wide range of areas for usage. In SAR Interferometry, two observations of the same region either in a single pass or repeat pass are required. Phase difference of the two SAR images for same feature is a combination of phase differences from sources like orbital position of two sensors, atmospheric delay, target elevation and target deformation over time. For analysis related to target elevation and deformation, phase difference induced due to different orbital positions must be cancelled. Thus, it becomes utmost important to have precise knowledge of orbital positions of sensors. Imprecise knowledge of sensor positions results in inaccurate baseline (distance between two sensor positions) which is used for compensating phase difference due to different orbital positions.

Also, depending upon the duration between two passes, decorrelation between targets occurs. Larger the time duration between the two observations, more is the phase noise and hence it directly affects the quality of unwrapped phase.
Research in this area focuses on development of techniques for improving the Interferogram quality & there by improving accuracies in various interferometric applications.

9.5.2. Moving Targets identification and their parameter estimation from SAR Image

During Synthetic Aperture Radar (SAR) imaging, the sensor is flown in an Aircraft/spacecraft, pulses are sent and the return echo's are recorded. While processing, the range and the relative motion between sensor and target (earth) is utilised to generate images. In SAR, the background region, called clutter, is the region of interest and it is assumed to be stationary and SAR image focusing is done.
Moving targets likes cars, Trains, etc in the images are defocussed and/or displaced and may appear as artifact in the image.
Getting information of moving targets for SAR image will provide valuable information in utilisation of SAR images in strategic applications. Additionally, the work will help in designing the state of the art SAR systems for moving target indication. In the scope of this research, software implementation of various methods of Moving Target detection using SAR raw data, single/multiple SAR image has to be done. Parameters for moving target like position and velocity must be estimated. Refocusing of moving targets in SAR image should be attempted.

9.6. Image Geometric quality improvements

9.6.1. Image Geometric quality and Satellite Platform performance assessment

Level-1 products are the basic products without geometric correction and any other-processing, therefore are of prime importance for any feedback on platform performance and stability. Location errors in Level-

1 products can be traced back to the errors in attitude or residual-attitude, orbit, drift and micro-vibrations of the platform. The main aim of this research is to analyze the Level1-products over different orbits and time to understand the behaviour of residuals in attitude, orbit and drift. Once these parameters are properly modelled, the eventual location errors on the ground should not significantly vary. Under this research, a simulation using the physical sensor model will also be required to generate the bias-compensated Level-1 product and will be used for accuracy assessment. It is expected under systematic coverage conditions, location errors on the ground should remain stable. Also, consistency of the parameters under different imaging conditions (different roll, pitch, yaw, for instance) can be analyzed.

9.6.2. IRS satellites Orbit accuracy estimation from Ephemeris parameters

The aim of this research is to estimate the orbit accuracy using orbital parameters in conjunction with satellite broadcast ephemeris. The error in orbit essentially contributes to various system level errors in data products, namely location error, targeting error etc. and the effect of orbit errors on the accuracy of the data products cannot be neglected.

The broadcast ephemeris typically contains the time-tagged GPS coordinates of the satellite. Precise orbit determination and state vector generation require actual GPS based position vectors of the satellite in ECI (Earth Centred Inertial) frame. First, the preliminary or approximate orbit is determined using established techniques (ref: P.R. Escobal, “Methods of orbit determination”). Then the refined orbit is obtained by using batch least square process and differential correction procedure.

A full force model is required for orbit propagation and the predicted positions can be validated against the GPS data. This study mainly requires an accurate full force model development, which accounts for gravitational forces due to Sun and Moon, solar radiation pressure, etc., for the orbit propagation. Further, modelling errors and orbit drift with time can also be investigated.

10. EARTH, OCEAN, ATMOSPHERE, PLANETARY SCIENCES AND APPLICATIONS

EPSA is responsible for activities related to understanding Earth System, its components, processes and interactions using earth observation data, and its applications towards societal benefits. It aims at identifying Earth Observational (EO) requirements, development of techniques to analyse data to address the science issues and applications related to land, ocean, atmospheric and planetary sciences. The research pertains to operational retrieval of biophysical and geophysical parameters from space borne sensors, sensitivity analysis, calibration and validation of the sensor and retrieved parameters, assimilation of remote sensing derived parameters, in-process modelling pertaining to interactions within the geosphere-biosphere system and atmosphere. EPSA as an excellent multi-disciplinary scientific team has the following major research themes:

- Sensor definition studies towards development of state-of-the art EO Sensors
- Development of operational retrieval techniques of bio-geophysical parameters from Indian Earth
- Observation as well as Planetary missions
- Advance R & D on retrieval of Geophysical and Biophysical parameters
- Synergetic use of space borne data to derive value added bio-geophysical parameters
- Development of procedures and advanced techniques for inventory and monitoring of natural resources using geo-informatics.
- Modeling of dynamic physical processes for improved weather and ocean state prediction
- Development of assimilation techniques for improved predictions
- Assessment of environmental impact and associated climate change over different ecosystems.
- Utilization of data from Indian Satellite Missions including INSAT-3D/3DR, Oceansat-2, Oceansat-3, Cartosat-1/2, Resourcesat-2/2A, SARAL AltiKa and Megha-Tropiques.
- Planetary Sciences
- Designing, generation and updating of resource database ranging from local to national scale.
- Capacity building of scientists at national and international level for EO application programs.
- Archival, Dissemination of the Meteorological & Oceanographic Satellite data, Experimental forecasts and value added products
- Archival, Dissemination of the Earth & Planetary Science Data
- Providing platform to students, academicians & researchers for the analysis of Satellite data

Major research areas are summarized below:

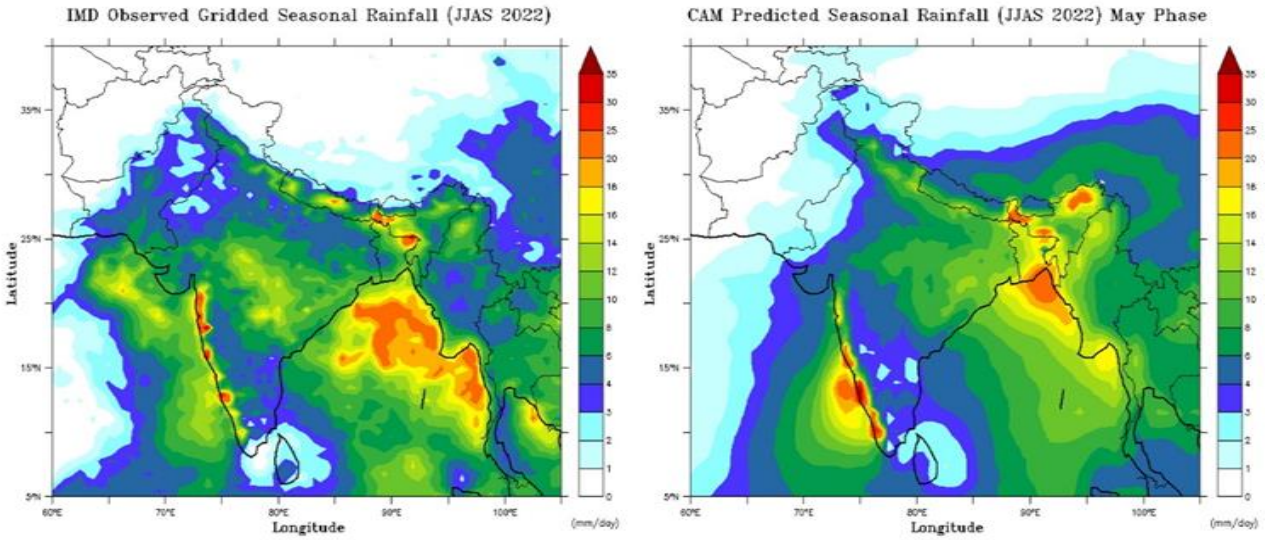
10.1. Research Areas in the field of Atmospheric Sciences

Atmospheric science is the study of the Earth's atmosphere and its various interacting physical processes. Atmospheric dynamics in particular is the study of motion systems of meteorological importance, integrating observations at various spatiotemporal scales. It includes diverse phenomena such as thunderstorms, monsoon, tropical cyclones, and global-scale circulations. The objectives of such studies incorporate improving weather forecasting, developing methods for predicting seasonal and inter-annual climate fluctuations, and understanding the implications of human-induced changes on the global climate.

Important research areas and challenges involved in ongoing program is as follows.

10.1.1. Seasonal Prediction of Indian Summer Monsoon rainfall (ISMR) using Climate Model

The Indian summer monsoon (ISM) occurring every year from June through September, is one of the most dominant features of the global hydrological cycle. It causes more than 75% of annual rainfall over the country during this period. Although, the onset of the monsoon over Kerala in India takes place at the start of June with the seasonal reversal of wind over the Arabian Sea with a consistent manner from year after year, the seasonal prediction of ISMR during the recent times become more and more challenging. It is mainly due to several external factors both natural and manmade viz. the fast changing climate, the manmade changes in land-use-land-cover, The fast growing infrastructure development activities in large scale over a landmass that significantly modify the respective land surface properties, heat and water budget, composition of atmospheric gases, aerosols etc. One of the biggest challenge is to model these changes and incorporate the impact of them in medium to long-term model prediction.



Therefore, there is a recognized need to demonstrate the state-of-art seasonal prediction of ISMR describing both the spatial and temporal variability of rainfall in conjunction with the satellite and in-situ observations. A seasonal prediction system has been setup at Space Applications Centre (SAC) Ahmedabad in research and operational mode. The experimental prediction of ISMR has been generated through 50-member ensemble CAM model simulation during April every year and updated monthly till September. Each ensemble member has been started with different initial conditions and sea-surface boundary conditions. End of season (EOS) validation has been conducted every year to measure the model prediction skill and to identify the shortcomings and lacuna of the prediction system. It is a continuous evolving process of the prediction system to improve its skill of prediction year after year.

10.1.2. Impact of Atmospheric Chemistry on Weather Prediction

Atmospheric aerosols have a large influence on air quality and, also in the well-being of human and ecosystem. Aerosols affect the earth-atmosphere radiation budget directly by scattering and absorbing the incoming solar radiation and indirectly by influencing the processes of formation of clouds and precipitation. Assimilation of satellite derived aerosols and other chemical constituents in NWP along with the chemical transport modelling have been planned (Figure). The impact of chemical data assimilation on mesoscale weather prediction will be also studied.

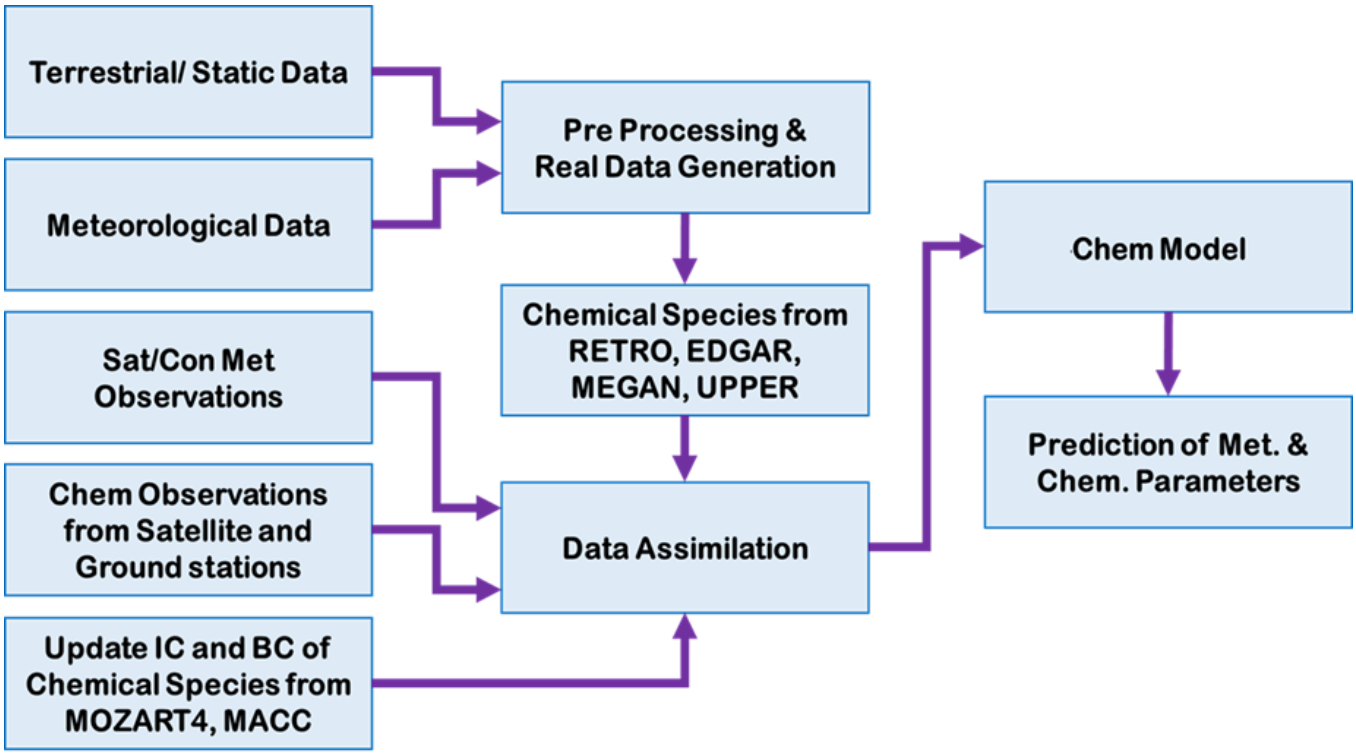


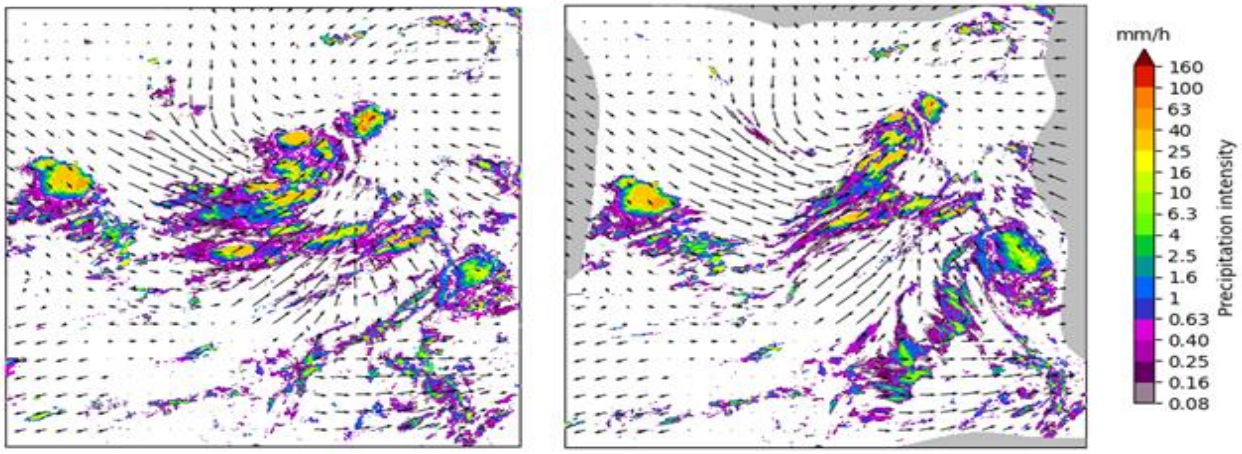
Figure. Design of Study

10.1.3. Assimilation of Satellite Data in Numerical Weather Prediction Models

Accurate prediction of high-impact weather events and the area of the greatest threat represent a major challenge for planners to minimize the loss of lives and damage to property. Advance research is being planned to carry out non-linear data assimilation of satellite measurements in the numerical weather prediction (NWP) models. ISRO is aiming at improving short-range weather forecasting using satellite observations. For this activity various satellite observations are ingested in the NWP model using advance data assimilation techniques. In addition, research is also focused to improve NWP prediction using combination of Data Assimilation and Machine Learning methods

10.1.4. Satellite and radar based weather nowcasting

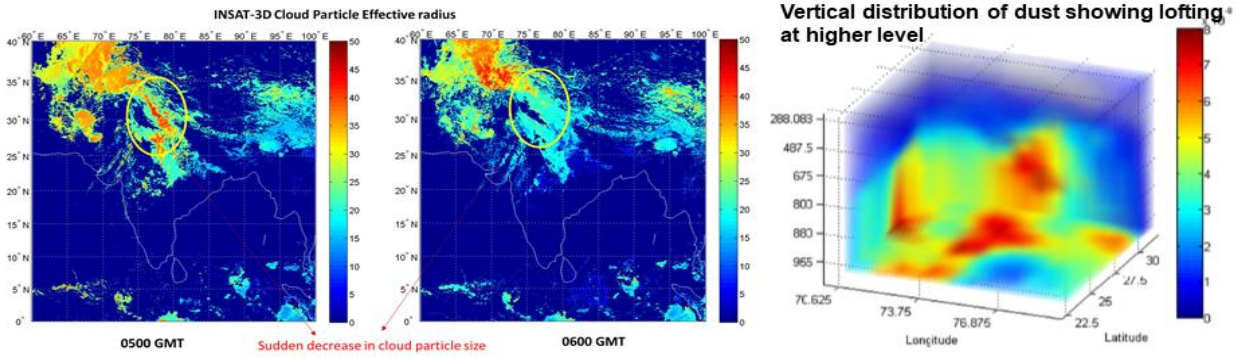
Satellite and radar data is being used for development of algorithms for nowcasting and tracking of cloud and precipitating systems. INSAT-3D/3DR data is extensively used for monitoring cloud growth and also for predicting the flow fields associated with precipitating systems. The research outputs feeds into the operational nowcasting application hosted on the MOSDAC webportal for societal benefit. In conjunction, Doppler weather radar (DWR) data is also used for developing algorithms to track and predict the movement of convective systems. Polarimeteric radar has also been used to develop Hydrometeor classification algorithm for more potential lightning prediction. Furthermore advanced AI/ML are been experimented on, for better accuracy and longer lead time. In near future blending of data / model outputs from different sources is future.

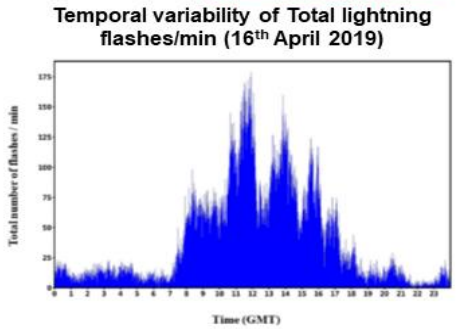


Optical Flow using LK **1 Hour Nowcast**

10.1.5. Satellite based Cloud Microphysical applications

Data from multitude of satellite sensors are used to derive information about cloud microphysical parameters. The study of cloud processes in microscale is also carried out to improve our understanding of many meteorological phenomena like monsoonal active and break phases, tropical cyclone development, intrusion of dust into thunderstorm and its impacts. In addition, we are also experimenting on different schemes to generate a merged cloud microphysical product from optical sensors onboard different satellites.





- **Entrainment of dust acting as cloud condensation nuclei as well as ice nuclei induced a favourable condition for charge separation.**
- **A dust-boosting feedback loop was set up due to the prevailing intense WD which further accelerated the electrification process and led to catastrophic lightning.**

Did dust intrusion and lofting escalate the catastrophic widespread lightning on 16th April 2019, India? , 2022 Atmospheric Research, https://doi.org/10.1016/j.atmosres.2021.105933

10.1.6. Cyclone Track and Intensity Prediction Using Satellite Data and Numerical Models

Advance and accurate prediction of tropical cyclones is highly important for issuing the warnings and saving the lives. Real-time winds obtained from scatterometer (SCATSAT-1) are used for

tropical cyclogenesis predictions of all the low-pressure systems formed in the North Indian Ocean. The cyclone track and intensity prediction is being done using numerical models and satellite data that involves empirical and dynamic modelling and assimilation techniques. The cyclone centric satellite products are generated, which are very useful for cyclone positioning and its structure and intensity estimation.

10.2. Research Areas in the field of Physical Oceanography (Development of Blue Economy)

Physical oceanography research at the Space Applications Centre aims towards making use of current and future satellite observations in combination with in situ and numerical models to provide a holistic approach and to develop new techniques, novel modelling concepts, advanced data assimilation schemes, usage of very high-resolution satellite data for the wider areas of applications like monitoring and forecasting oceans for safe navigation, productivity and climate/long-term change impact in and around the Indian Ocean. These dedicated research activities would finally serve towards the sustainable development of the ocean based Blue Economy: an economy model that aim towards shifting society from scarcity to abundance with locally available resource. (Figure-9.2.1)

10.2.1. Assimilation of Satellite/In Situ Data in Numerical Ocean Prediction Models: Observation System Studies Experiment (OSSE)

Assimilation of Satellite/In Situ Data in Numerical Ocean Prediction Models: Observation System Studies Experiment (OSSE)

Advance research is being carried out for assimilation of satellite derived parameters salinity, temperature, sea level, wave height, ocean color and wave spectrum) in ocean prediction models. This involves development of various assimilation techniques for improving the initial condition in the models. Apart from satellite data, lot of in situ measurements (glider, HF Radar, wave rider buoys etc.) are also being taken in the present. The outputs from these models are routinely available on the mosdac.gov.in through the "Ocean Eye" and disseminated on request through an automatized email based system.

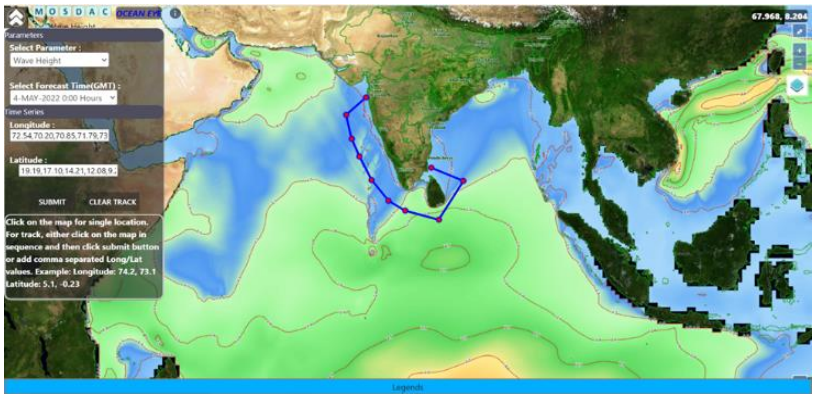


Figure 9.2.1: Snapshot of Ocean Eye web portal displaying the forecast map of significant wave height for a particular day. Blue lines indicate the track od ship, which can be overlaid using tools provided in the ocean eye web portal.

In order to identify gap areas in the current space based observing systems, observing system simulation experiments are performed for defining future sensor missions. This require intensive modelling and optimization techniques to ascertain the importance of satellite-based and in situ-based observations and to suggest optimum sensor characteristic. Model tuning by parameter estimation using data driven techniques (like AI/ML) can be an important step in improving the model simulations

10.2.2. High Resolution Oceanography

In the view of high resolution (temporal and spatial) satellite observations from synthetic aperture radar, forthcoming Oceansat-3, Surface Water and Ocean Topography mission (SWOT) mission, and optical imageries, high resolution oceanography is fast becoming a reality. Synergistic use of these information will be key to understanding many unresolved processes at sub-mesoscale level, which can help in better ocean estimation. Interaction of mesoscale scale dynamics (eddies) with sub-mesoscale is another interesting area of research for energy cascading. Region specific high resolution models with relocatable grids are being utilized for this purpose.

Procedures are under development to correct for the currents in high resolution models by means of high resolution image assimilation techniques (Fig-9.2.2)

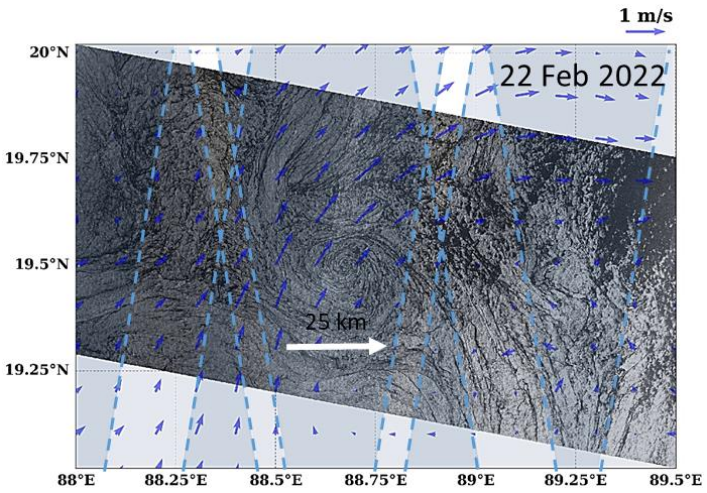


Figure 9.2.2 An example of high resolution of high resolution eddy field from SAR which will be used to correct high resolution model generated currents (overlaid in blue vectors), in which the eddy is displaced by around 50km

10.2.3. Ocean Reanalysis and Air Sea Interaction Studies

One of the future goals is to develop a methodology to generate high quality three dimensional ocean reanalysis product for last 30 years based on satellite observations and numerical ocean model. This will be utilized not only for various oceanic process studies but also to initialize seasonal prediction coupled models. Some of the reanalysis fields that are currently being generated are of sea level, currents and chlorophyll.

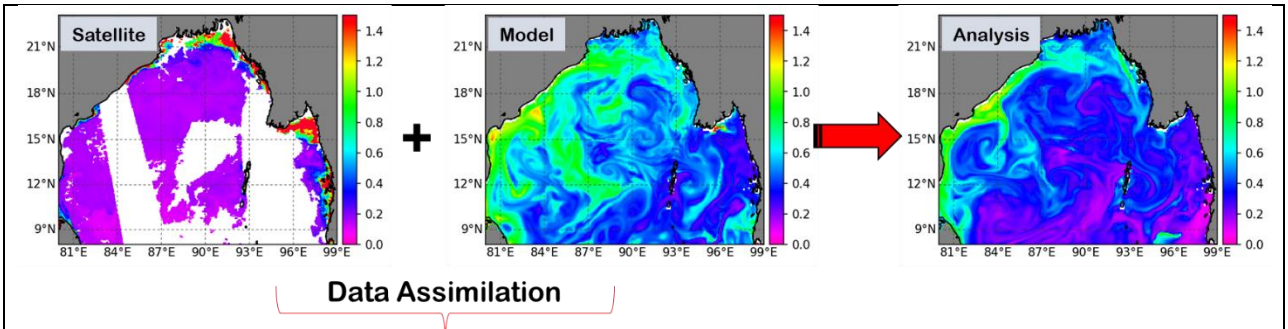


Figure 9.2.3. Generation of high resolution chlorophyll analysis using a combination of numerical model, satellite data and data assimilation technique

Research is also being carried out in generating merged products (like for e.g. SST) by combining observations from various Indian and International missions in order to provide continuous and gridded space-time observations for various applications and process studies.
Efforts are also being carried out to generate high resolution salinity field from low resolution satellite observations using Lagrangian based techniques. These fields will be useful for fine scale process studies.

10.2.4. Study on Coastal dynamics Using Satellite and High Resolution Numerical Models

Coastal dynamics are extremely important to understand as it has significant implications on coastal population. Currently following research topics are being envisaged in SAC:

1. Storm surge and coastal inundation: In this component, numerical models and satellite data are used to simulate and forecast the storm surge and inundation along the Indian coasts during the event of cyclone. Impact of satellite derived winds is also studied. This activity will be further extended to generate vulnerability maps for Indian coasts due to storm surge inundation in the climate change scenario.

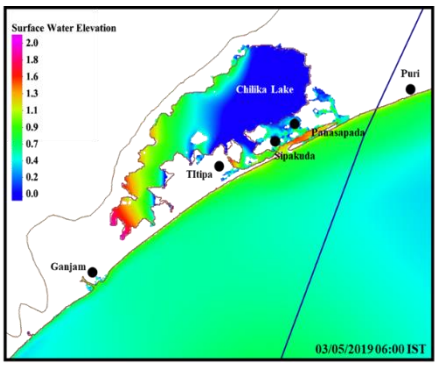


Figure 9.3.4 Coastal Inundation during TITLI Cyclone.

2. Oil spill trajectory forecasting is extremely important for planning the mitigation steps in order to minimize the damage to the marine ecosystem due to an event of oil spill. Advection based models have been developed in house in order to identify the source of tar balls found on the beaches of various Indian coasts. Further research with high resolution satellite currents (from combination of SWOT and Oceansat-3) and introducing complexities in the trajectory models is being carried out. Finite time Lyapunov exponent (FTLE) fields derived from satellite currents are available on MOSDAC that help to forecast pathways of oil spill.

10.2.5. Seasonal Ocean Prediction with Coupled Atmosphere-Ocean Models

Forecast of anomalous oceanic conditions (Dipole/El Nino) at least one season in advance is of high importance as it has direct influence on the Indian Summer Monsoon. These seasonal to long term forecasts are required to be done by making synergistic use of satellite observations and couple Ocean Atmosphere models. Effect of satellite data assimilation on the skills of these forecasts are also required to be assessed.

Regional Sea level rise is analyzed from the 36 years of altimeter observations and the mechanisms responsible for difference in Service-level Agreement (SLA) rise rates in different basins (Arabian Sea and Bay of Bengal) are being studied. One of the major challenges is the coastal sea level rise, for which the only source of observations are the tide gauge stations because of the non-availability of altimeter data near to the coast. Hence it is required to develop AI/ML based/dynamical techniques for interpolating/downscaling sea level observations from altimeter to the coastal regions by making use of numerical models and tide gauge stations.

