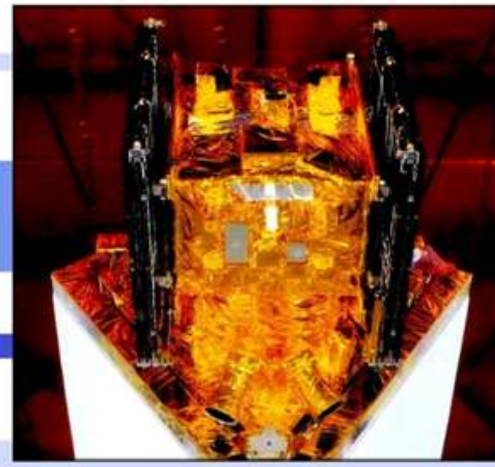
Signatures

Newsletter of the Indian Society of Remote Sensing- Ahmedabad Chapter

Volume: 24, No. 2

April-June 2012



Special Issue:

RISAT-1

India's Active Eye in the Sky

ISRS

Signatures

Newsletter of the Indian Society of Remote Sensing –Ahmedabad Chapter

Volume: 24, No.2, April- June 2012

Special Issue on

RISAT-1: India's Active Eye in the Sky

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Dr. K. Radhakrishnan
Chairman

MESSAGE

It gives me immense pleasure to learn that ISRS Ahmedabad Chapter is bringing out a Special Issue of **'SIGNATURES'** focusing on RISAT-1. It is a tribute to the ISRO community, which has been relentlessly working in the field of Microwave Remote Sensing during the past few decades. With the successful and majestic launch of RISAT-1 on 26th April, 2012, India has leaped into the select band of countries capable of space borne Synthetic Aperture Radar sensing technology. With the subsequent maneuvering of the satellite into its final orbit, and the switching on of the C Band SAR payload, on 1st May, it ushered in a new era into the field of remote sensing in India. In a tropical country like India, RISAT data is expected to have many useful applications.

I am happy to learn that the Signatures team has been able to get articles on RISAT-1, encompassing all the segments from the various ISRO centres. Another notable feature of this issue is that the articles encompass the new technology developments and the industry contributions that has gone into the making of this successful programme.

My heartiest congratulations to the editorial team, and all the contributors.

Best wishes,

(K Radhakrishnan)
August 16, 2012

आ.सी. किरण कुमार
निदेशक
A.S. Kiran Kumar
Director

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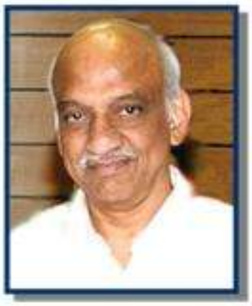

MESSAGE

It is extremely heartening to learn that the Indian Society of Remote Sensing - Ahmedabad Chapter (ISRS-AC) is bringing out a Special Issue of `SIGNATURES' on RISAT-1. It has been a dream come true for all the scientists and engineers of ISRO who have been relentlessly working in the field of Microwave Remote Sensing during the past two decades. With the successful launch of RISAT-1 on April 26, 2012, and the much awaited switching on of the C Band SAR payload, on May 01, 2012, it ushered in an era of a microwave remote sensing for India, from our very own sensor. In a primarily tropical country like India with a lot of cloud cover during the monsoon period, availability of such a sensor is essential.

I am happy to see the `SIGNATURES' team taking an initiative to bring together the contributions from across the centres of ISRO, to get interesting and highly valuable articles on RISAT-1 starting from Launcher, Satellite Systems, Ground Reception Systems, Mission Control Systems, Payload, Data Processing to the potential applications apart from the overall RISAT project and its configuration. Another interesting feature of this issue will be the highlighting of the new technology developments and industry contributions to the making of this project.

I hope this special issue will be of technical interest to all our readers. The team has made sincere efforts to get special articles from some of the retired employees of SAC, who are well known as the pioneers in the field of Microwave Remote Sensing in India.

Apart from that, interviews with some of the pioneering scientists in the field of SAR, is an interesting feature for this special issue.

My heartiest congratulations to the editorial team.

(A.S. Kiran Kumar)

Ahmedabad
August 11, 2012

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INDIAN SPACE RESEARCH ORGANISATION

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From the Chairman's Desk

Dear Readers,

ISRS-AC, has been taking initiatives, during the past few years, in order to bring out theme based Newsletter-Signatures which has been well appreciated by the ISRS members. The positive feedback from members is truly heartening.

The Signatures editorial team has been working along with the ISRS-AC team to evolve themes which are not only dealing with current issues in the field of remote sensing in India, but also are informative to all the readers. The special issue on RISAT-1 comes just after the launch of this satellite. The Signatures team has taken extra initiatives to bring together the scientific community from across the centres of ISRO, in order to get interesting and highly valuable articles on RISAT-1 starting from the Launcher, Satellite systems, Ground reception systems, Mission control systems, Payload systems, Data processing systems upto the potential applications, apart from the overall RISAT project and its configuration. The team had to toil hard in order to get such quality papers from the experts in their respective fields, and they have done an excellent work in this matter.
I am sure that this special issue will be of great interest to all our readers. The retired employees of SAC, who are well known as the pioneers in the field of Microwave Remote Sensing in India, have also taken active interest and have contributed very informative articles.
We, the ISRS-AC members would like to thank Dr. K. Radhakrishnan, Chairman, ISRO, for encouraging the various activities taken up by ISRS-AC.
The ISRS-AC is grateful to Shri A S Kiran Kumar,Director, SAC, Dr T K Alex, former Director, ISAC, Shri S. K. Shivakumar, Director, ISAC, Shri Veeraraghavan, Director VSSC and Dr V K Dadhwal, Director, NRSC for encouraging the experts to contribute their papers for this issue. I am also thankful to Sri D R M Samudraiah, ISRS, Vice President for his valuable suggestions.
Finally, I am extremely grateful to the Editor of Signatures, Ms Arundhati Misra and her editorial team, who have been relentlessly working towards making this issue a grand success. I on behalf of the executive committee am extremely pleased to acknowledge the enthusiasm extended by all the members.
My heartiest congratulations to the editorial team.
Best wishes.

D Subrahmanyam
Chairman, ISRS-AC

Theme for the Forthcoming Issue of *Signatures*:

Jul-Sep 2012: Megha-Tropiques Mission- Radiometers for the Tropics

"WE MUST BE SECOND TO NONE IN THE APPLICATION OF ADVANCED TECHNOLOGIES TO THE REAL PROBLEMS OF MAN AND SOCIETY" -

DR. VIKRAM A SARABHAI

With the successful and majestic launch of RISAT-1 on 26th April, 2012, India joined the league of Spaceborne Synthetic Aperture Radar sensing countries after USA, Russia, Europe and Japan. This mission was a dream come true for many a scientist and engineer, in ISRO and maybe India too. Microwave Remote Sensing activity had started in SAC,ISRO as early as the 1970s, as is evident from some of the articles. The MRSP was conceived in the eighties, in order to launch India's first Spaceborne MW satellite, comprising of SAR, Scatterometer, Radiometer and Altimeter. Surely, Dr Sarabhai's dreams are coming true with each successful mission of ISRO. SAR will be catering to multiple civilian issues including flood mapping, monitoring natural and man made disasters, agriculture, forestry and even ocean applications such as oil spill detection, coastal bathymetry, oceanic wind etc.

The Signatures team took a special initiative to get articles on RISAT-1, from all the centres of ISRO, encompassing the whole gamut of development in this mammoth mission. We have tried to include articles which highlight the new technology developments and the industry contributions which went into the making of this programme. We are thankful to all the authors from all across the ISRO centres, for sparing their time and writing such informative papers for this issue.

The roadmap to the SAR development had been laid out long before, the baton has now been handed over to the future generation scientists who will be marching forward. To this effect, I hope that this will be an invigorating fly-by for the readers of this special issue.

To add more spice to this magazine, we have taken interviews of some of the pioneering global scientists in the field of SAR. This will be enlightening the readers , I am sure.

My heartiest congratulations to the editorial team.

We are also including the nice feedback from our readers for the past issue. It will be our utmost pleasure, to get feedback from our readers, which will help us in taking 'Signatures' forward.

Happy reading.

Best wishes.

Arundhati Misra (Ray)

Editor, ISRS-AC

An Interview with Shri O P N Calla Former Area Chairman, CSA, SAC/ISRO

Questionnaire: Compiled By Ms Arundhati Misra

Signatures: Sir, ISRS-AC is extremely fortunate to have an eminent personality like you for the interview session. You are known as the Father of India's Microwave Remote Sensing activity. What prompted you to think about this field of activity during a time when optical remote sensing systems like LANDSAT, TM, and SPOT etc. were ruling the world?

Prof. Calla: It was the time (1972) when Remote Sensing was getting introduced in ISRO and at that time the Microwave division of ISRO was formed with a view to work on Microwave Systems. Later Microwave Division became part of Space Applications Centre. This was the time when on global scene the Microwave Remote Sensing was just getting introduced and various universities and research laboratories were being funded by Space Agencies to work in the field of Microwave Remote Sensing. For that the Ground based and airborne campaigns provided and generated inputs for futuristic Microwave remote Sensing. Looking into all these developments taking place in NASA, USA and CNES France, DFVLR Germany and USSR I could see the future of Microwave Remote Sensing in our country as I had always worked for futuristic applications ahead of times in which we were working. I had always even from any college days would venture during that time. But I always took challenges of taking new possibilities and tried to convince the policy makers. It was not easy but I could succeed in some fronts. The Microwave Remote Sensing was ONE. The potential of Microwave Remote Sensing was definitely visible to me because only using Microwave sensors one can take image or get target information in night. Most important aspect of initiating Microwave Remote Sensing was that I was firmly convinced that future is in Microwave Remote Sensing and this was part of my way of working that I always believed in taking challenges. My way of working is that "If any technology or work related to science and technology has been done elsewhere then we can do that without any difficulty." If the technology has not been developed anywhere else then we should initiate it and take the development as challenge and work very hard to achieve the same. This is how I was able to initiate work hither to unknown to us in India and that is "Microwave Remote Sensing". I very humbly submit that this could be possible because I got support from the policy makers.

This philosophy I follow even today while working at ICRS. I preach my colleague this and my they do follow this.

Signatures: I remember that there was a programme called MRSP (Microwave Remote Sensing Programme) during 1986-87. The programme was envisaged as a multi sensor microwave satellite like SEASAT-A and ERS, with four proposed sensors of SAR, Scatterometer, Altimeter and MW Radiometer on board. Can you kindly elaborate a little bit on that for the younger generation readers of ISRO?

Prof. Calla: Yes you are right in year 1986-87, Microwave Remote Sensing programme was given a separate status and I was made Programme Director of this Microwave Remote Sensing Programme. I was given a team to work with and first task was to prepare a Microwave Remote Sensing Programme document. During that we were looking into the possibility of sensor combination to meet the requirement of National Natural Resource Management System (NNRMS). The group of persons supporting me were from SAC and ISAC both hardware and application as well as to look into the space craft and sizing of payloads as per the applications.

The document was generated where applications were the guiding force. We looked at the frequency, polarization and sensors type. Here I should clarify in short that there are two types of Microwave sensors, they are Passive that includes Non Imaging and Imaging Radiometers that could be Total Power, Dicke and Noise Injection Radiometer and Active Sensors which include Non Imaging Radar Scatterometers, Altimeters and Imaging Side Looking Radar (Airborne) and Synthetic Aperture Radar (SAR). In the programme document we looked at all the applications of Microwave Remote Sensing that included Land, Ocean and Atmosphere. Then we further subdivided these applications and looked at the requirement of spatial resolution, the repetition required for each application and the swath width to cover large areas.

Based upon the literature survey and with our own experience of applications and available technology status, the programme was formulated. This was a comprehensive programme that included Space borne systems, airborne campaign as well as ground studies.

The Microwave Remote Sensing satellites that were proposed were multi sensor satellites. The programme document was written in 1986-Feb and by that time Sir A, Sir B and Sir C have been up in space. Looking into the application requirement multi sensor satellites were proposed.

The satellites were Microwave Remote Sensing 1A, Microwave Remote Sensing 1B, Microwave Remote Sensing 1C and Microwave Remote Sensing-2. These were to carry multi frequency Radiometers and multi polarization SAR and later multi frequency and multi polarization SAR, Altimeter and Scatterometers. Microwave Remote Sensing-2 was planned with Terra Hertz radiometers along with active sensors like SAR, Scatterometer and Altimeter.

Thus I have given you in very brief about the Microwave Remote Sensing Programme but this document is a comprehensive document which is still valid in terms of the thought process and the methodology covering from objectives to achievement of the objectives.

The Microwave Remote Sensing Programme document included the ground truth studies, airborne campaign method for data products generation including hardware requirement and the utilization aspect of Microwave Remote Sensing Programme.

Signatures: What is your reaction to RISAT-1? What would be the expectation from such a complex system? Would you suggest a repeat mission for the same, in future? Why?

Prof. Calla: The RISAT is a MILE STONE in the journey of Microwave Remote Sensing activities of INDIA. It is the culmination of the efforts of the group of people, who dreamt of having Microwave Remote Sensing as one path of providing the solution to the last man of the society that may be a Farmer in the field, Fisherman in open seas, a Person living in the snow bound areas and the most needy person of the society by giving the required information to help him live better than what he is going through day to day. This is a dream that has been fulfilled for me and for many others.

For this singular achievement by the ISRO scientists I BOW to all includes ISRO CHAIRMAN, DIRECTORS of ISRO centers and all the **Scientists/Engineers** who have contributed to the success of RISAT. The date 26th April 2012 will be remembered as the Golden Day in the history of Microwave Remote Sensing in India and the 1st May 2012 on which the images for the **FIRST** time from **RADAR** a Microwave EYE were obtained will go in the history as the day of remembrance for all.

The RISAT-1 is a multi functional full polarimetry Synthetic Aperture Radar of the STATE OF THE ART technology. This is a very complex system and the successful operation of this Radar in space is indicative of the level of technology, our scientists and engineers have developed which is as good as anywhere in the world and achieving resolution of 3 meter in STRIP MAP MODE is as good as anywhere else in the world.

The RISAT which has four modes of operation with varying resolution and swath is a complex system and best resolution of 3m with 30 Km swath provides to the application Scientists the opportunities to work for different applications. All the application Scientists have been eagerly waiting to have the data products of RISAT.

The RISAT utilization plan in which different Govt. agencies, Educational Institutions, Non Govt. Research organization in India are getting ready for utilizing the RISAT data.

I can understand as the SAR of RISAT is very Complex. So also the generation of data product for such a complex sensor will also be challenging and I am sure my Colleagues at Space Applications Center will take this challenge and generate the data products to be utilized by application Scientists for Land, Ocean, Cryosphere and Atmospheric applications.

Now the question is whether we should have repeat of RISAT-1. My personal view will be that we should repeat RISAT-1 but with little modification. In RISAT-1B, we should have along with the SAR at 5.35GHz couple of Radiometers operating in frequency band 1.4GHz, 6.6GHz, 10.65GHz, 18GHz, 21GHz and 37GHz. If there is weight constraint the choice of frequency could be limited. Then at least 1.4GHz, 2.5GHz, 21GHz and 37GHz should be included. Another important point is the time of launch. I suggest that RISAT-1B should be launched as early as possible because the application Scientists will need regular data for their applications projects.

In future we should have series of Microwave Remote Sensing Missions which will have the combination of the Microwave Sensors both Active and Passive. That will give us opportunity of using Microwave Remote Sensing for the applications related to Land, Ocean and Cryosphere as well as Atmosphere

The continuity of the programme is required because the users will start utilizing the microwave data for various applications. As we know that microwaves have unique capabilities in terms of penetration through clouds, day and night availability of data, soil moisture and penetration through vegetation. Because of these unique capabilities users of these data for land, ocean and snow studies will need microwave data on regular basis. My experience of using MSMR data for SNOW studies, SMOS data for Soil Moisture and Salinity and SSMI and AMSRE data for land, ocean and snow has created appetite for getting more and more data for the utilization of microwave data of both passive and active sensors on regular basis. This has happened to us at ICRS who are using these data in limited way but for those scientists who will be using these data on operational or semi operational mode, these data will be of utmost importance and they would like to receive these data regularly.

Signatures: Sir, India is primarily a tropical country with a very long coastline. Apart from the regular monsoon, a large part of the eastern and southern part of India is prone to the vagaries of nature. The role of MW remote sensing during such times does not need to be under scored. Yet we do see a lacuna in developing and using MW sensors in a large scale in our country. Can you please give a possible reason as to why MW RS had taken a back seat in India during the early part of this century, when the whole world marched ahead?

Prof. Calla: The Microwave Remote Sensing activity in India was initiated in 1973-74. In fact after AUG 1972, when Microwave division of ISRO was formed which later became part of SAC, we got people trained and that was the time when Microwave Remote Sensing was getting initiated all over the world NASA, CNES, DFVLR, USSR had started working in the field of Microwave Remote Sensing. In India also more or less at the same time we started working on ground based scatterometer in eighties but the golden opportunity we got was the start of Earth Observation Satellite (EOS) which was renamed as BHASKARA.

The ARYABHATTA BUS was utilized for making EOS. In this EOS we were able to get satellite Microwave Radiometer (SAMIR) accepted as one of the primary payload. The SAMIR in BHASKARA-I had three channels, two of 19 and one 22.235GHz radiometers and in BHASKARA-II we put 19, 22 and 31GHz radiometers. They were launched in 1979 (BHASKARA-I) and 1981 (BHASKARA-II). Then only in 1999 that we launched OCEANSAT-1 with MSMR multi frequency scanning microwave radiometer operating at 6.6, 10.65, 18 and 21GHz. Then we had OCEANSAT-2 with a scatterometer operating at 13.4GHz and now in 2012, we have RISAT, with Megha Tropiques launched in 2011 having multi frequency radiometers working upto Terra Hertz.

Yes, I agree that during these years that is from 1979-2012 almost 33/34 years, we could launch only three satellites whereas world over launching of ERS, ENVISAT, RADARSAT, JERS, Poseidon to name a few have been working in space with passive and active microwave sensors but we were not able to keep the same pace. Finally I can say India has arrived now and there is a popular saying "BETTER LATE THEN NEVER".

I agree with you and your concern is right. Looking at the geographical location of our country for ocean studies, Cryosphere studies and quite a few Land applications the microwave remote sensing only has answer. I feel now having started with RISAT, (the RADAR Imaging Satellite). We have arrived and our technology is as good as that available in other countries. The unique capabilities of Microwave Remote Sensing has stand alone applications in some areas does provide answer which are of great value for NNRMS. As was mentioned in the programme document of Microwave Remote Sensing Programme prepared in 1986 the role of Microwave Remote Sensing was envisaged for NNRMS. Now we have to move fast and invest more in Microwave Remote Sensing activities all over India that includes ISRO and universities and Research Institutions. The area of activities of Microwave Remote Sensing has to be increased and more and more Institutions of our country should be involved in enhancing the utilization of Microwave Remote Sensing data.