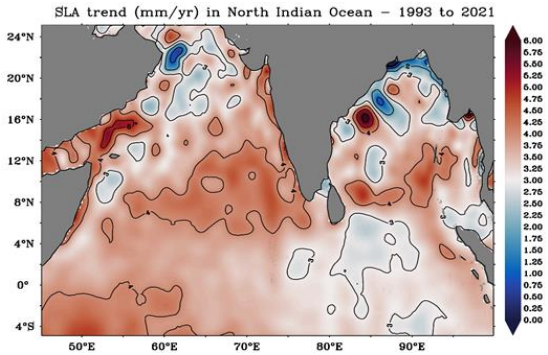


Figure 9.2.5 Regional sea level trend using altimeter observations from 1993-2021

This is an important activity which will further help in identification of vulnerable zones in the climate change scenario.

10.3. Research Areas in the field of Geophysical Parameter Retrievals

Retrieval of geophysical parameters from satellite observations refers to assessment of surface and atmospheric parameters that have contributed to the observations. Innovation, accuracy, and timeliness are the key requirements for the parameter retrieval, particularly for their effective use in the operational services. Continuous efforts are needed to define new sensors for future missions, develop retrieval algorithms for new parameters from existing sensors and from advanced sensors proposed for the future.

10.3.1. Retrieval of Geophysical Parameters from Satellite Data

ISRO has planned for launching a number of meteorological and oceanographic satellites in near future. Presently it has INSAT-3D/3DR satellites in the orbit. In near future, it has plan to launch many satellites in Geostationary and polar orbits for the same such as Oceansat-3 and INSAT-3DS. This also includes many advanced sensors such as Microwave Temperature Sounding Unit (TSU) and Humidity Sounding Unit (HSU) in future missions. There is also possibility of inclusion of an advanced microwave radiometer similar to GPM Microwave Imager (GMI) in future missions. Future generation of INSAT satellite may also have advanced imager, lightning imager and hyperspectral sounder on-board. It is a challenging work to retrieve geophysical parameters from the sensor data of these satellites. This involves Radiative Transfer modelling, Geophysical Model Function development and the Inverse modeling techniques.

10.3.2. IRNSS/GNSS Applications

IRNSS/GNSS offers unique opportunity to retrieve atmospheric geophysical parameters such as TPW. ISRO may also develop satellite-borne receivers for IRNSS/GNSS reflectometry, which has potential to provide various surface parameters including sea surface height, intense sea surface wind speed and direction under severe weather conditions, soil moisture, ice and snow thickness, etc. Theoretical modelling and simulations of the reflectometry observations is desired for the retrieval of the parameters. Until IRNSS receivers are not available, International missions such as TDS-1 and Cyclone Global Navigation Satellite System (CYGNSS) can be used to validate the simulation studies and retrieval algorithms.

10.3.3. Merged Data Products

Develop data fusion methods to derive most optimized products using a synergy of observations. The examples are (a) Optimized temperature/humidity profiles using IR and microwave sounders (b) Optimized SST and rainfall products from IR and Microwave imagers.

10.3.4. Advanced System Studies for New Sensor Definition

For measurements of atmospheric and Oceanic parameters, new advance sensors have to be defined for future satellites. System studies are being done with the help of Radiative transfer models to define the appropriate frequency, NEDT/SNR and bandwidth of new sensors. Sensitivity analysis is also being carried out to understand the error budget and appropriate resolutions (both spatial and temporal) required for the retrieval of geophysical parameter.

10.3.5. Development of Procedures for Long Term Records of Essential Climate Variables

Long term records of essential climate variables such as SST, wind, radiation budget, water vapour, clouds, ozone, precipitation, sea surface salinity, sea level, sea state, etc., which are defined by Global Climate Observing System (GCOS), are necessary for characterising the trends in earth's climatic variations. Measurements from different satellite instruments suffer from different accuracies and biases due to

evolution/performance of the instruments and/or retrieval algorithms. Thus there is need to intercalibrate the instruments/parameters to reduce the measurement biases among them.

10.3.6. Other Research Areas related to Parameter Retrieval

- Cloud/Rain type classification using INSAT/Kalpana observations.
- Study of cloud micro physics using 157 GHz of MADRAS and INSAT data
- Combination of INSAT-3D Imager and Sounder products to improve the quality of a few critical atmospheric products, such as atmospheric stability, total WV contents, SST etc.
- Improved tracer selection, tracking and height assignment methods for Atmospheric Motion Vectors (AMV) retrieval from VIS, MIR, WV, TIR1 channels.
- Retrieval of high-resolution winds is a challenging research area that may be attempted with Geo imagine Satellite (GISAT) satellite.

10.4. Research Areas in the field of Hydrology

Hydrology is the science that deals with the occurrence, distribution, movement and properties of the waters on earth and their relationship with the environment within each phase of the hydrologic cycle. Land hydrology aims to develop techniques to retrieve hydrological parameters from satellite data and develop hydrological models to simulate and forecast various hydrological fluxes to solve water-related problems and manage it efficiently. Currently studies are being conducted under SARITA program towards development of water watch system to monitor quantity and quality of water resources in India. Important research areas and challenges involved in ongoing program is as follows.

10.4.1. Automatic detection of wetlands for National wetland Inventory and Assessment

Regular Wetland inventory at national scale is important activity required by Ministry of Forest Environment and Climate Change. This involve development of automatic algorithm to delineate wetland and its type based on advanced techniques such as Deep learning/ machine learning etc.

10.4.2. Groundwater Assessment

Assessment of ground water potential zone and its dynamics is important to regional water resource planning. There is need to develop hydrological model incorporating aquifer properties to simulate the infiltration and ground water variations in different hydrological regime. It is required to develop tools to relate the groundwater fluctuations with GRACE water equivalent height information, existing surface water components and groundwater recharge and abstraction scenario.

10.4.3. Flood Inundation modeling and Forecast

Extreme events are increasing due to global warming and it results in frequent floods in many rivers and urban areas. Satellite data helps in delineation of flood prone region but due to limitations of revisit period there are some gaps in observations. There is need to develop flood inundation modeling system using meteorological data, high resolution DEM and historical records of flood conditions for major flood region of India. Efforts are required to have weather forecasting coupled hydrological system (WRF HYDRO) for forecasting river discharge and water inundation of India.

10.4.4. Water Level and Discharge Modeling

Monitoring Water level from space platform is important to augment existing ground network in remote and inaccessible regions including Trans-boundary rivers. There is need to develop advanced approach to estimate water level from Nadir Microwave as well as LIDAR based altimeters. Estimation of water

velocity and discharge is challenge from remote sensing. Methods need to be developed to address Swath altimetry which consists of nadir altimeter as well as two SAR system working in interferometric mode (SWOT) to assess water height and inundation volumes simultaneously.

10.4.5. Water quality Assessment

Hyperspectral remote sensing is known to have potential to estimate some of the water quality parameters of river and reservoirs. It involves development of radiative transfer modeling and simulations. There is need to develop method and carryout model simulations to assess the water quality issues of important rivers like Ganga and Yamuna.

10.4.6. Isotope Hydrology

Partitioning Evaporation and Transpiration in terrestrial vegetation is a concern. Hyperfine spectroscopy provides information on isotopic composition of water molecules. There is need to develop methods to estimate the evaporation and transpiration components of major forest ecosystem as such measurements help in more accurate assessment of water cycle and Land surface processes.

10.4.7. Submarine Ground Water Discharge (SGD)

Quantification of water flow into ocean through sub marine ground water discharge is a challenge for Indian coast. Thermal remote sensing data provide initial signals of SGD in coastal region. There is need to explore the regions of SGD in Indian coast and model the discharge of water into the ocean.

10.4.8. Integrated quantitative understanding of the change in water cycle due to anthropogenic activities;

How surface and ground water availability is changing in space and time along with science of changing water cycle which is accelerating/decelerating will be studied.

10.4.9. Hyperfine hydrological modelling to address the social hydrology involving local drivers of change.

Hydrological modelling at high spatial resolution by ingesting detailed local information as well as climate projection to fulfill the societal needs.

10.5. Research Areas in the field of Cryosphere Sciences

Remote sensing science and applications of Cryosphere at SAC has mainly focused on two regions, i.e. Hindu-Kush-Himalayan (HKH) mountainous region of Northern part of Indian sub-continent and polar areas on Earth. Cryosphere of HKH region consists of snowpack (both seasonal and permanent), varieties of glaciers in terms of type and size and permafrost. Inventory, monitoring and applications of cryosphere elements of HKH region is must for the nation as water resources of northern India largely depend on freshwater melt discharge from snow and glaciers from large drainage basins of Indus, Ganga and Brahmaputra (IGB) rivers of earth surface. Occurrence of hazards such as Avalanches and Glacial Lake Outbursts Flood (GLOFs) are also associated with high altitude region. Polar cryosphere mainly consists of ice sheets and sea ice including snow over these two cryospheric elements. Mapping, monitoring, modelling and science of polar cryosphere elements in the Antarctic and Arctic regions is equally important for the nation as large areas of sea ice and ice sheets govern energy exchange processes between ice surface and atmosphere and melt from these elements contribute to global sea level. Although a large

amount of applications using earth observation data acquired by Indian and other sensors has been carried out to study various dimensions of cryosphere in the last two and half decades but still a lot needs to be done at present and in future. Keeping in view the needs of nation and international research, following are the activities and challenging research areas in the mountain and polar cryospheric regions.

10.5.1. Himalayan snow

SAC has been generating sub-basin wise snow cover products database using Advanced Wide Field Sensor (AWiFS) data since 2004 in the Himalayan region. These products are the best available time series snow cover products having fine spatial and temporal resolution so far in the world. INSAT-3D/R provides daily snow cover products at India Meteorological Department (IMD) from geostationary platform. Snow products have been used in snow melt runoff estimations, in understanding of accumulation and ablation pattern of snow in different climatic zones of HKH region, and in assessing the snow cover trends to ever-changing climate. However, there are important challenging areas where research is needed to address cryosphere studies. These are estimation of annual seasonal snow mass using photogrammetric/interferometric and scattering mechanism using PolSAR data. Snow parameter retrieval using SAR/Hyperspectrl data, Radiative transfer modelling and role of snow parameters in climate model will be helpful to understand the impact of climate on Himalayan mountains. Disaster applications such as Avalanche, GLOF etc. are other crucial areas of research. Development of snow-melt runoff at high altitude area, suitable site selection for micro hydroelectric projects using geospatial modelling and real time assessment of discharge for Indian rivers using satellite data are important in the field of surface hydrology

10.5.2. Himalayan glaciers

Inventory and monitoring of Himalayan glaciers within periphery of IGB basins has been a foremost requirement of our nation to know the stock of glacier stored water, and variations in dimensions of glaciers as an impact of climatic variations. SAC has carried out extensive work in this direction using data from Indian sensors such as AWiFS, LISS III and LISS IV of Resourcesat series satellite. The glacier inventory in IGB basins is available at VEDAS portal of SAC for visualization. However, automatization of glacier feature extraction and change detection from space platform in Himalayan region are the research areas to be addressed. Glacier mass balance is important to assess the status of their current response to climate change, and requires improvement in estimates to minimize the uncertainty. Major research domain in mountain glacier region includes geodetic mass balance estimation with field validation at sub-basin scale using Carto-1 images, improvement in Accumulation Area Ratio (AAR) and Mass Balance relationship in HKH region, retrieval of ice velocity and facies using SAR/PolSAR data, understanding the glacier dynamics, Regional Climate model and impact assessment on cryospheric elements in different scenarios.

10.5.3. Himalayan Permafrost

The permafrost is very important element of Cryosphere studies. The distribution and changes occurring at permafrost in the mountainous HKH region as a result of climatic variations needs to be known in view its importance to ecology and land cover changes. Exploration of Permafrost might give new insights to high altitude environmental changes through optical, thermal and active microwave data. Estimation of permafrost zonation, geomorphological signatures, degradation, and interaction with SAR/PolSAR data are essential to understand the dynamics of permafrost in high altitudes of HKH region to assess the impact of climate change.

10.5.4. Polar ice sheets

One of the most challenging research area in polar ice sheets is estimation of ice sheet mass balance and resulting sea level rise. State of art techniques, development of algorithms utilizing SARAL/AltiKa data and analysis of results have been demonstrated at SAC through various studies. It needs to be expanded further by using globally available LASER/RADAR altimetry datasets. Another important research area is to investigate the dynamics of polar ice sheets using optical, SAR data along with incorporating numerical Ice sheet modelling. Development of techniques to automatize monitoring of ice shelves margin and calving events, to access the impact of various surface melt processes on the polar ice dynamics and exchange of surface energy fluxes are another important activities in polar ice sheet studies.

10.5.5. Polar sea ice

One of the major contribution of SAC in polar ice studies is extraction of sea ice area from ISRO's Scaterrometers data and understanding its spatial-temporal variability. Technique development has been demonstrated to measure sea ice thickness using data from SARAL/AltiKa. It needs to be a continuing activity by using other globally available LASER/RADAR altimetry datasets to enrich and analyse long-term trend in sea ice thickness. More research is required to address sea ice drift estimation, sea ice albedo & energy exchange processes and understanding the oceanic and atmospheric driving factors for global sea ice variability. Automatic techniques using multi-sensor approach along with iceberg detection and tracking are needed for improving sea ice advisories required for safer ship navigation during Indian Scientific Expedition to Antarctica.

10.6. Research Areas in the field of Geosciences

Geosciences deals with study of the earth and encompasses geology, geophysics, geodesy, geochemistry and environmental geosciences. SAC is currently involved in carrying out research related to study of earth surface and geodynamic processes for developing applications related to early warning of geohazards, sustainable coastal zone management, geo-resources and geo-archaeological exploration using space technology and geo-informatics. Following are the major research areas:

10.6.1. Geo hazards

It is required to develop techniques for early warning of geo-hazards using space technology and geoinformatics. In this context, one of the most challenging research area is to understand mechanism of earthquake triggering geodynamic processes. Study of geodynamic processes using advanced space based techniques is required to understand regional seismic hazard vulnerability in regions like the Himalayas and active seismic zones in peninsular India. Research related to quantification of the active tectonic deformation, modelling inter-seismic slip and strain rate and estimating moment-build up rate from geodetic, seismological and paleo-seismic data is required. Inter-seismic deformation measurement from space geodesy, their analysis and advanced modelling techniques are required to be developed. Study of land subsidence due to over exploitation of ground water, coal, hydrocarbons and crustal deformation associated with volcanos and slow-moving landslides using geodetic measurements for hazard assessment is another potential research area.

10.6.2. Marine Geosciences

Offshore exploration using satellite altimetry is a major research area. Altimeter derived geoid undulation and free-air gravity anomalies over Indian Ocean needs to be utilised to understand plate tectonic processes relating to oceanic ridges, subduction zones, formation of marine sedimentary basins and the

evolution of continental margins. There is a need to improve the marine geoid and gravity data by including high precision altimeter data in geodetic mode for detailed work. The structural frame work of the Indian Ocean is quite complex with numerous fracture zones, abandoned spreading centers, aseismic ridges, seamounts and subduction zone. The Indian Ocean lithosphere is constantly under stress due to spreading activity south of it, resulting in fractures and intense deformation in this region. The thick sediment deposits in the Bay of Bengal mask the underlying crust and pose severe restrictions in constructing the geodynamical history of the basin. Splitting the geoid data into different wavelengths and correlating them with geology/tectonics and also their modeling may help to better understand structure and dynamics of the Indian Ocean lithosphere and may also help in offshore hydrocarbon exploration.

10.6.3. Coastal Geosciences

Coastal zones are the interface between land and ocean and are dynamic fragile ecosystem, where interaction among complex natural coastal processes, coastal hazards, vital habitats and human activities occur and integrated studies for sustainable coastal zone management are required for protecting life, property and environment. Some of the major coastal geoscience research area includes coastal sediment transport modelling using satellite retrieved parameters, understanding coastal processes and causes of coastal erosion, dynamics of various coastal processes and its impact on evolution of coastal geomorphology, modeling coastal erosion and developing methods to predict shoreline changes, use of advanced automated methods to delineate shoreline (high Threshold Logic (HTL)/ Less than Truckload (LTL)) from satellite data, understanding impact of coastal processes on critical/vital habitats, understanding impact of predicted sea level rise on coastal zone, understanding coastal hazards and vulnerability/risk assessment, developing techniques for automated coastal landforms/wetlands/land use/land cover mapping, detecting and monitoring coastal pollution, understanding impact on coastal ecosystem and developing models for integrated coastal zone management.

10.6.4. Mineral Exploration

Although large part of the country has been conventionally surveyed and location of most of the economic mineral deposits have been investigated in detail, still new mineral deposits needs to be explored to meet ever-increasing demand of the industries. Mineral exploration using conventional techniques involve geological mapping followed by geophysical and geochemical investigations, pitting, trenching, exploratory drilling, estimating reserves etc. Remote sensing based methods have been so far limited to updating the existing geological/structural maps and in identifying hydrothermal alteration zones as a useful guide. Alteration halo is much more widespread of rocks surrounding a mineral deposit that are caused by solutions that formed the deposit. Research is required to explore integrated use of multispectral, hyperspectral, thermal and radar data along with high resolution DEM (space-borne as well aerial), geochemical and geophysical data sets in diverse geological and environmental settings to identify and map new mineral prognostic zones. Methods for automated mapping of minerals associated with alteration zones, development of spectral-geochemical relationship using spectral and geochemical datasets need to be developed.

10.6.5. Geo-Archaeology

Space based geo-archaeological exploration along with geo-spatial tools is one of the most fascinating geoscience application. It involves interpretation of multi-sensor satellite data to explore new archaeological sites, understand development, preservation and destruction of archaeological sites in context of regional scale environmental changes, evolution of physical landscape and impact of human groups by applying concepts and methods of geosciences (especially geology, geomorphology, hydrology,

sedimentology, pedology and exploration geophysics). Research is required to develop methods/approach to explore archaeological sites using multi-sensor satellite data (Radar and high resolution multispectral data in particular) in conjunction with geospatial database of known archaeological sites. It is required to understand impact of neo-tectonic activities and palaeo-climatic changes on evolution of ancient civilisations.

10.6.6. Environmental Geosciences

Desertification and land degradation constitutes one of the most alarming geo-environmental global problem affecting two third countries of the world on which one billion people live (one sixth of world's population). Land degradation is reduction or loss of productive land due to natural processes, climate change and human activities. Desertification is land degradation in arid, semi-arid and dry sub-humid areas (also known as Drylands). The processes of desertification and land degradation are observed to have accelerated during recent years globally. There is a need to stop and reverse the process of desertification and land degradation. It is required to develop advanced digital classification techniques using object based approaches, machine learning/artificial neural network for automated land degradation mapping using multi-temporal and multi-sensor satellite data, vulnerability and risk assessment and developing action plans to combat land degradation.

10.7. Research Areas in the field of Geospatial Data and Information Science

Development in space technology and associated launch of advanced satellites has started an operational era of theme specific satellites providing applications specific images with quick revisit and wide swath.

Global collaborations and data sharing are playing key role in optimal utilization of space data in effective and efficient ways. Both optical and microwave remote sensing are playing complimentary roles and providing operational solutions globally through remote sensing. Geospatial and Information science is key emerging area, which has potential to explore existing and long term satellite data to derive new information, data products and develop new advanced applications. Meteorology and Oceanography Data Archival Centre (MOSDAC) is a data centre of Space applications Centre (SAC) and has facility for satellite data reception, processing, analysis and dissemination.

MOSDAC is operationally supplying earth observation data from Indian meteorological and oceanography satellites, to cater to national research requirements. The vast amount of data available in MOSDAC provides scope of carrying out research in the field of geo-spatial data and information processing. Themes under which Research is solicited under RESPOND

10.7.1. Advanced Data and Computing Architecture

- Optimized Data Cubes for multi-dimensional aggregation of satellite images and their spatiotemporal analysis.
- Techniques for forecasting and in-painting in Data Cubes
- High Performance Computing of satellite images on Cloud

10.7.2. Data Visualisation and Web Processing

- Advanced data rendering and fast visualization techniques of 2D and 3D satellite data.
- Fast Tiling and caching techniques for visualization of satellite Images
- Development of techniques for automatic on-demand web mashup generation.
- Cloud and Semantic enabling of Web Processing Services.

10.7.3. Data Security and Information Dissemination

- Data encryption and compression techniques for multicasting of satellite data
- Customization and optimization of multi-cast protocol using critical distance of client nodes to cater to requirements of real-time data dissemination.
- Content based data multicasting
- Information and Data security models for small devices
- Location aware satellite data dissemination for mobile devices

10.7.4. Data Mining and Web Analytics

- Real time analytics for Big Earth Data
- Pattern recognition based techniques for Event detection
- Geospatial feature extraction using deep learning techniques
- Automated event tracking (Cyclone, dust storm, etc.) using machine learning techniques
- Region growing algorithms for identification and tracking of meteorological and oceanographic events (Fog, bloom, convective initiation, etc.)

10.7.5. Data and Information Lifecycle Management

- Automated algorithms for value evaluation of data and information
- Techniques for automatic Quality checking of data
- Techniques for Persistent identifier management
- Techniques for generation of Linked data
- Faceted search and Browsing of satellite images
- Semantic annotation and labelling of satellite images

10.7.6. IoT and Sensor Network

- IoT enabled sensor network for acquisition of weather data
- Smart weather data acquisition systems
- RTOS based Data acquisition system
- Virtual Sensors for Weather data acquisition
- Optimal data capture and processing in Sensor Network

10.7.7. Virtualization and Cloud Computing

- High Performance Cloud for Satellite Image Processing
- Network Virtualization and Software Defined Network
- Software Defined Storage

10.8. Research Areas in the field of Visualization of Earth Data & Archival System (VEDAS)

To meet the user expectations of fast access to EO derived product for societal applications, there is a need to develop newer applications for better visualization and understanding of cause / effect of various covarying features. For that to happen, advanced tools and technologies have to be used in conjunction with improved algorithms and efficient analytics. Research and analysis of the following thrust areas by independent and expert researchers and academia will strengthen the impact of the work. It is expected that with such a handshake between data generators and potential analysts, newer and innovative ways

will emerge which will meaningfully bring about transformation in decision making for benefit of population of our country.

10.8.1. Algorithms / Procedures for Time Series Visualization

VEDAS is responsible for archival and dissemination of thematic data and data products available within SAC. Large amount of spatial time series data is collected over time and visualization of available spatiotemporal data is essential for exploring and understanding structures and patterns, and to identify unusual observations or hidden patterns. However, the volume of data available and number of concurrent users that may be accessing the data challenges current time series map visualisation. The start and end time of episodic events or span of intensive observations may also be dynamic. So algorithms are required to be developed and modern techniques are required to be used for visualization of large spatio-temporal (ST) datasets ordered in time for animated mapping. This will be further used for exploring or monitoring unusual observations in large datasets like NDVI, snow, temperature, solar insolation etc.

10.8.2. Data Analytics and Knowledge Discovery

To understand and appreciate a natural phenomenon and attach cause and effects to an evolution, there is a growing demand of rendering "on the fly" multi-layer information. There may be concurrent users accessing same set of data. So there is motivation to parallelize computation to improve turn around time of a service. The research initiatives will be useful steps towards achieving this goal. Design & Development of parallelizable algorithms for interactive geospatial data analysis with high temporal resolution. Design & Development of parallel execution frameworks and/or distributed computing libraries for geospatial data processing operations. Design and Development of scalable general purpose systems/algorithms for removing noise from spatiotemporal datasets. Design and Development of scalable general purpose systems/algorithms for predictive analytics from spatiotemporal datasets. Design and Development of data-mining algorithms for spatial-temporal datasets. Design and Development of scalable techniques for semantic segmentation of orthoimagery.

10.8.3. Super Resolution Image Generation

Super Resolution is an Image Processing technique which is used to enhance the image resolution of scene from a number of lower resolution images of same area by reducing effects of noise in the reconstructed image. In case of satellite images, this can be seen as a powerful tool of getting high resolution multispectral images (spatial) from low resolution panchromatic images. This will facilitate improved (in spatial scale) Land cover for better natural resource management.

10.8.4. Web Enabled Sensor System for Efficient Resource Management

There is need to develop a prototype and demonstrate the applicability of wealth of information that can be gathered by set of remotely located instruments. Instruments can measure the meteorological conditions as well as ambient conditions and transmit the data to a central hub. Air quality monitoring of a region is a one such example where measurements of PM2.5 and PM10, concentrations of target gases (NOx and SOx – for example), their dispersal (based on wind direction and speed), temperature and humidity are all required by administrators and managers to issue advisory and / or take pro-active preventive measures.

10.9. Research Areas in the field of Urban Studies

10.9.1. Urban Feature Extraction (Road Network Delineation)

Transportation networks such as roads and railway lines are important for several urban applications including disaster management, urban planning, impervious surface extraction, urban growth modelling etc. The automatic methods such as template matching, object-based classifiers and machine learning methods such as neural networks, support vector machines, deep learning etc. can be used to efficiently extract road network from very high-resolution optical and SAR images acquired by Indian Remote Sensing satellites.

10.9.2. Urban Feature Extraction (Impervious Surface / Urban Area Mapping)

The mapping of urban land cover remains a challenging task owing to the high spectral and spatial heterogeneity of urban environment. The accuracy of urban area extraction can be improved by combining multi-temporal, multiresolution and multi-sensor optical and SAR earth observation data.

10.9.3. Urban Feature Extraction (3D Building Reconstruction)

The 2D and 3D information of buildings and other urban structures are needed not only for impressive visualisation of urban areas, but also as an input in several urban applications like population estimation, roof-top solar energy potential assessment, visibility studies etc. Building extraction from high-resolution satellite images in urban areas is an intricate problem. Techniques are to be developed for automatic extraction of buildings from Very High Resolution optical data. The availability of very high-resolution imagery from Cartosat series data necessitates development of techniques and algorithms for 3D building reconstruction.

10.9.4. Urban Heat Island

Spatial and Temporal Distribution of Urban Heat Islands on Land Surface and Near Surface Atmosphere Development of models for deriving day-time and night-time air temperature from satellite-derived land surface temperature and vegetation indices can assist in identification and analysis of spatial and temporal distribution of urban heat islands.

Impact of Land Cover Types on Urban Heat Islands The changes in land use-land cover pattern and declining vegetation cover in cities are predominant factors influencing the growth of urban heat islands in the cities. Satellite data derived land use land cover information can be compared with the temperature profiles to assess the impact of land cover on urban heat islands.

10.10. Research Areas in the field of Calibration and Validation

The success of any satellite mission is depending on usefulness of sensor measurement and its derived geophysical products. This goal is achieved through theoretical and experimental procedures, which generally called post launch vicarious calibration methods. The error inducted due to uncertainty of sensors performance, atmospheric correction and retrieval algorithm on geo-physical products is quantified through the validation procedure using in-situ data sets. These techniques vary by depending on sensor type and derived geo-physical products. To achieve these major task, calibration sites are being identified specific to sensor, sensor and target specific calibration methodologies development, and calibration site identification, establishment of sites and its qualification to standards.

10.10.1. Optical sensor calibration

- The optical sensor calibration exercise is performed by vicarious (absolute), relative and inter-sensor calibration methods. The absolute calibration is performed through simulation of top-ofAtmosphere radiance for calibration gain and offset calculation. For this purpose we developed ocean site at Kavaratti and land site at Little Rann of Kutch (partially campaign). In each aspect of operational methods are based on R&D carried out here.
- The relative sensor calibration exercise for radiometric performance monitoring is performed through land, ocean, snow and deep convective cloud targets.
- The sensor performance is also cross verified with contemporary sensors using synchronous nadir pass and its measurements. These exercises is performed by normalizing the central wavelength and out off band contribution in case of optical sensors.
- Radiative modeling of satellite sensor measured radiance though ground truth measurements.
- Periodic monitoring and updating of radiometric performance of optical sensor through terrestrial surface radiance measurement and model simulation.
- Radiometric performance monitoring using moon, deep convective clouds, desert and ocean sites for optical sensors (both high and coarser resolution).

10.10.2. Microwave sensor calibration

- Synthetic Aperture Radar (SAR) radiometric calibration is one of the important aspects to characterize and maintain image quality throughout the mission and to provide stable, quantifiable image products to the users.
- Radiometric parameters of SAR sensors like sigma0, speckle index and radiometric resolution are monitored over invariant, distributed calibration targets like Amazon rainforest, Boreal forest, Antarctica for the data sets with same instrumental parameters (beam, polarization). This exercise is used to estimate noise equivalent sigma0 to ensure the data quality.
- Corner reflector based calibration is done to compute the impulse response parameters. A regular and systematic analysis helps to estimate the radiometric accuracy and stability using corner reflector based data.
- Monitoring of SAR instrument subsystem components is used to study gain variations or linearity.
- Generic software for estimation of calibration parameters using SAR images and orbital parameters over synchronized satellite pass with various Corner reflectors.
- A novel approach for Data quality evaluation of Scatterometer (OceanScat or upcoming mission ScatSat-1) is being worked out where one can relate the parameters available at different levels of product to geophysical parameters.
- Scatterometer calibration includes the monitoring of on-board calibration data to keep a check on transmitted power. Invariant sites like Amazon rainforest, Sahara Desert, Antarctic snow are required to be monitored regularly and time series of backscattered or brightness temperature can be generated to check the system behaviour.

10.10.3. Geo-physical products validation

- The most important exercise of validating sensor derived geo-physical products are done using community vetted matchup methodology and qualifying various data sets (in-situ, contemporary missions, climate data sets, data from various collaborative agencies, etc.)
- Protocol development on measurements, instrument operation, quality control, and calibration standards.

- Inter-comparison of rainfall estimates measurements made by various ground based instruments like Micro Rain Radar, Disdrometer and rain-gauges over a validation site.
- Optimization of disdrometer/ rain-gauges distribution and number for addressing beam filling problem in validation of satellite derived rainfall estimates.
- Satellite derived geo-physical products plays an important role in making effective use of satellite data by various user community. These activities are achieved through partnership of collaborative agencies, autonomous measurement systems (land, ocean) and also through special measurement campaigns.

10.11. Research Areas in the field of Hyperspectral Techniques Development

Hyperspectral remote sensing combines imaging and spectrometry. Most of Earth's surface materials contain characteristic absorption features which are very narrow in the spectral appearance, hence using high spectral resolution sensors called hyperspectral sensors, we can detect hundreds of very narrow, contiguous spectral bands throughout the visible, near-infrared, mid-infrared and thermal infrared portions of the electromagnetic spectrum. The very high spectral resolution facilitates fine discrimination between different targets and its inherent chemical compositional characteristics based on their spectral response in each of the narrow bands. Sophisticated and complex data analysis methods are required due to high dimensionality and size of the hyperspectral data, the spectral mixing and contamination in the measurement process such as noise and atmospheric effects. Therefore, we need to explore and develop advance hyperspectral data analysis techniques and tools, which may be organized in different themes: data fusion, unmixing, classification, target detection, physical parameter retrieval etc.

10.11.1. Machine learning models for Hx classification

The application of deep learning with hyperspectral images is less straightforward as compared to other optical datasets since hyperspectral datasets are represented by high dimensionality with high spectral resolution. Supervised classification faces challenges like the imbalance between high dimensionality and limited availability of training samples which often limits the depth of deep CNN networks. Another relevant aspect is to incorporate both spatial and contextual information in the classification process so as to take advantage from both the sources of information. The addition of the time domain to the learning model apart from contextual and spectral information adds an additional dimension to the input data making the learning process much more challenging. Following challenges are needed to be taken up;

- To explore Residual-3D-CNN, standard computer vision models such as LeNet-5, AlexNet, VGG, Darknet, Squeezenet to Hx classification with different learnable filters such as using 1D, 2D and 3D to see their effectiveness for remote sensing data classification.
- Another relevant challenge is to integrate spatial-contextual information in spectral- based classifiers for hyperspectral data to take advantage of the complementarities. For Example: 3D deep convolutional neural networks (CNN).
- The Challenge in Vegetation (multi-crop, forest species) classification now is learning temporal information from time series hyperspectral data. The addition of the time domain to the learning model apart from contextual and spectral information adds an additional dimension to the input data making the learning process much more challenging.
- Current research on simultaneous contextual information extraction and temporal information extraction can also be further explored by combining the concept of Convolutional and Recurrent neural Network (RNN) such as Convolutional Long Short-Term Memory (LSTM) or Convolutional

Gated Recurrent Unit (GRU) to the temporal image data. This can be very effective for time series data classification.

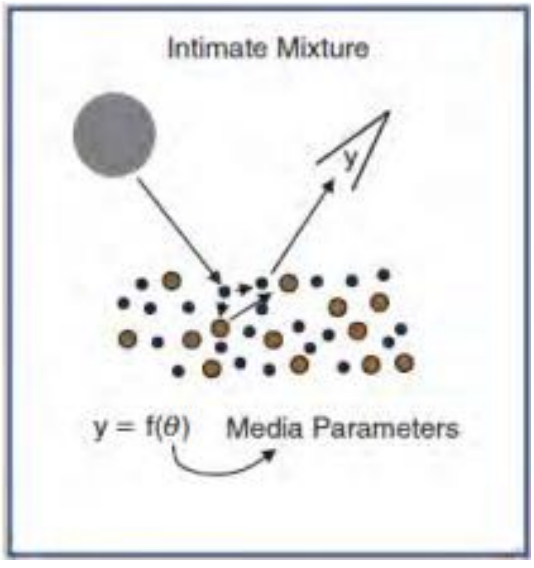
- Physics inspired Deep-Learning based Inversion models for geophysical parameter retrieval.

10.11.2. Challenges in Hyperspectral-Multispectral Data Fusion

There is a trade-off between Spatial Resolution and Spectral Resolution as can be seen in the case of Hyperspectral data and Multispectral data. In order to fully utilize the advantage from both the sensors like having data with both high spatial resolution and high spectral resolution data fusion is required. Another challenge is the introduction of noise in the dataset during the fusion process. Current methods often fail to address the issue of registration errors and are widely ignored thereby in the future comprehensive modelling and compensation of realistic noise and registration error can also be addressed.

- To explore hypersharpening based methods for denosing which are based on component substitution (CS) and multiresolution analysis (MRA).
- The unmixing based strategies such as Hyperspectral Image Superresolution via Subspace-Based Regularization (HySure) and CNMF (Coupled Non Negative Matrix Factorization) have great potential even when Spectral Response Function (SRF) has limited overlap.
- A possible future for further performance improvement lies in developing hybrid approaches that combine the advantages of different classes of methods such as MRA and Unmixing. Current Unmixing approaches rely mostly on the assumption of Linear Unmixing Model which can be further extended to Bi-linear or Non-Linear based models.
- VNIR-Hx and thermal-Hx data Fusion and Hyperspectral, LIDAR and SAR data fusion for precision agriculture, soil characteristics, forest biomass etc. studies. 9.11.3. Spectral Nonlinear Unmixing Spectral unmixing is the most important and challenging in hyperspectral imaging. It is known as blind source separation problem. The spectral unmixing problem includes two major tasks a) Identifying the pure pixels (materials) called endmembers b) Estimates their corresponding fractional quantities (abundance) presented in the mixed pixel. There is need to develop robust models for non-linear spectral unmixing where light typically interacts with more than one component as it is multiple scattered such as the case of minerals, soil grains etc.

A complete physics based approach to nonlinear unmixing would involve the inversion of the radiative transfer theory (RTT), which is an extremely complex ill-posed problem. Therefore we need to take up following challenges;



- To develop physics-inspired and sparse based non-linear un-mixing models.
- Real-Time robust spectral unmixing algorithm and tools
  (Which can be used in airborne or drone based sensor).
- Development of high performance / parallel computing model for spectral unmixing (Sparse unmixing models depend on spectral library which takes too much time).
- Dictionary Learning based Estimation and data recovery
  for sub-pixel classification of Hx data. For eg. soil property estimation from mixed pixels.

10.11.3. Aerosol retrievals, atmospheric corrections and air quality

Aerosol and atmospheric corrections involves following challenges;

- Aerosol and dust characterization.
- Atmospheric corrections of VNIR sensors is a challenge in absence of SWIR channels. In this direction, there is need to develop methods for AOD and surface reflectance retrieval for VNIR sensors such as AWiFS, Linear Imaging Self Scanning (LISS-III), Cartosat-2 etc.
- Mapping and analysing the patterns of ground level particulate matter (an important factor to determine the ground level Air-Quality) using satellite data and modelling. Development of models to estimate particulate matter using satellite data specifically for Indian atmosphere. The quantification of factors leading to harmfully high levels of particulate matter.

Challenges/Opportunities

- Requirement of hyperspectral CubeSat-constellation for high-temporal hyperspectral data
- Development of on-board Parallel/FPGA algorithm for real-time application of hyperspectral data.
- Simulation of synthetic hyperspectral data using Radiative Transfer and Ray tracing models.

10.12. Research Areas in the field of Microwave Techniques Development

Microwave remote sensing instruments, like Synthetic Aperture Radar (SAR), Scatterometer, Radiometer, Altimeter and Ground Penetration Radar (GPR), provide valuable inputs for geophysical parameter retrievals, monitoring and investigative studies. Though, data from these sensors is regularly processed using various retrieval algorithms, to cater to corresponding user applications, there is still a huge scope to develop and employ advanced techniques to fully exploit the data for maximum utilization. There is also requirement to simulate and demonstrate newer techniques, which will enable definition of future microwave sensors. With the above requirements in perspective, following are the potential areas of research:

- Development of techniques to simulate Geosynchronous Synthetic Aperture Radar (GeoSAR) data and its processing algorithms, to study geophysical parameters retrieval accuracies.
- Development of object/feature detection techniques using GPR and Wall-Penetration radars, and their performance evaluation.
- Development of processing methodologies for Rail-mounted Interferometric SAR system for landsubsidence monitoring; system development, demonstration of processing methodology and its performance evaluation
- Full-wave numerical Maxwell Model 3D simulations for microwave scattering from forests including detailed 3D modeling of forest canopy structure.
- Signal processing techniques for forest mapping using 3D-SAR Tomography and Higher dimensional SAR Tomography; applications of SAR tomography for forest mapping in plains and hill slopes.
- Tree height and structure mapping and species diversity mapping from LIDAR and fine resolution optical data.
- Classification and discrimination of vegetation types from time series vegetation profiles; Vegetation phenology mapping for assessing the vegetation characteristics for studying impact of climate.
- Long time series monitoring of crop sowing shifts and impact on the potential yield of crops.
- Detection of vegetation disturbance and generation of alert system; Dryland agriculture and yield gap analysis.
- Data Driven Techniques development for Daily Real Time Soil Moisture Estimates and Forecast using Deep Learning

- Development of techniques for root-zone soil moisture estimation
- Development of Polarimetric SAR models for Permafrost characterization in Himalayan regions
- PS- and DS-InSAR based algorithms for land-deformation estimation; Algorithms for Landslides damage assessment from SAR data; development of regular monitoring system with alert generation capability

10.13. Research Areas in the field of Marine Biology and Ecosystem

The last two decades has seen an increased use of ocean remote sensing data since it provides a synoptic view of Earth's marine ecosystem on spatial and temporal scales unattainable via in situ methods. Ocean colour data is used for mapping and monitoring essential climate variables like green microscopic algal biomass, total particulate matter, coloured dissolved organic matter etc. ISRO has a dedicated Ocean Colour program and with successful launch of two Ocean colour sensors OCEANSAT1- Organizational Change Management (OCM)-1 (May,1999-2008) and OCEANSAT2- OCM-2 (September, 2009-present), is geared for the launch of Oceansat-3- OCM -3 in 2022. Apart from Indian ocean colour sensor OCM2, globally operational ocean colour sensors are MODIS –AQUA, National Power Portal (NPP)- Visible Infrared Imaging Radiometer Suite (VIIRS), Joint Polar Satellite System (JPSS1) & JPSS2, Sentinel 3 A&B - Ocean and Land Colour Instrument (OLCI). SAC is involved in the use of ocean colour data in science and climate related applications. It focusses on various parametric and non-parametric algorithms for retrieval of geophysical parameters, use of these geophysical parameters for various applications like algal bloom detection and monitoring, water quality phytoplankton community structure and biodiversity, carbon biogeochemistry, R & D projects for generating novel applications and defining new sensor requirements. Some of the challenging areas for research are

10.13.1. Bio-Optical characterization of estuaries, brackish water lagoons and coastal wetlands.

Estuaries, lagoons and wetlands are important components of marine ecosystem, heavily influenced by anthropogenic activities and susceptible to climate change. These are categorized as optically complex waters (OCW). Challenging areas of research are

a) Accurate estimation of optically active components such as chlorophyll concentration, coloured dissolved organic matter (CDOM) absorption, total particulate matter and total suspended sediments in optically complex waters .
b) Development of atmospheric correction models for accurate estimation of remote sensing reflectances in OCW
c) Hyperspectral characterization of optical constituents in VIS-NIR region
d) AI –ML based techniques for retrieval of optical constituents in OCW.

10.13.2. Biogeochemical dynamics in coastal –estuarine ecosystems

Biogeochemical transformation and pathways of aquatic carbon in coastal, estuaries, lagoons and wetlands is an important area of research and use of ocean colour data along with in-situ observations in biogeochemical models are important for climate change studies. Some of the challenging areas are

a) Quantifying various components of the aquatic carbon in diverse marine ecosystems using ocean colour (Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), Dissolved Inorganic Carbon (DIC), Particulate Organic Carbon (POC), Phytoplankton C, Detritus C)
b) Quantifying nitrogen components of the aquatic system using remote sensing
c) Evaluating nutrient dynamics in estuarine- coastal regions using remote sensing
d) Modeling primary, new and export production from remote sensing

10.13.3. Marine Living Resource Management

Climate change is profoundly effecting habitat, breeding and population dynamics of marine living resources. Some of the challenging areas of research in this field are

a) Habitat identification of endangered marine organism using geospatial information
b) Site suitability for mariculture using remotely derived parameters and in-situ observations in GIS based models
c) Ocean colour remote sensing in zooplankton, secondary production and tertiary production studies
d) Ocean colour remote sensing for microbial ecosystems
e) Habitats of large pelagics using remotely sensed parameters and fishery data

10.13.4. Biodiversity and ecosystem Studies

Climate change and global warming is rapidly effecting species biodiversity with native population replaced by few fast growing species and loss in biodiversity. Major areas of research are

a) Ocean colour remote sensing in biodiversity studies of micro and macroalgae of Indian marine waters
b) Optical and biological studies of harmful and beneficial algal blooms using remote sensing
c) Optical and biological characteristics of benthic ecosystems (Sea grass, Seaweeds, benthic microalgae)
d) Phytoplankton fluorescence and physiological studies
e) Impact of ocean acidification on biodiversity
f) Climate change studies on phytoplankton functional groups, size classes and ecosystem structure.

10.14. Research Areas in the field of Agriculture, Terrestrial Biosphere and Environment

Estimation of agricultural crop yields and production at different spatial scale is of paramount importance for global food security. Crop production estimation at coarser scale such as at district and state levels is required for decision making and export-import policy formulation and trade-related activity while that at finer scale is necessary to understand the yield variability at farm level, which in turn is useful to improve the productivity of small and marginal farm holdings through proper management and to settle claims under crop insurance. Recent developments related to Automation, Geospatial pest forewarning, Crop insurance towards MoAFW, Digital agriculture initiative Individuals with Disabilities Education Act (IDEA) many research challenges. Research areas in the field of agriculture are as follows:

10.14.1. Crop production, yield and Price Forecasting

1. Monthly forecast of major crops & long-lead forecast
2. Automated crop yield estimation thorough process-based model
3. Prediction of market arrival & price through statistical and AI/ML approaches
4. Acreage of rabi pulse types, Kharif onion through Opti-SAR observations
5. Fodder type-wise area, yield & production
6. Site suitability of medicinal plants

10.14.2. Agro advisories and crop loss assessment

1. New Drought product from Satellite and its use in crop loss
2. Prototype demonstration of Digital agro-climatic atlas
3. Horticulture-specific weather-based insurance product using satellite data
4. Local-scale / high-resolution weather forecast using AI/ML
5. Modelling macro/micro climate & animal disease prediction

10.14.3. Precision Agriculture

1. Resource-use efficiency (Crop Water Productivity, Nutrient Use Efficiency), Soil carbon dynamics.
2. Fodder nutrient, Active medical ingradient & pesticide residue investigation (UAV, satellite hyperspectral, thermal, Imaging microscopy – Experiments, analysis, data fusion).
3. Investigations on Solar-Induced Fluorescence (SIF) & hyperspectral related to photosynthesis & early disease detection.

10.14.4. Research Areas in the field of Forest Ecosystem Studies

1. Quantification of Essential Ecosystem Services for assessments and monitoring of ecosystem service supply, demand and benefit.
2. Essential biodiversity variables (distributions, abundances, morphology, physiology, phenology) for modelling & monitoring in space-time for species distribution monitoring.
3. Forest Physiognomic Studies using LiDAR remote sensing
4. Forest Phenological Studies and PhenoMet model developments
5. Mapping Invasive Species using AI/ML
6. Forest Fire Mapping, Biomass Burning Emission & Forest Fire Risk Zonation

10.14.5. Atmospheric Trace gases, Aerosols and Air quality research

Atmospheric trace gases include greenhouse gases (CO2, CH4, etc.) and air pollutants (O3, NO2, CO, SO2, etc.) which play momentous role in climate change, atmospheric chemistry and air quality. Development of retrieval techniques for retrieving methane and carbon dioxide from space is a gap area in the context of Indian Remote Sensing Program.

1. Development of Retrieval Technique for Atmospheric Methane and Carbon Dioxide through Differential Optical Absorption Spectroscopy (DOAS) based technique.
2. Modelling the Vertical Particulate Extinction and Backscatter Profiles from satellite and ground LIDAR observations.

10.14.6. Research Areas in the field of Heliophysics, Space weather and THz astronomy

1. Understanding temporal evolution of elemental abundances in solar flares X-ray observations through theoretical modeling and satellite observations.
2. Ionospheric properties of Earth with modeling and satellite observations for understanding the space weather.
3. Sub-mm astronomy can answer some of the most profound questions related to the cold components of the Universe on scales of galaxies, molecular clouds, star and planets. Precursor studies using multi-wavelength studies using observations from global sub-mm telescopes.

10.15. Research Areas in the field of Planetary Sciences

Planetary Sciences activities deals with analysis & interpretation of science data from past planetary missions (Moon, Mars etc.), planning science experiments for future planetary missions (Venus, Mars etc.) and studying the Planetarty Analogues on Earth for understanding the geological processes on other planets.

10.15.1. Lunar Surface Sciences

Planetary Sciences division is mainly involved in analyzing the data from the contemporary Indian and international planetary missions, formulating the objectives of future science missions and carrying out Planetary Analogue studies for developing customized spectral library.

Following are some of the present and future research interests of PSD

10.15.2. Planetary Geology

10.15.2.1. Moon:

i) Characterizing the mineralogical diversity of the lunar crust and understanding the nature of lunar water cycle:
   a) Constraining lunar crustal composition through high-resolution hyperspectral data of the Moon obtained from recent, ongoing and upcoming lunar missions.
   b) Comparative compositional studies of lunar near and far side mare and their implications in thermal and chemical evolution of the Moon.
   c) Unambiguous detection of lunar hydration features (molecular water /hydroxyl ions) and characterizing their nature using hyperspectral data.

ii) Investigation of lunar volatiles at polar regions: Development of new techniques and radar-based models for detection and quantitative estimation of water-ice deposits inside the permanently shadowed regions at lunar poles.

iii) Lunar morphological studies:
   a) Detailed investigation of global lunar geological and morphological features and preparation of seleno-morphological maps.
   b) Morphometric and rheological study of lunar domes.
   c) Analysis of spatial and statistical distribution of boulders from high-resolution optical datasets.

iv) Characterization of physical properties of lunar regolith:
   a) Inversion of global regolith thickness and physical properties of the lunar near-surface using multi-wavelength radar studies.
   b) Development of physical models for dielectric constant and surface roughness estimation over lunar surface.
   c) Development of empirical and semi-empirical radio-wave scattering models to address scattering from surface and subsurface heterogeneities.

v) Lunar crustal shortening studies: Understanding the lunar crustal shortening through morpho-structural analysis of wrinkle ridges distributed at different regions of the Moon.

vi) Retrieval of Photometric parameters from optical remote sensing data: Development of algorithms and simulation of physics-based models to retrieve topographically corrected photometric parameters and comparison with lab-based BRDF measurements collected over Apollo samples.

vii) VNIR and thermal remote sensing simulation Studies:
   a) Visible-Near Infrared (VNIR) reflectance calculation using physics-based models and studying the effects of optical properties, viewing geometry, grain size, etc.
   b) Estimation of thermal radiation from lunar regolith.
   c) Development of physical retrieval algorithms for lunar surface temperature and spectral emissivity in 3–5 μm range.

viii) Lunar Emissivity & Temperature: (a) Developing algorithms and models for simultaneous retrieval of Lunar temperature and emissivity using infrared thermal data sets

10.15.2.2. Mars:

i) Simulation of Martian subsurface for characterizing water ice layers: Shallow buried Ice detection using multi-frequency microwave radiometer and Brightness Temperature estimations.
ii) Global albedo mapping of Mars: Using data from optical and Shortwave Infrared (SWIR) observations.
iii) Martian geological studies: Mineralogical and morphological studies of volcanic provinces, and monitoring of Polar Ice caps on Mars using optical and hyperspectral remote sensing data.

10.15.2.3. Venus:

i) Venus geological studies using microwave remote sensing data:
   (a) Scattering properties of Venusian geologic features, i.e., volcanic landforms and highland regions using ground-based and orbital-based radar data and development of radar scattering models.
   (b) Characterization of large-scale Venusian volcano-tectonic structures by integrating observations from Magellan SAR, Radiometer and Altimeter observations.
ii) Limb darkening studies of Venus using thermal remote sensing observations.

10.15.2.4. Asteroids:

i) Constraining the origins of Asteroids: Investigation of Visible and Near Infrared spectra of Main Belt and Near-Earth Asteroids obtained from spacecraft-based observations and link with those obtained from meteorites to understand their origins.
ii) Polarimetric radar studies of Near-Earth Asteroids to characterize their near-surface physical properties.

10.15.2.5. Mercury:

Ground-based polarimetric radar studies of Mercury Poles to constrain the potential distribution and purity of water ice deposits associated with permanently shadowed regions.

10.15.3. Planetary Atmospheres

1) Radio Occultation Techniques for Atmospheric Profiling of Venus and Mars: Development of end-to-end retrieval algorithms for deriving atmospheric profiles of temperature, pressure and sulfuric acid concentration for planetary atmospheres such as Venus and Mars using Radio Occultation (RO)

techniques. In addition, research towards error propagation analyses in RO experiments for characterization of system noises feeding towards system definition for realization of future indigenous RO missions.

2) Understanding the atmospheric circulation dynamics of the Venusian atmosphere: Retrieval of atmospheric winds from UV channels and dynamical modelling of the Venusian Atmosphere to understand the atmospheric circulation dynamics.
3) Understanding the diverse wave characteristics and induced angular momentum forcing in the Venusian atmosphere: Study of atmospheric waves and oscillations of winds at different altitudes in Venusian atmosphere using retrieve winds and dynamical model to understand the diurnal, seasonal and annual periodicity.
4) Investigating the elusive nature of Venusian lightning using synergistic observations. Synergistic measurements from instruments aboard upcoming Venus mission of ISRO are targeted to probe unambiguous detection of Venus lightning in a more decisive manner.
5) Measurements of Venus cloud top brightness temperature statistics at different locations, emission angles, and times, and generation of cloud top temperature maps.
6) Retrieval of Venus surface emissivity and near-surface atmospheric parameters.
7) Investigations of dust storms and dust devils on Mars.
8) Estimation of atmospheric optical depth (AOD) as a function of altitude and scale height of aerosols on Mars.

10.15.4. Planetary Analogues

1) Terrestrial hot springs and their Astrobiological implications: Field studies, sample collection, and characterization of mineral assemblages in the spectral range of 0.4– 25 μm found in the vicinity of different hot springs located along various faults of North Western Himalayan region.
2) Lunar and Martian Water Ice Analogues: Permafrost deposits present in the North-western Arid Himalayan regions are analogous to the water ice deposits thought to be present on Mars and the Moon. These frozen grounds are studied using longer wavelength Synthetic Aperture Radar (SAR) observations combined with in situ Ground Penetrating Radar (GPR) observations.

11. ELECTRONICS AND MICROELECTRONICS DESIGN, FABRICATION AND TESTING TECHNOLOGIES

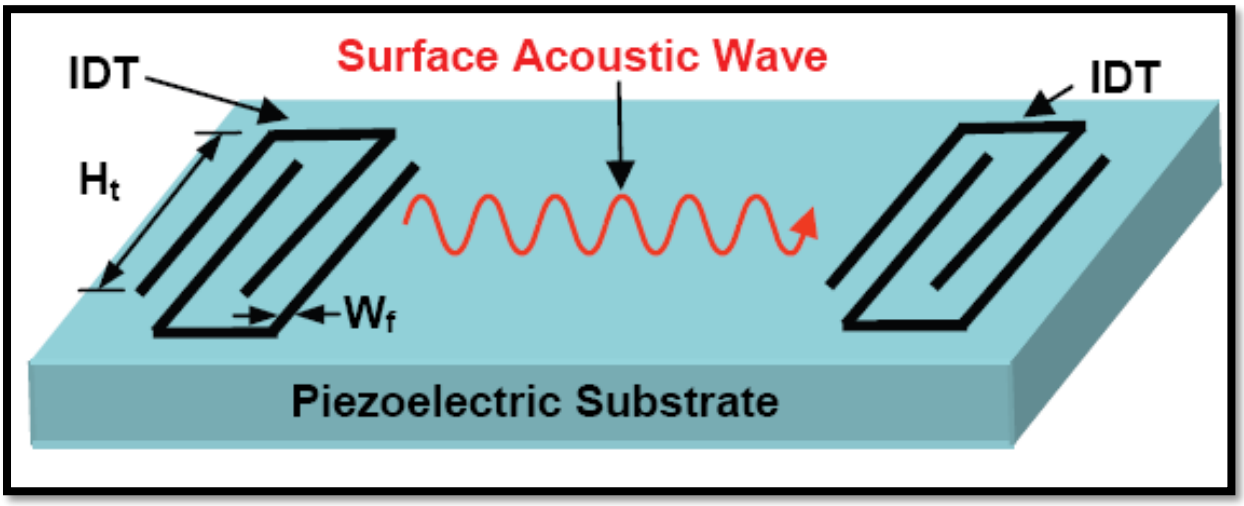
In order to be self-reliant in the realization of sophisticated Communication, Navigation, Remote Sensing and Planetary payloads, SAC has developed expertise in a host of design, modeling, fabrication, assembly, packaging and testing technologies and has established associated state-of-art infrastructure. SAC plans to augment this capability with a focus on payload miniaturization through development of micro/nano technologies and advanced assembly and packaging solutions. SAC also intends to augment its specialized space environment simulation capabilities to meet the needs of future missions.
In keeping with the above stated objectives, research proposals are invited on the topics that appear in the following sections:

11.1. Research areas in active and passive device and component technologies

11.1.1. Simulators for SAW filter design

Surface Acoustic Wave (SAW) filters provide efficient RF filtering in a compact footprint, in the frequency range of 10 MHz to 3 GHz. In spite of the prevalence of these devices in modern communication equipment, general purpose design tools for the simulation of these filters are non-existent.
The scope of the proposed research work, hence, shall be to develop accurate simulation tools for the prediction of SAW filter performance. Target specifications and fabrication support shall be provided by SAC. The accuracy of the developed tools shall be checked against the measured performance of fabricated filters.

Typical schematic of a SAW filter



References:
[1] Hiroyuki Nakamura et. al., “A practical SPUDT design for SAW filters with Different-Width Split-Finger interdigital transducers”, Proc. IEEE Ultrason. Symp. 2000, pp. 105–108
[2] Hiroyuki Nakamura et. al., “A New Design Concept for Low-Loss SAW Filters Based on Different-Width Split-Finger SPUDT”, IEEE Transactions on Microwave Theory and Techniques, Vol. 49, No. 4, April 2001

11.1.2. Development of Silicon micromachined THz interconnects

High transmission losses associated with planar transmission lines obviates their use at mm and sub-mm wavelengths. Metal waveguides realized through fine CNC milling techniques have hence become the preferred medium for signal transmission at THz frequencies. However, they need accurate hand alignment and are non-compatible to planar integration with THz active and passive devices. Since the last few years, Deep Reactive Ion Etching (DRIE) based Silicon micromachining has shown immense promise for the realization of THz interconnects and hence are being actively pursued in research.

Proposals are invited for development of DRIE based Silicon micromachining processes for realizing THz interconnects. The scope of the proposed work shall include (a) development of Si micromachining processes for THz interconnects suitable up to 500 GHz and (b) demonstration of performance through fabrication and testing of interconnects. The process recipes developed and the hardware realized shall serve as the deliverables of the project.

References:

[1] G. Chattopadhyay, T. Reck, C. Lee, and C. Jung-Kubiak, "Micromachined packaging for terahertz systems," Proc. IEEE, vol. 105, no. 6, pp. 1139–1150, 2017.

11.1.3. TCAD based modeling of GaN HEMTs

Gallium Nitride High Electron Mobility Transistor (GaN HEMT) has become the device technology of choice for the realization of high frequency-high power amplifiers. However, GaN HEMT being a comparatively nascent technology, many of the effects that manifest at the device level are still in the domain of research. Models are required to be developed for these devices for their use in circuit design. Measurement based empirical models can be fast but not very accurate. Physics based compact models are fast and offer better accuracy. However, these models themselves need some validation at different stages of their development, where some of the real device effects are ignored while others are considered. This validation is carried out through a comparison with the predications of TCAD simulators, where the number of real device effects, physical parameter values etc. can be independently chosen.

Proposals are invited for TCAD based 3-D modelling of GaN HEMTs. The scope of the proposed work shall include (a) development of Silvaco TCAD 3-D models based on device geometrical and physical parameters provided by SAC and (b) validation of DC, RF, noise and non-linear behaviour predictions of the developed models with measurement data to be provided by SAC. Models developed and the simulation flow shall serve as the deliverables of the project.

References:

[1] Reddy M K, et. al., "Physics Based TCAD Simulation and Calibration of GaN/AlGaN/GaN HEMT Device", Proceedings of 6th International Conference on Systems and Informatics, 2019.

[2] Stanislav Vitanov, et. al., "Physics-Based Modeling of GaN HEMTs", Proc. IEEE Transactions on Electron Devices, Vol. 59, No. 3, March 2012.