Now time has come that in the area of Microwave Remote Sensing the Research Institution, Universities and the user agencies should get involved and more and more investment in Microwave Remote Sensing is the need of the day.

Signatures: There is a popular saying – 'If you can't beat them, join them'. Taking cue from that, I would like to ask you, whether India should join the global community (international cooperation) in developing microwave remote sensors, especially for the high frequency bands? Or should we rather stay apart, develop our own industries and become self sufficient in building such complex technologies? Why?

Prof. Calla: This popular saying 'If you can't beat them, join them' is applicable when one finds that there is an urgent need of taking on the applications that need to be answered to meet the requirement of the country. The joining hands with others should always be done at equal level. We should be strong in areas to a level that if required we should be able to take up the activity in case of the collaborator agency has some difficulty in meeting the schedule. There is no harm in collaborating with the agencies those who are willing to collaborate with us. In the space programme, this is true for every country. Recently in COSPAR meeting ISRO Chairman has indicated that ISRO will collaborate with other countries and this is indeed excellent idea and we should do this for the good of our people.

We should develop these complex technologies at higher frequencies like Terra Hertz in very near future. The present example of Megha Tropiques where sapphire pay load working in THz has been supplied by CNES but in future ISRO should develop these technologies to become self reliant.

Another point is that the MICROWAVE REMOTE SENSING activity is for helping our country through National Natural Resource Management System and the needs as well as the solutions for providing answers to the demand put in by the NNRMS will not be same for agencies outside our country. Every Nation has their own priorities and so for meeting our priorities we have to be on our own. We cannot depend on the collaborating agency and wait for their inputs for meeting our needs.

I would say India should have options open and should have participation in International cooperation but should not be at the cost of our own programmes and the National needs.

Lastly as said earlier it is always advisable to have collaboration with other countries which will be for the Good of our Country.

Signatures: How do you foresee the future of Microwave Remote Sensing using multi frequency, and multi polarization sensors (for SAR), from space borne platforms, in operational mode? Shuttle imaging Radar, SIR-C was the only such mission, but none afterwards for the routine operational satellites.

Prof. Calla: To me it is crystal clear that the future of Microwave Remote Sensing is in Multi-frequency and Multi-polarization SAR as well as Multi-frequency Radiometers from space borne platforms and single frequency Scatterometers and Altimeters.

You can see as early as in 1986 in the Microwave Remote Sensing programme document we had proposed multi-frequency multi-polarization SAR in MRS 1-C. This had multi-frequency and multi-polarization SAR operating at frequencies – C, L or X with like and cross polarization and multi-frequency Radiometers operating at 6.6, 10.6 , 18, 21, and 37 GHz in horizontal and vertical polarization along with scatterometer and Altimeter both operating in Ku band of Microwave frequencies.

Also the MRS-2 satellite was similar to MRS 1-C in terms of Active Sensors and there were additional lower & higher frequency channels for Radiometer that included 1.6, 6.6, 10.65, 18, 21, 31, 37, 50.3, 53.74, 57.95, 183.1, 183.3, and 183.5.

Thus you can see that in 1986 itself we had thought of having multi-frequency, multi-polarization sensors to be placed on the space borne Microwave Remote Sensing missions.

At that time Dr. Keith Raney and Dr. Wolfgang Martin Boerner had not proposed the Hybrid polarimetry and fully polarimetry sensors and so these concepts were not available but we did plan the linear multiple polarization that is HH, VV, HV and VH.

It is true that after Shuttle Imaging Radar there have not been such operational satellites, But the ERS-I, ERS-2, ENVI SAT, RADARSAT-1, RADARSAT-2 have been providing the data of Active sensors(synthetic aperture Radar) and separately Altimeter like Poseidon has been available. Also the separately passive sensors in NIMBUS, SSMI, AMSR-E and now SMOS and SMAP in future have radiometers. SMAP has both Active and Passive sensors. I think this multi sensor approach was dropped possibly because non availability of launcher which could carry such heavy payload weighing some Tons, in case of our own RISAT Radar Imaging satellite is the heaviest payload launched by ISRO till date. In case of Microwave Remote Sensing the requirement of the launchers which could carry heavy satellites is a major concern. Thus the payloads are separated and as ISRO did they launched Oceansat-I with radiometers, in 1999 and OCEANSAT-2 with scatterometer in 2000 and now planning to launch SARAL with altimeter. The OCEANSAT-2 is giving very good data and is in operational mode. I am very much hopeful that RISAT which has given excellent images of our mother land India will also become operational very soon.

Signatures: 'Seeing is believing'. Hence optical images are not only beautiful to see, but easier to interpret, as it is the same as that provided by our vision sensor-'netra'! Microwave images from SAR sensors or data from Microwave sensors such as scatterometer, radiometer etc. are not directly understandable to the normal users. Advanced techniques and rigorous analysis tools are needed to utilize such data. However, the scientific communities all over the world have been working relentlessly during the last three decades to develop tools to render such data more and more useful to the end user community .What is your vision about the means by which the Microwave Remote Sensing data can be of maximum use to the users in India?

Prof. Calla: I agree "Seeing is believing" but I would like to be excused for differing from your point of view because the SAR images are as good as optical images even at first look. I have seen images obtained by RISAT and they have been compared with other optical sensors onboard RESOURCESAT and I can say that they are as good as that obtained from RESOURCESAT and especially of Gangotri Glacier RISAT give much more information when compared with RESOURCESAT.

However I do agree that for interpretation of the images obtained from Microwave Sensors we need to understand the interaction of electromagnetic waves with the target. There are many parameters both of sensor and that of the target that includes the electrical and physical properties of target, have to be understood for interpreting the images obtained from Microwave Sensors.

I agree with you that scientific community world over has been working for last three decades on various aspects of the Microwave Remote Sensing that includes the development of new technologies for the hardware and understanding of the interaction of electromagnetic waves with the target and the effect of sensor parameters on the signature obtained from the target.

To some extent for interpolation of optical images also various indexing like NDVI and ratioing etc. are used when multiband data are obtained.

In case of electromagnetic waves which have unique capabilities for remote sensing over optical and infrared wavelengths do require proper understanding of sensors performance parameters and dielectric constant of the target material and the physical properties.

But this is not a big issue. The normal user can use Microwave Remote Sensing images both from SAR and mapping using Radiometers as well as winds from scatterometer and significant wave heights using Altimeter for interpolation with the help of Ground truth. For detailed analysis one needs deeper understanding of what I have said earlier.

Signatures: How do you foresee the future of Remote Sensing in India using THz bands?

Prof. Calla: I can see a very bright future of Remote Sensing with THz sensors.

The successful launch of Megha Tropiques which has THz sensors operating at 183 GHz with number of channels is just beginning of the utilization of higher frequencies. The application of THz is going to be increasing many folds in future.

Presently it is being used for cloud top precipitation but their utilization for minor constituents for monitoring Carbon monoxide (CO) in the atmosphere which can be monitored at 115 GHz and Water vapors at 183.3 GHz and Ozone at 160 & 380 GHz in the atmosphere and the vertical profile will provide inputs to the scientific community which no other sensor can give.

I can say with certainty that the future utilization of the THz for Remote Sensing will increase with time.

Signatures: Sir, you had a long experience in the field of Microwave Remote Sensing. What is your assessment of Indian Remote Sensing program?

Prof. Calla: You are right I have been a witness to the Remote Sensing program in our country. Before space borne Indian Remote Sensing program started from Bhaskara in 1979, the Microwave Remote Sensing using ground based sensors activity had started and training of people in the field of Microwave Remote Sensing had started from 1973-74. It has been now 39 years and during these years Microwave Remote Sensing applications using the data from space borne sensors were utilized by the scientist. Some acceleration in using Microwave Remote Sensors data was achieved with launching of SAMIR (Satellite Microwave Radiometer) in the year 1979 and 1981. India was third country in the world after USA and USSR to have placed Passive Microwave Sensor in Space. But lack of availability of Indian space borne sensors data slowed the pace at which the Indian scientists would have used the data and there number would have increased.

In any case ISRO and those institution including DRDO laboratories, IIT's who could afford to purchase data have done some work.

But this is obvious that these data have not been available freely to the number of scientists working in this field all over India and so this number has remained very low.

Because of this full potential of Microwave Remote Sensing has not been exploited and I am confident that in very near future we in India will be able to use Microwave Remote Sensing on operational and semi-operational mode.

Signatures: Sir, on a different note I have some special questions for you. If I may recollect correctly, you had some vision of incorporating the industry, the medical and bio-engineering fields, and the academic world into ISRO's programmes for carrying out some innovative work in the field of Biomedicines during the eighties itself! Today it is a reality in the world arena. NASA, ESA etc have been doing this type of research along with the universities and medical centers. Can you share with us your own experiences in this domain, and throw some lights in this regard for our future programme?

Prof. Calla: I think what you have brought out in your this signature it takes me back to the time period of Eighties, when utilization of Microwave for detection of cancer was initiated using the laboratory prototype model of SAMIR payload in collaboration with NIOH (National Institute of Occupational Health) Ahmedabad and we were successful in detecting Cancer in the animals under test. At the same time we started with the help of some Doctors the Biomedical Engineering society of Gujarat and also initiated conducting of Biomedical Engineering courses in Govt. Polytechnic college at Ahmedabad. Later on the degree courses in Biomedical Engineering were started in many colleges.

I was always keen to have industry as our partner to work with us for delivering hardware which we need in large numbers for our space programme. I was on Board of Directors of Gujarat Communication and Electronics Ltd. (GCEL) an initiative of Govt. of Gujarat and thought that we can have a joint activity with GCEL for ground hardware but it did not work out. We gave technology of earth station to ECIL Hyderabad. Now RISAT has done this by having T/R modules produced by industry. Also ISRO is doing many activities throughout surely.

Regarding academics I was also of the opinion that we should involve the academics in our programme and should develop centers of excellence in various institutions and universities. At Ahmedabad at Gujarat University we helped them to run one year diploma in space related subject. Like that IIT's also were supported but not much we should have done much more.

It is our responsibility that any technology that we develop should have fall out and should be available to other disciplines. For example the Microwave sensors which are used for remote sensing of Land, Ocean, Cryosphere and Atmosphere should be available to help the common men. One example could be in future when we develop THz sensors they have number of applications in Medical diagnostics and we should provide this help to our common man through the Doctors who could be given the knowledge about its utilization.

Signatures: You are ardent follower of swami Vivekananda. As a scientist and a technical person, who was your role model who provided you with zeal to think and act differently, during your formative years? How?

Prof. Calla: You are right, I am a devotee of Bhagwan Shri Ramakrishna Deva, Sri Ma Sharda and Swami Vivekananda the HOLY TRIO. Shri Thakurji is my spiritual guide and I have totally surrendered to HIM and all acts of mine including these answers to your signature are HIS. I am only instrument in his hands and whatever thought process that he gives comes out through me. All good are his and any faulty situation if created is due to my human limitation.

In early days I am not sure who was my role model but I do remember while studying science. I used to think, had I been born in the times when those discoveries were done maybe I could have been one of them. Now I can say that my inspiration I get now is from Sir JC Bose. I am working now a days for International Center for Radio Science (ICRS) at Jodhpur and this institution is guided spiritually by Bhagwan Shri Ramakrishna Deva and scientifically by Sir JC Bose.

At ICRS we work in those areas which were discovered by Sir JC Bose. He generated Microwaves in 1895 in Presidency College, Calcutta and today we all are enjoying the fruits of his discovery. I can say today that Scientifically Sir JC Bose is my role model.

In my formative years when I came to Ahmedabad from Atomic Energy Est. Trombay, (AEET) now BARC and started working at PRL. I always thought about the way Dr. Vikram Sarabhai worked as a selfless scientist only worrying about how one can use the science and technology for common man. His concept of SITE which is the direction he gave to our space people that it is meant for the last man of the society and that is what has impressed me and even today always think how whatever research I do can be of use to the last man of the society and so in this way I can say that Dr. Vikram Sarabhai has molded my way of thinking and even today I cannot forget his working, day and night to create new ideas, new institutions and all with humbleness and without any ego. He never taught but you could learn from the way he worked and behaved, I can say that Dr. Vikram Sarabhai's life was a class room and it was for the students to pick and learn.

Signatures: During last few decades you have been actively associated with the academics field. It is well known that in USA, most of the research work even in complex fields such as Microwave Remote Sensing is being carried out under the banner of the universities. How do you foresee the involvement of Indian universities in our future space programmes?

Prof. Calla: I have worked for Dept. of Atomic Energy and ISRO from Feb 1962 to Dec 1995 around 33 years and now from 1995 for last 18 years I have been teaching in university and doing research in the field of application of microwaves for all aspects which include Communication, Remote Sensing, Medical and Industrial.

I am fully convinced that for achieving the goals in Microwave Remote Sensing we have to involve Universities, IIT's, and NGO's whoever is capable of delivering goods. We have to choose right institutions which have good track record and involve them to take up the work related to the Microwave Remote Sensing and provide input to the Microwave Remote Sensing activities of ISRO. It is not possible for ISRO Scientist to generate all the required inputs for success of the Microwave Remote Sensing.

I think it is time although we are bit late but it is better whenever we can initiate action in this direction. I think ISRO has taken initiative in this direction but much more can be done. It is also a very important aspect of any programme or activity that we locate right people and provide them support which will become your partner in achieving goal.

It is true that in USA as well as in Europe for Microwave Remote Sensing programme the research institute and universities are involved from the day the programme is conceptualized. The SMOS mission of ESA had involved many universities and institution for utilization of SMOS data. They had worked for SMOS application, data product as well as validation and calibration and the work was totally funded by ESA.

On similar lines ISRO has been doing but much more is required for Microwave Remote Sensing.

I can say from learning that ISRO in future will involve more universities, institution, NGO and IIT's who have capability to provide inputs. The way RISAT utilization programme is shaping where universities and IIT's have been involved and non govt. organization which are registered and are capable of delivering can provide inputs to Microwave Remote Sensing activities.

I see a very bright future for involvement of various institutions for future space programme.

Signatures: Sir, do you have something special to say to the younger scientist in ISRO/DOS?

Prof. Calla I am not in a mood to preach but with all humbleness and humility I would like to say to our younger generation that you are part of an organization which has a Glorious Past and Fantastic Present and Excellent Future with full of challenges. What we need is dedication, commitment, the will to take challenges, self-confidence and the mental makeup that the work and the organization is first in life and everything else is secondary. Once you develop this attitude the organization will be able to maintain and even supersede many of the space organization of the world. What we need is NISKAM KARMAYOGI. Every person working for ISRO has to be that.

Signatures: Sir, thank you very much for sparing your time for ISRS-AC. Would you like to say something else to our readers?

Prof. Calla: The ISRS - AC is the organization very close to my heart. I was the founder Chairman of ISRS AC. I remember how the Ahmedabad chapter was formed and with support of all we were able to organize the society activities. By now this ISRS - AC has grown and all the members contributed to the activities of this chapter.

I can only say to the readers of this ISRS-AC special issue on RISAT, that what has been achieved now by having RISAT up in the space we have to reap the Harvest by utilization of the data of RISAT for all the application which the active microwave sensors with excellent specification can provide in Land, Ocean, Cryosphere and Atmosphere.

I would like that, all, in whichever area of Remote Sensing or others they should think that whatever research output they are getting; it is useful to the last man of the society that may be a farmer, fisherman or the person living in the snow bound Himalayas and the most needy person of the society.

If our readers will think in this way then I will feel satisfied that the purpose of my telling all in most humble way has been amply rewarded and will give me sense of satisfaction.

Lastly I would like to personally thank from the deepest point of my heart, the Chief Editor and the Editorial Board to provide an opportunity to the most humble worker in the field of Microwave Remote Sensing to share the thoughts; who worships Microwave as God and has been doing so from 1961, for almost more than 50 Years. May this input if found of any use by the readers I will feel blessed.

An Interview with Dr. Keith Raney
Eminent Scientist, JHU/APL & 2kR-LLC, USA

Questionnaire: Compiled By Ms Arundhati Misra

Signatures: Dr Raney, ISRS-AC is extremely fortunate to have an eminent personality like you for the interview session. You are one of the pioneers in Microwave Remote Sensing Technology, especially in the field of Synthetic Aperture Radar (SAR). Your pioneering works in the field of SAR processing algorithm development, during the last three decades are well known by all microwave scientists in the world. You originally proposed and have done extensive work in the field of Hybrid Polarimetry also, which was first flown in MiniSAR, in the Chandrayaan-1 mission. Taking a cue from your work, we also have ventured into the field of Hybrid polarimetric SAR in RISAT-1, and as you are aware, this is the first compact polarimetric (CP) SAR sensor for an EOS satellite mission. With the actual data of Hybrid polarimetric SAR being made available, we will be having an entirely new field of research work involving the Earth's land surface and oceans. You have been actively involved with many earth and planetary missions, and your contributions in these fields are internationally acclaimed. What is your vision about the future of SAR using this new technology?

Dr. Raney: Thank you for your kind introduction. It is an honor for me to participate in this interview. Yes, it is exciting to see the successful early CP results from RISAT-1. Quad-pol SAR has been promising since its introduction in the early 1980s by JPL, but in spite of beautiful results from numerous international airborne campaigns, quad-pol measurements from space have been limited almost completely to proof-of-concept demonstrations. I know of no operational use of space-based quad-pol EOS SAR data. Compact polarimetry (CP) in general, and hybrid polarimetric (CL) operations in particular, should reverse this situation.

The over-riding high-level challenge at this stage is user acceptance. As your question noted, this is a new technology. User acceptance will develop only after extensive investigations into specific applications that show positive results. Users must be satisfied that their needs are better met with CL data such as RISAT-1 can provide, and that the learning curve and processing burden for such data prove to be much more manageable than for quad-pol data. This opens an opportunity for the RISAT-1 program to make such data available to investigators world-wide, through an Announcement of Opportunity or the like, so that the enthusiasm and skills of the wider community can be informed, and eventually convinced of the value of this new technology. With adequate first-hand experience, user acceptance eventually should mature into user demand.

Signatures: Until RISAT-1, polarimetric SAR implied quad-pol data for SAR missions such as Radarsat-II, ALOS_PALSAR, TerraSAR-X, RISAT-II etc. Would you recommend more such SAR sensing modes in the future missions both for India, and for the rest of the world. Why? In fact if the CP data is self sufficient for most applications, then would you say that the quad-pol is basically redundant or would you want complementary data sets from both?

Dr. Raney: Whereas the cognizenti appreciate that CL data may be sufficient for most applications, the vast majority of the user and research community does not yet believe that to be true. Further, there always will be applications for which quad-pol data will be preferred. For these reasons alone it is essential that early EOS SAR missions include a quad-pol mode as well as a hybrid-polarimetric mode.

The marginal cost for a quad-pol mode in addition to a CL mode in the space segment should be small. The benefits, however, are large, for two reasons:

- Quad-pol data can be collected over key sites under controlled conditions, and processed to emulate CL data as well as quad-pol data. The results will support quantitative comparisons of the two techniques. This process should be an essential component of a user development campaign.

- Quad-pol data are useful for characterizing the polarimetric properties of the CL mode. Although in principle the receiving end of a CL radar and processor can be calibrated to be essentially perfect, the transmitted field cannot be so calibrated. Quad-pol data can be used to characterize the transmitted polarimetric field when operated in the CL mode. Although the choice of left-circular vs right-circular transmit polarization has no effect on the information content of data products, inevitably one of the two transmitted fields will have preferable polarimetric properties, namely, an axial ratio close to unity. The better transmit polarization should be selected as the operational default.

It is now known that the optimum form of a quad-pol SAR from the engineering point of view is hybrid-polarimetric, that is, alternating left-circular and right-circular polarizations on transmit, while in both cases receiving orthogonal linear polarizations. RISAT-1 is the first EOS SAR equipped to implement that mode. One disadvantage of the conventional all-linearly-polarized quad-pol implementation is that the nearest range ambiguities are the opposite orthogonality, hence troublesome, which results in an upper bound on available incidence. RISAT-1offers an opportunity to exercise both versions, thence to measure the difference in their corresponding range ambiguities. Bingo! I predict that the hybrid-polarimetric form of a quad-pol SAR will come out ahead in such a contest.

Signatures: SAR sensors are not only complicated but also quite expensive to build. However the need for such sensors out-weighs these challenges. Thus NASA, ESA, Canada, JAXA, Russia, and Chinese Space agencies among others, have been building SAR sensors for earth observations. Do you think that there should be more international cooperation for global missions for the next decade of RS activities, for better utilization and interpretation of such data?

Dr. Raney: At the outset it should be noted that many space agencies that are responsible for EOS assets have had in place for several years an agreement that authorizes free and rapid availability of data in the event of a natural or man-made environmental disaster. This has led to near-real time coverage of the BP oil spill in the Gulf of Mexico and the earthquake in China, among several other examples. Further, there would seem to be an informal concord regarding choice of frequency (hence wavelength), through which Japan, and in near future Argentina, favor L-band, Germany and Italy X-band, and Canada, the European Space Agency, and now India opting for C-band. China has an S-band system, although those data are not as readily available as the others.

That said, a long term agreement among national and international space agencies to assure continuity and coordinated coverage would be in the common interest. Easier said than done! Virtually all systems, in orbit and in preparation, have been motivated to no small degree by national interest, rather than by an idealistic contribution to the "common good". It would make sense for the several interested agencies to negotiate liberal data sharing and/or exchange protocols for the growing number of EOS SAR assets, a protocol for which all parties should come away winners. Once in place, then anticipated weaknesses in coverage or continuity could be offset by participants authorizing and implementing replacement systems.

Signatures: Dr. Raney, we all know about the potentials of Polarimetric SAR. Until today the LEO based satellite SAR as well as the airborne SAR sensors, all over the world have been using only quad polarization technique. Why has Hybrid polarimetry never been attempted (even for experimental purpose), in EOS sensors, even though

it has the advantages of having simpler H/W architecture and larger swath with the same PRF?

Dr. Raney: Why? Short answer, "box mentality". Earth-observing radar remote sensing, either airborne or space-borne, has always used linear polarizations: H, or V, or combinations there-of. Over the years there have been several experiments that looked at HH, HV, & the relative H/V phase (or the equivalent with V transmission), which as one should recognize is a legitimate form of a compact polarimeter. Invariably the results of such experiments have been disappointing. The investigators turned away, rightfully so. They were trapped inside the "linearly polarized" box.

Then, in the early 1980s, led by vanZyl and Zebker at JPL, airborne quad-pol SARs were demonstrated, and an elegant theory was developed, based on decades of analytical precedent. The paradigm shift was cataclysmic; there was no one left who was interested in the polarimetric middle ground between conventional (non-coherent) dual-pol systems and (oh praise be!) quad pol systems. Quad-pol became the de facto "gold standard" for polarimetric imaging radars. That remained the status quo until Chandrayaan-1, and the MinSAR, followed by the Mini-RF SAR on NASA's LRO.

Although little known nor appreciated by the EOS SAR community, there has been for decades an active (and productive) imaging radar astronomy community. In 1964 the first polarimetric radar images of the Moon were generated using data from the then newly commissioned radar/radio telescope at Arecibo, Puerto Rico. In order to defeat Faraday rotation, radio/radar astronomy routinely uses circular polarization. If the relative phase of the received signals is retained, then the data are sufficient to form the four Stokes parameters of the observered field. Once the data are cast as Stokes parameters, the polarimetric basis of the received data is immaterial. One early radar experiment that transmitted circular polarization intentionally chose the coordinates of the linearly-polarized received data to align with the Moon's libration axis, from which analysis led to the first estimate of the thickness of the lunar dust layer (regolith). The MiniSAR on Chandrayaan-1 was inspired in part by that early Arecibo experiment: transmit circular polarization, and receive orthogonal linear polarizations and their relative phase. The choice of transmitted polarization—circular—was the means of escape from the "linearly polarized" box. MiniSAR was designed to be an operational polarimetric SAR, the first of its kind. It has worked very well at the Moon, and it is at least as promising as an operational EOS SAR mode.

Signatures: After the ENVISAT program of ESA, Sentinel programs will be there, which will be having a judicial mix of active and passive sensors (but still not similar to ERS, ENVISAT etc) on board the same platform. But we haven't seen any US program with such a combination since 1978 (SEASAT-A whose host spacecraft failed three months after launch). Is the global strategy going to tilt towards multiple small satellites with fewer sensors on-board, but in more numbers (constellation), at a time, instead of a single massive satellite program with multiple sensors?

Dr. Raney: Both scenarios are likely, indeed, already having operational examples. "Small" is relative, of course. As is well known, the minimum area of a SAR antenna is proportional to wavelength. Thus, all else equal, a SAR antenna at L-band (nominally 23 cm wavelength) must have an area nearly 10 times that of a SAR antenna at X-band (nominally 3-cm wavelength). Thus the German SAR-Lupe constellation, comprised of five small satellites, is at X-band. By the way, those radars were cleverly designed to minimize cost and complexity, using pre-existing space-qualified hardware for most sub-systems "borrowed" from the communications industry, including in particular their antennas, which are simple reflectors. Italy's COSMO constellation is comprised of three mid-sized X-band EOS SARs, while Canada is implementing the Radarsat Constellation Mission (RCM) whose architecture has evolved from their C-band Radarsat precedents. The default operational mode for RCM will be CL, in all combinations of resolution and swath width. Quad-pol is included, but only as a technology demonstration mode. Meanwhile, Japan is nearing completion of its ALOS-2 SAR, which at L-band implies a rather large spacecraft. ALOS-2 includes CP modes (pi/2 and CL) for technology demonstrations.

Remember ERS-1 and ERS-2? I was once told by an ESA executive that there had been two important decisions bearing on their remote sensing activities: (1) commit to implement ENVISAT-1, and, later, (2) drop the "1" from ENVISAT since there never would be a follow-on large multi-instrumented RS spacecraft, at least as part of ESA's program!

In my view, the US program has been thwarted by a technology push mentality, rather than being motivated by a knowledgeable and unified operational user community. Successful national programs, including in particular that of India, have been developed in response to applications having well-identified and legitimate data needs. Since 1978 there have been many proposals within the US for an orbital SAR, but in each case their price-to-payoff ratio was not acceptable to the nominal sponsor, NASA, since the systems were too aggressive hence costly, and the respective user communities were too small.

Signatures: What are the difficulties (excepting a larger hardware system) expected, for realizing a P band LEO based SAR? With the advancement of H/W technology when can we expect a P band satellite SAR? What are your experiences with P band airborne PolSAR data? Would you suggest P band SAR for land applications? Why?

Dr. Raney: Although the technical challenges confronting an EOS P-band SAR are significant, they are not insurmountable, even at (relatively) moderate cost. The antenna is the big (!) issue, of course, but there now are space-qualified unfolding reflector antennas large enough to satisfy the minimum area constraint for a SAR antenna at P-band. The most serious obstacle is the limitation imposed by the international protocol for frequency allocations, which allows only a 6 MHz bandwidth at P-band. That implies a ground-range resolution no better than about 40 m, which is not sufficient for many potential applications. In spite of this limitation, ESA has under consideration the BIOMASS proposal for a polarimetric P-band system, one of three finalists in the current Earth Explorer selection process. P-band, at nominally 70-cm wavelength, is appealing for penetrating forest canopy, thus suited for generating DEMs over vegetated terrain. BIOMASS exploits this characteristic, together with repeat-pass interferometry, for which P-band is suitable since decorrelation time is, to first order, proportional to wavelength. P-band data also are more sensitive to higher biomass populations, unlike shorter wavelengths (including in this case L-band) which tend to saturate under moderate biomass conditions.

Signatures: On ground data processing for microwave signal data involves numerous complex processing steps, in some applications requiring iterations to improve the products. Though fast computing systems are available today, still the demand for faster and faster turnaround time for products is becoming the major goal of RS in today's scenario. Another related issue is the faster dissemination of the processed data products to the concerned agencies. What is your opinion about these matters for future?

Dr. Raney: It appears that limitations in the delivery of products to the user are due more to infrastructure and data dissemination bottlenecks than to image processing delays. It should be safe to posit that SAR data processing, including interpretations and value-added procedures, will gradually disappear as a limiting factor in the timeliness of data/information available to the end user. It follows that ground segment design and implementation should start with the user data delivery linkage stages, and work backwards. For certain applications, specialized "fast-track" channels could be appropriate.

Signatures: Although accurate product generation currently is ground based, how would you rate the importance of real time products (RT, with an on-board processor)? What would be the consequences if such RT products were to have slightly reduced accuracy and perhaps poorer resolution, for critical events such as flash floods, tsunami, landslides etc? Does RT have a fruitful future in this field? If yes,

how is it going to benefit mankind and the environment (including the flora and fauna) of our 'mother earth'?

Dr. Raney: Let's stipulate in this context that RT means real rate processing, on board the SAR spacecraft, with only a small delay between completion of data collection and beginning generation of the focused product. What is implied? SAR processing invariably increases the data volume of the product, often by a large factor. In other words, there are more bits per frame in the image domain, than in the original signal domain. The only way to offset this data volume growth is to do multi-looking on board as part of the RT algorithm. As a rule of thumb, the data volume of the image product is smaller than that of the corresponding signal frame only if 16 looks or more are taken. Such data would be worthless for applications that need complex data, such as polarimetry or interferometry, and would be compromised for applications requiring finer resolution. Thus one consequence of RT processing is that the richness of the original data is lost. Of course, one could envision two parallel channels, raw signal and RT data, but that has its own implications.

The downlink data rate always is a limiting factor. If the radar is operated such that the raw signal fills the downlink channel capacity, then any increase in the data volume due to RT processing to be transferred through that same channel implies a reduction in coverage.

If operating through a sparse network of ground stations, then the inherent latency between data collection by the SAR and down-link opportunity may become a major factor limiting timeliness. One may circumvent this latency by establishing a more dense network of ground stations, or by implementing a set of relay spacecraft, such as the TDRS of the US. Neither approach is trivial.

Flora and fauna change slowly, at least relative to SAR data processing speeds, and even relative to a SAR satellite's orbital period. Data availability for such applications should be satisfied by routine down-links of the raw signal, timely processing, and efficient delivery of the product to the end user. RT processing, near-real-time down-link of the resulting product, and fast-track delivery of the product to the user is justified only for rapidly changing circumstances, such as occur in tactical situations. Even then, latency in the data transfer channels is likely to be the pacing factor.

Signatures: Dr Raney, how do you foresee the future of Microwave Remote Sensing using multi frequency, and multi-polarization sensors, from spaceborne platforms, in operational mode? Shuttle Imaging Radar, SIR-C was the only such mission, but it lasted less than ten days, and so was not suited for routine operational applications.

Dr. Raney: SIR-C convincingly demonstrated the value of near-simultaneous SAR coverage over a variety of scenes by two or three wavelengths (L, C, and X). It is not likely that such a montage of frequencies will fly on one bird again. However, this may be emulated by two or three SAR spacecraft flying in close formation, in the same spirit as NASA's A-train, each operating at its own wavelength, and with its own polarimetric paradigm. This would be an excellent opportunity for multi-national cooperation, with one spacecraft each. The underlying international inter-agency framework would have to include an agreement on orbit, and closely coordinated navigation of the constituents. Orbit should be a minor concern, since many agencies have opted for a dawn-dusk sun-synchronous orbit for their SAR systems. Japan is an important exception, as its ALOS orbits are sun-synchronous, but mid-day phased. Down-link of the data generated by such a multi-band constellation would have to be coordinated, perhaps steered to the corresponding ground segments of the participants. There are early steps in this direction, however, as Argentina and Italy are cooperating on their respective SAR satellites SAOCOM at L-band, and COSMO at X-band, both polarimetric.

Signature: SRTM mission generated high accuracy global digital elevation models (DEMs). Is there any requirement for such a mission in the future for Interferometric use, or any other application?

Dr. Raney: Yes, although implementation on NASA's Shuttle or the equivalent is not likely. The closest thing to that precedent is the combination of Germany's TerraSAR-X and TanDEM-X, which has the advantage of an elegantly designed orbit configuration, and the disadvantage of a short wavelength (3 cm). Several important applications, such as DEM generation over forested terrain and differential interferometry would benefit from a longer wavelength such as L-band.

Signatures: Dr. Raney, if I may ask a slightly different question related to SAR, what is your idea about higher frequency SAR systems (around 35GHz) for getting finer resolution images? Since, the atmospheric effects will be significant, can we envisage combined active and passive (poorer resolution) microwave sensing to derive products of significance to earth observation?

Dr. Raney: It is often assumed that shorter wavelength opens the door to finer resolution, but that is not true in general. The only domain in which wavelength becomes a limiting factor is when the system is operated as a spot-light SAR over a full aspect sector of 180 degrees. In this unique situation, and only if the backscattering feature remains mutually coherent over the entire span of observation angles, then the resulting azimuth resolution is one-quarter of the radar's wavelength. (There are certain in-situ seismic arrays that approach this limit, but at much longer wavelengths.) Within all reasonable spans of aspect angle, however, SAR azimuth resolution is proportional to the inverse Doppler bandwidth, which is in effect independent of wavelength. Why? Because for longer wavelengths, the radar may be designed to cover a wider span of aspect angles, thus collecting coherent data having the same Doppler bandwidth.

Your 35 GHz example (Ka-band) corresponds to a wavelength of about 0.86 cm. That implies that the area of a suitable SAR antenna could be smaller than one usually encounters. However, in addition to the propagation effects mentioned in your question, there are hardware challenges implied, especially power and device efficiency which for space-based systems could be limiting factors. There are nice airborne Ka-band examples, but none to my knowledge intended for EOS applications, certainly none designed for space-based operations.

Signatures: You have been involved with ISRO for the MiniSAR in Chandrayaan-I. What are the significant achievements from MiniSAR ?

Dr. Raney: MiniSAR is the first polarimetric SAR outside of earth orbit. That is no small accomplishment. Its measurements are comparable at fundamental levels to the polarimetric observations from earth-based facilities such as the Arecibo Radio Telescope whose antenna area is about 71,000 m2, in stark contrast to the MiniSAR whose antenna area was only 1 m2. MiniSAR during 9 months of lunar observations collected over 300 strips of polarimetric SAR imagery covering more than 90% of both poles, thus exceeding its minimum requirements. In fact, MiniSAR's only mode was polarimetric, thus making it the first operational polarimetric orbital SAR. It is ironic that this "proof-of-concept" hybrid-polarimetric imaging radar was flown in lunar orbit, thus opening the way for the first CL SAR in earth orbit, RISAT-1.

Based on the analysis of polarimetric radar observations of 40 permanently shadowed craters near the North pole, MiniSAR offered evidence of substantial water-ice deposits whose mass has been estimated at many tons. Although the evidence is compelling, it is too much to claim that the MiniSAR discovered ice. Confirmation by other means remains.

Signatures: Dr. Raney, what is your opinion and vision about the combined use of Optical and MW sensors' data for monitoring of the Earth's resources?

Dr. Raney: The combination of MW and optical (including infra-red) is essential, but not necessarily on the same platform. After all, the key MW sensor is a SAR, which looks to the side, in contrast to most optical sensors whose natural field of view is below the host spacecraft. By definition, the two sensors cannot view the same scene simultaneously. Co-hosting the two types of instruments on the same platform complicates (read, increases the cost of) the design, and would serve no practical application. Assuming sun-synchronous orbits, optical sensors prefer a mid-day phasing, whereas the optimum orbit (at least from an energy budget point of view) for a SAR is dawn-dusk.

Signatures: Dr Raney, you have had several decades of experience in the field of MW RS. What is your assessment of Indian RS program?

Dr. Raney: India's space program has a long and impressive record, with earth observation, primarily for domestic purposes, a major theme for the past several decades. I recall being told many years ago about India's first domestic build of a remote sensing satellite, which after completion in a proper clean room, was wrapped in a plastic sheet, and conveyed to the integration and launch facility over dusty rough roads on a cart pulled by oxen. I was cheeky enough to recount this story to the director of the ISRO facility in Bangalore during the early days of the Chandrayaan-1 project, then three years before launch. It was deflating, to say the least, to have the director tell me that I was wrong. "It did not happen that way", he said. (Oops, I thought, now I really have been foolish.) "No", he told me, "they were bullocks, not oxen!" I have watched India's progress in the airborne SAR field since the early 1980s, and have known about ISRO's extensive use of Radarsat data since 1995. Many of India's lead radar scientists have been resident at major international centers, such as JPL, Canada's Radarsat Project Office, Germany's DLR, and with French polarimetric experts. I have been fortunate to work with Indian radar scientists through the Chandrayaan-1 mission, and, as a consequence, with several lead individuals in the RISAT-1 project. Without a doubt, India's RS program in general, and her radar program in particular, ranks among the top tier of such programs world wide.

Signatures: Dr Raney, thank you very much for sparing your time for ISRS-AC. Would you like to say something else to our readers?