11.2. Research areas in micro and diffractive optical component technologies

11.2.1. Development of 45° Bending Mirror for out-of-plane coupling in Polymer Optical Waveguides for Optical Interconnects

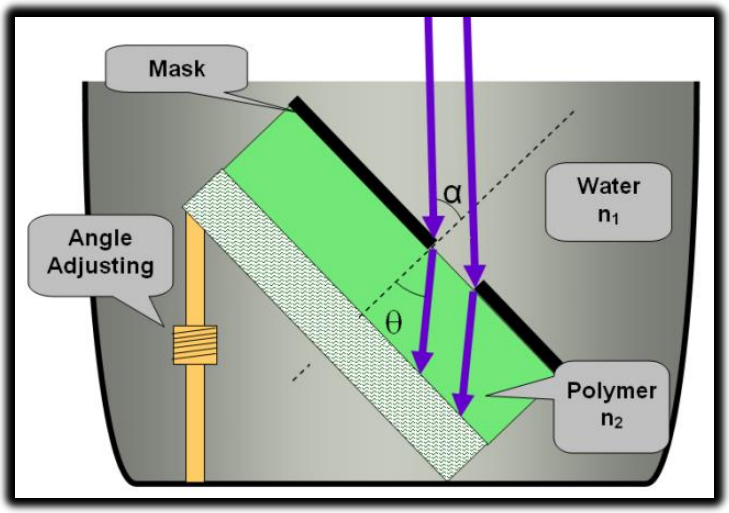
Bending Mirror is one of the simple solutions for out-of-plane coupling of light between optical waveguides and optoelectronic devices fabrication. In this type of coupling, light is reflected due to either a metal coating or total internal reflection at the end of a polymer waveguide. A PCB compatible 45° bending micro mirror is to be fabricated on polymer optical waveguides using tilted beam

photolithography. After successful fabrication, the mirror needs to be characterized for coupling efficiency.

The activity shall include the following:

a. Survey and selection of required materials and process as per detailed SAC requirements.
b. Development of fabrication process.
c. Component demonstration and measurement of coupling efficiency.

Schematic of improved UV photolithography on PCB substrate



References:

[1] Wang, Fengtao. Optical interconnects on printed circuit boards. Georgia Institute of Technology, 2010.
[2] Jiang, Guomin, Sarfaraz Baig, and Michael R. Wang. "Flexible polymer waveguides with integrated mirrors fabricated by soft lithography for optical interconnection." Journal of lightwave technology 31, no. 11 (2013): 1835-1841.

11.2.2. Development of Precision Slits / Apertures / Bar Targets

Precision slits, apertures and bar targets are one of the essential components for realization / calibration of optical imaging cameras. These components when fabricated with high precision provide a well-defined desired image without problems like beam scattering etc.

The precision slits / apertures / bar targets may be fabricated in Si (with appropriate optical coatings) or in metal foils (of appropriate metal) so that it works with the visible and IR spectrums. The coated Si substrate / metal foil shall work as an opaque material with the gaps in them allowing the light to pass through as per the design of the pattern.

The activity shall include the following:

a. Survey and selection of required materials as per detailed SAC requirements.
b. Development of fabrication process, typically Si through etch / Lithographie, Galvanoformung, Abformung (LIGA) based processes.
c. Process, component demonstration and qualification.

References:

[1] Matthias Mohaupt, Uwe Zeitner, Gerd Harnisch- Fraunhofer Institute for Applied Optics and Precision Engineering, Germany, Albert-Einstein-Strasse 7, D-07745 Jena "Slit manufacturing and integration for the Sentinel–4 NIR and UV-VIS spectrometers"

[2] "Fabrication and Optical Measurements of Multi-slit Grating Based Infrared micro-spectrometer" S.H. Kong, D.D.L. Wijngaards, G. de Graaf and R.F. Wolffenbuttel Electronic Instrumentation Laboratory I DIMES (ITS/Et), Delft University ofTechnology, Mekelweg 4, NL-2628 CD Delft, The Netherlands
[3] "New design for highly durable infrared-reflective coatings" Chaoquan Hu, Jian Liu, Jianbo Wang, Zhiqing Gu, Chao Li, Qian Li, Yuankai Li, Sam Zhang, Chaobin Bi, Xiaofeng Fan & Weitao Zheng

11.2.3. Development of Deformable Mirror

Deformable mirror is an integral part of a variety of modern adaptive optics system, which are used to correct the optical aberration of the wave front. It is carried out by deforming the shape of a membrane (mirror) in response to an applied control signal.
A Polysilicon Multi-Users MEMS (PolyMUMPS) type or similar process is to be developed for Fabrication and Packaging of the deformable mirror array device. It is desirable that fabrication and packaging be followed by relevant characterization steps to validate the performance of the device.
The activity shall include the following:

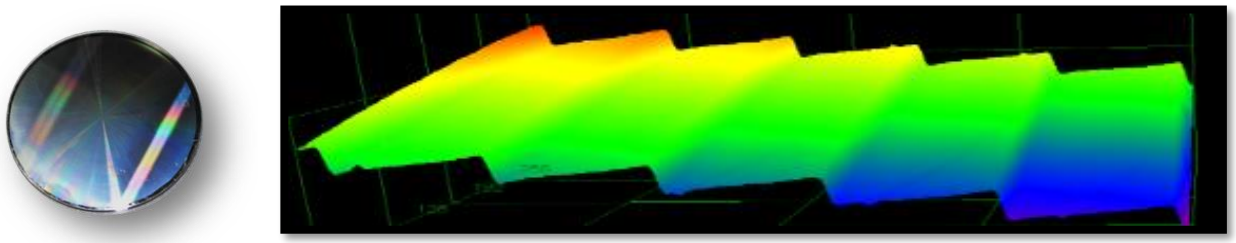
a. Survey and selection of required materials and process as per detailed SAC requirements.
b. Development of the fabrication process.
c. Process, component demonstration and qualification.

References:
[1] Gupta, Amita; Kumar, Shailesh; Singh, Ranvir; Chaudhary, Monika; Meena, A K; et al. Defence Science Journal; New Delhi Vol. 59, Iss. 6, (Nov 2009): 590.
[2] W. Jung, Y. Peter, E. Carr, J. Wang and O. Solgaard, "Single-Crystal-Silicon Continuous Membrane Deformable Mirror Array for Adaptive Optics in Space-Based Telescopes," in IEEE Journal of Selected Topics in Quantum Electronics, vol. 13, no. 2, pp. 162-167, March-april 2007, doi: 10.1109/JSTQE.2007.893560.

11.2.4. Development of Reflective Optical Coating over PMMA Resist

Optical coating is an important process in several micro/diffractive optical devices in order to alter the way light interacts with them. To achieve required reflectance in the desired wavelength range appropriate reflective optical coatings are used. This application requires reflective optical coating on 2D/3D shapes fabricated over Poly Methyl Methacrylate (PMMA), a polymer.
This work requires the development of optical coating over 950K PMMA Electron Beam Sensitive Resist. The structure shall have either binary or greyscale resist pattern over planar or non- planar substrates of irregular sizes. The coating shall have excellent adhesion with resist (PMMA) and shall preferably be abrasion free.
The activity shall include the following:

a. Survey and selection of required materials as per detailed SAC requirements.
b. Development of optical coating process over Patterned PMMA Resist Structures.
c. Process, coating performance demonstration and qualification.



Blazed grating on Silicon plano-convex lens

11.3. Research areas in microfabrication process technologies

11.3.1. Development of Electron Beam Sensitive and Dry Etch Compatible High Resolution Resist

Electron beam lithography has been an attractive technology to delineate nano-structures. These patterned structures can further be transferred on underlying metals (such as Aluminium in this case) using Dry Etching technique. This process requires the resist to be electron beam sensitive as well as dry etching compatible.

Scope of Work:

A Dry etching compatible electron beam sensitive resist with its developer is to be prepared.

The activity shall include the following:

a. Survey, selection and development of required materials for synthesis of resist, developer etc. as per detailed SAC requirements.
b. Process, material demonstration and qualification - Process with Aluminium Deposition, Electron Beam Lithography, Aluminium Dry Etching over an area of 15mm x 15mm with 70nm half pitch (preferable 40nm) Binary Grating structures.

11.3.2. Development of Electron Beam / Photo Lithography and Dry Etch Compatible Resist with High Stability at Elevated Temperatures

In certain applications, e.g. for MESA isolation, it is required to perform multiple processes such as Etching, Deposition and further lift off in a single lithography step. This demands the resist to be not only dry etching compatible, withstand subsequent high process temperature during deposition process but also support lift off afterwards.

Scope of Work:

Resists with suitable developer (as per detailed SAC requirements) are needed to be synthesized that should be dry etch compatible, withstand high temperature deposition process without getting deformed and then support lift off process in a single lithography step.

The activity shall include the following:

a. Survey, selection and development of required materials for synthesis of resist, developer etc. as per detailed SAC requirements.
b. Process, material demonstration and qualification.

11.3.3. Development of Dry Film Resist for Thin Film Integration on LTCC

Low temperature co-fired ceramic is a useful technology for RF applications. Integration of multilayer structure in LTCC is based on thick film processing. Development of dry film resist (DFR) is required for thin film integration on LTCC. This is needed for the fabrication of certain circuit elements having smaller (<100μm) features.

Scope of Work:

A Dry Film Resist is to be developed and using it process needs to be demonstrated meeting SAC requirements. The LTCC contains slots (cavities) and may have process-induced warpage, bow etc.

The activity shall include the following:

I. Survey, selection and development of required materials, resists, developer, plating chemistries, suitable equipment etc.
II. Development of fabrication process, which includes seed-layer deposition, DFR lamination, lithography, electroplating, seed layer etching etc.
III. Process demonstration and qualification.

11.3.4. Electrically controlled tunable integrated devices using Magneto-electric (ME) composites (Thin film/Bulk & Thin film/thin film) for microwave integrated circuit applications

The emerging research area of Magneto-electric devices where the magnetic characteristics are controlled by an electric field and/or the electric characteristics are controlled by a magnetic field, the magnetoelectric (ME) effect, is a very attractive subject for novel microwave circuit applications. The composite systems usually include Ferrite-Ferroelectric/Piezoelectric combinations. In such bilayer system, the ferrite, when driven to Ferromagnetic Resonance (FMR) and an electrical signal is applied; the FMR frequency can be shift thereby facilitating tunable characteristic. It is proposed to develop suitable composite material system with at least one component in thin film form and demonstrate dual-tunable integrated microwave components like tunable inductor, phase-shifter, attenuators, filters etc. using the developed material system.

References:

[1] "Electrostatically tunable magnetoelectric inductors with large inductance tunability" J. Lou, D. Reed, M. Liu, and N. X. Sun, Applied Physics Letters 94, 112508 (2009)

[2] "Strong magnetoelectric coupling at microwave frequencies in metallic magnetic film/lead zirconate titanate multiferroic composites" C. Pettiford, J. Lou, L. Russell, and N. X. Sun, Applied Physics Letters 92, 122506 (2008)

[3] "Electric-Field-Tunable Low Loss Multiferroic Ferrimagnetic–Ferroelectric Heterostructures" Jaydip Das, Young-Yeal Song, Nan Mo, Pavol Krivosik, and Carl E. Patton, Advanced Materials. 2009, 21, 1–5

11.3.5. Studies on energy dependent Secondary Electron Yield of Carbon Nanotube (CNT) coatings on OFHC Copper for high frequency (Ka band) TWT

One of the prime objectives of very high frequency (e.g. Ka band) TWT especially for Space use, is to reduce the secondary electron emission (SEE) from Multistage Depressed Collectors (MDC) so as to improve the TWT efficiency. Variety of techniques have been investigated and being deployed for the intended objective. One of the recent research areas is developing CNT coating on conducting surface of collector which is expected to reduce secondary electron yield by a factor compare to other materials like Graphite. The activity aims to develop suitable method for CNT synthesis, deposition of CNT coating on OFHC cupper collector surface and characterizing the SEE.

References:

[1] "Secondary Electron Yield Measurements of Carbon Nanotube Forests: Dependence on Morphology and Substrate" Brian Wood, Jordan Lee, Greg Wilson, T.-C. Shen, J.R. Dennison, IEEE Transactions on Plasma Science, vol 46, no. 9 August 2019

11.3.6. Development of Nanostructured Magnetostrictive thin films for Surface Acoustic Wave Applications

Surface Acoustic Wave (SAW) devices are widely used in communications such as filters, delay line etc. Conventional SAW devices consist of metallic IDT on top of piezoelectric film or substrates. Research involves the development of high quality thin films of giant magnetostrictive materials (e.g. Fe-Si) which exhibit high magnetostriction coefficient suitable for low insertion loss SAW devices.

Ref: [1]: 'Magnetically tunable SAW-resonator" Smole, P. Frequency Control Symposium and PDA Exhibition Jointly with the 17th European Frequency and Time Forum, 2003 IEEE international.

11.3.7. Brazing/Attachment media for Ceramic /Quartz substrates for high reliable micro assembly

This work shall include selection of reliable micro assembly Candidate material based on thermomechanical modelling and experimentations for the following applications:

A) Void free low temperature (~ 300 degC) attachment media and process of large ceramic substrate (1"x1 "to 3"x5") attach over metallic carrier plates suitable to withstand -55 to +125 degC temperature cycle regime.

Configuration study and recommendations on metallic carrier mechanical properties are also to be devised for reliable assembly for a given substrate configuration/design.

Simulation & experimental study of attachment void v/s over RF performance up to Ka Band Amplifier circuit made with discrete elements and alumina substrates.

B) Void free, thin bond line thickness (~ 200 nm) attachment media and process of quartz substrate (with 25:1 aspect ratio) attachment on metallic carrier plate, suitable to withstand 0 to – 4K temperature cycle regime.

References:

[1] Qiu Yingxia, "Effects of Solder Voids on Microwave Transmission Performance in Passive Circuits", 5th International Conference on Computer Sciences and Automation Engineering (ICCSAE 2015).

[2] Chengshuo Jiang, "Effects of Voids on Mechanical and Thermal Properties of the Die Attach Solder Layer Used in High-Power LED Chip-Scale Packages", IEEE Transactions on Components, Packaging and Manufacturing Technology (Volume: 8 , Issue: 7 , July 2018).

[3] P.W. Barnes, "Void free die attachment for multichip modules using solder alloys", Proceedings. 1998 International Conference on Multichip Modules and High Density Packaging.

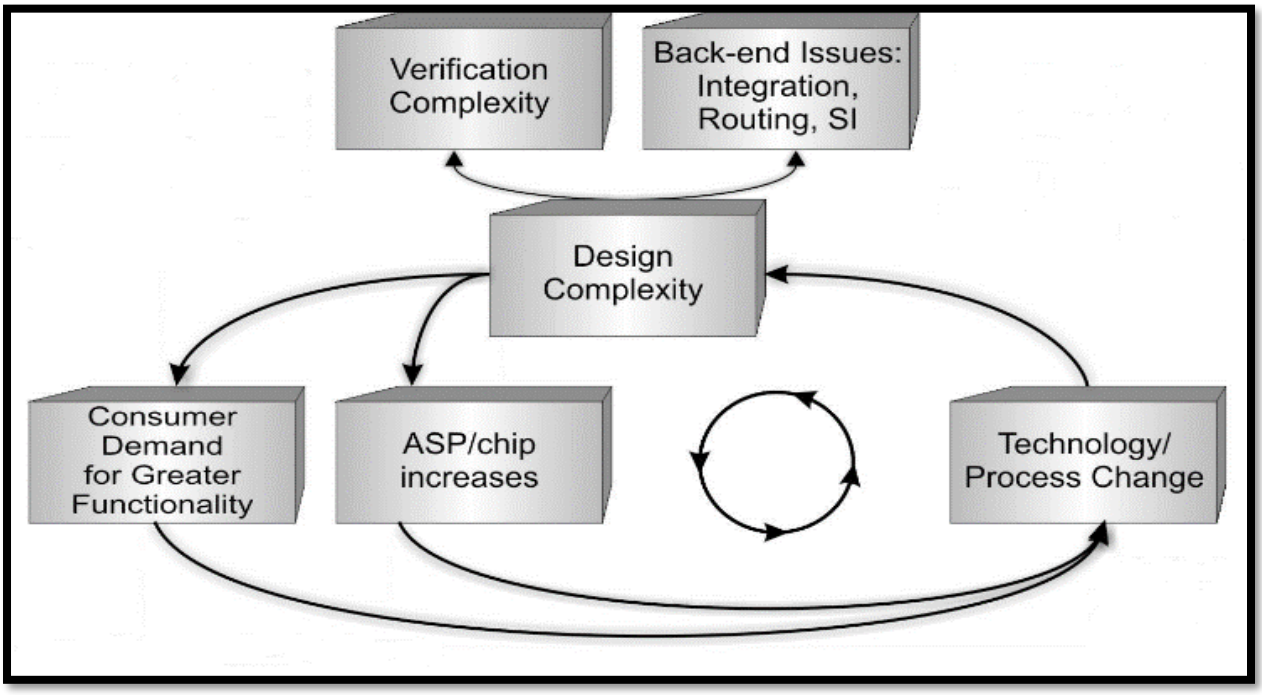
[4] Chunlei Liu, "Novel Large-Area Attachment for High-Temperature Power Electronics Module Application", 2017 IEEE 67th Electronic Components and Technology Conference (ECTC)

[5] Linda Del Castillo, "Electronic packaging and passive devices for low temperature space applications" 2018 IEEE Aerospace Conference

11.4. Research areas in Electronic circuit simulation

11.4.1. Functional Verification of Digital circuit and Model development for Equivalence checking at Gate level with Resistor Transistor Logics (RTL) logics

Electronic circuit simulation uses mathematical models to replicate the behavior of an actual electronic device or circuit. Some electronics simulators integrate a schematic editor, a simulation engine, and on-screen waveform display, allowing designers to rapidly modify a simulated circuit and see what effect the changes have on the output. They also contain extensive model and device libraries. These models typically include IC specific transistor models like Pspice, Verilog A and Hardware Description Language (VHDL)- Additional Member System (AMS) etc. Printed Circuit Board (PCB) design requires specific models such as transmission lines for the traces, I/O Buffer information Specification (IBIS) models for driving and receiving electronics.



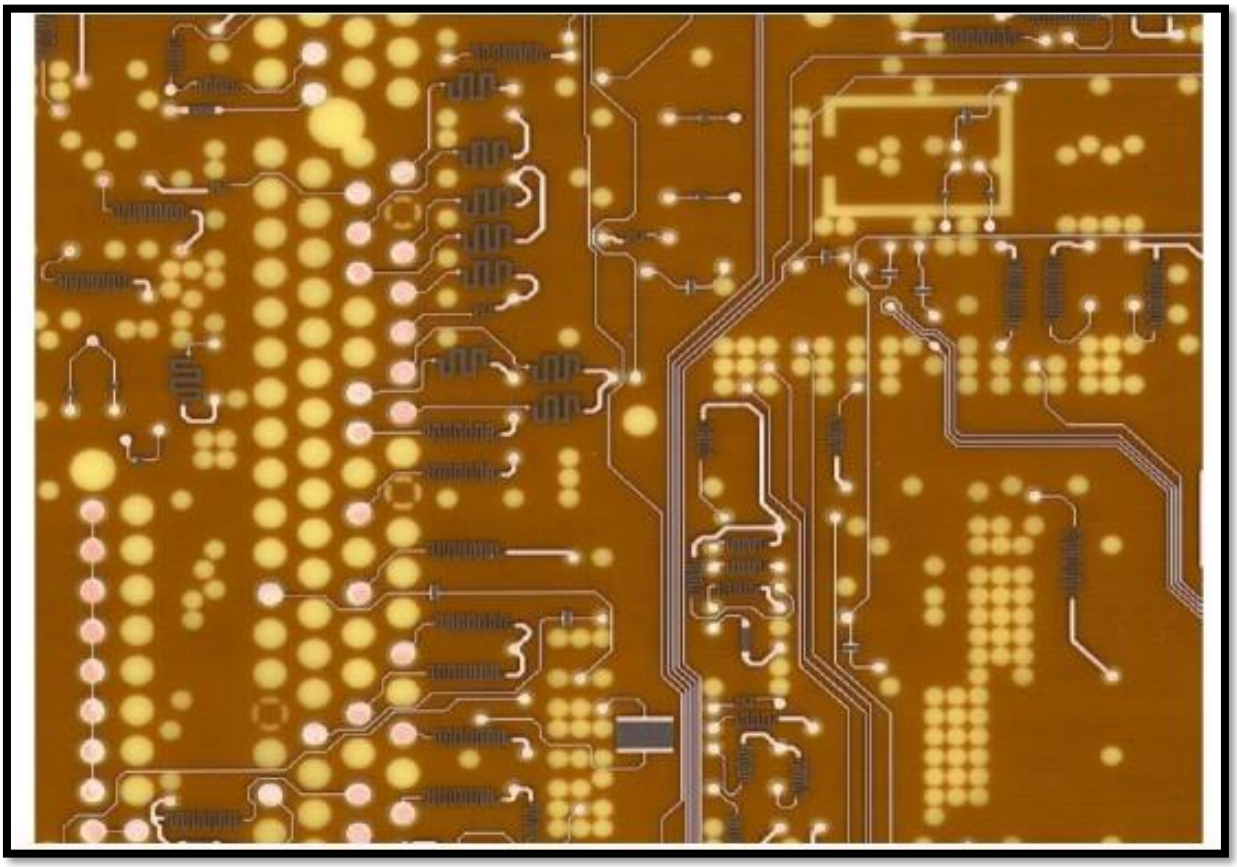
The problem related to the functional simulation of the digital device and circuit, Functional simulator is required which can perform various tasks viz. static timing analysis, gate level simulation and transistor-level or circuit-level simulation. By this methodology, it is expected to verify the logic level functionality of the critical devices like as FPGA, DDR, ADC/DAC, and other digital devices. However, for this type of simulation, we require specific device model like Simulation Program with Integrated Circuit Emphasis (SPICE)/VHDL-AMS and other suggested suitable model. This will enable us to do better what if analysis so that our PCB board shows least deviation after final test and evaluation. It will also enable us to understand the complexities of digital devices which can't be resolved with the help of Behavioral level simulation. This is performed mainly at post layout thus enabling us to reduce time and save our effort.

References:

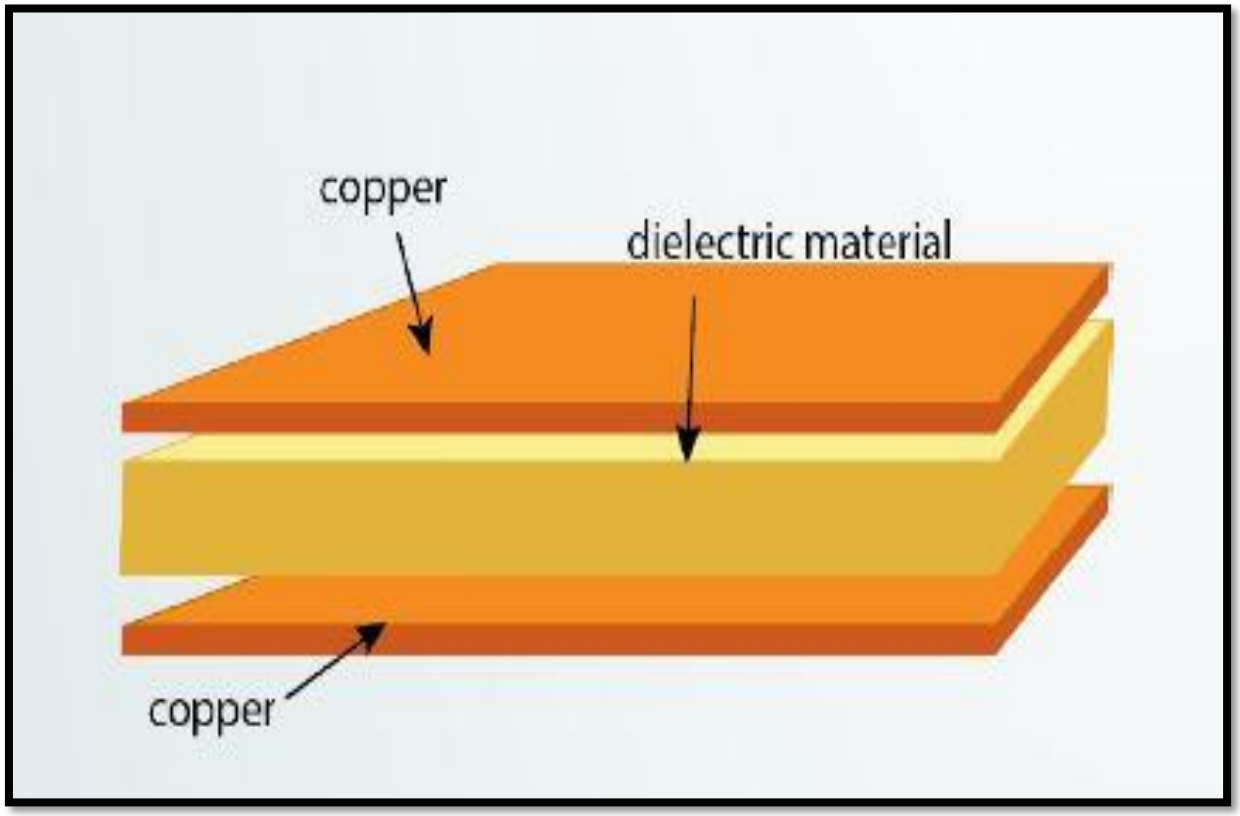
[1] Functional Verification: Approaches and Challenges by A. MOLINA and O. CADENAS published in 2006 by Latin American applied research, researchgate/publication/ 237116903

11.4.2. Design and Simulation of Embedded passive technology (EPT) based PCB

Embedded Passive Technology (EPT) is the process of building passive components such as resistors, capacitors and inductors inside Printed Wiring Boards (PWBs) during board fabrication. The need for embedded passives technology is driven by multiple factors such enhanced electrical performance (SI & PI) higher packaging density and potential cost saving.



Embedded Resistors



Embedded Capacitor

Under this project, advanced design and simulation of EPT based PCB layout along with critical components Like FPGA, ADC, DDR and DAC having passive components (i.e. Termination & pull up/down resistors & decaps) is envisaged. One of the challenges in designing embedded passives is the lack of availability of good Computer Aided Design (CAD) tools. Most CAD tools only allow components to be placed on the outer surfaces of the PCB/ substrate. Thus the development of design tools and knowledge base to design these parts fit well with the requirements for embedded passives in PWBs.

References

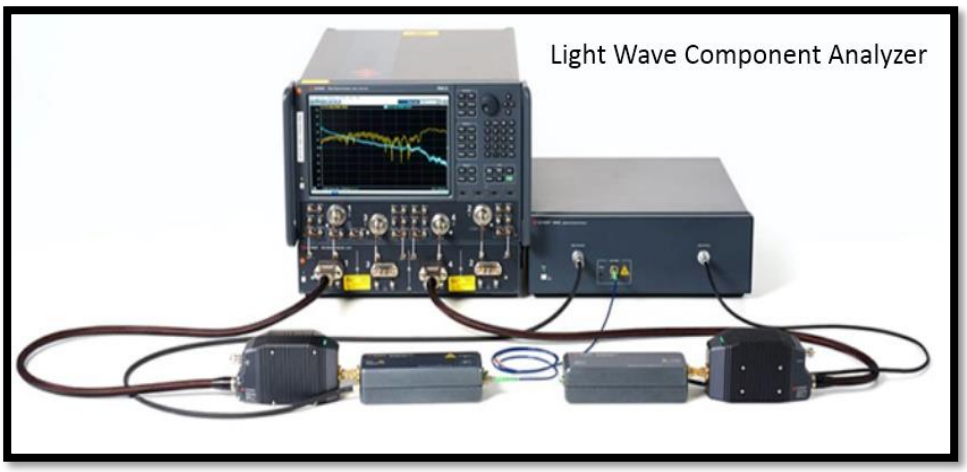
[1] Embedded Passive Technology by Hikmat Chammas Published in the Indian Panel Code (IPC) Advanced Programming Experience (APEX) Exposition large- Scale Public Exhibition (EXPO) Conference

[2] Fabrication of Embedded Capacitance Printed Circuit Boards by Joel S.Peiffer, 3M, St. Paul, MN Presented at IPC Printed Circuits EXPO® 2001

11.5. Research area in Electronic calibration

11.5.1. Calibration of Test & Measuring Equipment used in the field of Optical Communication

SAC is involved in development of optical communication devices like optical amplifier, photonics Analog to Digital convertor, optical switches, O-E & E-O convertors which are used in high speed optical links etc. For Testing of these devices Test & Measurement Equipments are used like Tuneable Laser Sources, Optical Power Meter, Optical Attenuator and Optical Spectrum Analyzers. So seeing increase in optical payload activity; SAC calibration facility is working for upgradation in the field of optical communication. For this Calibration lab is trying to establish the traceability for optical parameter especially in the band of 1550±20 nm and trying to find out the ways for calibration/validation of test & measuring equipment in optical communication field.



References:

[1] Optical Components for Communications: Principles and Applications, Author: Lin, Ching-Fuh, Publisher: Boston Kluwer Academic Pub. 2004

[2] https://www.exfo.com/en/products/lab-manufacturing-testing/

[3] https://www.coherent-solutions.com/application-notes/

[4]https://www.keysight.com/en/pc-00004%3Acsg%3Apgr/photonic-test-measurement?nid=-536900132.0&cc=IN&lc=eng

11.6. Research Areas in the field of Surface Treatment Process Technologies

11.6.1. Process Development to realize Electroforming Process for Aluminium Component

Electroforming is a technique used in fabrication of complex contoured components with high dimensional tolerances which are difficult to fabricate using conventional machining methodology. At present, electroforming process of copper components on Aluminium mandrels has been successfully realized at SAC. Copper has disadvantage of high density of 8.9 grams/cc.

Hence, efforts are invited to carry out in depth feasibility study to realize electroforming process of Aluminium components and develop detailed process & setup for the same. This process can be used for mm-wave components.

11.6.2. Non-cyanide based Electroless Silver Plating Process Development

Silver plated components are widely used in RF systems of satellites. With miniaturization of mechanical assemblies and usage of higher frequency bands like K-band & Ka-band, dimensions have decreased to around 4 mm & lower. Also long waveguides of the length of 1.2 meters are being used with twists and turns in various planes, making it extremely difficult to silver plate inside surface of the cavity using the conventional electrolytic silver plating methodology.