Dr. Raney: I have appreciated this opportunity to speak my mind on several issues technical and personal which are relevant to the RISAT-1 program. I extend my sincere thanks to you and your readers for the patience and perhaps interest to stay with this conversation.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures*, related to the specific theme "Megha-Tropiques Mission- Radiometers for the Tropics".

The deadline for inclusion in the next issue is **Sep 30, 2012.**

- Editorial Team

RISAT-1, A Long Cherished Vision Realised

N S Pillai,

Former Associate Programme Director, Microwave Payloads, IRS

The vision to realize a state of the art radar imaging satellite like RISAT-1 took shape way back in 1973 at the Microwave Division (MID), Microwave Antenna Systems Engineering Group (MASEG) at Ahmedabad, when many may not even be aware about Synthetic Aperture Radar (SAR) technology for remote sensing applications. It was only in 1978, the first spaceborne SAR onboard SEASAT-1 was launched by NASA. Under the ISRO-CNES exchange programme, an opportunity was availed in the year 1974 to work at Thomson-CSF, the leading French industry, on the study project awarded by ESA to study the feasibility and configure a satellite with SAR for remote sensing applications. In addition, an experimental study to understand the scattering characteristics of Paddy during its entire growth cycle using a ground based X-band scatterometer was carried out in the mid 70s by MID. With these exposures and the studies carried out, a proposal was made to develop an airborne SAR for remote sensing applications under the Microwave Remote Sensing programme envisaged.

A national committee on SAR was constituted in the late 70s by Chairman, ISRO to study the requirements in the country, the technology options and the production strategy. Based on the recommendations of this committee R&D activities were initiated to realize SAR technology. As a first step, an X-band real aperture Side Looking Airborne Radar (SLAR) was designed, developed and installed in a DC-3 aircraft. This was flight tested in 1980. This was the first radar imagery of Ahmedabad and the surrounding areas generated. Another first was the generation of the radar imagery of the Lonar crater, near Auranghabad, Maharastra formed by the impact of a meteorite hit. The SLAR picture of this crater is given in Fig2: and Fig3; Building of this airborne radar gave us an insight into configuring, designing, developing, integrating and installing in an aircraft as well as in data acquisition and processing, calibration and validation etc. Fig: 1 shows the SLAR system onboard the aircraft.

Following this, the design and simulation studies, design and development of critical components and establishment of facilities like SAW/MIC etc. required for the development of a SAR system were pursued under TDP/R&D activities. In addition, a transportable 1-18 GHz ground based Scatterometer with facilities like look angle and polarization switching facility was developed for signature studies. This was taken to Gujarat agriculture university campus and IARI campus, Delhi apart from other locations for signature collection.

A number of studies to configure a spaceborne SAR were carried out including some joint studies with international space agencies. A Microwave Remote Sensing Programme document was prepared in the mid 80s envisaging the launch of spaceborne SAR systems in different frequency bands meeting the different applications requirements. The space segment, the ground segment and the applications were defined along with schedule, budget etc. Though this did not get the final approval, a new R&D group viz. Microwave Sensors Development Group was formed at SAC and entrusted with the responsibility of developing an airborne C-band SAR. The airborne SAR was developed in a short span of 30 months and the first flight was successfully carried out in 1992 onboard a Beechcraft aircraft. The data acquired was processed to produce 6m by 6m resolution images. Apart from the antenna, transmitter, receiver, high speed digital data acquisition and recording system, a GPS aided INS based motion sensing system and antenna stabilization system were also developed. A complex software based processor apart from the hardwired real time processor was also developed to generate the high resolution images.

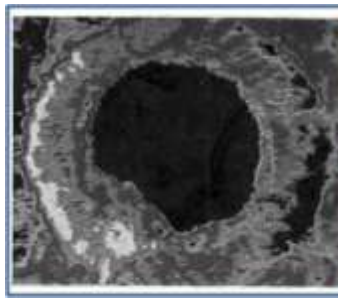
Along with the development of SAR technology, the system studies and critical technology development activities were also carried out for a Ku-band wind Scatterometer and Altimeter. Parallelly, the development of the passive microwave radiometers was also pursued right from the beginning. In Bhaskara 1 & 2, Microwave Radiometers operating in 18, 22 AND 37 GHz were flown to measure the sea surface temperature, sea state and atmospheric parameters. Even though due to the limited space and volume available in Bhaskara satellites, only a small aperture horn antenna could be flown resulting in moderate spatial resolution, the temperature sensitivity around 1 deg K could be achieved helping to demonstrate many applications.

A more sophisticated multi frequency Scanning Microwave Radiometer was developed later and flown successfully onboard IRS P4/Oceansat-1. Another multifrequency scanning radiometer was jointly developed along with CNES and flown onboard Megha-Tropiques in 2011. A scanning wind scatterometer operating in Ku band was also developed during this period and successfully launched onboard Oceansat-2.

Fig: 1 SLAR System inside the aircraft

All these efforts gave the wherewithal including a motivated team to embark upon the most complex active array multimode C-band SAR for RISAT-1in the late 90s. A lot of innovative features like stretched Spot Light mode, circular polarization transmit mode etc. have been added to the current in technology configuration of RISAT-1. Another laudable effort was to use the national facilities and the Indian industries maximally to develop the most complex subsystems like T/R modules, high speed digital subsystems etc. indigenously. Even in the domain of testing, first of its kind facilities like active array antenna test facility was established to characterize the active array antenna in the laboratory.

When RISAT-1 was launched successfully on April 26, 2012, the long cherished vision was realized. The data obtained indicates that the radar system is working as planned. It will be a matter of great satisfaction when this data will be utilized by the users by exploiting its full potential. In order to make use of the polarimetric data for various applications, there is a need to understand the electromagnetic interaction with the target more deeply. Significant efforts will be required in this direction.



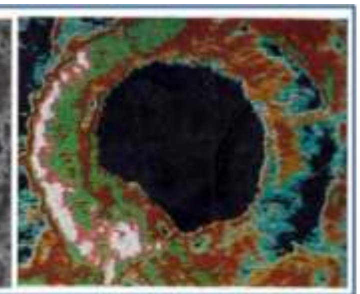


Fig: 2 Lonar Crater **Fig: 3 Density Sliced Image**

The importance given to system studies to get insight into the complex systems like SAR and understand the interplay of the system and subsystem parameters through simulation and analysis has helped in realizing a state of the art system like the multi-mode active array SAR successfully. Similarly the advanced R&D and critical technology development activities carried out also helped in realizing the hardware successfully. Though we have achieved world class functional performance, there is a need to reduce the weight and power requirements of the radar system significantly. Also, we have to build SAR systems in lower and higher frequency bands to serve the various applications. A multi-frequency SAR is the demand of the applications. Further, there is a real time data need. Onboard processors, multiple satellites etc. will be required to meet this need. SAR interferometery is one of the major applications that need to be addressed. There could be other innovative applications waiting to be unfolded. I am confident that the teams at SAC and other ISRO centers along with the active participation of industries, national centers and academic institutions will achieve the goals and take the SAR systems to meet the operational demands.

RISAT-1, An Upsurge

Dr S B Sharma, Director, INDUS Institute of Technology & Engineering,
Former DD, ASA/SAC, Ahmedabad

At the outset, I wish to express my gratitude for the kind invitation extended by Chairman, ISRO to witness the launch of RISAT on 26 April, 2012 at SHAR. The majestic sight of the RISAT launching away in the crimson sky will linger on in my memory forever. When I think about the happy faces in the control centre after the launch, it lights up my day. To witness such technological perfection and lively team spirit was truly a once in a lifetime experience and I sincerely thank the Chairman for giving me this opportunity.

Microwave remote sensing has come a long way since the first microwave remote sensing payload, SAMIR, onboard Bhaskara satellite launched on 7 June 1979. The abrupt eclipse of microwave payload after SAMIR and temporary vacuum after the launch of Scatterometer, on board Occeansat-II on 23 September 2009, was filled with the launch of RISAT.

Down the memory lane, it was an early summer morning on 24th May 1999, just two days before the launch of Multi-frequency Scanning Microwave Radiometer (MSMR) payload on board Oceansat-I satellite, when I circulated a brief proposal prepared by team of system engineers at SAC on RISAT-I to all the Centre Directors, at the SHAR guest house. It was the time when the Microwave Remote Sensing Program was struggling in ISRO. It was also the most appropriate time to transform Side Looking Airborne Radar (SLAR)/ Airborne Synthetic Aperture Radar (ASAR) to space borne SAR. With the circulation of this note the seed of RISAT was sown and the tone was set to convert this dream in to reality little by little. This definitely led the scientific thinking in new direction.

The development of a complex antenna system for RISAT required multi-faceted perspectives and a team of engineers from diverse fields. The available manpower consisted of some who were at the beginning of their career and others like me who had already entered the second phase of the career cycle. The common thread, though, was the drive to innovate. The realization of such a complex antenna system was a highly challenging task. We had no hands on experience on Active Phased Array antenna and were likely to commit many mistakes. But we at ASA, were filled with great sense of euphoria and confidence. Once we understood the system concepts of phased array antenna thoroughly, we started overcoming the deficiencies one by one in the design of the overall antenna system. Our design option of multilayer-microstrip-printed-array antenna was initially dismissed as naive or impractical. Everyone else thought that achieving the required bandwidth with such an antenna was impossible. But we were sure about our design approach and were confident of realizing the antenna in spite of the fact that such type of antenna had never been flown by any other country in the world.

Now, we can bask in the glory and wonder at the realization and integration of such a complex technological payload. The dream of young engineers of Antenna Systems Area (ASA) and Microwave Remote Sensing Area (MRSA) at SAC has turned into reality and their curiosity has found its expression in the operationalization of RISAT payload. The highly qualified and capable engineers associated with this program deserve all the praise and commendation. The launch of RISAT has strengthened the view that ISRO is second to none in the world. We at ISRO are known for rigorous research, dynamic self learning and thoughtful leadership. Our engineers engaged with R & D are highly innovative global thinkers and strive to be a force to be reckoned worldwide. ISRO's technological contributions have had a tremendous role to play in the growth and development story of India.

The launch of RISAT has symbolized the upsurge of energy. It is this upsurge that will motivate our engineers to set higher goals and to achieve them with hard work and dedication. It has left behind a heightened sense of pride and awareness on which the scientific community at ISRO will take a ride in future. Here's saluting the ISRO culture and wishing a happy imaging from RISAT – I.

Section 1 – RISAT-1 Overview

RISAT-1 Project Overview

Ramanand Tyagi, Ex-PD RISAT-1

ISRO Satellite Centre, Bangalore-560017

1. Introduction: ISRO has launched remote sensing satellites with payloads working mainly in the optical region of the electromagnetic spectrum starting with IRS -1A series to the latest Resourcesat-2A. These satellites are serving the needs of the users of remote sensing data, both nationally and internationally. The International users are served through the large number of globally established ground stations. While a comprehensive capability has been established for optical remote sensing data, a beginning was made with the launch of Multi-Frequency Scanning Microwave Radiometer (MSMR) on-board Oceansat-1 to serve the needs of microwave remote sensing data users on an operational basis. MSMR was preceded by SAMIR radiometers on board Bhaskara satellites. A pencil beam Ku-band scatterometer was launched on board Oceansat-2 to provide wind velocity globally.

The managers of natural resources, especially agricultural, forestry and disaster managers are handicapped to meet their data needs during cloud cover. This aspect is more pronounced in India and other tropical regions of the globe where the majority of the crops are grown in monsoon season. As microwave signals have the capability to penetrate clouds, haze, fog and can also work during day/night, Synthetic Aperture Radar (SAR) which is an active microwave sensor is better suited to serve these remote sensing applications.

ISRO initiated the efforts to realise a SAR payload by developing an airborne SAR and gained experience in utilising its imageries. This experience helped in choosing the payload parameters of RISAT-1 mission.

2. RISAT-1 Mission Objectives: The objectives for the RISAT-1 mission were defined for four areas viz: SAR payload, satellite mainframe, ground segment elements and application algorithms as following:

1) To develop a multimode, agile SAR payload, operating in ScanSAR, Stripmap and Spotlight modes to provide images with coarse, fine and high spatial resolutions respectively.

2) To develop and operate a compatible satellite to meet the mission requirements, operating in three axes stabilised mode in 536km altitude circular sun synchronous orbit.

3) to establish a ground segment to receive and process SAR data.

4) to develop related algorithms and data products to serve in well established application areas and also to enhance the mission utility.

3. Mission Elements of RISAT-1: The mission elements of RISAT-1 to realise the defined mission objectives comprise orbit, payload, satellite mainframe, ground segment elements and users interface as depicted graphically in the figure above. While the detailed description of all these mission elements are given in subsequent chapters in this issue, a brief background for choosing the broad specifications is described in the following paragraphs.

3.1 Orbit: A 536 km altitude sun synchronous orbit was chosen for RISAT-1, keeping in view σ_0 performance, systematic coverage for medium resolution mode of payload operation, atmospheric drag and the capabilities of PSLV.

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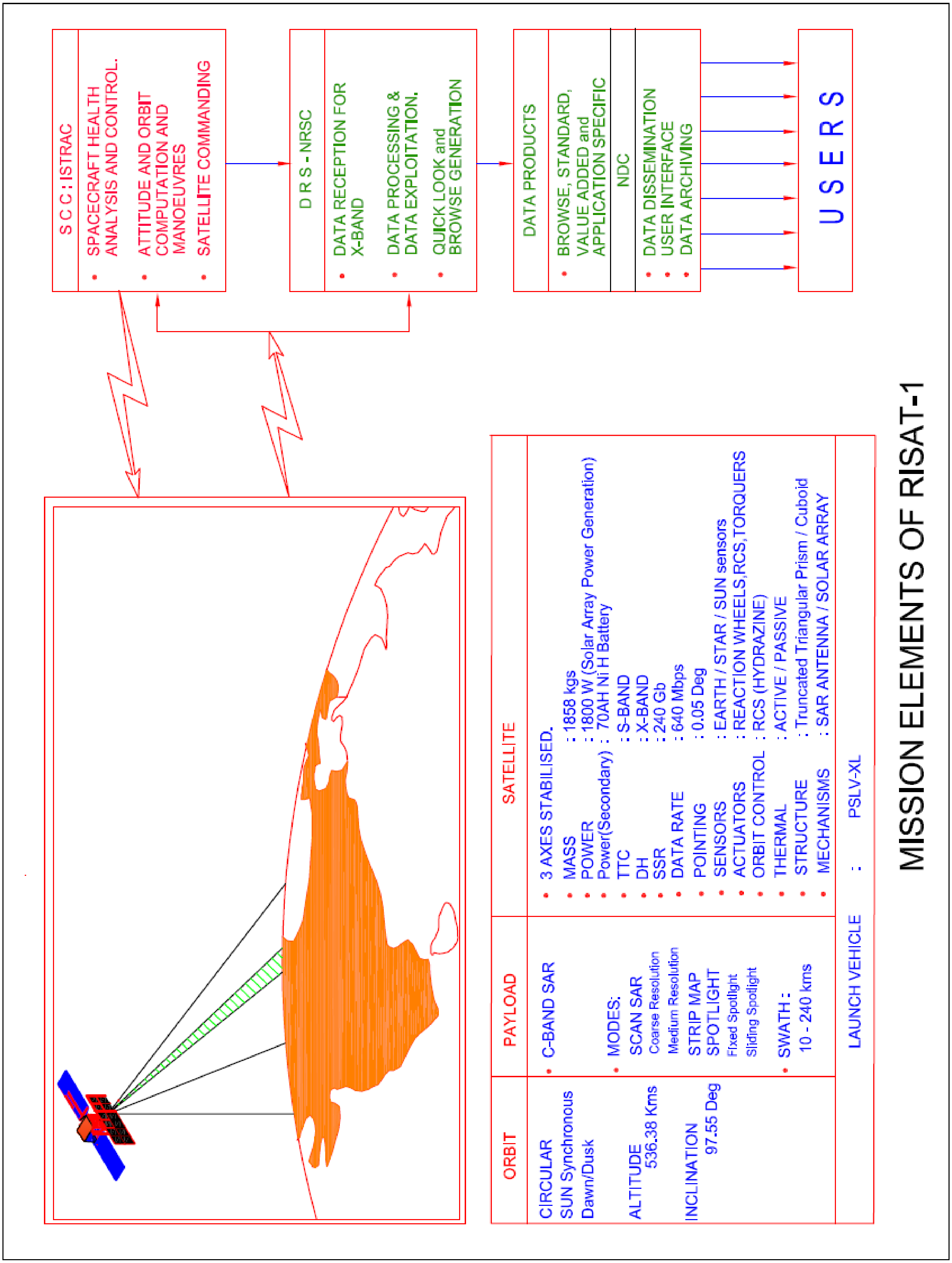
*Project Director, RISAT-1 (Till July 31, 2011) and currently working as Prof. Brahm Prakash Scientist



MISSION ELEMENTS OF RISAT-1

The choice of orbit ensures a worst case gap between two observations at any point less than four days for the large expanse of Indian land mass - best case can be as small as next orbit. The time of equatorial crossing is kept at 6AM/6PM to minimise the eclipse period and optimise on board power generation. The orbit, achieved by PSLV was 476 km altitude which was subsequently raised to 536 km using on-board satellite fuel.

3.2 SAR Payload: RISAT-I being the first SAR satellite of ISRO, it's important characteristics were chosen to have wide variety of spatial resolutions with compatible swaths and polarisation combinations. The first parameter to be decided was the frequency of operation which has impact on σ_o performance, size of payload hardware and the image data applications. It is difficult to meet all the user needs by a single frequency, that is why a compromise frequency in C-band was selected in order to serve the largest number of applications. All the defined modes with a chosen combination of spatial resolution, swath and polarisation may not be equally useful for making desired observations; nevertheless an experience can be gained through such observations in the first RISAT mission which will help in future to zero down on right combination of these parameters. The resolution chosen varies from 1 m to 50 m, swath from 10 km to 240 km with flexibility to operate in linear, quad or hybrid polarisation modes.

Such an all encompassing SAR design was accomplished by adopting an active phased array antenna technology having 576 TR modules along with their power supply and control modules. The size of the antenna is 6 m x 2 m divided into three equal segments. The accompanying electronics comprising frequency source, transmitter amplifiers, receivers modulator/demodulator, filters, signal processing electronics and payload controller are realised separately and mounted inside the main body of the satellite.

3.3 Satellites Mainframe

3.3.1 Structure: The purpose of satellite structure is to support the overall satellite mass of 1858 Kg , to be sufficiently stiff to withstand the launch loads of PSLV with its proper mechanical interfaces, to provide sufficient space for accommodating various subsystems, sufficient surface for mounting the external appendages including three segments of active phased array antenna of payload. The optimum shape of the structure was decided in favour of a triangular prism with a load-bearing cylinder at the Centre. A small cuboid at the top of the triangular prism provides the area for folding the solar panels on two sides, mounting various antennas and attitude sensors. Triangular prism and the cuboid sitting on top of it, in the stowed mode have overall dimensions such that they are accommodated within the heat shield of PSLV. The overall height of the satellite is 3.88 m, housed within the heat shield envelope of 2.8 m diameter.

3.3.2 Deployment Mechanisms: Deployment of solar panels and payload antenna after the launch is accomplished by suitable deployment mechanisms. While the hold down and deployment mechanism for the solar panels is a well proven subsystem, used in all ISRO satellites, a new hold down and deployment mechanism was required to be developed for two segments of payload antenna weighing 300 Kg each. The requirement for payload antenna deployment mechanism were stringent in order to achieve a flatness of 0.7 mm rms. This mechanism was developed using tension springs.

3.3.3 Thermal Control: The thermal control of the satellite was designed to meet the specific requirements of satellite operating in Dawn/dusk sun synchronous orbit, having large variation in power dissipation in subsystems, especially in payload, earth shine load and sun load during various modes of operation. This was successfully achieved with the help of heaters, MLI blankets, tapes and heat pipes. All the specific requirements of temperature ranges for various subsystems have been met with sufficient margins.

3.3.4 Baseband Data Handling System: The data handling system has two elements namely data formatter and solid-state recorder. The data formatter accepts the input from payload data acquisition and compression system through a serialiser/deserialiser interface. The data rate varies from 150.84 Mbps to 1418.76Mbps. This data is received in burst mode and converted into continuous data by using suitable memories before formatting. The formatted data is either directly transmitted to ground or stored in the on-board solid-state recorder with proper interfaces. Necessary interfaces are also provided with on-board controller to ensure proper operation of payload sequencer. Flexibility to format data with large variation in rates, compact design using the FPGA's, serialiser/deserialiser for interfacing and providing a serial interface at 160Mbps for I and Q channels of the transmitter, are some of the special features of data formatter.

Solid-state recorder is the other element of data handling system. It has a total capacity of 300Gb with its own control units to accomplish the necessary functions of recording, playback and self checks. It has standby, retention, record and playback modes.

3.3.5 On-Board Controller(OBC): The on-board controller meets the requirements of Telemetry Tracking and Command (TTC) functions on one hand and Attitude and Orbit Control System(AOCS) on the other. Baseband elements of TTC form part of on-board controller. The OBC processes the commands, sent from ground and distributes them to various subsystems and collects the housekeeping data from various points of the satellite and transmits it to the ground. Satellite tracking data collected by satellite positioning system is also handled by OBC. The OBC also provides the automatic temperature control of thermal heaters and Ampere-hour accounting of the battery.

The AOCS functions are implemented by taking the inputs from various attitude sensors, processing this data and feeding the output to the actuators like reaction wheels, thrusters and magnetic torquers.

Payload sequencer which simultaneously controls the necessary parts of payload, baseband and RF data handling system, is also implemented in OBC.

Remote programming facility to overcome any contingencies after the satellite launch is also provided to incorporate/ change the software modules.

RISAT-1 OBC is realised using ASICs in place of FPGAs in the earlier designs. The interfaces between OBC and various other subsystems are realised by using 1553 bus. It has hot redundancy.

3.3.6 Attitude Sensors: The specifications for attitude control of the satellite during imaging are -0.05°(3 sigma) for pointing and a drift rate of $3X10^{-4}$degree/sec. To realise the specifications the attitude is continuously measured by attitude sensors. A dual head star sensor is the main stay for attitude measurement for all the three axes, backed by a set of dual head conical sensor/digital sun sensor. An inertial reference unit is continuously in the AOCS control loop and gets updated either by star sensor or conical sensor/digital sun sensor combination. A Tri-Axial magnetometer forms part of the sensors combination which helps in attitude determination in the eventuality of loss of lock.

3.3.7 Actuators: Hydrazine-based reaction control system having 8+1 thrusters of 11N capacity are suitably mounted for orbit manoeuvres and attitude control. Four reaction wheels of 50Nms capacity and 0.3Nm torquing capability are used for dynamic attitude control about pitch, roll and yaw axes. Two magnetic torquers of 60 Am^2 capacities mounted along roll and pitch axis are used for momentum dumping of reaction wheels.

3.3.8 AOCS Modes: Right after the injection into the orbit, the satellite is in tumbling mode. It is brought to a 3 axes stabilisation in the next orbit. Launch vehicle dispersions are removed using thrusters and desired orbit is achieved. Whenever payload is to be operated, a tilt of 36° about roll axis is given for SAR operation in predetermined direction. Periodical orbit adjustments are required to remove the orbit degradation caused by atmospheric drag.

An important aspect of AOCS is the effective reduced velocity of satellite to achieve high resolution mode of payload operations, also referred to as step-and-stare mode of operation.

3.3.9 Power System Elements: Power subsystem comprises three main elements namely, 1)solar array to generate power from sunlight, 2) chemical battery to store the generated energy for use during the peak power requirements like payload operation and also eclipse period and 3) Power Electronics which regulates DC power to charge/discharge the battery, and input to various subsystems.

The solar array strings are designed to operate at 70V with a total power generating capability of 2085 W at the beginning of life by using improved triple junction solar cells. A solar array drive assembly is used to transfer the power generated by solar array to the satellite main body. Active solar array area is 10 sq. m.

A Nickel-Hydrogen chemical storage battery of 70AH capacity is part of RISAT-1 power subsystem. It has 42 cells in series. Battery output is regulated to 70±2 V by using battery discharge regulators and fed to the main bus. The input to the battery is regulated by frequency sequential switching shunt and series regulator.

Power electronics has bus voltage regulation, various protection circuits, control logics of its own elements and DC/ DC converters for various satellite subsystems. The main bus voltage for RISAT-1 is regulated 70V to supply to the high power consuming subsystems including SAR payload, reaction wheels and phased array antenna of data transmitter. An auxiliary bus is made available to heritage subsystems with a regulated voltage of 42V.

3.3.10 RF subsystems: The RF elements include 1) S-band TTC transponder,2) X-band image data transmitters,3) satellite positioning system and 4) the necessary antennas to support the functions of the three earlier elements.

Coherent S-band transponder receives command signal, sent from ground, demodulates them and sends to OBC. It takes the housekeeping data collected from various subsystems and modulates on S-band carrier and transmits to ground. By working in coherent mode it helps in getting the range and accurate range rate data for the satellite.

The high data rate from SAR payload after getting formatted in baseband data handling system is fed to QPSK modulator and transmitted to ground by X- band transmitter. The satellite has capability to transmit up to 640 Mbps by using two transmitters of 320 Mbps each and occupy the same allocated spectrum. This is achieved by frequency reuse in X-band wherein a phased array antenna transmits the output of two transmitters in RHCP and LHCP polarisations. This phased array antenna, working in dual polarisation mode points the beam in the direction of a receiving ground station.

A satellite positioning system is used to get the orbital parameters in real-time by using GPS signals.

3.4 Spacecraft Control Centre (SCC): The spacecraft control centre is located in ISTRAC, Bangalore to control the satellite by sending commands and receiving the housekeeping data for analysis and control. The functions like attitude and orbit determination, payload planning and interfacing with the various other ground stations are carried out at SCC. A dedicated mission control room provides the support in normal phase operations by using mission computers and communication links with the ground stations in the network.

3.5 Payload Data Reception and Processing: The ground station facilities at National Remote Sensing Centre (NRSC) at Hyderabad comprise a data reception station and data processing computers. A 7.5 m antenna dish with capability of dual polarisation reception in X-band along with the necessary receiver chains has been established at NRSC, specifically for RISAT-1 mission. Various data products ranging from browse to geo-coded ones are produced and disseminated to the end users.

3.6 Launch Support: RISAT-1 was launched by ISRO's PSLV on April 26, 2012 . This is the heaviest and most voluminous satellite launched, by the PSLV so far. The heat shield envelope was fully utilised including the area in the tapered zone. The vehicle placed the satellite in the designated orbit with minimum dispersions.

4. Realisation Aspects: RISAT-1 has a long list of subsystems which needed to be developed afresh, starting with SAR payload and the compatible subsystems in the satellite mainframe including baseband data handling system, dual polarisation RF data transmitters, solid-state recorder, solar array drive assembly, high-capacity high torque reaction wheels, ASIC based OBC, new structural elements specifically to meet the requirements of RISAT-1 satellite, hold down and deployment mechanism for payload antenna panels of approximately 300 Kg each and a very demanding design of thermal control system for a dawn/ dusk Sun synchronous orbit with a large variation in power dissipation and external thermal loads. For ground segment elements the development of data products algorithms and establishment of a data reception chain for receiving dual polarisation signal from the satellite.

RISAT-1 satellite was realised following a single model philosophy by drawing heavily on the past experience and extensively using the simulation tools. However, developmental models were realised at subsystem package level and qualified separately for all the new elements.

A special mention has to be made about the realisation aspects of the SAR payload because it is totally new and involved large number of hardware and software elements. While development of the SAR subsystems was taken up in-house, the technology was transferred to the industry, proper training about the qualification aspects necessary for realising space worthy hardware, was imparted. The development of large size printed circuit antenna on a in-house developed CFRP substrate by growing multiple layers with proper registration, power supply modules operating in pulsed mode, large number of T/R modules and firmware for the payload controllers through the industry for the SAR payload. Dedicated effort was required by the payload team to interact closely with industry to bring them to the qualification level, required for realising the space based hardware. Thus the RISAT-1 mission became a fine example of industry participation in realising the satellite subsystems.

The satellite level testing proceeded on the well proven lines of other missions except that the arrangements were made for conducting the thermo-vacuum test wherein SAR antenna panels were required to be in deployed as in-orbit condition inside the chamber so as to ensure the proper temperature ranges for the subsystems and keeping the satellite ON continuously.

The necessary algorithms and softwares for the generation of imagery and data products and establishment of dual polarisation feed for data reception antenna were successfully installed at NRSC. Necessary elements at Satellite Control Centre to meet the specific requirements of RISAT-1 mission have also been installed.

5. Satellite Operations: The satellite was made ON before the launch on ground itself and since then it has been satisfactorily operating through the launch, initial acquisition, orbit manoeuvres and finally the successful payload operation phases. Ground segment elements at Satellite Control Centre and data reception and processing facilities at NRSC have performed satisfactorily.

6. SAR Data Validation: The calibration exercise for SAR data in various modes of operation is being carried out. This exercise will be carried out in three phases - first level by collecting the imagery over homogeneous sites, the second level will be done by using large number of corner reflectors in an open space and finally a limited number of corner reflectors will be placed within a water body to fully calibrate the SAR data.

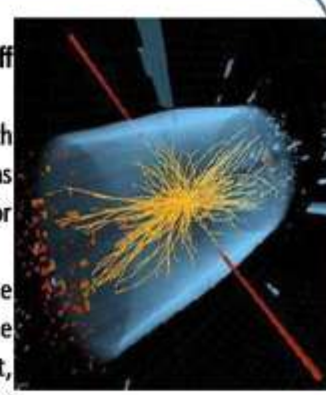
7. Acknowledgements: I thank the project team members who successfully realised the challenging RISAT-1 mission. I gratefully acknowledge the encouragement provided by the ISRO management at various work centres, especially Dr T.K. Alex, Director ISAC and the Chairman, ISRO during project implementation phases and also for encouraging writing this paper.

Spacedaily.com (05/07/12)

A new particle has been discovered - chances are, it is the Higgs boson by Staff Writers Tel Aviv, Israel (SPX) Jul 05, 2012

The long and complicated journey to detect the Higgs boson, which started with one small step about 25 years ago, might finally have reached its goal. This was reported by LHC particle accelerator scientists at the European Laboratory for Particle Physics, CERN, near Geneva.

The Higgs boson is the final building block that has been missing from the "Standard Model," which describes the structure of matter in the universe. The Higgs boson combines two forces of nature and shows that they are, in fact, different aspects of a more fundamental force. The particle is also responsible for the existence of mass in the elementary particles.



RISAT-1 Synthetic Aperture Radar Payload

Tapan Misra

SAC, Ahmedabad

Introduction: Radar Imaging Satellite-1 (RISAT-1), carrying India's first indigenously developed space-borne, C-Band active antenna based, Multi-mode Synthetic Aperture Radar (SAR) payload was launched on 26th April, 2012 by PSLV-C19 flight. Satellite after its positioning at 536 km sun-synchronous **dawn-dusk** circular orbit was operated on May 1, 2012 and the SAR images of good quality, have been received. RISAT SAR system is based on Active Antenna Array technology. Success of mission marks entry of ISRO into a select group of space agencies operating C band SAR. At present only Canadian RADARSAT -2 mission is providing images in this frequency band. However, a number of agencies have been providing SAR images in X band (TerraSAR-X from Germany, Cosmos Skymed from Italy and RISAT-2 from India). Presently no L-band SAR system is operational.

Capability of RISAT-1 SAR: Unlike optical imagers, SAR imagers are capable of operating in all weather conditions like both day, night, through clouds, rains, haze, dust, fog and smoke. Target applications for RISAT-1 include agricultural crop acreage and yield estimates (Rice, Jute etc.), disaster monitoring like flood affected area estimation, hydrology, geology, land use, terrain studies, change detection and oceanography, bathymetry, wave spectra etc.

RISAT-1 Mission and SAR Payload Configurations: RISAT-1 Mission is designed to provide SAR images covering the country with a repetivity period of 24 days. The orbit design takes the space craft crossing the equator in its descending path (north to south) at 6 AM and crosses the equator in its ascending path (south to north) at 6 PM. This results in imaging the country at Dawn (6AM) or Dusk (6 PM). In this period the entire country can be covered twice (one coverage at 6AM and another coverage at 6 PM at equator crossing) with a resolution of about 25 meters. In the same period by operating the payload in 50 meter resolution mode the country can be covered 4 times (twice at 6AM and twice at 6PM) It is possible to operate RISAT-1 for up to 10 minutes duration in each of its 14 orbits per day around the earth. It is possible to send the image data collected by the payload to ground station in real time or use the onboard solid state recorder and down link later to the ground station. This recorder capability enables imaging of any portion of the globe.

The spacecraft design features a very high transmission data rate of 640 Mbits/sec in X-band. This is achieved using two carriers in X band with Right hand circular and Left hand circular polarisations.

RISAT payload is an active remote sensing system as it carries its own source of illumination. The payload transmits a series of electromagnetic pulses of radiation in C band using an active antenna array of 576 transmit-receive modules mounted on panel of ~6 meters by ~2 meters. The electromagnetic pulses strikes the earth surface and the back scattered signal is received by the receive modules mounted on the antenna and by time correlated processing of this signal, information about the earth surface is deciphered. The large number of Transmit receive modules on the antenna panel enables generation of a beam of electro-magnetic pulses in C band. By controlling the phase and number of modules energized. it is possible to change the beam direction. This is known as electronic beam steering. Beam steering capability enables operation of the payload in a mode called ScanSAR mode.

The system is also designed to send and receive the signals in different linear and circular polarisations. These capabilities make RISAT 1 payload a unique SAR currently in operation from space. This payload is unique because of its ability to provide a large swath (~200 kilometers) images in multi polarization modes. These modes cover transmit in Horizontal Polarisation and receive in horizontal Polarisation (HH mode). Similarly one can transmit in Horizontal and receive both in Horizontal and vertical polarizations. (HH+HV modes). In similar fashion one can obtain VV or VV+VH. One can even obtain Quad polarization data (VV+HH+HV+VH) by transmitting the signal in H and V in periodic bursts and receiving the data in both H and V polarization simultaneously. RISAT SAR has unique Hybrid polarimetry modes, where signal is transmitted in circular polarization and signal is simultaneously received in H and V polarization.

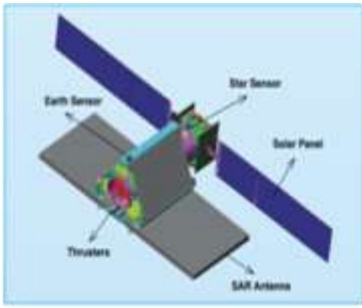


Fig.-1 RISAT Spacecraft Configuration

Figure-1 illustrates overall satellite configuration and Table-1 gives the salient features.

RISAT-1 has imaging capabilities in Stripmap and ScanSAR modes with resolution from 1-50 m and swath coverage from 25 km to 223km, with multi-polarization capabilities. Imaging mode configurations are illustrated in Figure-2 and salient imaging specifications are shown in Table-2. The basic imaging modes, identified for RISAT-1 SAR payload, are as follows:

Table-1 Salient Features of RISAT-1 Spacecraft

Salient Features

Orbit	:	Circular Polar Sun Synchronous
Orbit Altitude	:	536 km
Orbit Inclination	:	97.552°
Orbit Period	:	95.49 min
Number of Orbits per day	:	14
Local Time of Equator Crossing	:	6:00 am/6:00 pm
Repetivity	:	25 days
Lift-off Mass	:	1858 kg
Attitude and Orbit Control	:	3-axis body stabilised using Reaction Wheels, Magnetic Torquers, and Hydrazine Thrusters
Power	:	Solar Array generating 2200 W and One 70 AH Ni-H2 battery
Nominal Mission Life	:	5 years

- **Fine Resolution Stripmap Mode-1 (FRS-1):** It is based on conventional mode of SAR Stripmap imaging. The orientation of the antenna beam is fixed with respect to flight path so that constant swath (25 km) is illuminated along the flight direction. The intended resolution is 3m for FRS-1 mode.
- **Coarse Resolution ScanSAR Mode (CRS):** This mode allows for a multifold increase of the swath. This is achieved by periodically stepping the antenna beam to the neighboring sub-swaths (in the range direction). Swath in CRS mode would be 223 km with a resolution of 50 m.
- **Medium Resolution ScanSAR Mode (MRS):** This is a 6-beam ScanSAR mode, similar to the CRS mode, providing a resolution of 25 m over a swath of 115 km.
- Fine Resolution Stripmap Mode-2 (FRS-2): This mode has quad polarization capability. Philosophically, this mode is a hybrid stripmap and scanSAR.
- **High Resolution Spotlight Mode (HRS):** In the spotlight mode, the antenna beam is oriented continuously to illuminate a particular 10 KM x 10 Km spot on the ground which can be imaged with 1m resolution.
- **Circular Polarimetric Modes (C-HRS, C-FRS-1, C-FRS-2, CMRS, C-CRS):** All the modes mentioned above can be operated in hybrid-circular polarization.