Hence, efforts are invited in the area of non-cyanide based Electroless silver plating chemistry for plating aluminium 6061T6 alloy components with plating thickness of >=2 microns of silver inside complex multi planar wave guides.

11.6.3. Development of Electroless Gold Plating Process

Gold plating on aluminium 6061T6 boxes and Kovar carrier plates is being carried out for EMI/EMC requirements, corrosion protection, solder ability etc.

Hence, efforts are invited in the area of Electro less gold plating process using either cyanide based or non-cyanide based chemistry for plating aluminium 6061T6 alloy components/Kovar substrates with plating thickness of >=2 microns of gold. Once developed, this process will be used for all ISRO projects as per requirements.

11.7. Research Areas in the field of Space Environment Simulation and testing technologies

Environmental Testing is an important activity in the process of Payload development. Facilities have several hot and cold chambers and Thermo-vacuum chambers up to 6.5m Dia. which meets the environmental test requirements of various payloads being developed at SAC, Ahmedabad.

Establishment of new facilities and augmentation of existing facilities to accommodate special test requirements is a continuous process. This demands innovative solution to emerge in close collaboration with the academic institutions and industrial research units. Collaborative efforts are invited from academic institutions in following upcoming requirements/research areas as outlined below.

11.7.1. Super Insulated Cryogenic Transfer Lines

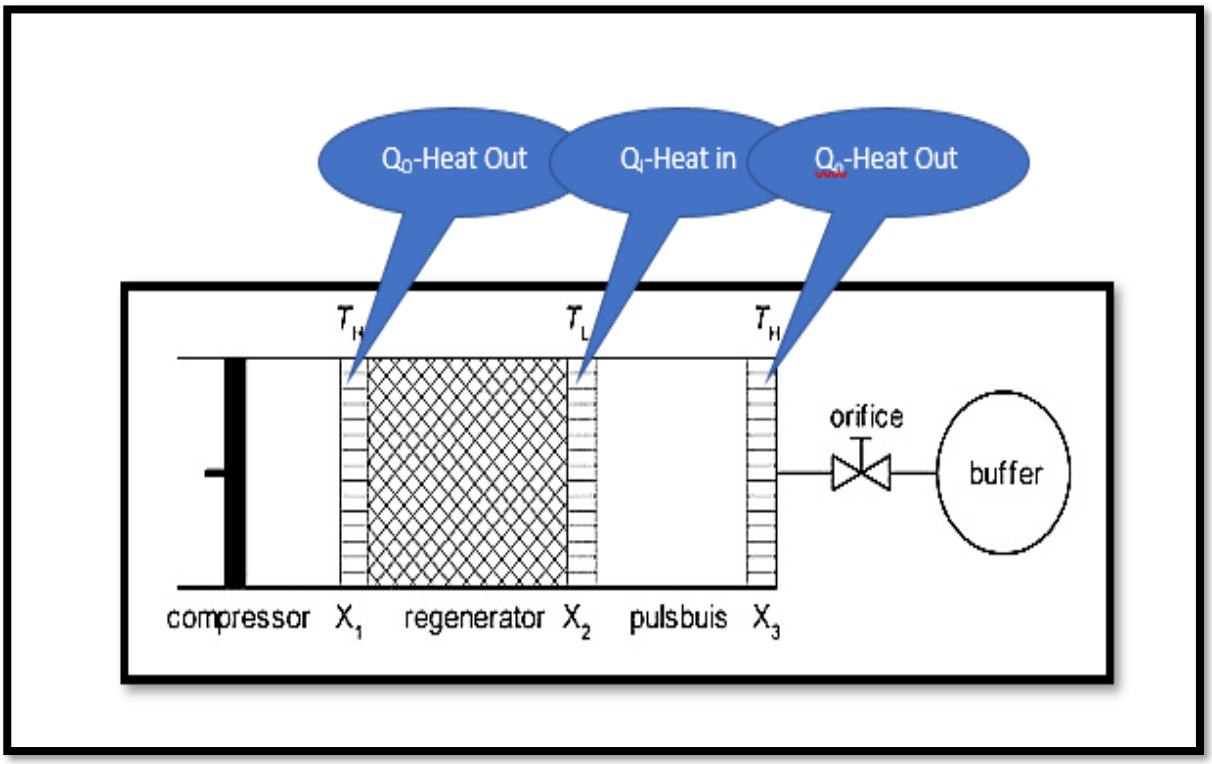
Vacuum jacketed Cryogenic transfer lines are an integral part of a thermal vacuum system, as they offer compact size footprint, extremely low heat inleak, aesthetic layouts, ease of installation and lower long-term maintenance costs.

The scope of this work will involve development for non-metallic, light weight; low loss cryogen transfers lines especially for efficient distribution of Liquid nitrogen. The functional temperature range to be considered for the SI lines should be -196degC to +50degC.

11.7.2. Pulse-Tube Cryo Cooler

Pulse tube cryo-coolers have been evolved in recent years and matured as a promising technology for meeting the challenging cooling requirements of space industry. They provide significant advantages in terms of overall size, extremely lower vibration levels, and higher reliability. These coolers have been used in ground segment testing of space hardware as well as for onboard applications.

The scope of this work shall entail development of compact, low cost single stage/ double stage Pulse Tube cryo-coolers to facilitate testing tiny devices at low temperature as well as for low cooling requirement for IR/CCD detectors. Expected cold tip temperature for this development activity is 80K with ~10-watt cooling capacity @80K, which can be verified in existing facilities at SAC with appropriate set-up.

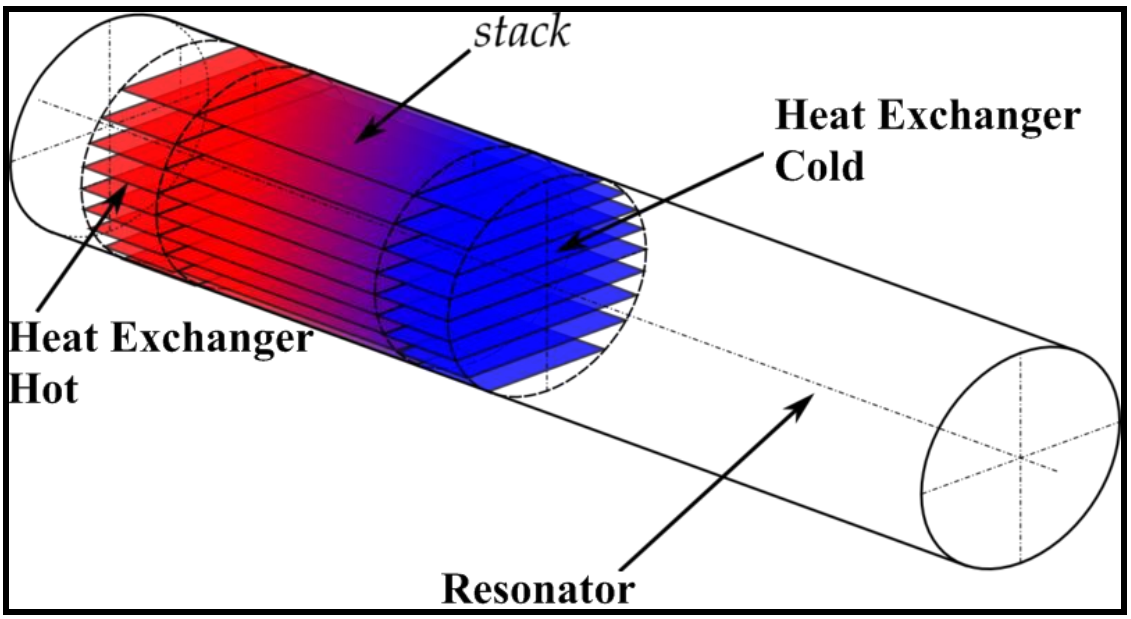


Representative schematic of a typical pulse tube cooler

11.7.3. ThermoAcoustic Cooler

Thermoacoustic coolers can provide a very compact, simple & reliable way for producing the desired refrigeration effect. This cooler also has an advantage of using inert gases and produces very low environmental impact.

The scope of this work will involve development of acoustic coolers for small detector cooling application and handling heat from the heat sinks etc.



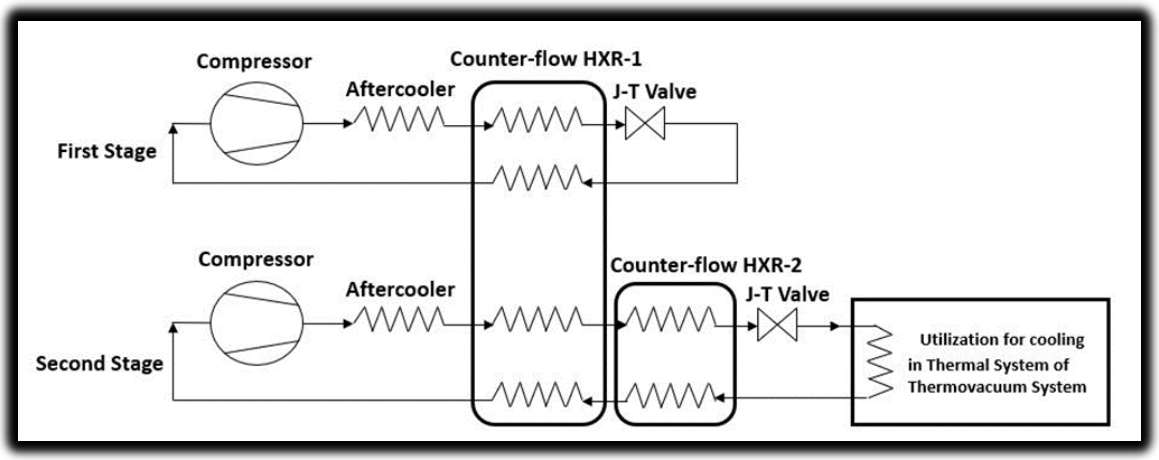
Representative schematic of a typical acoustic cooler

11.7.4. Mixed Gas Refrigeration System

The recent advancements in the development of mixed gas refrigeration systems has generated considerable interests in potential application of such systems, which were earlier out of reach for mechanical refrigeration systems particularly for cryogenic temperatures.

The scope of this work shall involve development of mixed gas refrigeration based thermal system for compact climate test chambers and thermal vacuum chambers. The researchers shall be responsible for design, simulation, analysis, optimization & realization and testing of thermoelectric coolers.

The expected lowest temperature for mixed gas refrigeration system is -150degC in cascade mode. The performance of the realized system will be tested and verified against the target specifications.



Representative schematic of a typical mixed gas refrigeration system

11.7.5. Contamination Control study

Contamination control plays an extremely important role particularly in realization of electro-optical payloads, where any unintended activity/process can lead to severely impact the mission life.

The present proposal entails a study, simulation and analysis of various forms of contaminations like surface and airborne particulates, surface and airborne molecular contaminants in and around thermo-vacuum chambers. Carryout in–depth measurement of such contaminants using APC, PFO, RGA, TQCM available and carry out detailed process study as well as make recommendations in this regard for implementation.

11.7.6. Liquid nitrogen consumption and optimization study

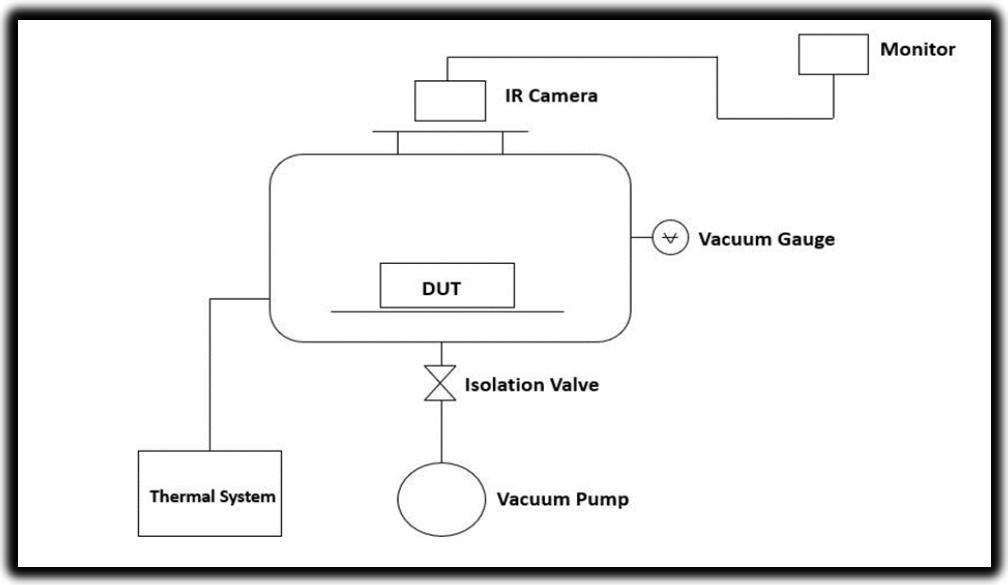
Liquid nitrogen is a fluid of choice for majority of thermal vacuum chambers due to its characteristics like low temperature of liquefaction, very wide temperature range in single phase, large latent heat of evaporation and lower cost. As LN2 is utilized across the facilities in majority of thermal vacuum chambers, its overall usage and optimization is equally important.

The present proposal will involve Study and analysis of Liquid Nitrogen consumption in Thermo-vacuum test facility with respect to different type of tests being carried out in different LN2 based thermo-vacuum chambers. Study and analyze transfer, static and flash losses taking place in various system elements during thermo-vacuum tests and carry out detailed process study as well as make recommendations in this regard for implementation.

11.7.7. InfraRed imaging system for temperature monitoring

Real time temperature monitoring of different critical components and surfaces during a thermal vacuum testing necessitates availability and utilization of an accurate & fast response-based temperature measurement system. Temperature sensor mounting at the required locations on a subsystem is an essential but laborious and time intensive activity, and an IR based imaging system can provide a non-contact type real time temperature monitoring inside a thermal vacuum chamber.

The present scope of work involves a development of IR mapper-based temperature measurement system for monitoring the package temperature inside a thermal vacuum chamber, thereby eliminating the need of physically temperature sensor mounting. The required temperature range for the measurements is, from -40degC to +85degC.

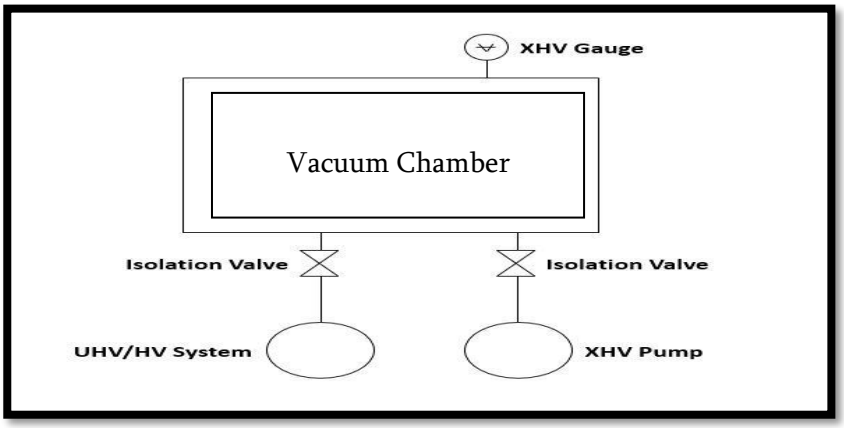


Representative schematic of a typical IR camera-based imaging system

11.7.8. Design and realization of XHV system

Achieving Extreme High vacuum has been a holy grail of vacuum science. Simulation of interstellar space, processing of some advanced semiconductor devices, surface science experiments and measurements are few important applications for XHV level.

The present scope of work will involve development of a small experimental cavity/volume XHV system for achieving better than 1e-12 mbar vacuum.

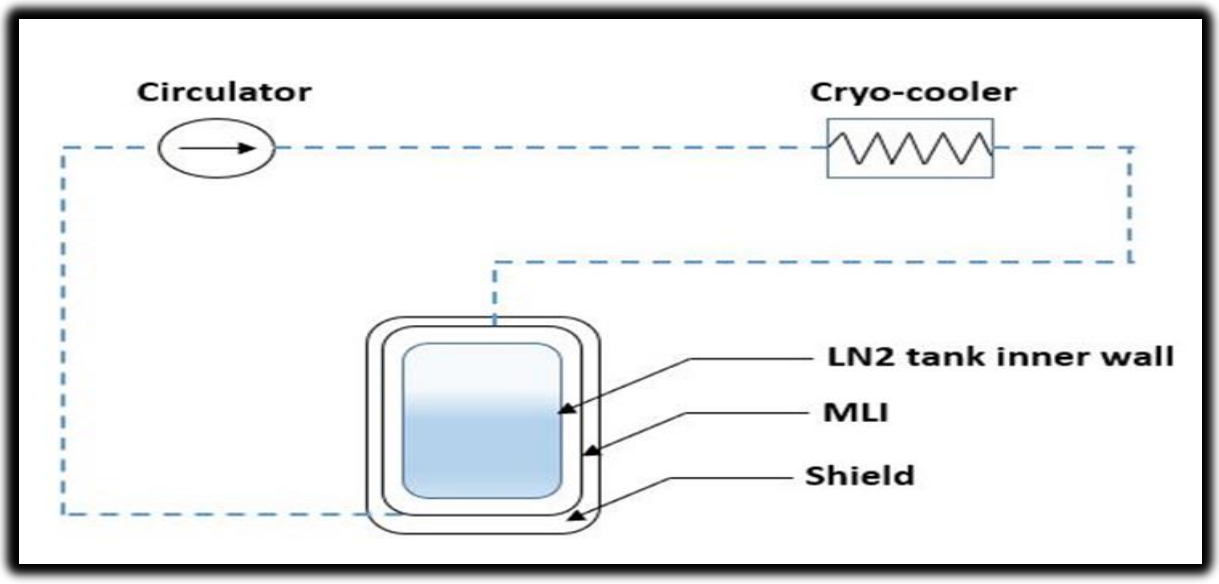


Representative schematic of a typical XHV system

11.7.9. Zero-Boil-Off System

Zero-Boil-Off (ZBO) systems can provide considerable savings for mission critical cryogens particularly for interplanetary missions. These systems become more critical for human space missions needing long duration in space. ZBO-Zero Boil Off Cryogenic system will demonstrate long term storage & saving of cryogen (Experimental system) with minimal cryogen losses from the storage tanks due to natural boil-off. The proposed prototype may also be utilized as a platform for future interplanetary type missions which will certainly have this requirement.

The present study will involve study of different options, simulation and analysis of ZBO system, realization of an experimental system to validate the theoretical models and to make proposal for an operation system.



Representative schematic of a typical ZBO-Zero Boil Off scheme

12. MECHANICAL ENGINEERING SYSTEMS

Research areas in Thermal Engineering

12.1. Efficient Heat Transfer/Transport devices/Energy Storage Systems:

- Loop Heat Pipe
- Pulsating heat pipe (PHP) and its characterization in zero/micro gravity environment
- Micro heat pipes for device level thermal management
- Cryogenic heat pipes
- Heat Pipes with Self-Rewetting Fluids for Space Applications
- Diode Heat Pipes
- Metal-based submillimetre-thick flexible flat heat pipe with innovative wick structures
- Cooling/Pumped Loops
- Phase Change Materials
- Honeycomb panel with heat pipes and PCM
- Any other innovate concept for efficient heat transfer

12.2. Variable Emissivity Coated (VEC) Micro-electromechanical System (MEMS) radiators:

Technologies/process related to development of VEC/MEMS based radiators for optimizing radiator size for deep space missions need to be developed. Collaboration is envisaged in any experimental/numerical aspect of the same.

12.3. Deployable Radiators:

Technologies associated with deployable radiators to optimize heater power need to be developed.

12.4. Cryo Coolers:

Following types of cryo-coolers and its associated technologies (experimental and numerical aspects) need to be developed for cooling of various kinds detectors/systems in various temperature ranges upto 4.2K:

a) Stirling Cryo-cooler
b) Pulse tube Cryo-cooler
c) J-T Cooler
d) Peltier effect Coolers

12.5. Various Cooling technologies for low and ultra-low temperature range cooling :

12.5.1. Adiabatic demagnetization refrigerator (ADR):

Collaboration is envisaged in development of various subsystems and critical technologies related to ADR like salt pill, Magneto Resistive Heat Switches, Superconducting Magnets, etc. Development of numerical code for modelling of magneto calorific effect (MCE) and system level modelling of ADR also need to be taken up in joint academic collaboration.

12.5.2. Dilution Refrigeration:

Dilution refrigerators are a common technique for reaching temperatures below 1K, particularly where continuous cooling at these temperatures is required. Helium exists in two stable isotopes: 4He and 3He. Naturally occurring 3He is extremely rare, constituting less than 1 part per million of helium gas. However, 3He can be manufactured, as it is a radioactive decay product of tritium (3H), an isotope of hydrogen. Almost all 3He used today is artificially produced. A dilution refrigerator uses a mixture of liquid 3He and liquid 4He and takes advantage of physical attributes of these mixtures.

In its simplest form, then, a dilution refrigerator can be created by creating a bath (referred to as the mixing chamber) containing a mixture of 3He and 4He below 0.8K and then pumping on the 4He rich zone. This will preferentially remove 3He atoms. In order to maintain equilibrium, 3He atoms will move from the 3He rich zone to the 4He rich zone, causing the mixture and whatever is thermally attached to it to cool. Without any additional heat load, dilution refrigerators can reach a temperature of less than 10mK. More typically, dilution refrigerators remove 200 – 400 μW at 100mK.

12.5.3. Optical Cooling:

Optical refers to a number of techniques in which atomic and molecular samples are cooled down to near absolute zero. Laser cooling techniques rely on the fact that when an object (usually an atom) absorbs and re-emits a photon (a particle of light) its momentum changes. For an ensemble of particles, their temperature is proportional to the variance in their velocity. That is, more homogeneous velocities among particles corresponds to a lower temperature. Laser cooling techniques combine atomic spectroscopy with the aforementioned mechanical effect of light to compress the velocity distribution of an ensemble of particles, thereby cooling the particles.

Research areas in Composites and Advanced Materials Applications

12.6. Development and characterization of High Strain Tolerant Infusion Grade Resin System for realizing elastic foldable structures for space applications

Resin System are the essential elements for the Development of the Composites materials and components. The resin systems are primarily responsible for the load transferring between the reinforcement materials and protecting it for the environmental effects.

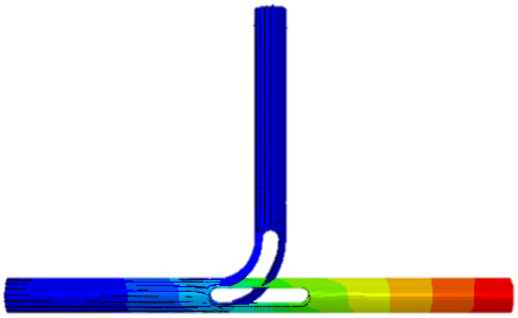
The composites material exhibits linear behavior against the applied load near to its fracture. Large strain tolerant resin system will lead this for the foldable structure to minimize the space requirements by folding it in the launch vehicle envelope. The development of the large strain tolerant (>20 %) resin system will pave the way for minimizing the space about 50% in the stowed conditions.

12.7. Design & Finite Element FE simulation of non-linear behaviour of bendy and foldable composite booms.

In recent years, satellite size is increasing or multiple satellites have been launched in one go but it is constrained by payload fairing size of the launch vehicle. Therefore, it is necessary to make compact and lightweight components in the payload of the spacecraft. Self-deployable composite booms would be very useful candidate to fulfil this requirement.

Design of bendy and foldable composite boom involves geometric non-linearity behaviour because of large deformation, bending and folding. FE simulation is must to predict the bending feasibility, strain energy, stresses, elasticity and establish design margins. Post deployment stabilization timing of the boom is also an important parameter. Shock waves generated by the deployment action are also to be evaluated.

Deployed Boom



Bent or Stowed Boom

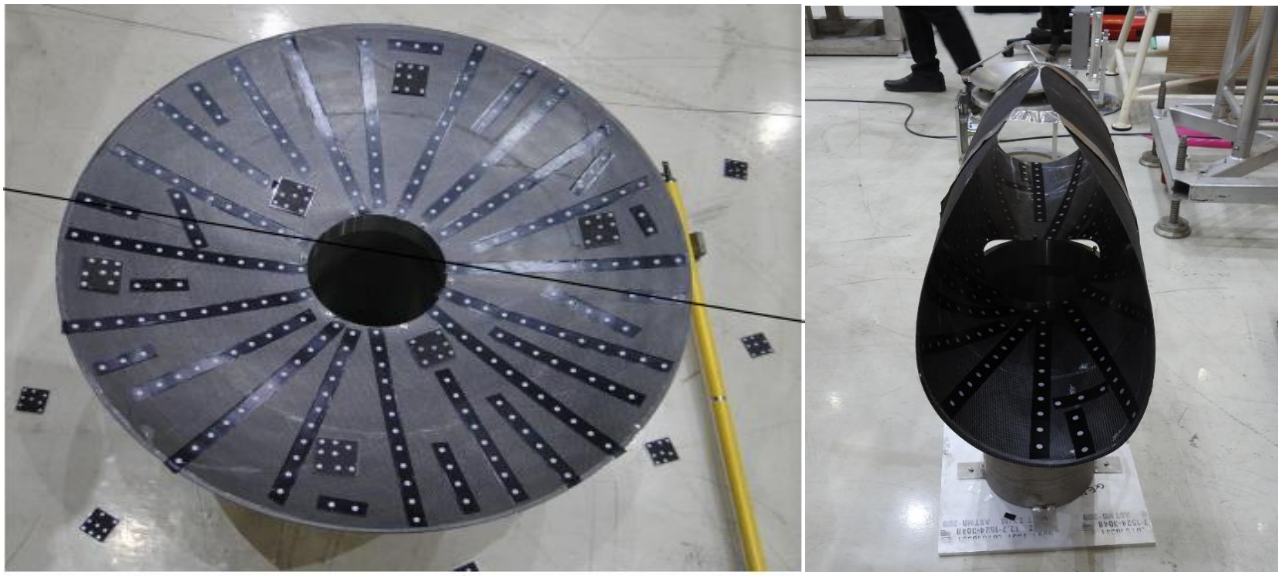
12.8. Development of High Strain Tolerant Infusion Grade Resin System for the Space Applications.

Resin systems are the essential elements for the Development of the Composites materials and components. The resin systems are primarily responsible for the load transferring between the reinforcement materials and protecting it for the environmental effects.

The composites material exhibits linear behaviour against the applied load near to its fracture. Large strain tolerant resin system will lead this for the foldable structure to minimize the space requirements by folding it in the launch vehicle envelope. The development of the large strain tolerant (>20 %) resin system will pave the way for minimizing the space about 50% in the stowed conditions.

12.9. Design, FE Simulation and Development of Elastic Foldable Reflector for Large Aperture Antenna.

Antenna Reflector are the main element for the satellite communication. Due to requirement of the large shape antenna for the future space missions and limitations for the space in the launch vehicle for the accommodation, elastic foldable antenna reflectors are the prime candidate for the future satellite based communications and navigations.



Reflector surfaces in deployed and stowed conditions (indicative)

Development of the large aperture antenna reflectors (at least 2.5m diameter) for the foldable volume <50% to be targeted for stowing. Non-linear FE simulation to be carried out for folding, deployment and stability conditions. A prototype reflector is to be developed and characterized.

12.10. Design and Development of all Composites Mould/Tooling for the Realisation of CFRP Components with high Surface Accuracy for the Space Applications.

Lightweight and dimensionally stable composites Components are the prime candidate for the space applications due to its high specific strength, specific modulus and low CTE properties. Metallic mould/tooling are generally used for the realization of the composites components and Antenna reflectors for the payload applications. But there are mismatch between the designed shape and the realised shape of the composite components because of high CTE of the metallic mould.

All composites tooling/mould having close CTE of composites materials will result in better surface accuracy of the composites components/reflectors. The service temperature of the mould should be up to 250°C. Thermo-structural design and FE simulation of the mould along with CFRP layup should also be carried out.

12.11. Development of shape configurable/deformable parabolic reflector using shape memory alloy (SMA) or equivalent actuation.

Development of large flexible antennas is becoming critical today; such antennas can be realized with shape memory alloy actuated mechanism. It can be reconfigured in space for variable antenna footprint, and hence can be utilized for signal transmission to different geographical locations. Requirement of changing the shape is quasi-static and hence SMA based actuators and very much suitable for this application.

12.12. Metallization of composites for enhancing electrical and thermal conductivity for development of RF components.

Light weight & high modulus composite structures are the need of the current Space scenario. These composite structures provides excellent load carrying member as well as maintaining dimensional stability in harsh space environment. The use of composites are limited to only structural parts. To utilize in realizing RF parts, there is need of improvement of electrical and thermal conductivity of the composites. Metallisation on a composite part itself calls for the various qualification and always leaves uncertainty in terms of quality. The biggest challenge is survival of the metallization in extreme space environment in the orbit. There are various methods, which may be tried for metallization.

- Conductive surface coating or metallization of CFRP. Surface activation & Electro plating or Electro-less plating.
- Development of Electrical Conductive Prepregs /Resin system (lamination) for Space grade composite systems.
- Development of carbon-carbon composites with excellent electrical and thermal conductivity for realization of RF components.
- Metallization of CFRP may also be done by inclusion of graphene/CNT at layup stage.

Existing properties of CFRP:

Electrical Conductivity: 10^{4} S/m

Electrical Resistivity: 10^{-3} Ω.m

Thermal Conductivity: < 1 W/m/K

Desired properties of CFRP:

Electrical Conductivity: 10^{7} S/m

Electrical Resistivity: 10^{-8} Ω.m

Thermal Conductivity: > 50 W/m/K

12.13. Development of techniques for tri-axial in-plane weaving of carbon fibres for realization of spring-back antenna reflectors.