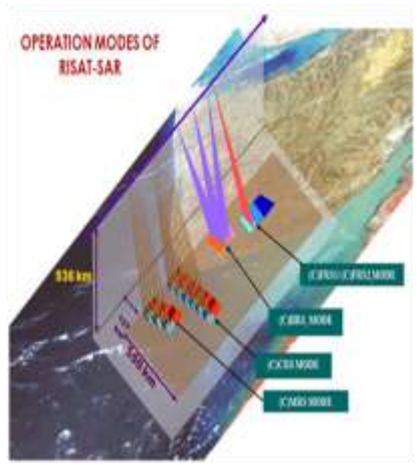


Fig.-2 Illustration of Imaging Modes of RISAT-1

RISAT-1 has the capability to cover both sides of the sub-satellite track by roll-tilting the satellite. The antenna will be mounted on satellite with antenna normal coinciding with satellite yaw axis.

Before start of the imaging, the satellite will be roll-tilted by ±36° to enable left/right imaging. With this position

Table-2: Salient Performance Specifications of RISAT-1

	Single Pol HH/HV/VV/VH	Dual Pol HH+HV/VV+VH	Hybrid Polarimetry TX: CP Rx: V and H	Quad Pol HH+HV+VV+VH
Fine Resolution Stripmap Mode-1 (FRS-1)	3-6 m resolution 25 Km swath σ_o = -17 dB			
Fine Resolution Stripmap Mode-2 (FRS-2)			6 m resolution 25 Km swath σ_o = -20 dB	9-12 m resolution 25Km swath σ_o = -19dB
Medium Resolution ScanSAR Mode (MRS)	25 m resolution, 115 Km swath σ_o = -17 dB			
Coarse Resolution ScanSAR Mode (CRS)	50 m resolution 223 Km swath σ_o = -17 dB			

of the satellite, electronic beam steering will be used to cover the ground range distance of 107km to 659km off-nadir covering an incidence angle of 12° to 55°. To provide near-constant swath, elevation beam width is varied from 2.48° to 1.67° by varying the electrical width of the antenna by switching-off certain rows of TR-

Modules, when imaging closer to the satellite track and switching-on all the rows when imaging farther off-nadir regions. Total 122 antenna-beams (61 for left- and 61 for right-imaging) have been defined to cover the entire given range. Out of these, any 12 beams can be used to define a particular imaging session. During imaging, satellite will be steered in both yaw and pitch to align the beam to zero Doppler line to reduce Range Cell Migration (RCM) to minimum.

The earth viewing part of the antenna is a printed microstrip patch array. 24 dual polarised linear arrays are printed in each of 12 tiles. Each of these linear arrays, consisting of 20 patch arrays, is fed by one pair of TR modules, each of which is dedicated for one polarisation. The active-antenna configuration will also help tolerate random failure of upto 10% TR-Modules, with only graceful degradation of antenna pattern. Four Tiles make one panel. RISAT-1 antenna has total 3 panels, of which one is fixed and adjacent two are deployable. The radiating surface of the antenna is covered with glass wool blanket to prevent heating by earth's radiation.

Both of the TR pair receives DC power from a miniaturised EPC called Power Control and Processing Unit (PCPU). Each such TR pair is controlled for synchronous operation by an ASIC based TR control computer (TRC). All the 24 TR module pairs in a Tile are managed by a Tile Control Unit (TCU). TR modules, each with maximum pulsed power of 10 watts, along with other Tile Electronics (TRC, TCU, PCPU, RF power dividers & harness) are mounted on the back side of antenna. Typical Configuration of a Tile and Panel is shown in Fig.-3.

The deck elements constitute conventional Pulse Doppler Radar, consisting of two chains of Receivers for simultaneous reception of V and H signals, one Frequency Generator, one Feeder SSPA and two sets of Data Acquisition and Compression units (DACS). The complete payload management is done by radar Payload Controller (PLC). Block diagram and photograph of Deck elements are presented in Fig.-4. Printed side of Patch Antenna side of the deployed antenna is shown in Fig.-5. Fig.-6 depicts RISAT SAR payload at different stages of testing and integration with spacecraft.

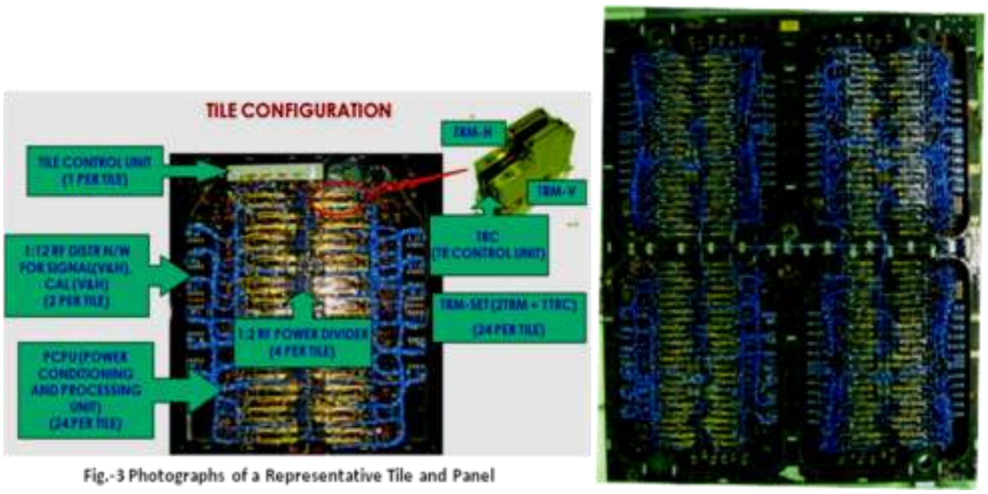


Fig.-3 Photographs of a Representative Tile and Panel

Table-3: List of New Technologies and Concepts Implemented in RISAT

NEW TECHNOLOGIES/CONCEPTS IMPLEMENTED IN RISAT		
A	IMAGING MODES	
1	EXTENDED SPOTLIGHT	FIRST TIME IN RISAT
2	CIRCULAR POLARIMETRY	FIRST TIME IN RISAT
B	HARDWARE TECHNOLOGY	
1	SPACE QUALIFICATION OF MMIC FOUNDRY	
2	DESIGN,PRODUCTION OF SPACE QUALIFIED MMICS INVOLVING THREE PROCESS	
3	DESIGN,DEVELOPMENT OF CHARACTERISATION OF INDIGENOUS TR MODULES	
4	MINIATURISED EPC WITH 3 HMCs AND PLANAR TRANSFORMER	
5	LASER GUIDED PRINTED ANTENNA FABRICATION	
6	DUAL CHANNEL DIGITISER (1.2 GHz BANDWIDTH, 250 MHz SAMPLING AND 22 W DISSIPATION)	
7	INHOUSE DESIGNED ASIC WITH 8 BIT PROCESSOR CORE	
8	3 TIER SYNCHRONISED REALTIME SOFTWARE CONTROL SPREAD OVER 314 ASIC BASED PROCESSOR	

NEW TECHNOLOGIES/CONCEPTS IMPLEMENTED IN RISAT		
C	MEASUREMENT TECHNOLOGY	
1	NEAR FIELD PROCESSOR	COPYRIGHTED
2	NOVEL TIME GATED NF ANTENNA MEASUREMENT SYSTEM	PATENT APPLIED
3	NOVEL BEAM COLLIMATION METHOD	PATENT APPLIED
4	SIMPLIFIED TR MODULE CHARACTERISATION METHOD	PATENT APPLIED
5	PRECISE MEASUREMENT OF GROUP DELAY OF RF CABLES WITH ACCURACY BETTER THAN 1 pico sec	COPYRIGHTED
D	FABRICATION TECHNOLOGY	
1	GROUP DELAY EQUALISED CABLE FABRICATION WITH S.D OF BETTER THAN 4-5 pico sec WITH BETTER THAN 90% YIELD	KNOW HOW TRANSFERRED
E	ALGORITHM DEVELOPMENT	
1	EXTENDED SPOTLIGHT PROCESSING ALGORITHM	PATENTED
2	DECOMPOSITION ALGORITHM FROM STOKE'S PARAMETER TO RGB IMAGE	PATENT APPLIED

What is new in RISAT-1 SAR?: RISAT-1, when conceived in way back 2002, was an ambitious project where many new technologies were required to be mastered. The access to these technologies was restricted because of international technology embargo, imposed on ISRO. The number of subsystems needed for this system was prohibitively large (precisely 1391 subsystems of them 314 are 8 bit computers). To qualify each of these subsystems to space grade, it required almost 3 weeks testing of each of these subsystems. ISRO's experience with satellites never exceeded dealing with more than 100 subsystems. ISRO's resources were inadequate to carry out fabrication and testing of such large number of elements. Indian industry was not equipped to handle space quality fabrication, let alone handle such large numbers with zero defect production and testing approach. A number of industries were needed to be hand-held, with training and expertise impartment to carry out mass productions based of final blueprints which were designed and perfected in-house. The many firsts of RISAT-1 are (Table-3):

1. SAR Feature wise:

- Only C-band SAR capable of giving 1 m resolution over 10 kmx100 km spot. It is to be mentioned that 1 meter SAR is presently possible with X-band only, that too over an area of 5-10 km spot.
- It is the first SAR with Hybrid polarimetry. There are linear polarimetric modes available in spaceborne SAR where data rate gets doubled and imaging is restricted within below 35° incidence angle. This limitation is not imposed on Hybrid polarimetry and it is available seamlessly for all imaging modes. Further, this polarimetry mode can be self-calibrated using normal imaging data.
- It has a very low incidence angle modes operating at incidence angle as low as 12°. It will usher in new application in soil moisture, glacier studies and better imaging in hilly regions.
- Apart from SAR, RISAT carries India's first space-borne Active antenna array. The SAR payload, along with this antenna, is a complex array of electronics consisting of 1391 subsystems including 314 units of 8 bit computers.

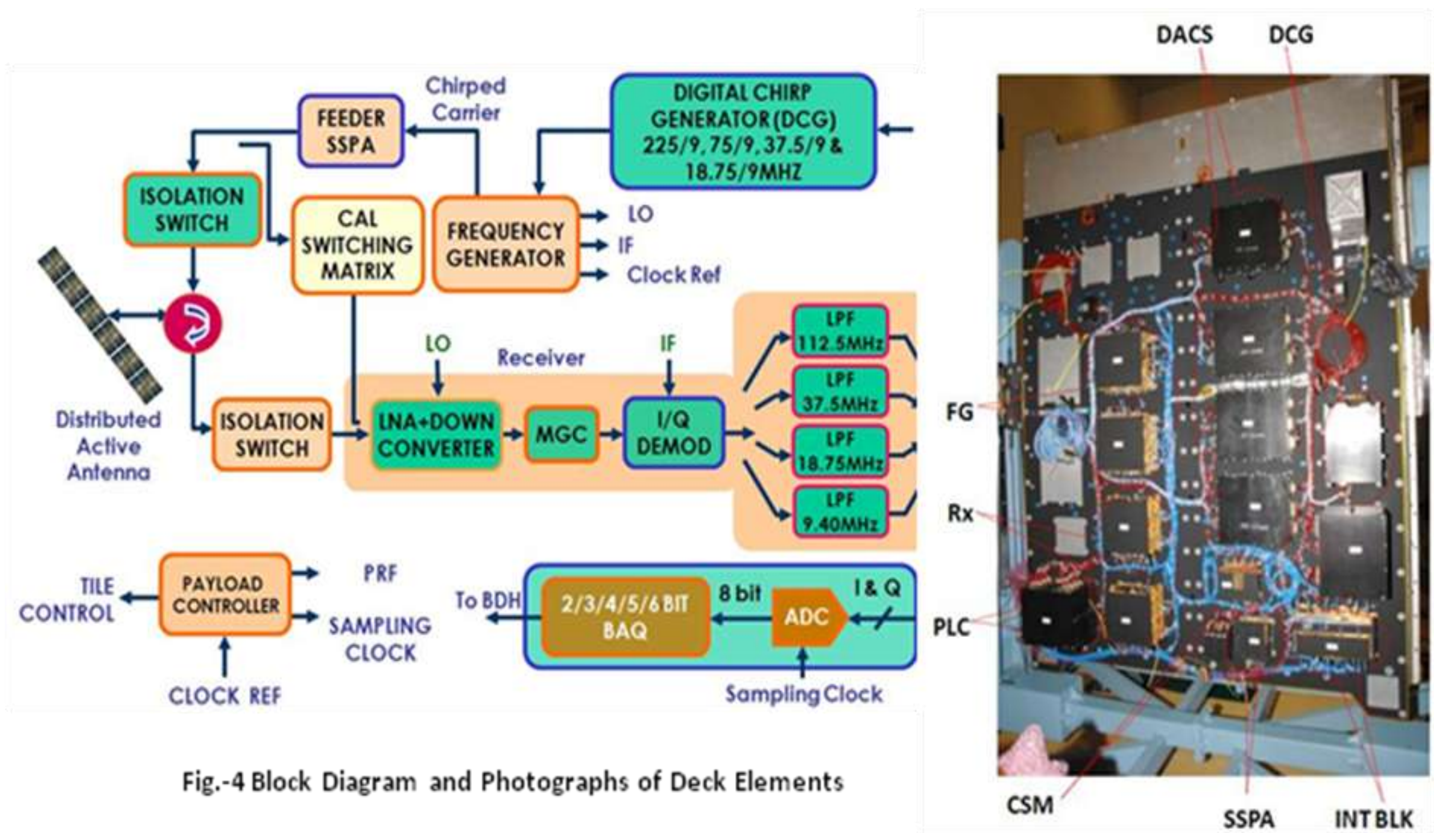


Fig.-4 Block Diagram and Photographs of Deck Elements

2. Payload Technology:

- Completely indigenous
- Space qualified MMICs were fabricated in India
- Miniaturised TR modules
- Miniaturised EPCs with planar transformer technology where transformer windings are achieved by printing them on 16 layer PCB
- Programmable digital Chirp generators
- High speed digitization

- High data rate communication all the way upto 1.5 Gbits Downlinking data in two orthogonal circular polarizations with speed of 640 Mbits On-board recorder capability of 300 Gbits (240 Gbits at End of Life, EOL)
- Designed for truly Global operation

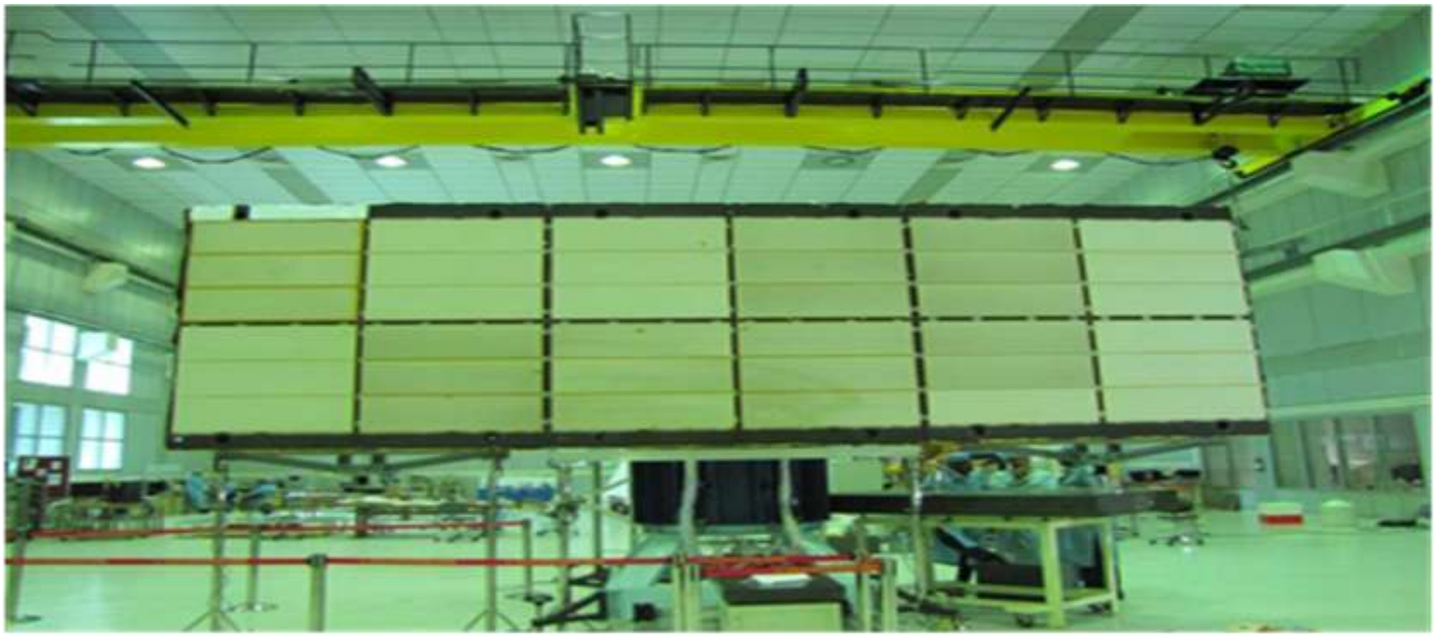


Fig.-5 Patch Antenna Side of The Deployed Antenna

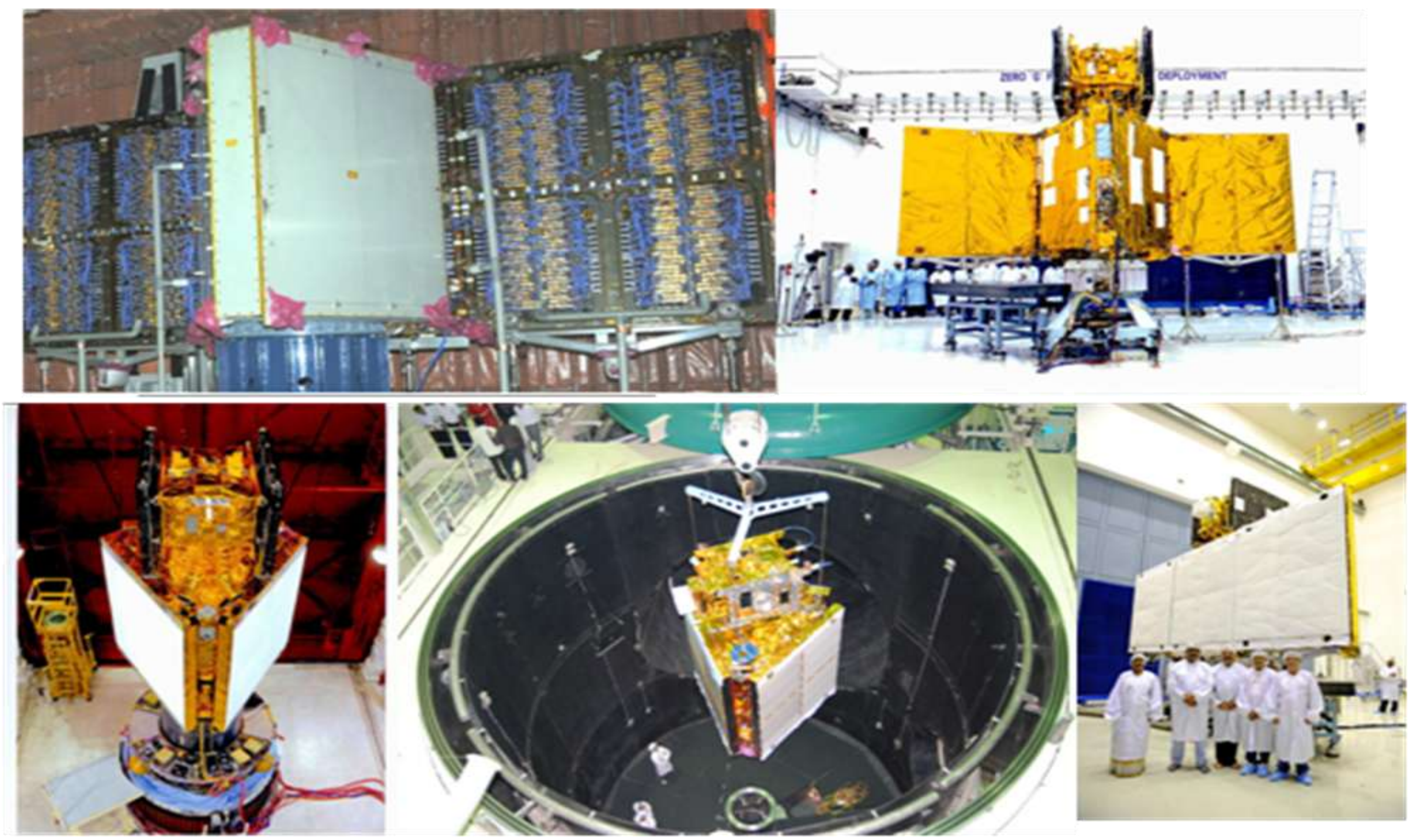


Fig..-6 Clockwise from Top Left: RISAT SAR in Testing; RISAT-1 in Deployed Condition Backside and Frontside; R ISAT-1 Being Lowered in Thermovac Chamber; RISAT-1 Mounted atop PSLV