Future communication space programme require larger and highly accurate/precise space borne reflector antennas, while earth observation and scientific missions require even higher frequency operation. To realize such reflectors, flexible thin fabric membranes are to be developed and qualified. These type of reflectors are mainly known as spring-back reflectors and can be developed using tri-axially woven carbon fabric.

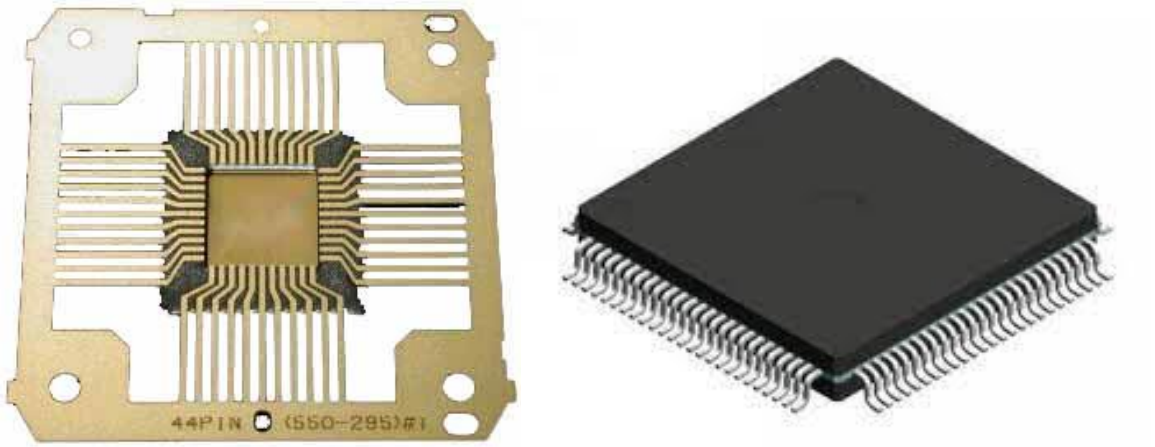
Scope of research may include study, experiment and develop tri-axial (60°/0°/-60°) weaving technique for space grade carbon fibre.

Research Areas in Microwave Payloads Mechanical

12.14. Prediction of metal component behaviour beyond linear elastic range

Behaviour of metal components beyond linear elastic range has remained a gray area in the field of space payload component development. Understanding behaviour of material post plastic deformation will enable accurate life estimation and mass optimization in payload components. For comparison one can take example of an L-angle realized using matching and the other realized by bending a sheet of same material and cross section. The structural behaviour of both the components will be in a way that machined component will be more rigid than the formed component.

The study will enable us to mathematically understand the behaviour, which can be further included in analysis programs to predict accurate life of metals components and joints, where metal forming is inevitable. Such applications are forming of connector and CQFP pins, formed structural components.



QFP before and after pin bending

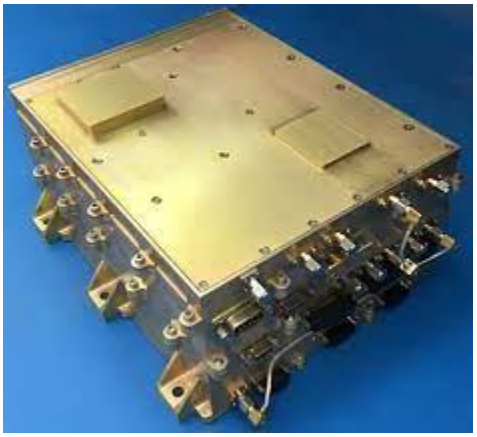
It's expected to evolve mathematical formulation, FE code for behaviour of metals post plastic deformation & Experiment set-up for validation of the mathematical code.

12.15. Implementation of Active cooling methods for Microwave packages of space payloads.

With increase in heat dissipation densities due to increase in power of RF devices and miniaturization of subsystems, current passive cooling techniques have a limitation, which can be overcome by design of compact Active cooling for such devices, which enables utilizing the device capabilities to the fullest. The proposed cooling methods may include Phase change materials, Thermo-electric coolers, micro heat pipes etc.

12.16. Reduction of structural dynamic response in Multi-level Stacked package assemblies.

Payload subsystems are stacked one over the other in order to reduce footprint of electronics subsystems on spacecraft deck. With each level increase in package stacking, the structural dynamic response of the stack on the top increases, which forms limiting factor for the packages/ devices planned to be stacked on the top. A methodology to reduce structural dynamics responses on the stack-up top, without compromising thermal coupling between packages, will enable further reduction in footprint by accommodating more packages on stack-up top.



Multi-level stacked package example

12.17. Effect of Annealing (Heat Treatment) on Surface roughness of Pure metals such as Copper and Aluminium.

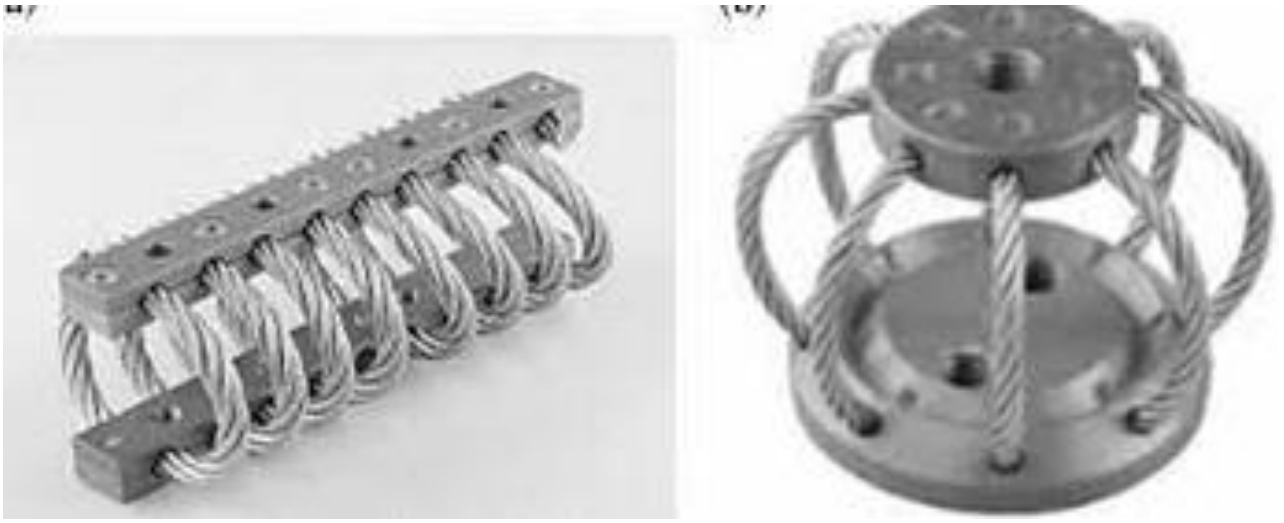
Objective of this study is to examine effect of annealing on surface roughness and its effect on thermal contact resistance. This study is to be done for annealed samples as well as for non-annealed samples to quantify the variations. All experiments are to be done in temperature range of 4-10K, 20-40K & 80-100 K.

This exercise is to be done using OFHC Copper and various metal joint combinations such as 1) Oxygen free High Conductivity (OFHC) Copper to OFHC Copper. 2) Aluminum to OFHC Copper 4) OFHC Copper to Tellurium Copper (TeCu) etc.

Effect of bulk material conductivity and thermal contact resistance is to be also studied after machining annealed samples to achieve better surface roughness.
All the results are to be consolidated and guideline based on the experiments is to be made.

12.18. Finite element simulation of behaviour of Wire rope isolators under vibration environment

Wire rope isolators have been widely used in transportation industry ranging from Rail, road, sea, air to Space transportation. The isolation products made of wire ropes cater to both vibration isolation as well as shock suppression and provide a robust solution to the transportation industry. The products are robust, durable & reliable.



However, the behaviour of such product is less understood in FE environment. Through, the characterisation details of each type of isolator are widely available, if a capability of 'simulating wire rope isolator behaviour' in FE environment is developed, it will enable us to explore many more geometries/ topologies/ arrangements and various loading conditions along with the behaviour of suspended system.

12.19. Measurement of structural & thermal material properties of adhesives for a temperature range of 4K to 500K

Objective of this research is to carry out measurement of structural material properties of adhesives such as Elastic modulus, Poisson's Ratio, yield strength, ultimate strength, shear strength, surface hardness, thermal expansion co-efficient and thermal properties such as thermal conductivity, specific heat capacity. Epoxy based structural, thermal and Room Temperature Vulcanizing (RTV) adhesives, which are used for Aerospace applications, can be considered for the purpose of evaluation of the above mentioned properties for a temperature range of 4K to 500K.

This results obtained from this research should be compiled in a report for use of structural and thermal designers.

12.20. Micromachining of metal components for space use

Future microwave payloads are to be developed in Terahertz frequencies starting from 235 GHz and beyond. Looking to the stringent micro sized geometrical features required for millimetre wave / terahertz

payload components, there is a requirement to establish new facility/augment the existing facilities for manufacturing and metrology in SAC and to explore such state of the art facilities within the country with either Indian industry or academia. To realize such components, methodology for machining of metals such as Al Alloy 6061-T6, OFHC Copper, Copper Tellurium (CuTe) etc., are to be developed and qualified. For said purpose, micromachining process simulation to fine tune the process parameters needs to be done to achieve proper geometrical tolerances and surface finish which is essential to meet the final RF performance parameters. Following table shows some of the feature sizes and tolerances are to be achieved on micro machined components.

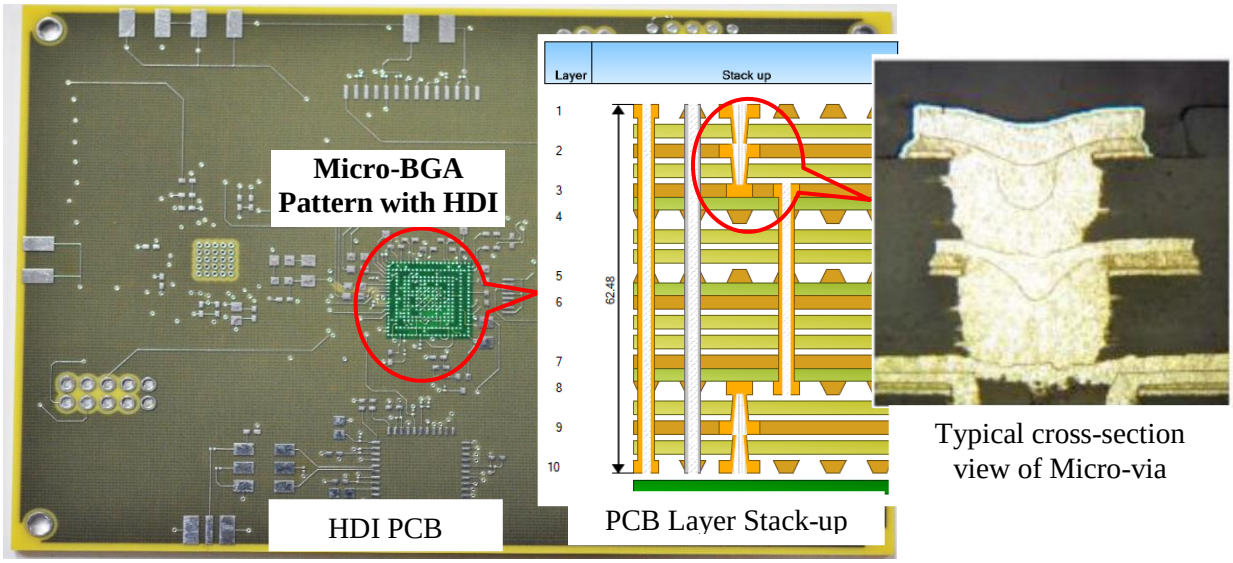
Sr. No.	Feature size	Tolerance (mm)
1	0.56 mm	+0.015 -0
2	0.05 mm	+0 -0.05
3	0.14 mm	+0 -0.01
4	0.1 mm	+0 -0.01
5	0.39 mm	+0 -0.015

Sr. No.	Geometrical Tolerance	Value
1	Flatness	0.01 mm
2	Perpendicularity	0.01 mm
3	Parallelism	0.01 mm
4	Position	0.025 mm
5	Machining finish in microns	0.025 to 1.6 microns

13. SYSTEMS RELIABILITY

Systems Reliability Area (SRA) of Space Applications Centre (SAC) Assures Quality and Reliability for various types of payloads like Communication, Remote Sensing (Optical & Microwave), Navigation, payloads for planetary missions and Sensor Systems for Human Space Program of ISRO.

To achieve this goal, the quality concepts are interleaved into the system from the induction of component, realization of sub-system, to the stage clearances and final launch clearance. SRA made significant contributions in quality assurance activities related to design, component / material selection, procurement, testing, process qualification, surveillance and test & evaluation. The activities includes important aspect of failure analysis of catastrophic and degradation failures encountered during realisation and testing stages, including in-orbit observation; identifying corrective and preventive actions and procedure to reduce recurrence of failure.
This was followed by participation in the spacecraft level tests and In-Orbit testing. SRA played a pivotal



Typical HDI PCB and its construction

role in all phases of development including, parts selection, screening, extensive design reviews of circuits and mechanical assemblies, Quality audits, process verification and subjecting them to rigorous cycles of T&E including life testing. Software QA was also carried out for on-board, checkout and all ground applications software.

Systems Reliability Area (SRA) continued to be guided by its mandate to assure quality and reliability of all onboard and ground systems developed in the center. SRA recognizes the need for continuous update of tools, techniques and procedures to be employed for assuring quality and reliability of increasingly complex and miniaturized payloads with aggressive development schedule. Other than that in order to meet the challenges of new payload development, SRA has continued to build & augment infrastructure and facilities to cater for future payloads. Over the years, SRA has also played a vital role in the indigenization efforts of the Centre.

SRA recognises the importance of continuous research and implementation of innovative techniques; to meet the challenges posed by induction of state of the art technologies & reduced delivery schedules. The present document provides a brief summary of research areas identified by SRA. This is intended to encourage universities and academic organisations to come forward with focused proposals on QC/ QA/ Reliability engineering/ Qualification aspects of systems reliability of payload realisation for funding under RESPOND program of Indian Space Research Organisation (ISRO) through SAC. The document is inspired by a need for pro-active request for research proposals from academic sector in addition to usual mode of receiving and processing funding proposals. The backdrop for this initiative comes from realization of deepening and broadening research fronts at the Centre and the greater professionalism and sophistication of domestic academic sector in the field of system reliability.

13.1. Research Areas in Systems Reliability

13.1.1. Reliability and life estimation of Mechanical Systems and Parts

Mechanical subsystems used in the satellites have to operate continuously and are "mission critical" (i.e. Rotary Joint). Reliability of these subsystems are very important, as they cannot be repaired in case of any failure. Reliability estimation of electronics parts are being done, assumptions are made for mechanical parts and certain relevant factors such as process performance, physics of failure etc. related to design are not considered.

Space subsystems are expected to be purely metallic or a combination of metallic and composite structures. These structures are likely to experience different types of loading such as static, dynamic, fatigue, thermal and thermo elastic etc.

Further above such structures are expected to undergo testing with varying intensities and duration. These combinations of hardware configuration, operating environment and test severities dictate the life of a product.

Scope:

- Define the most suitable methods to analyse and assess the reliability and life of mechanical parts.
- Provide methods and procedures for reliability and life verification by testing (Accelerated testing).
- Provides inputs for development of a handbook on reliability and life assessment of mechanical systems and parts, which can be used for future missions also.

Anticipated Benefits:

Analytical modelling of operating environment and test severity and their impact on life consumed and life remaining of mechanical hardware supports key decision making process.

13.1.2. Development of flexible waveguide for space applications

Waveguide plays crucial role in satellite functionality and transmission of Microwave signals within the satellite. In the confined space of the satellite, or in the large satellite with long waveguide lengths; integration of these interconnecting elements needs critical alignment. Mismatches in waveguide flange

joint results in large stresses at various interfaces. Additionally, thermal excursion results in large stresses in the assembly.
Flexible waveguides provide the required solution to mitigate the joint stresses in waveguide assembly.

Scope:

- Development of flexible waveguide in Ku and Ka band through detailed study of materials and processes suitable for low losses in RF signal and operating in space environment for long life.
- Performance demonstration under defined environmental conditions.

Anticipated Benefits:

Flexible waveguides aids in perfect RF alignment with stress free transponder assembly.

13.1.3. Non-contact method for estimation of Preload in Bolts in the assembled Condition

Assembly of large number of electronics subsystems with the satellite panels is done through bolts. In addition to the subsystems, waveguides, RF cables etc. also form the part of payload. To ensure long and reliable life of each junction; the applied torque is to be verified for each and every fastener / bolt. After integration, there is limited accessibility for verification of the applied torque; and any novel technique to verify torqued stress would overcome this problem, and be very useful to quickly assess integrity in cases of suspected loosening of bolts.

Scope:

- Development of a non-contact method for estimation of the stress/ load/ looseness in the bolts in the assembled condition.

Anticipated Benefits:

This method enables to estimate the applied torque on a remote inaccessible fastener in a space payload

13.1.4. Automated Assembly Inspection using Artificial Intelligence in Image Correlation

A typical space hardware consists of multiple parts in a functional arrangement through various types of joints and processes. All the parts and processes used needs to be evaluated through inspection. In cases of large number of identical subsystems, automation in inspection offers a suitable solution in saving time and achieving consistency in inspection standard.
It is proposed to develop a concept of using Artificial Intelligence in the automation of inspection process of space hardware.

Scope:

- Preparation of setup including Algorithm, Code and related hardware including camera and respective data acquisition hardware etc.

Anticipated Benefits:

Automated inspection system with associated hardware and software supporting rapid and consistent inspection process.

13.1.5. Development of low-weight Passive damping and isolation solution for critical Electronics and Optical components and subsystems aimed at reduction of vibration response.

In Space hardware it is necessary to qualify components/subsystems. Conflicting requirements in terms of weight volume and functionality are often encountered, in such cases solutions are needed to ensure that responses are limited so that failures can be avoided during the flight and testing also. The role of passive damping/isolation solution is critical to avoid high responses at critical components/subsystems.

Scope:

- Understanding and literature survey of tailor made damping and isolation solutions for Space subsystems.
- Optimization and customization of damping and isolation specific to our needs.
- Demonstration of effectiveness of solution on STM and QM of targeted subsystems.

Anticipated Benefits:

Passive damping and isolation solutions will help in reduction of responses at critical interfaces.

13.1.6. Study & Evaluation of Coefficient of friction between different types of materials, interfaces & surface conditions.

Evaluation of Coefficient of friction between different material is of prime importance in space industry to determine the slippage margin, possibility of screw loosening during dynamic vibration testing.
Incorrect coefficient of friction increases uncertainties, which can lead to failures during testing, it can be avoided, if accurate values are taken at the time of design and structural analysis.

Scope:

- Literature survey of International standards and compilation of standard coefficient of friction between the material interfaces encountered in space hardware and method of determination of coefficient of friction.
- Creating an indigenous database of coefficient of friction values for various material interfaces for usage at the time of design.

Anticipated Benefits:

Study and tabulation of Coefficient of friction values will decrease failures/anomalies observed post dynamic testing and improve the design review process.

13.2. Research Areas in Material and Process Development

13.2.1. Development of Nano material based components for Space Applications

Satellite payloads require a large range of mechanical elements. Some are having structural requirements with critical CTE (brackets, spider etc) others require resilience to thermal excursions (feeds, Filters and cavities etc) or high thermal conductivity with zero CTE (for mounting of heat sinks / pipes for detectors and other high power devices) and many are serving as enclosures for electronics.
Nanomaterials such as CNT, Fullerenes, Graphene, Quantum Dots are used as reinforcement in composites such as metal matrix, ceramic matrix and polymer matrix to achieve required bulk properties.

Further, surface properties can be tailored using nano materials like Titanium dioxide, Gold & Silver nano particles, Zinc oxide as surface treatment for future aerospace components.

Scope:

- Theoretical study, optimization and testing of nanomaterial reinforced composite structures for space applications.
- Demonstration of these material for typical payload structures in terms of customisation of desired properties coupled with miniaturization.

Anticipated Benefits:

Mass reduction combined with high thermal & electrical conductivity low CTE culminating into a miniaturised functional product.

13.2.2. Failure Modes & Strength characterization of Composite Sandwich constructions for Space Applications.

Currently Space hardware developed from Composite sandwich constructions using aluminium alloy core with aluminium skin and CFRP skin. Qualification tests evaluates the Mechanical Properties and strength for different types of loading for characterization. The strength Properties are useful to simulate the design of Space Hardware to determine the margins and failure modes.

Further, Process & Product Qualification carried out as per American Society for Testing and Materials ASTM Standard, determines the criteria for Process repeatability evaluation on witness coupons.

Scope:

- Understanding and interpretation of failure modes vis-à-vis types of loading through analysis and experimental validation.
- Optimization of CFRP laminate pattern and vis-à-vis core thickness.
- Defect Characterization through Modal Impact Hammer Test via comparison of Mode shape and amplification.

Anticipated Benefits:

Study results in understanding and rationalisation of correlation between sandwich laminate thickness and core finally leading to anticipation of failure modes.

13.2.3. Metallisation of CFRP for Space Hardware

CFRP (Carbon Fibre Reinforcement Plastic) materials are used for fabrication of space hardware such as Feed horn, Waveguide, Antenna reflectors etc. due to light weight and high strength to weight ratio. Since, CFRP is electrically nonconductive, metallization is necessary to improve RF performance through electrical conductivity and in some cases, to enable its soldering of electronic parts to such CFRP elements.

Scope:

- Development and qualification of Metallisation (Copper/ Nickel / Silver) process on CFRP laminates.
- Demonstration of RF performance including adhesion on a standard component.

Anticipated Benefits:

Electrically and thermally conductive CFRP Based sandwich construction finds many applications in space hardware.

13.2.4. Development of new smart materials for space applications

Smart materials possess adaptive capabilities to external stimuli, such as loads, force or environment, with inherent intelligence. Smart materials which possess the ability to change their physical properties in a specific manner in response to specific stimulus input. The stimuli could be pressure, temperature, electric and magnetic fields, chemicals, hydrostatic pressure or nuclear radiation. The associated changeable physical properties could be shape, stiffness, viscosity or damping. Smartness describes self-adaptability, self-sensing, memory and multiple functionalities of the materials or structures.

Probable Applications:

Spacecraft & Antenna deployment, shape control, flexible structure vibration control, jitter isolation, precision pointing, etc.

Smart materials, regardless of technology field, can be broken down into the following categories:

- Sensing
  - System Identification
  - Health Monitoring
- Quasi Static
  - Deployment
  - Positioning
  - Shape Correction
- Vibration Control
  - Structural
  - Acoustic

Scope:

- Development of new material processes
- Testing & qualification methodology

Anticipated Benefits:

Smart Materials finds applications in harsh environments of space and where on-board actuations are necessitated.

13.3. Research Areas in Software Engineering

13.3.1. Development of Automated GUI testing Environment for Desktop, Mobile and Flash based applications.

Many GUI based applications are being developed and continuously evolved on regular basis in SAC for use within ISRO, as well as external user community for outreach to academia or industry. The testing of these GUI Desktop/ Flash/ Mobile based applications is a challenging task in terms of its test repeatability for multiple versions; evaluating the GUI controls written in multiple programming languages and technologies. Therefore, a test automation framework is desired to be implemented for carrying our regression testing of GUI based Desktop/ Flash/ Mobile applications. This helps in analysing an application from user's point of view for all the GUI controls available on the screen.

Scope:

- Establishment of GUI testing techniques for automated regression testing of desktop, mobile and flash based applications.
- Establishing an integrated functional, performance and security software testing techniques with provision of automated testing of web-based applications also.
- Development of Generic software framework for parallel test execution environment.

Anticipated Benefits:

Automation of GUI applications will aid in testing the continuously evolving multiple versions of applications and improve overall project release turn-around time.

13.3.2. Automating Scenario Based Testing with Unified Modeling Language (UML) and Aspect Oriented Programming (AOP)

Scope:

- The main goal of this project work will be to develop approaches and tools for the automatic generation of executable tests from UML behavioural models (particularly interaction diagrams), taking advantage of existing unit testing frameworks and aspect oriented programming techniques for test execution. These approaches and tools should enable a new generation of "model-based test- driven development (TDD)", that is, a TDD approach in which test are specified in UML.
- Intercept run-time behaviour and check conformance with the UML specification, using Aspect Oriented Programming (AOP) techniques
- User interaction testing in distributed and concurrent systems
- Support for complex features in UML interaction diagrams and the generation of executable tests in different platforms using Model-Driven Architecture (MDA) concepts.

Anticipated Benefits:

New techniques will be established to automate the executable tests from models and improve the overall programming modularity.

13.4. Research Areas in Optical Metrology and Inspection Systems

13.4.1. Development of measurement technique for rubidium atoms in Rb-bulb and Rb-cells

Rb-bulbs and cells are used in rubidium atom frequency standards (RAFS). Amount of rubidium in the bulb is an important parameter for a stable RAFS and it has to be monitored during different phases of screening and qualification of the Rb-bulbs and cells. Highly accurate and precise quantification of amount of Rb within the bulb are required for selecting a reliable Rb-bulb for use in the RAFS.

Hence, efforts are invited to develop accurate and precise measurement technique for Rb-atom in the bulbs and cells.

13.4.2. Development of automated scratch and dig inspection system for optical components

Coated optical components are frequently used in imaging systems. Coating imperfections such as scratch and dig are to be quantified for screening and qualification of the optical components. Manual scratch and dig inspection method is very exhaustive and cumbersome. For automated scratch/dig inspection system an imaging system of very high dynamic range to be developed which can acquire image of anti-reflecting

surface and light scattered from the scratch simultaneously. This acquired image has to be processed further for quantification of scratch/dig and finally generate an inspection report.
The scope of this work shall involve to develop imaging system with pixel level dynamic range control and image processing for image stitching & quantification of the scratch/dig parameters.

13.4.3. Development of high efficiency coupler for single mode (SM) fibre to SM silicon waveguide

Ultra-compact photonic integrated circuit is an emerging field in photonics. The dimension of the SM silicon waveguide is in sub-micron range. To characterise SM silicon waveguide, light has to be coupled to the waveguide from SM fiber and from silicon waveguide to the SM fiber. Coupling of light from fiber to the waveguide and vice versa is very critical for characterization of the waveguides.
Hence, efforts are invited to develop robust coupler for coupling light from the SM fiber to the silicon waveguide and from silicon waveguide to the SM fiber with high efficiency.

13.5. Research Areas in Space Radiation effects and mitigation

Space radiation is one of the environment encountered by Satellite systems. Electronic, Electro-optic and Opto-electronic components are sensitive to such space radiation. The environment and effects are well characterised for existing technologies. However, radiation effect and mitigation technique studies are required for State of the Art semi-conductor technologies. This calls for development of model as well as development of shielding materials.

13.5.1. Development of nano-particle based polymer composites flexible material

One of the possible technique to protect the electronic component from Total ionisation is providing shielding. The conventional techniques employ usage of high density metals to attenuate the radiation. However, this causes mass penalty and also the secondary radiation which may have adverse effect on the semi-conductor. Nano-particle impregnated polymer material is one of the possible solution providing shielding with advantage of lower mass as well as flexible material which can be shaped as per the component package.

13.5.2. Development of resin based Radiation shielding material

Study involves development of resin based shielding material having combination of thermally conductive materials like Bismuth and Boron to replace existing tantalum/ Lead based radiation shielding materials which is heavy and not flexible.

Scope:

- Activity involves identification of suitable materials, finalization of their chemical composition, process optimization, attachment compatibility with package, material fabrication and characterization.
- The developed material will be used to improve shielding effectiveness of the electronic hardware. Thus, the material should have good thermal conductivity and also provide high attenuation/ absorption to space radiations. Possibility for usage of Nano-composites shall be explored.
- Material should be 3D printable and cure at normal ambient temperature

Anticipated Benefits:

- Developed material can be used to provide shielding against space radiation for all the semiconductor devices of all payloads.

- ❖ Easy to Use over all-electronic components located anywhere on PCB.
- ❖ Weight reduction over conventional materials used for shielding.

13.6. Research Areas in Failure Mechanism in Composite Semi-conductors

State of the art semi-conductor technologies offer edge on performance with advantage of miniaturisation. However, usage of these technologies calls for qualification of components and thorough understanding failure mechanism. There are wide variety of EEE components realised in composite semi-conductors like GaN, InGaP, InGaAs with different technologies.
Scope of the work involves study of possible failure mechanism for the semi-conductor material and fabrication technology and generating models for the same.

13.7. Research Areas in Reliability Prediction

Design analysis is an important aspect in satellite payload reliability assurance. Reliability analysis, failure rate estimation is one of analysis carried out to assess compliance to mission goal. This needs the failure rate numbers, models to calculate the failure rates. For VLSI technologies, ASICs and state of the art technologies, the empirical numbers are conservative. For such applications models and failure rate numbers are to be derived based on the design and application conditions.

Scope: Studies on failure mechanism, its model generation and Reliability prediction of following technologies is targeted.

(a) FPGAs (with ≤ 65nm feature size process) considering different failure mechanisms and actual HDL/RTL design
(b) Rubidium Lamp for use in Atomic Frequency Standard for navigation applications.

Targeted outcome :

- Modelling of failure mechanisms as per literature and field data (commercial applications) to arrive at the failure rate (in FITs) under actual operating environment
- Consideration of technology and packaging attributes on reliability
- Contribution of design and environment on the reliability

14. MANAGEMENT & INFORMATION SYSTEMS

As SAC carries out many advanced R&D activities and executes many time bound projects with huge budget, a management support group is established for resource planning and monitoring. The functions related to Sponsored Research and Academic interface, Technology transfer and Industrial interface, Human Resources development, Management Information System and Networks planning and operations as well as managing the IT facilities, Mechanical and Electronics Capacity building and Centre Safety are the other tasks carried out by this Area. Through Capacity building, SAC facilitate planning and outsourcing of jobs to various external vendors for mechanical and electronics fabrication and associated activities along with development of new vendors.

Academia is invited to contribute in various aspects of R&D in Management and Information Systems.

Research Areas in the field of Management

14.1. Knowledge Management in Collaborative and Research Partnerships

Knowledge management is a process of capturing, developing, sharing and effectively using knowledge The importance of Knowledge Management is well recognized in all forms of organizations. Knowledge Management is all the more important in research and innovation led organizations, since most of the assets in these organizations are intangible in nature. To be productive and efficient in a competitive and dynamic environment, effective knowledge management is of critical importance and need R&D in an innovation led organization like ISRO.

The Knowledge generated can be broadly classified into two categories: explicit and implicit. Explicit knowledge includes research papers, documents, software, algorithms, and so on. Implicit or tacit knowledge involves observations, experience and so on that are not often documented and exists in the consciousness of the participants. The importance of tacit knowledge is equally important as explicit knowledge. While explicit knowledge exists in organizations, the implicit knowledge exists in people.

Effective management information systems in research and development enable innovation and help organisations avoid redundancy. Technology can also help the organisations capture tacit knowledge which is otherwise lost in passive communication among the research group. There is significant scope for developing an integrated solution for knowledge management and tacit knowledge capture. The objective of this research is to create a framework for a knowledge management system which is capable of both managing explicit information and boosting tacit information capture. The web based applications and new tools can be developed to capture tacit knowledge which is otherwise lost in passive communication among the research group. An integrated framework and management system for capturing tacit and explicit knowledge with enhanced knowledge management can be generated with academia support. Tools like Machine Learning (ML), Artificial Intelligence (AI) and in particular Natural Language Processing (NLP) can be used for information discovery, extraction, topic classification, fuzzy and semantic search which could be integrated in to the Knowledge Management system for better engagement.

In addition, Review and SWOT analysis on the existing processes of Knowledge Management Systems at other R&D organisations is also required. Establishing Key Performance Indicators (KPIs) and Metrics for

analysing the quality and quantity of knowledge captured based upon number of contributions, interactions, avg. response time, Daily & Monthly Active Users (DAU & MAU), Search activities, number of backlinks or number of times an article is shared, number of upvotes, number of views / reads, Avg. reading time duration etc. can ne included.

The Knowledge Management system framework will be very useful to capture tacit and explicit knowledge generated through execution and implementation of sponsored research projects in ISRO's current and future missions and programmes.

14.2. Fostering Innovation through Research in Science and Technology (FIRST)

A scientific invention is a new idea or concept generated by research and development. The scientific convention when transformed and applied as a socially useable product becomes an innovation. An intrapreneur is a visionary inventor who pursues the idea into a profitable reality. Developing innovation and intraprenurship culture in Govt. R&D Organizations may be a thoughtful approach for skill development and improving the research quality with growing organisational needs and future challenges. Fostering a creative and intrapreneurial environment is the requirement of the current times. The implementation strategy may include translational research domains relating to both enabling science and technology as well as government's citizen centric priorities in various fields viz. agriculture, environment, natural resources management, disaster preparedness and management etc.

14.3. Crowdsourcing, an emergent tool for Knowledge Management in a R&D organisation

Crowdsourcing principles when applied in R&D may result to technological innovations, which can enhance the knowledge management. 'Collective wisdom' through crowdsourcing gradually evolve into focussed problem solving. Crowdsourced R&D inputs may offer hitherto undiscovered potentialities for solving societal problems; in particular using space technology. Due to the increasing complexity of our world and the way change occurs "faster" than we can evaluate the changes, let alone respond to them, the process of crowdsourcing may yield timely capabilities and policies to support the systems in a R&D organisation.

14.4. Research Productivity Assessment and Evaluation of Research at Govt. R&D organisation

As it may be noted that more than 45% share of India's gross expenditure on R&D comes from the Central Government, it becomes imperative to explore the quantum of research contribution by these institutes. The main objective of research is to produce new knowledge. A research activity is a process with human intellect, tangible (scientific instruments, materials etc.) and intangible (accumulated knowledge, social networks etc.) resources used as inputs. The output in form of 'new knowledge' has a complex character of both tangible nature (publication, patent, database, paper presentations etc.) and intangible nature (tacit knowledge, experience gained etc.). Thus, research is a multi-input and multi-output process.

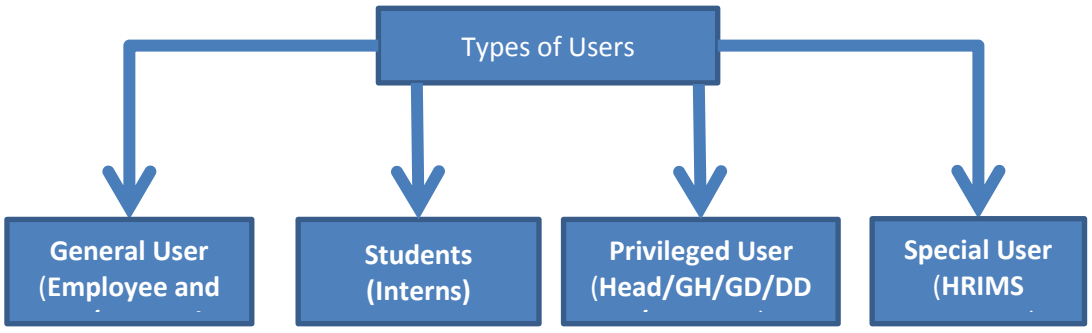
Currently, following Project Evalution approach is being carried out to carry out tehcno-managerial evaluation of completed Sponsored Research projects at SAC.

Academia can put forward their expertise and submit research proposals which may address:

- Study of standard tools for gauging institutional research contribution and feasibility of their application in present setup.
- Design and development of tools and matrices for institutional research productivity assessment.

14.5. Human Resources Development

- Engaged employees demonstrates organization citizenship behavior (OCB) and hence, employee engagement has significant influence on organizational performance. Understanding the employee engagement in Indian R&D context helps in designing effective HR practices in engaging millennials effectively.
- HR analytics is less explored area in R&D organization, particularly using big data generated at the user end. The research may include identifying potential use of social media analytics for HRM. The potential use of AI and ML might result in generating action-oriented HR practices in Organisation.
- Personality and performance are correlated and psychometric tool development is another possible area of research in the domain of HR.



Human Resource Information Management System (HRIMS)

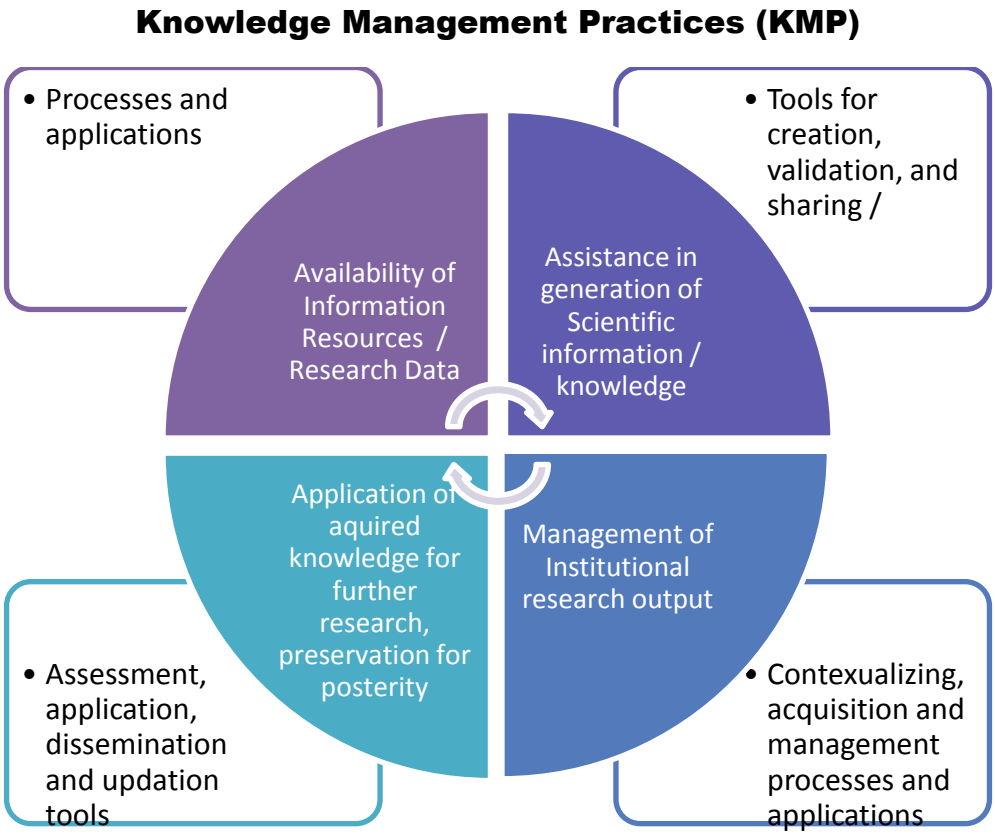
14.6. Work flow design/ management

Under this researcher should study work flow of the various electronics & Mechanical Fabrication and suggest the improvements. Also designing of the web-based tracking mechanism for the effective management.

14.7. Monitoring & Evaluating Projects: Contemporary Methods

Projects Management and Monitoring: Measuring Performance: Earned Value Analysis Methods and other methods like trend analysis etc.

14.8. Library Information Science: Knowledge Management Practices in Research and Development



Libraries represent an indispensable link in the scientific system chain, an important link in the knowledge innovation. Knowledge management (KM) has rapidly moved beyond the stage of a trend and has established itself as a key part of many libraries' knowledge strategy. Knowledge and information has become a key resource and is very vital for the survival of the organization in the future. Due to increasingly dynamic environment, organizations are beginning to realize that there is a vast and largely untapped asset floating around the organization.Major functions of Knowledge Management includes development of- processes and applications for transforming research data into scientific information; tools for creation, validation, standardization and dissemination or sharing of knowledge; the acquisition,

contextualizing, and management processes; and assessment and applications tools using information and knowledge. The core of the process is how to make implicit or tacit knowledge, explicit.

It involves a multi-disciplinary approach to achieve organisational objectives by making the best use of the explicit and tacit knowledge of researchers. The suggested research topics are:

- Exploring various Knowledge Management Systems (KMS) programs in different R&D organisations. Investigating missing interactions in present knowledge management system. Designing suitable framework for effective Knowledge Management System.
- Development and designing of processes and applications for access management; resource management, validation, contextualizing, and standardization.
- Development and designing of processes and applications for effective information retrieval and dissemination tools, integrated search and other applications for meaningful utilization of knowledge pool.
- Delivery of organized knowledge resources through innovative information services.
- Preservation of Institutional Intellectual output.

14.9. Research Data Management

Research is crucial for society's scientific advancement and prosperity and research data is indeed the primary component that conveys the research findings and implications. Organisations are also initiating research data management services to manage and preserve data for future reuse and transparency in research. Open Science has become a new paradigm for research and Research Data Management (RDM) supports open science through a standardized organisation of research data for access, reuse and long term preservation. To meet challenge of big datasets resulting from research RDM will play a vital role in an organisation.

14.10. Cyber Services and Information Security

The digital world is a reality today in all aspects of our lives. Digital infrastructure is the backbone of prosperous economies, vigorous research communities, strong state defense, transparent governments and free societies. As never before, Information and Communication Technology (ICT) is fostering transnational dialogue and facilitating the global flow of information, goods and services. The reach of networked technology is pervasive and global. For all organizations, the underlying digital infrastructure and information has become a critical asset.

For SAC, the information could be strategic (Project documents), personal (Employee data etc.), legal (Indents related activities), financial (Budget documents, PO copies), procedural documents (Design documents) etc. With the advent of technology and need for ease of access, SAC had also taken initiatives in the direction of digitalization. Digitization increases the productivity and efficiency that facilitates SAC users to focus on innovation and R&D. It also has other advantage like immutable backup of data for a longer duration of time, flexible and optimal archival policies based on user profiles etc. However, Digitization comes with its own set of challenges.

Threats to information of critical organization like ISRO are increasingly organized and targeted, helping criminals, state actors and hacktivists to reap immense benefits out of information compromise, theft or

espionage. Cybercriminals can carry out identity theft and financial fraud; steal critical information such as intellectual property; conduct espionage to steal ISRO's state related secrets; and disrupt critical infrastructures by exploiting the vulnerabilities in any system connected to the Internet. The cybercriminals could be located anywhere in the world and they can target a particular user, system or a particular service in ISRO IT assets. Worse still, the cybercriminals can cover their tracks so that they cannot be traced. Thus, there is a need to protect the critical IT assets of SAC without compromising the flexibility of SAC users in the internet connected modern era. Though the domain of research in cyber security field is immense and diversified, certain research areas like indigenous hardware-based VPN, cryptography and cryptoanalysis, side channel attacks, security of air-gap networks, zero day vulnerability detection of SAC IT assets, secured data flow between different trust networks, breach detection and response solutions, Zero Trust Network access, Network Admission Control, Botnet Detection & DNS Security, indigenous design and development of perimeter and endpoint security solution could be of major interest for SAC.

14.11. Design / Deployment plan of one space infrastructure on new technology platform

- Zero-foot print compute set up, office space & lab space: No overhead on client or user and only charge or audit on actual use (green computing).
- Use of active screen (wearable / non-wearable with embedded processor, ports and memory) similar to mobile with wi-fi network.
- Work at anytime, anywhere through high speed network, secure compute-data warehouse infrastructure similar to cloud on earth now (next in space).
- AI & ML adoption in demand & supply (similar to learning, fault prediction and solution): Actual thing start before and synchronize with thinking level from human brain from the present model and problem analysis, situation understanding, meeting and solution in best fit approach.
- Unified Platform for researcher, student, developer of any domain to try, adopt, implement, distribute the product. Plug and play (add, modify, model, visualize, analysis, discussion, meet, decision for engineering, medical and societal use).

14.12. Other topics

- Technology Forecasting with respect to State of the Art Technologies
- Organisational communication
- Information dissemination methods
- Learning & Development
- Development of Competency Framework for different categories of people
- Profiling New Generation S&T people
- Employee Engagement
- Organisational Commitment
- Research on Planning and development strategies
- Enterprise Resource Planning in Govt. R & D organization
- Impact Assessment of Sponsored Research at Academia

Acronyms

3GPP: 3rd Generation Partnership Project

AAR: Accumulation Area Ratio

ACeS: Adaptive Communication Environment

ACM: Adaptive Coding and Modulation

ACRs: Active cavity radiometers

ADCs: Analog to Digital Converters

ADR: Adiabatic demagnetization refrigerator

ADS-B: Automatic Dependent Surveillance-Broadcast

AGC: Automatic Gain Control

AI: Integer Ambiguity

AIS: Automatic Identification System

AIT: Assembly, Integration, Testing

AL/ML: Artificial Intelligence and Machine Learning

AMBA: Advanced Microcontroller Bus Architecture

AMR: Automatic Modulation Recognition

AMS: Additional Member System

AMV: Atmospheric Motion Vectors

ANN: Artificial Neural Network

AOD: Atmospheric Optical Depth

AOP: Aspect Oriented Programming

APB: Aadhaar Payment Bridge

APEX: Advanced Programming Experience

APS: Active Pixel Service

AR: Ambiguity Resolution

ARD: Analysis-Ready-Data

ARM: Advanced RISC Machine

AS: Autonomous System

ASG: Antenna Systems Group

ASIC: Application-Specific Integrated Circuit

ASICs: Application Specific Integrated Circuits

ASTM: American Society for Testing and Materials

ATS: Automated Test System

AVIRIS: Airborne Visible/Infrared Imaging Spectrometer

AVPU: Audio Video Processing Unit

AWGN: Additive white Gaussian noise

AWiSF: Advanced Wide Field Sensor

AWLR: Acoustic-Wave Lumped, Element Resonator

BaF2: Barium Fluoride

BAQ: Block Adaptive Quantization

BCH: Bose-Chaudhuri-Hocquenghem

BDU: Battery Disconnect Unit

BER: Bit Error Rate

BiCMOS: Bipolar Complementary Metal-Oxide Semiconductor

BISAG: Bhaskaracharya Institute of Space Application and Geoinformatics

BLDC: Brushless Direct Current

BOC: Binary offset carrier

BPF: Broncho Pleural Fistula

BPSK: Binary Phase Shift Keying

BUC: Block Up Converter

BW: Bandwidth

BWG: Beam Waveguide

CAD: Computer Aided Design

CAM: Computer Aided Manufacturing

CAN: Controller Area Network

CATR: Compact Antenna Test Range

CBOC: The Composite BOC

CBPO: Capacity Building Programme Office

CCD: Charge Coupled Device

CCSDS: Consultative Committee for Space Data Systems

CDMA: Code Division Multiple Access

CDOM: Coloured Dissolved Organic Matter

CFDC: Clock Fault Detection and Correction

CFRP: Carbon Fiber Reinforced Polymer

CGH: Computer Generated Holograms

CGMS: Continuous Glucose Monitoring System

CHEOPS: Characterising ExOPlanets Satellite

CIC: Carrier-In-Carrier

CLEO: Conference on Laser and Electro-Optics

CMM: Comparison Measurement

CMOS: Complementary Metal-Oxide Semiconductor

CNC: Computer Numerical Control

CNMF: Coupled Non Negative Matrix Factorization

CNN: Convolutional Neural Networks

CNT: Carbon Nanotube

COTM/SOTM: Communication on the Move / Satcom on the Move

COTM: Communication On The Move

COTS: Commercial-off-the-shelf

CPT: Coherent Population Trapping

CRPA: Control Radiation Pattern Antenna

CS: Component Substitution

CSI: Channel State Information

CSSTEAP: Centre for Space Science and Technology Education

CSSTEAP: Centre for Space Science and Technology Education in Asia Pacific

CTAG: Communication Technology and Applications Group

CuTe: Copper Tellurium

CW: Continuous Waves

CYGNSS: Cyclone Global Navigation Satellite System

DABF: Data Acquisition and Beam forming

DACs: Data Assimilation Converters

DAOs: Distributed Autonomous Organizations

DAU & MAU: Daily & Monthly Active Users

DC: Data Cube

DDM: Delay Doppler Map

DDR3: Double Data Rate 3

DEM: Digital Elevation Model

DIC: Dissolved Inorganic Carbon

DL: Deep Learning

DMA: Direct Memory Access

DMS: Dilute Magnetic Semiconductor

DN: Digital Number

DOAS: Differential Optical Absorption Spectroscopy

DOC: Dissolved Organic Carbon

DPA: Dual Polarization Antenna

DPRAM: Dual Port RAM

DRIE: Deep Reactive Ion Etching

DRT: Data Relay Transponders

DSP: Digital Signal Processors

DTH: Direct To Home

DVB-RCS: Digital Video Broadcasting - Return Channel via Satellite

DVB-S2/T2: digital video broadcast satellite/terrestrial

DVB-S2: Digital Video Broadcasting – Second Generation

DWDM: Dense Wavelength Division Multiplexing

DWL: Direct Write Laser

DWR: Doppler weather radar

ECLSS: Environmental Control and Life-support Subsystem

ECMWF: European Centre for Medium Range Weather Forecasting

ECTC: Electronic Components and Technology Conference

EDFA: Er Doped Fiber Amplifier

EDFAs: Erbium Doped Fibre Amplifier

EEPROM: Electrically Erasable Programmable Read Only Memory

EGNOS: European Geostationary Navigation Overlay Service

EKF: Extended Kalman Filter

EM: Electromagnetic

EMC: Electro Magnetic Compatibility

EMI: Electromagnetic Interference

ENOB: Effective Number of Bits

EO: Earth Observation

EO: Earth Observational

EO: Electro-optical

EOS: End of season

EPC: Electronic Power Conditioner

EPSA: Earth, Ocean, Atmosphere, Planetary Sciences And Applications

EPT: Embedded Passive Technology

ESA: European Space Agency

ESCES: Experimental Satellite Communication Earth Station

ESIM: Earth stations in motion

ESSA: Enhanced Spread Spectrum Aloha

ETSI: European Telecommunications Standards Institute

EVA: Extra Vehicular Activity

EVM: Error Vector magnitude

EXPO: Exposition large- Scale Public Exhibition

FD SOI: Fully Depleted Silicon On Insulator

FDTD: Finite-difference Time Domain

FE: Finite Element

FEC: Forward Error Correction

FEM: Finite Element Method

FFT: Fast Fourier Transform

FMCW: Frequency Modulated Continuous Wave

FMR: Ferromagnetic Resonance

FMT: Fecal Microbiota Transplantation

FOV: Field-Of-View

FPGA: Field Programmable Gate Array

FSO: Floating Storage and Offloading Unit

FSS: Fixed Satellite Services

FTLE: Finite time Lyapunov exponent

G/ T: Antenna Gain-To-Noise-Temperature

GA: Geometric algebra

GaAs: Gallium Arsenide

GAGAN: GPS Aided Geo Augmented Navigation

GaN HEMT: Gallium Nitride High Electron Mobility Transistor

GaN: Gallium Nitride

GCOS: Global Climate Observing System

GEO: Geostationary Orbit

GeoSAR: Geosynchronous Synthetic Aperture Radar

GIS: Geographical Information System

GISAT: Geo imagine Satellite

GLOFs: Glacial Lake Outbursts Flood

GMI: GPM Microwave Imager

GMR: Grandhi Mallikarjuna Rao

GMSK: Gaussian Minimum Shift Keying

GNSS: Global Navigation Satellite System

GNSS-R: GNSS Reflectometry

GOPS: Giga Operations per Second

GPR: Ground penetrating RADAR

GRIN: Graded refractive index

GRU: Gated Recurrent Unit

GSAT: Geo Synchronous Satellite

GSAT: Geosynchronous Satellite System

GSM: Global System for Mobile Communication

GSO: Geosynchronous Orbit

GTS: Ground-To-Satellite

GTU: Gujarat Technological University

HabEx: Habitable Exoplanet

HAD: Hazard Detection and Avoidance

HDLC: High-level Data Link Control

HDR: High Data Rate

HEM: Handheld Environment Monitor

HEMT: High-Electron-Mobility Transistor

HKH: Hindu-Kush-Himalayan

HMC: Hybrid Microcircuits

HRWS: High Resolutions Wide Swath

HSU: Humidity Sounder

HSU: Humidity Sounding Unit

HTL: High Threshold Logic

HTS: High Throughput Satellite

HySure: Hyperspectral Image Superresolution via Subspace-Based Regularization

IBIS: I/O Buffer information Specification

IC: Integrated Circuit

ICCSAE: International Conference on Computer Sciences and Automation Engineering

ICO: Initial Coin Offering

ICT: Information and Communication Technology

IDDCA: IR detector cooler assembly

IDEA: Individuals with Disabilities Education Act

IEMs: Interest Exploration Meetings

IF: Instruction Fetch

IFFT: Inverse Fast Fourier Transform

IGB: Indus, Ganga and Brahmaputra

IISc: Indian Institute of Science

IITs: Indian Institute of Technology

IMD: India Meteorological Department

IMD: Indian Meteorological Department

IMPRINT: IMPacting Research INnovation and Technology

IMS: Indian Micro Satellite Bus

INS: Indian Nano Satellite Bus

INS: Inertial Navigation System

INSAT: Indian National Satellite

INSAT: Indian National Satellite

IoT: Internet of Things

IPC: Indian Panel Code

IR: Infrared Radiation

IRNSS: Indian Regional Navigation Satellite System

ISL: Inter satellite link

ISM: Indian summer monsoon

ISM: Industrial, Scientific and Medical

ISMR: Indian Summer Monsoon rainfall

ISO: International Organization for Standardization

ISRO: Indian Space Research Organisation

ITU: International Telecommunication Union

ITWG: International Technical Working Group

IWV: Integrated Water Vapour

JPSS1: Joint Polar Satellite System

KaRa: Ka band RADAR

KMP: Knowledge Management Practices

KMS: Knowledge Management Systems

KPIs: Key Performance Indicators

LASER: Light Amplification by Stimulated Emission of Radiation

LDPC: Low density Parity check code

LEO: Low Earth Orbit

LIDAR: Light Detection and ranging

LIGA: Lithographie, Galvanoformung, Abformung

LISS: Linear Imaging Self Scanning

LMS: Least Mean Square

LN2: Liquid nitrogen

LNAs: Low-Noise Amplifier

LO: Local Oscillator

LOS: Line of Sight

Low-Swap: Low-Size, Weight And Power

LSPRs: Localized Surface Plasmon Resonances

LSTM: Long Short-Term Memory

LTCC: Low Temperate Co-fired Ceramics

LTF: Logistics Task Force

LTL: Less than Truckload

LUT: Letter of Undertaking

LVCMOS: Low Voltage Complementary Metal Oxide Semiconductor

LVDS: Low-Voltage Differ-ential Signaling

LWIR: Low-Wave IR

M2M: Machine to Machine

MATLAB: Matrix Laboratory

MBOC: Multiplexed binary offset carrier

MBSA: Mechanical Beam-Steering Array Antenna

MCC: Master Control Centre

MCE: magneto calorific effect

MDA: Model-Driven Architecture

mDBF-AC: Multi-Channel Digital Beam Forming & Autonomous Controller

MDC: Multistage Depressed Collectors

ME: Magneto-electric

MEMS: Micro-electromechanical System

MEO: Medium Earth Orbit

MF: Measurement Filtering

MHRD: Ministry of Human Resource Development

MHS: Millimeter Wave Humidity Sounder

MIC: Microphone Circuit

MIMO: Multiple-Input Multiple-Output

MLM: Mars Landing Mission

MMICs: Monolithic Microwave Integrated Circuits

MNIT: Malaviya National Institute of Technology

MOSDAC: Meteorological & Oceanographic Satellite Data Archival Centre

MOSFET: Metal-Oxide Semiconductor Field Effect Transistor

MRA: Multiresolution Analysis

MRAM: Magnetoresistive Random Access Memory

MRS: Magnetic Resonance Spectroscopy

MRSA: MICROWAVE REMOTE SENSORS AREA MICROWAVE REMOTE SENSORS AREA

MSK: Minimum Shift Keying

MSS: Mobile Satellite Service

MWIR: Medium-Wave IR

MWP: Microwave Photonic

MX: Multi-Spectral

NAND: Not AND

NASA: National Aeronautics and Space Administration

NavIC: Navigation with Indian Constellation

NCMRWF: National Centre for Medium Range Weather Forecasting

NCP: Network Control Program

NISAR: NASA ISRO Synthetic Aperture Radar

NIST: National Institute of Standards and Technology

NIT: National Institute of Technology

NLP: Natural Language Processing

NLP: Natural Language Processing

NMOS: N-channel Metal-Oxide Semiconductor

NMS: No Man's Sky

NOMA: Non Orthogonal Multiple Access

NPP: National Power Portal

NTA: Nanoparticle Tracking Analysis

NTAG: Navigation Technology and Applications Group

NTN: Non-Terrestrial Network

NTN: Non-Terrestrial Networks

NWP: Numerical Weather Prediction

OBC: On-Board Computer

OBDH: On-Board Data Handling

OBSP: Onboard SAR processor

OCB: Organization Citizenship Behavior

OCM: Organizational Change Management

OCT: Optical Communication Terminal

OCW: Optically Complex Waters

OFDM: Orthogonal Frequency-Division Multiplexing

OFHC: Oxygen free High Conductivity

OGS: Optical ground stations

OLCI: Ocean and Land Colour Instrument

OMA: Orthogonal Multiple Access

ONCLE: Onboard Clock Ensemble

ONFI: Open NAND Flash Interface

OSNR: Optical Signal To Noise Ratio

OSSE: Observation System Studies Experiment

PAA: Phase Array Antenna

PAT: Pointing Acquisition And Tracking

PCB: Printed Circuit Board

PCCC: Parallel-Concatenated Convolutional Codes

PCMA: Professional Convention Management Association

PHP: Pulsating Heat Pipe

PIC: Photonics Integrated circuits

PID: Proportional-Integral-Derivative

PIM: Passive Intermodulation

PLL: Phase Locked Loop

PMAs: Plasmonic Metamaterial Absorbers

PMMA: Poly (methyl methacrylate)