Industry Partnership: The highlight of RISAT-1 programme was development of hardware elements through industry partnership. Various new technology elements like different types of MMICs, Miniaturized C-band TR-module and Pulsed Power supplies, Dual Polarized printed antenna, Integration Block and Power distribution Network, High speed digitizers, Micro-controller and FPGA based central distributed control systems, etc. have been realized with the active participation and collaboration of public and private sector industries like GAETEC, SCL, ASTRA, CENTUM, CMC, SHAHJANAND LASER etc. Indigenous MMIC fabrication line has been qualified at GAETEC foundry. Design, development and qualification of an indigenous Onboard Controller ASIC for Tile Electronics have also been accomplished in collaboration with private industries like CG COREL. The participating industries had to go through a learning curve with issues of like space grade circuit fabrication, quality control, test facility development and testing methodology. Their contribution in mass production is illustrated in Figure-7 and detailed listing has been made in Table-4. This programme has also added to industrial capacity building within the country. Thus, the challenge of microwave SAR payload realization has been addressed and with industry participation in these activities, a new beginning has been made.

Fig.-7 Contributions of Indian Industry in Realisation of RISAT-1 SAR

Table-4
Industrial Partnership in RISAT Development

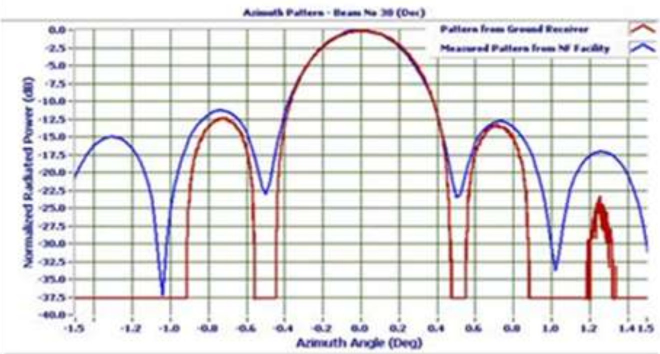
Industry	Hardware Contribution
GAETEC, Hyderabad	7 types of MMICS involving three processes
ASTRA Microwaves, Hyderabad	TR Module, TRC, 1:12 RF Power dividers, Power amplifier modules, Etching of Antenna
Komolin, Ahmedabad as part of ASTRA	TR Module, TRC, 1:12 RF Power dividers, Power amplifier modules
Solectron Centum, Bangalore	PCPU, TRC, harness, EPC for TCU, TCU
BEL, Ghaziabad	Power amplifier module
Agilent India	TR Module Characterisation System
CG-Correl/ UTMC	ASIC for TRC
SLT, Gandhinagar	Antenna fabrication
CMC, Hyderabad and A hmedabad	All digital subsystems for Design Verification Model (DVM) of RISAT
Bombay Machines, Bangalore	9 m x 6 m Scanner for Near Field Measurement
KV Microwaves, Ghaziabad	Indigenous Microwave absorbers for testing

Date: 16-05-2012 Beam No: 38 (Dec)

SAR Mode: cFRS-1

Beam No	No of Active TRM	Roll Bias	Look Angle (Deg)
38	276	$+36^0$	39.32

Transmit- V Azimuth Pattern Comparison



Date: 17-05-2012 Beam No: 57 (Dec)

SAR Mode: cFRS-1

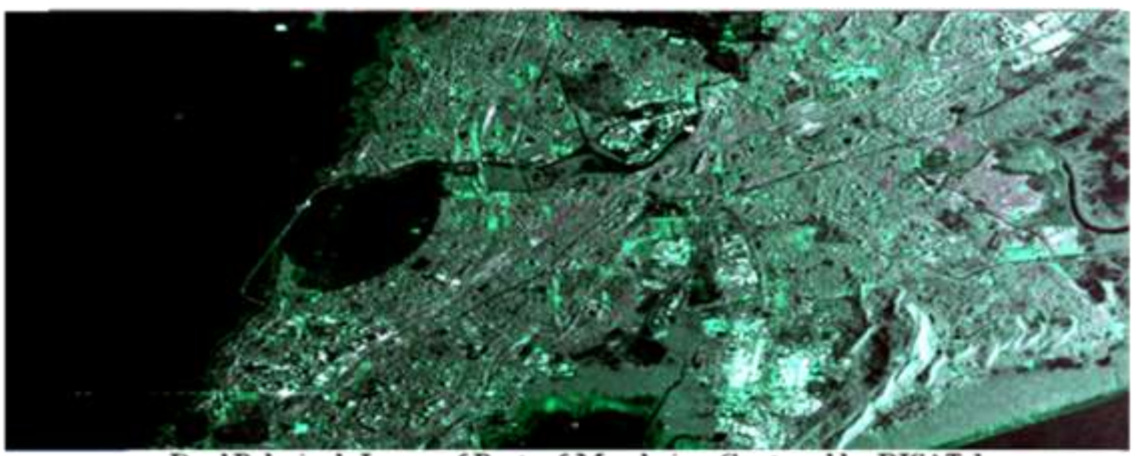
Beam No	No of Active TRM	Roll Bias	Look Angle (Deg)
57	288	$+36^0$	47.99

Transmit- H Azimuth Pattern Comparison

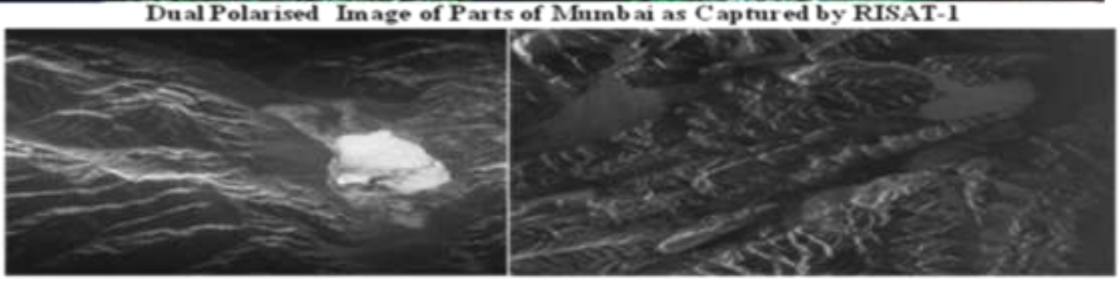
Fig..-10 Close Match of Measure Active Antenna Pattern during IOT with Predicted Ones

RISAT-1 Imaging Operations:

Since 1st May, 2012, RISAT is being operated for over India passes as well as over foreign countries. All the imaging modes except HRS have been operated successfully. Sample of images, including Hybrid Polarimetry ones, are shown in Figs.-8 and -9. By end of June, 2012, calibrated images are expected to be made available operationally. The behavior of Active antenna is as expected as shown in Fig.-10. Initial results indicate that system behavior is as per prediction and RISAT system is expected to meet users' expectations during its lifetime.



Dual Polarised Image of Parts of Mumbai as Captured by RISAT-1



Signature of Himalayan Glaciers as Captured by RISAT-1 for Low (12°) and High (40°) Incidence Angles- This Unique Signature Could be Captured by RISAT-1 Because of Low Incidence Angle Imaging Capability

Fig.-8 Sample Images Obtained by RISAT-1

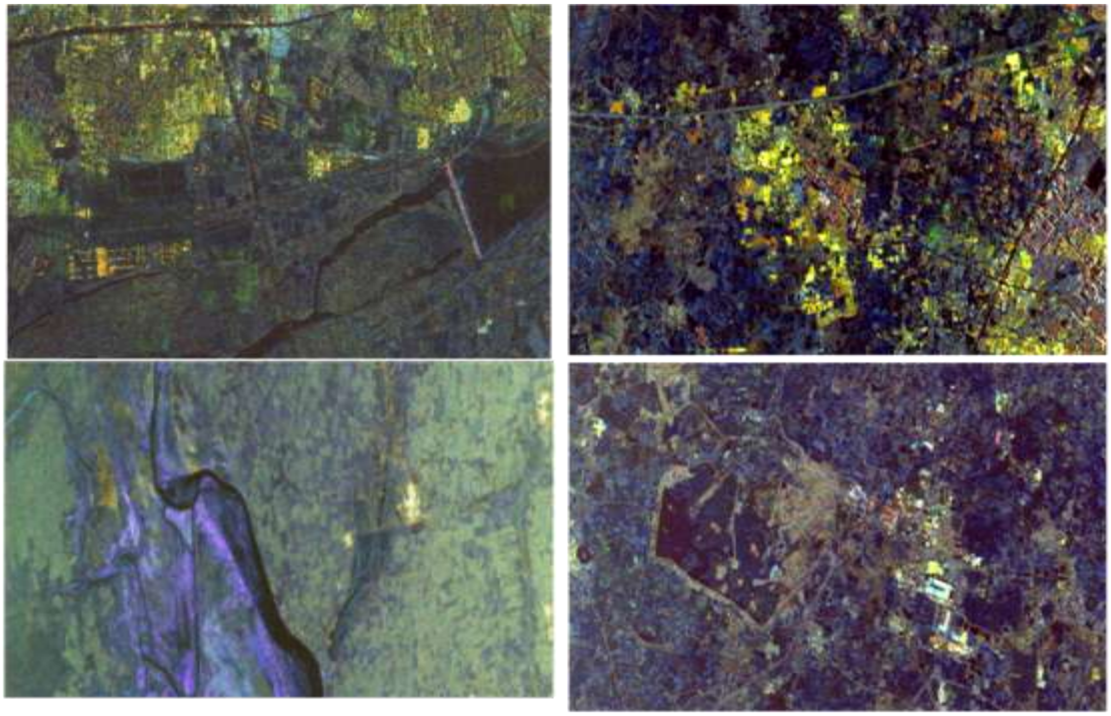


Fig..-9 Clockwise from Top Left: Hybrid Polarimetry Images of Sabarmati River, Outskirts of Ahmedabad, Thol Lake of Gujarat and Gulf of Cambay

Blue: Odd Bounce Targets, Red: Even Bounce Targets and Green : Depolarised Targets

Acknowledgement: In the words of Dr. K Radhakrishnan, Chairman, ISRO, RISAT-1 has arrived after 30 years of wait and 10 years of efforts, culminating in a remarkable success. Success of SAR payload on RISAT-1 is a tribute to dedications and contributions by a very large number of women and men, dreamers and achievers, technicians and engineers, subordinates and bosses, skeptics and believers. The author believes that these extraordinary individuals deserve all the kudos for putting their heart and soul in an idea, whose time had come. Its flawless operation, on the first go itself, is a testimony to their remarkable team effort. The author takes this opportunity to express personal gratitude to Shri S S Rana, who mentored and guided the team, made a pioneering contribution in developing industrial partnership, which will be guiding spirit for times to come. This project would not have seen the light of the day but for personal initiatives by Dr. AKS Gopalan, Dr. P S Goel and Dr. K Kasturirangan. The author is indebted to Dr. K Radhakrishnan, Chairman, ISRO, Dr. G Madhavan Nair, Dr. T K Alex, Dr. K N Shankara, Dr. R Navalgund, Shri A S Kirankumar who steered this activity through trials and tribulations and they have been a constant source of encouragement. The author is the present baton holder of an effort, initiated and nurtured by illustrious dreamers like Shri OPN Calla and Shri NS Pillai, who brought Microwave Remote Sensing to a stage, from where it was possible to initiate building of RISAT-1.

RISAT -1 Satellite Configuration

N Valarmati

PD, RISAT

Abstract: RADAR Imaging Satellite (RISAT 1) is a new generation satellite in the operational remote sensing satellites .It is an active microwave remote sensing satellite which takes images at day and night as well as in all weather conditions. RISAT 1 carries Synthetic Aperture payload along with the mainframe elements for its operation. This paper provides an overview of RISAT 1 satellite configuration.

Introduction: Remote sensing spacecraft (IRS) is to provide remotely sensed data for applications in the areas of agriculture, hydrology, forestry, drought and flood monitoring, land use as well as in other areas .ISRO has launched many optical remote sensing satellites from IRS 1A onwards covering the above applications on a regular basis .ISRO has proposed to launch a microwave remote sensing spacecraft for the above applications which will enhance the application potential in remote sensing area and additionally provide complimentary and supplementary data along with the existing optical remote sensing satellites.

The basic components of microwave remote sensing mission are

a. A three –axis stabilised polar sun-synchronous spacecraft with Synthetic Aperture Radar payload and compatibility with PSLV launch vehicle

b. Ground systems for in-orbit satellite control including the tracking network with the associated supporting systems

c. Data reception and processing system for the generation of user-oriented data products and timely dissemination of the requisite type and quantum of data to the users

d. Utilisation of the data by the user agencies in specific application disciplines

The specification of the mission is similar or better than the international missions which exists during its time frame.

Orbit: Main guiding parameter for choosing the orbit for RISAT is achieving a global coverage in a systematic way for a given swath. RISAT 1 is placed in polar circular Sun synchronous 6 a.m/-6 p.m orbit with 536km mean altitude.

RISAT 1 configuration overview: RISAT 1 has a unique configuration in order to support the heaviest SAR payload and its power requirement. It carries many new technologies in the areas of structure, thermal, mechanism, power, RF, Data handling, data storage and wheels in addition to heritage systems. The Onboard computer is also a new generation system with ASIC.

A major driving force for the overall satellite configuration has been the need to maximise the mounting area for SAR payload and to meet their viewing requirements and the heat shield accommodation requirements of PSLV.

RISAT 1 configuration can be classified functionally as

a. Mechanical systems covering structure, SAR and solar panel deployment mechanisms, thermal systems & Integration elements

b. Mainframe electrical systems covering onboard computers, power system &TT&C elements

c. AOCS elements which includes on board software with Sensors, SPS and actuators (including IISU elements and RCS systems).

d. Payloads chain cover systems of SAR payload, Data handling, X band RF, Phased Array Antenna and Solid state Recorder.

All the above systems are supported by the respective DC-DC converters. Majority of the sub-systems have 1553 interface with OBC .Tele-command, telemetry, power and signal/data interfaces have been suitably worked out for meeting its specification .Redundancy concept has been well utilised to improve the reliability of the mission. RISAT 1 **structure** is different from other IRS missions. Totally 18 equipment decks for main frame , 12 SAR tiles ,3 SAR frames and 37(approx) sub system brackets have been realised by the structures team. Payload structure forms a major part of the SAR payload. 290Kg SAR panel deployment **mechanism** plays an important role as SAR payload on orbit function commence from this event. 12 minutes of imaging per orbit for all seasons is the highlight of the design of the **thermal** system. Reaction control system **(RCS)** configuration with nine 11N thrusters was very critical immediately after launch as the satellite had to reach the intended orbit by firing the thrusters.

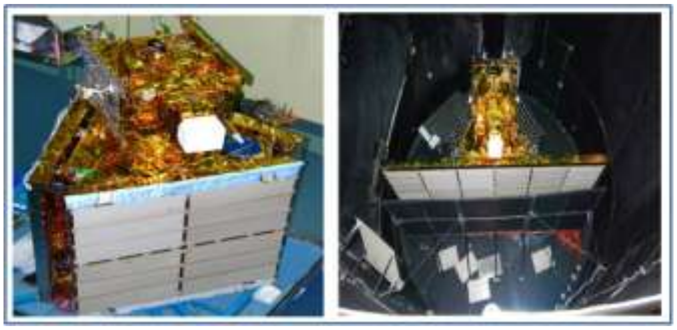


Fig1: Spacecraft Configuration in stowed and deployed conditions

Power system meets the high power requirement of the spacecraft during imaging .It supports various bus voltage requirements of subsystems. A 70 V Ni-Hd **battery** supports the payload imaging in orbit. Various safety logics as well as Remote programming capability of On board controllers (**OBC**) is always helpful for on orbit mission management. High capacity **wheels** of .3 Nm torque with 50Nms angular momentum handles RISAT 1 which is the heaviest satellite. AOCS elements along with sensors and actuators control the orbit & attitude requirement in addition to ± 36 deg roll bias during imaging and High resolution mode manoeuvres. High quality **SAR** payload (with various modes, polarisation ,swath, resolution etc), 320Mbps data rate **formatter,** 300Gb high capacity storage system **(SSR),** 320 Mbps data rate **modulator** and dual polarisation **phased array antenna** for 640Mbps data speaks about payload chain technical content .