PNT: Positioning, Navigation and Timing

POC: Particulate Organic Carbon

POL: Point of Load

PolyMUMPS: Polysilicon Multi-Users MEMS

PPP: Precise Point Positioning

PRN: Permanent Registration Number

PRT: Platinum Resistance Thermometer

PSU: Power Supply Unit

PTH: Pressure, Temperature, Humidity

PWM: Pulse-width modulation

PZT: Lead Zirconate Titanate

QA: Quality audits

QAM: Quadrature Amplitude Modulation

QKD: Quantum Key Distribution

QMBOC: Quadrature Multiplexed binary offset carrier

QoS: Quality of Service

QPSK: Quadrature Phase Shift Keying

QUTG: Quantum Technology Group

R&D: Research and Development

RAC-S: Regional Academic Centres for Space

RADAR: Radio Detection and Ranging

RAFS: Rubidium Atom Frequency Standards

RAIM: Receiver Autonomous Integrity Monitor

RC: Ritchey-Chritien

RDM: Research Data Management

RF: Radio Frequency

RFIC: Radio Frequency Integrated Circuit

RHBD: Radiation Hardening by Design

RNN: Recurrent neural Network

ROIC: Readout Integrated Circuits

RS: Reed-Solomon

RTIS: Real-time Train-tracking Information System

RTK: Real Time Kinematic

RTL: Resistor Transistor Logics

RTOS: Real Time Operating System

RT-PCR: Real Time Polymerase Chain Reaction

RTT: Radiative Transfer Theory

RTT: Round Trip Time

RTV: Room Temperature Vulcanizing

SAC: Space Applications Centre

SAL: Service-level Agreement

SAMIR: Satellite Microwave Radiometers

SAR: Search And Rescue

SARS-CoV-2: Severe Acute Respiratory Syndrome Coronavirus 2

SATCOM: Satellite Communication

SATNAV: Satellite-Based Navigation

SAW: Surface Acoustic Wave

SBAS: Space-Based Augmentation Systems

SBD: Schottky Barrier Diode

SCATSAT: Scatterometer Satellite

SDM: Software Defined Modem

SDR: Software defined radio

SEDA: Sensors Development Area

SEE: Secondary Electron Emission

SERDES: serializer/deserializer

SEU: Single Event Upset

SGD: Submarine Ground Water Discharge

SIC: Successive Interference Cancellation

SIF: Solar-Induced Fluorescence

SINR: Signal to Interference plus Noise Ratio

SIPG: SIGNAL & IMAGE PROCESSING AND DATA PRODUCT

SIS: Secret Intelligence Service

SIW: Substrate-Integrated Waveguide

SLM: Spatial Light Modulator

SM: Single Mode

SMA: Shape Memory Alloy

SMART: Satellite Meteorology and Oceanography Research and Training

S-NAP: Space National Academic Partner

SNPA: SATCOM & Navigation Payload Area

SNR: Signal-to-Noise Ratio

SNS: Satellite Network Simulator

SNSPD: Super Conducting Nanowires

SOC: System on Chip

SoPC: System-On-A-Programmable-Chip

SOS: Sum of Squares

SOTM: Satellite Communication On The Move

SPAD: Single photon avalanche diodes

SPDT: Single Pole, Double Throw

SPI: Serial Peripheral Interface

SPICE: Simulation Program with Integrated Circuit Emphasis

SPPU: Savitribai Phule Pune University

SPRAM: Single Port RAM

SPS: Standard Positioning Service

SRA: Systems Reliability Area

SRF: Spectral Response Function

SSLV: Small Satellite Launch Vehicle

SSPA: Solid State Power Amplifier

SSPA: Supplier Security and Privacy Assurance

SSR: Solid State Recorder

ST: Spatio-Temporal

STCs: Space Technology Cells

STG: Satellite-To-Ground

S-TICs: Space Technology Incubation Centres

SWIR: Short-Wave IR

SWOT: Surface Water and Ocean Topography mission

TCAD:s Technology Computer-Aided Design

TCC: Turbo convolutional codes

TCP: Transmission Control Protocol

TCU: Tile Control Units

TCXO: Temperature Compensated Crystal Oscillator

TDD: Test- Driven Development

TEC: Total Electron Content

TeCu: Tellurium Copper

TM: Telemetry

TMA: Three Mirror Anastigmat

TMBOC**:** The Time-Multiplexed BOC

TOAR: top of the atmosphere reflectance

TOC: Total Organic Carbon

ToT: Transfer Of Technology

TPC: Turbo product code

TRC: Transmit/Receive Controller

TREES: Training and Research in Earth Eco-System

TRIB: Transmit Receive Integration Block

TRM: Transmit Receive Modules

TRNG: True Random Number Generators

TSU: Temperature Sounding Unit

TSU: Temperature Sounding Unit

TTFF: Time to First Fix

TWI: Tilted Wave Interferometer

TWTA: Travelling Wave Tube Amplifier

TWTA: Travelling Wave Tube Amplifier

UART: Universal Asynchronous Receiver-Transmitter

UAV: Unmanned Aerial Vehicle

UAY: Uutachar Avishakar Yojna

UDL: Up-and-Downlink

UHDR: Ultra High Data Rate

UHF: Ultrahigh Frequency

UKF: Unscented Kalman Filter

ULPC: Uplink Power Control

UML: Unified Modeling Language

UMTS: Universal Mobile Telecommunications System

UV LEDs: Ultraviolet, Light-Emitting Diodes

UVGI: Ultraviolet Germicidal Irradiation

UVLO: Under Voltage Lock-out

UWB: Ultra wideband

VCM: Variable Coding and Modulation

VCO: Voltage Controlled Oscillator

VEC: Variable Emissivity Coated

VEDAS: Visualization of Earth Data & Archival System

VEDAS: Visualization of Earth observation Data and Archival System

VFB: Visible Flash Beacon

VGA: Video Graphics Array

VHDL: Hardware Description Language

VHG: Volume Holographic Grating

VHTS: Very High Throughput

VIIRS: Visible Infrared Imaging Radiometer Suite

VIS/NIR: Visible/Near-Infrared

VLBI: Very-Long-Baseline Interferometry

VOC: Volatile Organic Compounds

VSAT: Very Small Aperture Terminal

VVA: Variable Valve Actuation

WAAS: Wide Area Augmentation System

W-CDMA: Wideband Code Division Multiple Access

WDM: wavelength-division-multiplexed

WLAN: Wireless Local Area Network

WRF HYDRO: weather forecasting coupled hydrological system

WSS: Wideband Spectrum Sensing

XHV: Extreme High vacuum

ZBO: Zero-Boil-Off

Annexure: RESPOND Proposal Submission Guidelines and Formats

(For further details and latest information particularly on salaries etc. refer to Respond page on www.sac.gov.in or https://www.isro.gov.in *)*

Proposal Submission Guidelines

An individual or group(s) of scientists / faculty members affiliated to any academic institution/autonomous R&D institutions may submit proposals. Faculty of STCs and RAC-S established at various IITs/NITs; IISc and SPPU can select and generate proposals from Research Areas of SAC document. The Principal Investigator(s) should be full-time employee(s) of the concerned institution. The age limit for the Principal Investigator should be below 65 years (sixty five) including the project period. The Head of the academic institution must forward proposals with application for research grants. Proposals from individuals not affiliated to any recognized institution will not be considered.

Each proposal must name a Principal Investigator who is a domain expert in the area to which the proposal belongs and who is a full time employee/faculty of the institution forwarding the application. There may also be co-investigator(s) from the same/different institutions working on the project. But satisfactory completion of a project will be the responsibility of the Principal Investigator and her/his institution. The following information will be required for the submission of the proposal online.

- Detailed bio-data of all the investigators (Age also to be indicated) including publications/awards & recognition received.
- Contact details: address, email id, telephone/fax numbers of investigators as well as the institution.

- In case the institution belongs to Non-Government Category, NGO Darpan ID and PAN number of the institution.
- Brief description of the research proposed including the objectives and the scientific/application merits of the work.
- Description of the research methodology or technique to be used for the proposed projected.
- The extent of financial support needed from ISRO for executing the work within the shortest possible time.
- A list of research projects related to the proposal undertaken or carried out through funding by other Agencies.
- Scanned copy of the declaration form (Annexure 1- Page No. 226 in Respond BASKET - 2022) signed by head of the institution.

Proposals will be evaluated by domain experts (internal and/or external) for its novelty, usefulness to Indian Space Programme and other Scientific/ technical merits. The proposal may call for changes based on review and the PI will have to re-submit the proposal incorporating the recommended changes. Proposers are informed about the outcome of the evaluation of their research proposals.

Research Grants

The institutions proposing a project for support are expected to commit the use of the existing infrastructure available with them. ISRO provides financial grants to support fellowship, materials, consumables, internal travel, testing charges, data etc. The fund for purchase of only essential minor equipment's which are not available in the institution and would be useful for future projects will also be provided. There is no provision for any kind of payment to the Principal Investigator (or other staff) belonging to the Institution. The allocated funds cannot be used for travel abroad for any reasons. Guidelines governing the allocation of funds by ISRO are set out below. These may change from time to time.

- Grants for the purchase of equipment may be provided for the investigation. The equipment must be of a specialized nature, required exclusively for the project and is either not available at, or cannot be spared from, parent Institution for the project. Such equipment should be useful for new projects to be taken up in future. In this category, PC/Computer means desktop computer only. The overhead cost of the project shall not exceed 20% of the total project cost or Rs. 3.00 Lakhs whichever is less and shall be scattered over the years.
- Appointment of approved Research Fellows to support PI in the project activities can be made by the Academic/Research Institution for the approved project. The services of supporting staff like administrative personnel, support technical staff, technicians & technical Assistants, Surveyor, data entry operators etc., will have to be exclusively sourced by the academic or research institution undertaking the project and funds sanctioned under the project should not be diverted for any purpose. However, at the closure of the project, ISRO cannot assume any responsibility of providing continuity in employment either in the same or new project for the project staff. Such project staff who will have no claim whatsoever for recruitment in ISRO on any.
- The selection and appointment of the above project staff is the responsibility of the Principal Investigator as per the rules in vogue in respective / academic research institutions. These should be made according to the normal selection procedures of the university or institution submitting the research proposal. The qualification/ experience required and the salary offered shall be as per ISRO norms and the selection should have the approval of the head of the institution according to the rules followed in the respective Institution.

- The research personnel who are associated with the project may be awarded ISRO's research Fellowships according to guidelines laid down by ISRO for this purpose. Details on the award of Research personnel are given in following sections.
- Approved grant may be utilized for the following heads only:
  - Purchase of books and scientific literature, which are essential for the investigation, and are not available in the concerned academic/research Institution. Subscription for Journals are normally not permitted and expenditure towards Journals cannot be charged to project. In the event of a particular Journal which is not available in the academic/research institution and which is very important and relevant to the investigation may be procured on single copy basis or Photostat copies only on prior approval of ISRO. Subscription to journals on a regular basis cannot be covered by these funds.
  - Special consumable materials essential to the project.
  - Computer time, observatory time and other services.
  - Travel within India, in connection with the project or for attending seminars and symposia of relevance to the subject of the investigation.
  - Miscellaneous expenses (contingency) such as typing charges, stationery, postage, etc.
- All requirements of foreign exchange for the purchase of equipment and/or consumables should be clearly identified and mentioned in the budget. The Academic Institution /Research Institution shall arrange to provide the required foreign exchange to the project and ISRO will provide equivalent money in Indian Rupees.
- No funds are available for international travel either partly or fully, for personnel connected with the project.
- ISRO does not provide funds in the project for printing any material in connection with the project.
- ISRO does not grant any funds for buildings and civil works for housing any equipment or personnel. However, charges for equipment installation can be provided only on specific approvals.
- All travel in connection with the project should be approved by the Principal Investigator according to the TA/DA rules of the concerned Institution. The mode of Journey including air-travel may also be approved by him so that the implementation of the project takes place in time subject to the condition that the institution has no objection to such an arrangement and that the travel expenses are contained within the budgetary provisions for the project approved by ISRO
- The funds will be sanctioned under different specific heads and will normally be released by ISRO once in every year. Reappropriation of funds among different approved heads is not permissible.
- If the total grant released to an Institution is not fully spent, the unspent balance will be deducted out of the approved budget earmarked for next immediate release.
- Any unspent grant at the end of the project will have to be returned to Pay and Accounts Officer, Department of Space, Antariksh Bhavan, New BEL road, Bangalore-560 094

Terms and Conditions of ISRO Research grants

1. ISRO reserves the right to revoke in whole or in part the funds approved for a project at any time without assigning any reason.
2. Approved funds must be utilized solely for the purpose for which they have been granted unless ISRO agrees otherwise. A certificate that the funds have been so used must be produced by the grantee Institution at the end of each year of support.
3. Acknowledgement of ISRO support must be made in all reports and publications arising out of an approved project/investigation. The Institution will take prior permission of ISRO before publishing any work based on an ISRO supported project. Such permission will not be unreasonably withheld.

4. Two copies of all publications resulting from the research conducted with the aid of the grants should be submitted to ISRO.
5. Intellectual Property Rights
   - Any intellectual property rights or such information/knowledge being able to sustain or create or any such right arising out of the projects sponsored by ISRO will be held jointly by the Academic Institution/R & D institution and ISRO as per RESPOND norms.
   - Academic Institute/R & D institution and ISRO shall inform each other before filing for any protection of any Intellectual Property Rights resulting from any of the project sponsored by ISRO.
   - Academic institute/R & D institution and ISRO will ensure appropriate protection of Intellectual Property Rights generated from cooperation, consistent with laws, rules and regulations of India.
   - The expenses for filling the Patent protection in India and abroad shall be borne equally between Institute and ISRO.
   - Any/all financial accruals due to any commercial exploitation, of this patent shall be shared equally between them, on 50:50 basis. However any of the parties is free to utilize the IPR for their own use on non commercial basis.
6. The Principal Investigator is required to submit two copies of yearly reports indicating the progress of the work accomplished. He is also required to submit two copies of a detailed scientific/technical report on the results of the research and development work after the completion of the project. One copy of these reports should be sent to the address to which the proposal was sent and other to the Director, CBPO, ISRO Headquarters. Annual reports should be sent to enable release of funds for the subsequent year. The reports will become the property of ISRO.

7. ISRO may designate scientists/specialists to visit the Institution periodically, for reviewing the progress of work on an ISRO-funded project.
8. An inventory of items purchased from ISRO funds should be sent to ISRO giving the description of the equipment, brief specifications, cost in rupees, date of purchase and name of supplier along with a purchase certificate from the Head of the Institution. All items of equipment and non - consumable items costing more than Rs. 5,000/- remain the property of ISRO and ISRO reserves and right to recall, transfer or dispose them off either during the tenure or on the termination of the project.
9. The accounts of the expenses incurred out of ISRO funds should be properly maintained and should be audited by an approved auditor. The final financial documents comprising of audited accounts statement and fund utilization certificate in duplicate, should be sent to ISRO at the end of each financial year of support. The final financial documents pertaining to the project should be sent to ISRO for every operational year of the project sufficiently in advance to enable the release of funds for the subsequent year. It is the responsibility of the institution to submit the Fund Utilization Certificate (FUC) and Audited Accounts Statement (AAS) to Pay and Accounts Officer (PAO), Department of Space at the end of 12 months from the date of drawl of grant(s) from ISRO for Research Projects and at the end of 6 months for Conferences/ Seminars/ Workshops/ Symposium etc. It is mandatory for all institutions drawing grants from Department of Space to submit all financial documents within the stipulated period and any delay in the submission of the financial documents for all grants drawn from Department to Pay and Accounts Officer (PAO), Department of Space will result in delay in release of funds. In such situations, the PI cannot seek extension of project or modification of objectives of the project.

10. The funds for the projects are released on annual basis. Further release of funds for ensuing year will be based on the technical performance of the project and utilization of the funds released for the project during the previous year. Any unspent balance shown in the reporting year, will be adjusted with the funds due for release during the next year.
11. If the total amount sanctioned is not spent during the whole period of support, the remainder amount must be surrendered to the Pay and Accounts Officer, Department of Space, within one month after completion of the project.
12. The Institution cannot divert the grants for a project to another institution if it is not in a position to execute or complete the assignment. In such a case the entire amount of the grant must be immediately refunded to ISRO.
13. A register of assets, permanent and semi-permanent, should be maintained by the Institution and this should be available for scrutiny by ISRO staff.
14. The assets acquired wholly or substantially out of an ISRO grant should not, without prior sanction, be disposed off or transferred to other agencies or utilized for purposes other than that for which the grant is sanctioned.
15. The terms and conditions of ISRO research grants are subject to change from time to time, but the funding of any project till its completion will be governed by the terms and conditions existed on the date of starting of the project, unless mutually agreed to otherwise. The academic institution/PI cannot claim revision of fellowships or any of its elements from a retrospective date.
16. ISRO reserves the right to transfer any approved project(s) from one institution to other institutions in the event of institution's inability to continue the project , PI leaving the institution etc.

General rules

- ISRO Research Fellowships, Research Associateships and Research Scientists hereinafter referred to as Fellowships/ Associateships/ Scientists are awarded for specific projects or Education/Research Schemes approved by ISRO.Change of level of Research Fellow, subsequent to the approval of the project will not be permitted.
- The recipients of these Fellowships/ Associateships /Scientists are expected to conduct research work whole time under the Principal Investigator of the ISRO sponsored project. In special cases of individual Research Fellows/Associates, the candidates could be governed by the conditions of Research work as specified by the projects/ programmes/ schemes for which the Fellowships have been offered by ISRO.
- ISRO may nominate a member in the committee(s) appointed by the institution in connection with the approved project.
- The Fellows/ Associates/ Scientists, appointed for ISRO project, shall not be transferred from one institution to another.
- The award of ISRO Fellowships/Associateships/ Scientists does not imply any assurance or guarantee by or from ISRO or any kind of employment to the beneficiaries.
- Generally the upper limit for the period of Fellowships/ Associateships/ Scientists will be the same as that of the project. However, in exceptional cases, mainly to enable the Fellow to complete all formalities required for submission of doctoral thesis, ISRO may consider extension of the fellowship purely based on the merit on case by case basis. However, such extensions cannot be claimed as right by either fellow or PI.
- Monthly emoluments of the Fellowships/ Associateships/ Scientists will be paid by the concerned institution by utilizing the project grant.

Note: The scales of pay, service benefits, terms and conditions, etc for appointment are subject to revision from time to time by the Department of Space/Government of India.

Research Fellowships

There is a provision for engaging research personnel in RESPOND projects. The norms governing as per DOS orders, the qualification required for each category and service conditions of the research personnel are given below:

Junior Research Fellow (JRF) Senior Research Fellow (SRF)

Designation and Qualification	1st & 2nd Yr (monthly emoluments) (w.e.f 01/01/2019)
A: Junior Research Fellow (JRF) Post Graduate Degree in Basic Science OR Graduate/Post Graduate Degree in Professional Course selected through a process described through any one of the following : a. Scholars who are selected through National Eligibility Tests - CSIR-UGC NET including lectureship (Assistant professorship) and GATE. b. The selection process through National level examinations conducted by Central Government Departments and their Agencies and institutions such as DST, DBT,DAE,DOS,DRDO,MHRD, ICAR, ICMR, IIT, IISc, IISER etc.	Rs. 31, 000/- + HRA
B: Senior Research Fellow (SRF) Qualification prescribed for JRF with two years of research experience	Rs. 35, 000/- + HRA

Note: *The performance of the Junior Research Fellows (JRF) shall be reviewed on completion of the two years, by an appropriate Review Committee duly constituted by the Directors of Centres/Units. Based on the recommendations of the review committee and approval of the Director of Centre/Unit, Junior Research Fellow may be awarded the position of Senior Research Fellow (SRF).*

NET Examinations and Its Equivalent for Coverage under the OM.

Any National Level Examination conducted by the Central Government departments/agencies for admission to PhD programme are considered equivalent to NET. The following are the list of examination which can be equated to NET:

I. CSIR-UGC National Eligibility Test including NET –Lecturership.
II. Graduate Aptitude Test in Engineering (GATE) conducted by MHRD.
III. Joint Admission Test (JAM) conducted by MHRD.
IV. Graduate Pharmacy Aptitude Test (GPAT) conducted by MHRD.
V. Biotechnology Eligibility Test & Test conducted in Bio-Informatics by Bio-Informatics National Consortium.
VI. Joint Entrance Screening Test (JEST), Joint Graduate Entrance Examination for Biology & Interdisciplinary Life Sciences (JGEEBILS) conducted by Department of Atomic Energy.
VII. JRF Entrance Examination conducted by Indian Council of Medical Research.
VIII. All India Competitive Examination (AICE) conducted by Indian Council of Agricultural Research.

Associate-ships/Research Scientists

Research Associates (RA)

The fellowship for Research Associated may be fixed as consolidated amount at any of the three pay levels given below depending upon the qualifications and experience.

Educational Qualification : Ph.D/MD/MS/MDS or equivalent degree or having 3 years years of research, teaching and design and development experience after MVSc/M.Pharm/ME / MTech with atleast one research paper in Science Citation Indexed (SCI) journal.

SI. No.	Category	Fellowship per month(in Rs)(w.e.f 01/01/2019)
1.	Research Associate I (RA-I)	Rs. 47, 000
2.	Research Associate II (RA-II)	Rs. 49, 000
3.	Research Associate III (RA-III)	Rs. 54, 000

Research Scientists (RS)

The fellowship for Research Scientists remains unaltered:

SI. No.	Levels in the Pay matrix (as per VII CPC)
1.	Level 10
2.	Level 11
3.	Level 12
4.	Other Scales below in the Level 10 of pay matrix, as recommended by VII CPC and approved by Govt. of India.

Service Conditions:

Dearness Allowance (D.A.):
JRFs, SRFs and Research Associates will not be entitled to this allowance. The Research Scientists will be eligible to draw DA as per rates of Central Government as per rules of the local institutions where they are working

House Rent Allowance:
House Rent Allowance will be allowed to all research fellows viz.Junior Research Fellows (JRF), Senior Research Fellows (SRF), Research Associates (RA) and Research Scientists (RS), if they are not provided with hostel accommodation, as per rules of the institutions where they are working. For this purpose, the fellowship amount for JRF/SRF / Research Associates and Research Scientists will be taken as Basic Pay.

Medical Benefits:

The JRF, SRF, Research Associates and Research Scientists will be allowed medical benefits, as per rule of the institution where they are working

Leave and other services benefits:
JRFs/SRFs are eligible only for casual leave while Research Associates/Scientists are eligible for leave as per rules of the Institutions. Maternity leave as per Govt. of India instructions would be available to all female JRFs/SRFs/ RAs/RSs
Participation of JRF/SRF/ RA/RS in any scientific event in India or abroad will be treated as "on duty". The travel entitlement for JRF/SRF/RA/RS for participation in scientific events/ workshops In India will continue to be the same as earlier i.e., IInd AC by rail.

Bonus & Leave Travel Concession:
Not admissible to any category.

Retirement Benefits:
JRFs / SRFs / Research Associates and Research Scientists will not be entitled to these benefits.However, Research Scientists who are appointed for the duration of the project may be allowed to be members of the New Pension Scheme (NPS) of the Institution

Encouragement for pursuing higher studies:
JRFs/SRFs may be encouraged to register for higher studies and the tuition fees to undertake these studies may be reimbursed from the contingency grant sanctioned under the project grant, if required.

Benefits to Host Institutes:
Overhead expenses of 20% of the total project cost not exceeding Rs 3.00 lakhs may be permitted to the host institutions for meeting their costs including infrastructural facilities.

Obligations of JRF/SRF/RA:
1. JRF/SRF/RA/RS shall be governed by the disciplinary regulations of the host institute
2. The JRF/SRF/RA/RS must send a detailed consolidated report of the research work done during the entire period of Fellowship on completion of the tenure / resignation at the earliest.

The periodic Enhancement of research Fellowship:
The Research Fellows, Research Associates and Research Scientists are not entitled for annual increment.

The revised emoluments will take effect from January 01, 2019 for all categories of JRF/ SRF/ Research Associates /Research Scientists.

Other Categories:

Sl. No.	Manpower Position	Essential Qualification	Upper Age limit (years)	Monthly Emoluments (Rs.)
1.	Project Associate-I	Master's Degree in Natural or Agricultural Sciences/MVSc or bachelor's degree in Engineering or Technology or Medicine from a recognized University or equivalent	35	31,000/- + HRA
2.	Project Associate-II	(i) Master's Degree in Natural or Agricultural Sciences/MVSc or bachelor's degree in Engineering or Technology or Medicine from a recognized University or equivalent; and (ii) 2 years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services	35	35,000/- +HRA
3.	Senior Project Associate	(i) Master's Degree in Natural or Agricultural Sciences/MVSc or bachelor's degree in Engineering or Technology or Medicine from a recognized University or equivalent; and (ii) Four years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services OR Doctoral Degree in Science/Engineering/Technology /Pharma / MD/ MS from a recognized University or equivalent	40	42,000/- + HRA
4.	Principal Project Associate	(i) Master's Degree in Natural or Agricultural Sciences/MVSc or bachelor's degree in Engineering or Technology or Medicine from a recognized University or equivalent; and (ii) Eight years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services OR (i) Doctoral Degree in Science/Engineering/Technology /Pharma /	40	49,000/- + HRA

		MD/ MS from a recognized University or equivalent; and (ii) Four years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services		
5.	Project Scientist I	Doctoral Degree in Science or Master's Degree in Engineering or Technology from a recognized University or equivalent	35	56,000/- + HRA
6.	Project Scientist II	(i) Doctoral Degree in Science or Master's Degree in Engineering or Technology from a recognized University or equivalent; and (ii) Three years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services	40	67,000/- + HRA
7.	Project Scientist III	(i) Doctoral Degree in Science or Master's Degree in Engineering or Technology from a recognized University or equivalent; and (ii) Six years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services	42	78,000/-+ HRA

Service conditions of other categories:

(i) DA & CCA: Scientific/Technical Manpower in projects are not entitled to DA & CCA.

(ii) House Rent Allowance (HRA): HRA is allowed to all categories, except for Project Investigator (PI)/Project Coordinators in Non-Governmental/Voluntary Organizations (NGO/VO)/Project Manager as per Central Government norms applicable in the city/location where they are working. The percentage required for calculating HRA will be based on the remuneration.

(iii) Medical Benefits: The Scientific/Technical manpower will be entitled for medical benefits as applicable in the implementing institution.

(iv) Leave and other entitlements: The Scientific/Technical manpower are entitled to leave as per rules of the host institution. Maternity leave as per the Govt. Of India instructions issued from time to time would be available to all categories. The travel entitlement is as per Institute norms.

(v) Bonus, Gratuity & Leave Travel Concession: The Scientific/Technical manpower

Formats for submitting research proposals under Space Technology Cell (STC) and Regional Academic Centres for Space (RAC-S)

Academic Interface is one of the most important activities of CBPO and it aims at encouraging joint collaborative research with academia/Labs/institutes and establishing the Knowledge/incubation/research etc., across the country.

In March 2022, ISRO launched "**I-GRASP**" online portal (ISRO **GR**ant in **A**id for **S**pace **R**esearch **P**rogrammes). In the initial stage this webportal was launch for submission of only RESPOND Basket proposals, however, it is planned that this portal will serve for all sponsored research programme. The portal invites proposals from academia. The PIs from the academic institutions based on their area of interest and expertise select and submit the research proposals through this portal, where the entire process will be carried out through this portal which includes submission of proposals under RESPOND/STC/S-TIC and Other programmes are submitted online through **I-GRASP** (https://i-grasp.isro.gov.in/) portal only.

https://i-grasp.isro.gov.in/

Formats for submitting research proposals under Space Technology Incubation Centres (S-TIC)

The project proposal under S-TIC should have the Content as detailed below.

Contents

1. Title of the Proposal:
2. **Project Team**
   - 2.1. **S-TIC Principal Investigator,** (Name, Designation, Email ID, Mobile number)
   - 2.2. **S-TIC Co-Principal Investigator/s**, (Name, Designation, Email ID/s, Mobile number/s)
   - 2.3. **Student/s** (Name/s, Course/PhD, Email ID/s , Mobile number/s)
3. **ISRO Mentor:** Name, Designation, Email ID, Mobile number
4. Objective
5. Scope
6. Scientific / Technical Need Aspect
7. Stake holders
8. Product / Service Marketability
9. Brief description
10. Experimentation / Studies / Field Work
11. **Expected Results** (please highlight Envisaged outcome that can be indigenised / realised at the end of the projects that would lead to start-ups in collaboration with S-TIC)
12. Deliverables (Software / Hardware)
13. Project duration(in years)
14. Milestones including **end to end schedule**
15. Budget
16. **Necessary equipment/tool/software** required to carry out the S-TIC TDP. Please also mention whether the same is available at or not.
17. Describe the Societal application part of the outcome of this project.
18. Describe, how it is going to generate business.
19. Describe how it will help start-ups.
20. Describe how it will help students to become future entrepreneurs.
21. Other Details (if any)

Note:

1. The ideas conceived for Serial numbers 17, 18, 19 and 20 need to be elaborated for better clarity.
2. Project number (PR No.) will be provided by ISRO-HQ.

वार्षिक रिसपांड समीक्षा
Annual RESPOND Review

अंतरिक्ष प्रौद्योगिकी कक्ष (अं.प्रौ.क.) परियोजनाओं की वार्षिक समीक्षा
Annual Review of Space Technology Cell (STC) Projects

2017

2018

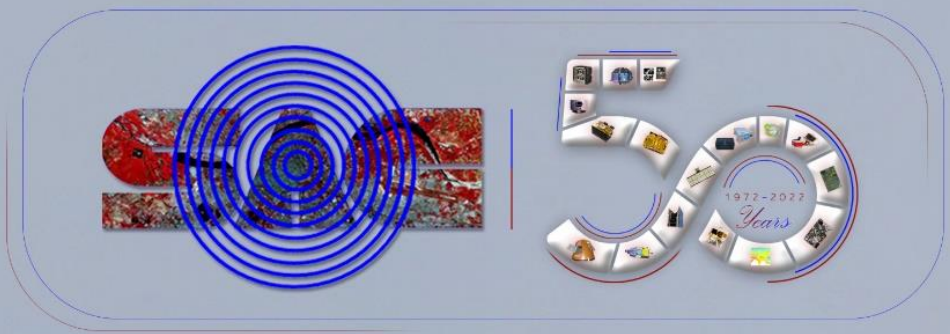
2019

सैक वार्षिक प्रायोजित अनुसंधान समीक्षा
SAC Annual Sponsored reseArch Review
(सैक-असर /SAC-ASAR)

2020

2021

2022



रिसपांड एवं अनुसंधान प्रबंधन प्रभाग RESPOND and Research Management Division
अनुसंधान, बाह्यसंपर्क एवं प्रशिक्षण समन्वय समूह Research, Outreach and Training Coordination Group
प्रबंधन एवं सूचना प्रणाली क्षेत्र Management and Information Systems Area
अंतरिक्ष उपयोग केंद्र, इसरो, अहमदाबाद Space Applications Centre, ISRO, Ahmedabad - 380015

www.sac.gov.in/respond/