Structure, SAR payload, Power, Battery, TTC–RF, BDH, SSR, X-band data transmission system, Phased array antenna ,Reaction wheels & WDE are new elements whereas RCS, Solar panels ,SPS ,OBC, SPSS, DSS ,Star sensor, Conical sensor, IRU, SADA, solar panel deployment mechanism are heritage systems which have been tuned for RISAT 1.

Integration and project played its role in maintaining the total weight of the spacecraft to 1858Kg in order to meet the requirement of PSLV.

Considering the complexity involved in the design of many sub systems, the following model philosophy was adopted for the program. Flight models have been realised for the heritage systems whereas for the new elements, the concept was proved using Bread board developmental model followed by Qualification Model and Flight model. Performance of the systems were reviewed at each stage of realisation .Thermal analysis, FMECA and derating analysis were carried out for all the electrical systems.

All the subsystems went through an acceptance test prior to integration to the spacecraft .Flight spacecraft underwent a complete electrical and radiation test at ambient and electrical test in thermovac condition to ensure the performance of the hardware to meet the mission goal .The flight spacecraft underwent vibration and acoustic test before launch.

Conclusion: RISAT 1 is the first satellite in microwave remote sensing class which has been realised with state of the art technologies in SAR payload and main frame elements. The development has crossed qualification stages successfully and the flight model has been launched successfully in April 2012.

PSLV-C 19/RISAT-1 Mission

THE LATEST SUCCESS WITH HEAVIEST SPACECRAFT

P. Kunhikrishnan, Project Director, PSLV

Polar Satellite Launch Vehicle (PSLV), the work horse of ISRO, is a four-stage launch vehicle primarily designed and developed to place spacecrafts in the Sun Synchronous Polar Orbits (SSPO). Subsequent to the three developmental flights, PSLV was operationalised with the launch of PSLV-C1 on 29th September, 1997 carrying the 1205 kg Indian Remote Sensing satellite IRS-1D.

During the operational phase, the payload capacity of PSLV was further improved through the introduction of augmented liquid 2nd stage (PL40), high performance solid motor for the 3rd stage (HPS3) and Carbon Fibre Reinforced Plastic (CFRP) based structures for the upper stages. Spacecraft interfaces have been suitably modified for accommodating multiple spacecrafts either by using Dual Launch Adaptor or Passenger Payload decks on the Equipment Bay of the vehicle.

Today, PSLV is the universal launch vehicle of ISRO, versatile with its three variants viz. the generic version with six regular strap-on motors, the Core Alone version without any strap-on motors and the more powerful PSLV-XL with the extended version of regular strap-ons in terms of length and propellant loading. The fourth stage has three variants designated as L1.6, L2.0 and L2.5 based on the propellant loading capacity of 1.6t, 2t and 2.5t respectively required for a particular mission.

Lift-off of PSLV C19 with RISAT-1 on 26th April 2012 at 05.47 hrs IST

The vehicle configuration for a mission is selected based on spacecraft characteristics and the mission requirements. The current payload capability of the PSLV-XL vehicle is 1750kg for 600km SSPO and 1425kg for the Sub-Geosynchronous Transfer Orbit (Sub-GTO) of 284 x 21000km.

All the variants of PSLV mentioned above have been successfully employed to place the spacecrafts in different destinations like planar orbits with specific inclinations and Sub-Geosynchronous Transfer Orbits, in addition to Sun Synchronous Polar Orbits. Each mission of PSLV is unique with respect to its intended orbit, the trajectory parameters and diverse spacecrafts, posing fresh challenges to the planning and execution teams.
PSLV-C19 / RISAT-1 mission which marked the 20th successive success of the launcher on 26th April 2012, was a challenging one in many respects. The mission employed PSLV-XL configuration of the vehicle with PS4 L2.5 stage to launch the **heaviest spacecraft (1858kg) ever entrusted to PSLV**.

Though PSLV-C19 was the third launch of PSLV-XL variant, after PSLV-C11/Chandrayaan-1 and PSLV C17/GSAT-12 missions, this was the **first XL variant of PSLV to a polar orbit**. The spacecraft was placed in the intended polar orbit of 480km altitude, with an inclination of 97.626º. RISAT-1 was later raised to 536 km SSPO using its thrusters onboard. After the orbit raising, about 62 kg of propellant (out of 100 kg initially loaded) remained in the spacecraft because of the precise orbital placement by PSLV and the performance of the spacecraft thrusters, extending the spacecraft life further.

There were several new aspects and requirements specific to PSLV-C19 mission with RISAT-1, the following being the salient ones:

- **Accommodation of RISAT-1 within the payload fairing of the launcher** : The spacecraft occupied almost the entire payload envelope of PSLV. The spacecraft configuration was optimized by swapping the locations of payload and the spacecraft bus in the conceptual stage itself to ensure required clearances.

RISAT-1 before the heat shield closure

Vibration test of PS4 stage with simulated RISAT-1 mass for dynamic characterization

- **Handling of RISAT-1 at launch pad**: An additional spacer had to be implemented in the spacecraft container of SDSC, SHAR in order to augment its volume to accommodate the larger spacecraft. Handling scheme for this spacer in the spacecraft Preparation area at launch pad was worked out based on trial and finally implemented.

- **Structural Characterization:** The structural characteristics of upper stage with the heaviest spacecraft were closely scrutinized with respect to the PS4 stack frequencies and their impact on control capability of the vehicle.

Dedicated vibration tests were carried out on a stacked configuration of a flight-identical PS4 stage with simulated spacecraft mass of about 2t for the structural dynamic characterization. Based on exhaustive analysis of the test results and a series of reviews, the Digital Auto Pilot (DAP) was fine tuned to take care of changes in the structural responses on account of carrying the heavy spacecraft.

Assembly of PSOM-XLs in PSLV-C19 at First Launch Pad

- **First PSLV-XL launch from the First Launch Pad (FLP) of SDSC, SHAR**: As this was the first XL launch from FLP, an assembly trial of PSOM-XL was carried out to confirm the handling feasibility and assembly access. Detailed analysis was carried out to validate the **vehicle lift-off dynamics, launch pad acoustics and also the thermal aspects** related to the usage of FLP for PSLV-XL launch for the first time.

- **New Mission Control and Launch Control Centres** : The vehicle check-out and the countdown operations for PSLV-C19 were carried out from the new and state of the art Mission Control Centre (MCC) and the Launch Control Centre (LCC) at SDSC, SHAR.

The success of space launch missions can be achieved only with perfect planning, proper preparation and persistent pursuit of the final goal with absolutely no compromise on quality and reliability. With its excellent track record, sustaining the success of PSLV is a challenge by itself for all the associated teams. With the continued dedication, co-operation and support extended by all the teams, PSLV can shoulder the increased responsibility to meet the commitments of ISRO to the nation.


PSLV-C19 with RISAT-1 on the launch rehearsal day

Spacedaily.com (26/07/12)

GPS Can Now Measure Ice Melt, Change In Greenland Over Months Rather Than Years

by Pam Frost Gorder

Columbus OH (SPX) Jul 26, 2012

Researchers have found a way to use GPS to measure short-term changes in the rate of ice loss on Greenland - and reveal a surprising link between the ice and the atmosphere above it. The study, published in the early online edition of the Proceedings of the National Academy of Sciences, hints at the potential for GPS to detect many consequences of climate change, including ice loss, the uplift of bedrock, changes in air pressure - and perhaps even sea level rise.

RISAT-1 Mission Configuration

V. Mahadevan, ISAC, Bangalore

1. Introduction: To meet the RISAT-1 Mission objectives the orbit chosen was 536 km Sun-Synchronous orbit. The PSLV launcher placed RISAT in 476km as per the nominal scenario. The injection orbit had very benign dispersions of about 6km less in semi-major axis and an inclination of +0.06 with respect to the nominal injection parameters which are well within the dispersion specifications of PSLV. In this article the Mission operations carried out to normalize the s/c are highlighted.

2. Launch Pad Configuration: Normally at Launch pad spacecraft (s/c) will be configured with the required configurations to aid the On-Orbit commissioning of the s/c effectively. After injection, in the subsequent orbits the required subsystem turn on & the commissioning is carried out.

The s/c is powered on about 4 hours before the lift off time. The nominal lift off time planned for this mission was 00:17:00 UT (05:47 IST) 26th April 2012 and the lift off of the s/c by PSLV has happened at the planned time. In general, the launch window for sun synchronous missions of this type is 20 minutes, and the lift-off for RISAT-1 occurred within the planned launch window.

The s/c configuration during Lift off was with RCS fuel of 100kg. Battery charging and the set values are as per the guidelines laid down for the Launch Pad temperature conditions for the battery. The battery is new type compared to the earlier Remote Sensing missions. It is Nickel Hydrogen type and hence it has been left with appropriate charge levels only based on the experienced temperature at Launch Pad. These are all the subtle variances with rest to earlier missions.

There were as many as 862 Launch Pad commands were uplinked to the s/c leaving the s/c in a configuration suitable for further operations in the on-orbit after injection.

3. Early Orbit Operations: The PSLV injected RISAT-1 to the 476km orbit with the rates on the body -0.12deg/sec, 0.06deg/sec & -0.01deg/sec in yaw/roll/pitch axes respectively which are very benign to aid the direct earth acquisition using the Gyros. The required attitude orientation at the defined position in the orbit is pre-loaded in the launch pad itself and using gyros the orientation is captured at the defined point in the orbit after injection. For this type of attitude capture the rates imparted by PSLV is required to be less than 2deg/sec. As the injected rates are very less the capture was nominal as planned in the Mission Sequence.

Immediately after the snap of the s/c from vehicle automatic deployment of solar panels and SAR panels are the critical autonomous events. The deployments of Solar panel & SAR antenna panels were smooth & perfect as per the nominal expected scenario.

Initially through Earth Sensor the earth pointing orientation is achieved as per plan. The Solar array is commissioned for the tracking of the sun to get the adequate power generation. The onboard orbit determination component was enabled once the GPS based Satellite Positioning System (SPS) performance was evaluated nominal. Initially thrusters were used to capture the required orientation of the s/c with nominal expenditure of the fuel. Subsequently Reaction wheels were switched on and commissioned to take control with Star Sensors in the overall control loop. With Star Sensors the pointing of the s/c is better with an accuracy of less than 0.05 deg.

4. Orbit Maneuver Operations: The Nominal Mission Orbit is 536km & PSLV injected orbit was around 470km and about 66 km increase in altitude was carried out by 4 orbit maneuvers after launch within 2 days spending a fuel of 37 kg. The cumulative duration of firing using 5 thrusters is 1844.371 seconds. The total DeltaV is 37.86 m/sec.

5. Payload Commissioning: The payload commissioning related exercises started from 29th April onwards after the Mission Orbit of 536 km is reached after 4 orbit maneuvers. Nominally before starting the Payload operations straight away it is a recommended practice that Data Handling Tests are done first and then only Payload.

In this s/c for the first time, using single X-band carrier both the V&H polarization data are transmitted using RHCP & LHCP mode. In earlier satellites RHCP mode of X-Band transmission was only used. Hence a methodical DH tests were carried out using RHCP mode alone in one pass, LHCP separately in one pass & then both of them together in another pass separately. This way the ground reception systems were characterized.

The payload commissioning started with the already planned way of operating the payloads in step by step process of FRS-1 mode first with single beam operations and then MRS /CRS modes where multiple beams will be operated. The near beam(s) and Far beam(s) energizing exercises were conducted for various modes and their power profiles were characterized on-orbit.

About 27 test cases including onboard calibration operations were exercised on-orbit during the commissioning of payload. As some of the modes & beams require SSR recording, prior to this scenario Solid State Recorder (SSR) was commissioned with recording & downloading of the PN sequence (which is a fixed pattern sequence). All the operations were normal and the power consumption & variations were as per the design expectations.

6. Yaw Steering & Pitch Steering: As the SAR P/L operates on the Doppler principle, it is a must that the earth rotation effect on the Doppler to be compensated. This can be achieved by yaw steering of the satellite during payload operations. Additionally to compensate for orbital eccentricity pitch steering was also planned so that residual Doppler experienced is minimal. By ground computation both Yaw & Pitch steering coefficients were computed and uplinked. With the s/c attitude data the residual Doppler estimate is about 50 to 150 Hz. About 5 different payload passes were taken for estimating this. Once the frozen perigee manoeuvres are completed then re-uplinking of the coefficients will be carried out.

7. Payload Programming System & Command Generation: The payload programming system (PPS) & Command Sequence Generation (CSG) are very important component of the Mission Management system. The payload programming system is installed at NDC NRSC which is the front end for all the users. The requirements from various users for p/l data acquisition are consolidated, prioritized, optimized for maximum number of servicing in a day. Through the PPS S/W system every day the Payload Operation on a given day is generated including Recording operation elsewhere in the world. These consolidated P/L plan (modes of operation, duration etc) is sent to SCC ISTRAC for the command generation through the CSG s/w system located at SCC. The generated commands are uplinked one day in advance for the payload operation of a given day.

8. Eclipse & Lunar shadow operations: In RISAT-1 due to orbit geometry orbital eclipse is encountered seasonally only unlike in other IRS missions where eclipse is encountered every orbit. For this height of 536km & 6am local time geometry the eclipse is expected from 2nd May to 12th August with peak eclipse of around 22 minutes experienced around 23rd June where the sun declination is 23.5 deg. During eclipse period payload operation is avoided as the full load of the Payload along with the mainframe to be fully supported by the battery which is planned to be avoided.

Similarly during the Solar eclipse time (Lunar Shadow on earth), the occurrence is predicted and necessarily the p/l operation is not planned. These operational disciplines are integrated in the Payload planning S/W systems itself.

9. Calibration Sites: For payload calibration not only internal onboard calibration is carried out but also the external calibration is planned using corner reflectors located at Gujarat state , receiving antenna located at SAC campus itself & the Amazon rain forest. These are imaged as and when the opportunity to image the site is available.

10. Conclusion: In the overall from launch of the satellite on 26th April 2012 up to now the satellite performance & Mission Operations are nominal. At present the Calibration exercises of Payload using corner reflectors & Amazon forest imaging are scheduled along with the normal imaging operations over INDIA & outside using SSR (Solid State Recorder).

RISAT-1 Mission Operations at ISTRAC

M Pitchamani

DD,ISTRAC, Bangalore

ISRO Telemetry Tracking & Command Network (ISTRAC) with its headquarters located at Bangalore, India is responsible for providing Space Operation services that include

- Telemetry, Tracking and Command (TTC) activities through the ISTRAC TTC ground stations located at various places during all phases of the mission,
- Health monitoring and control of the spacecraft during pre-launch, LEOP and normal phase of the mission
- Payload data (science data) reception, processing, archival and dissemination to users.

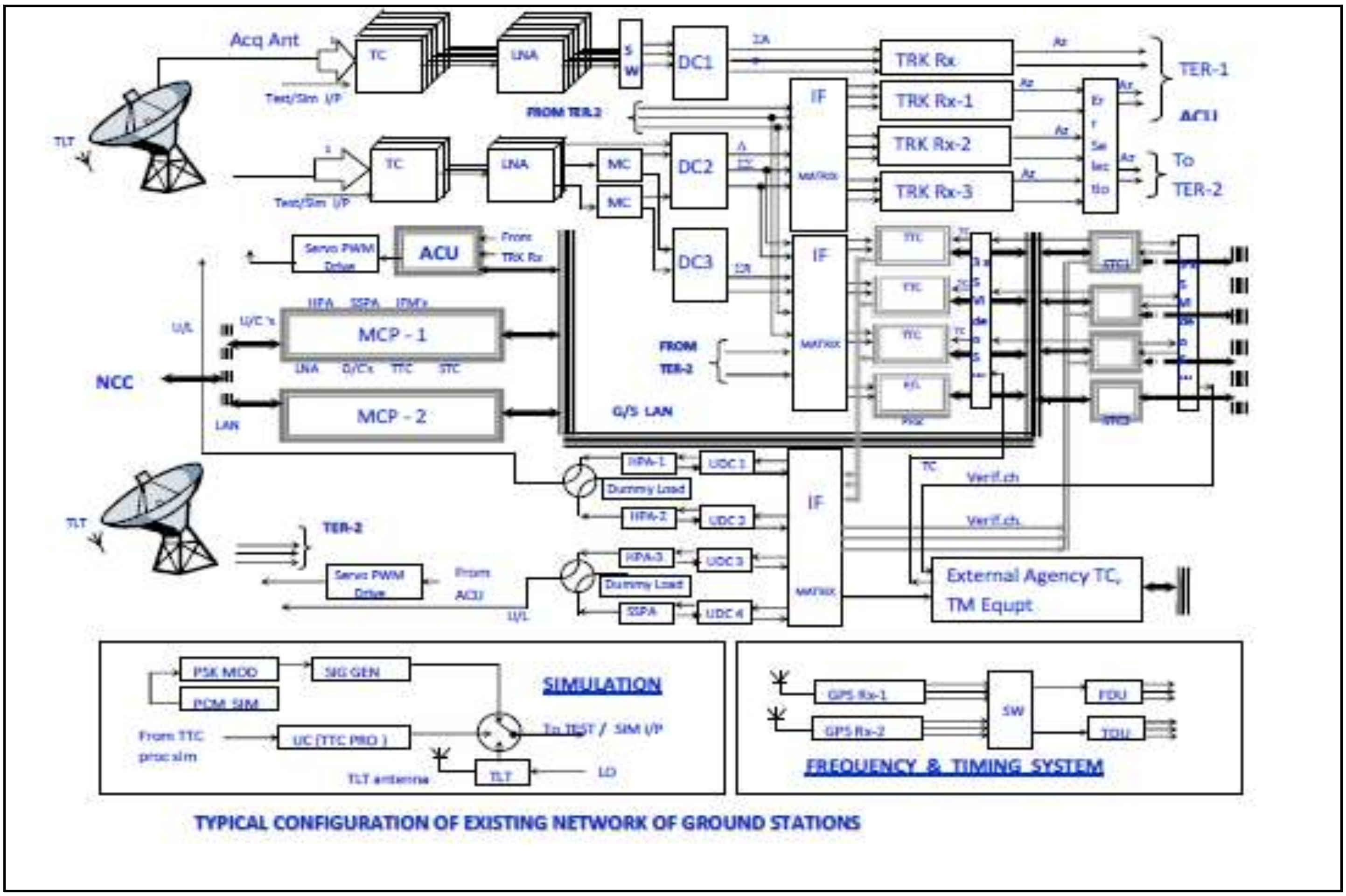


Fig1: Configuration of Existing Network Of Ground Stations

ISTRAC ground segment consists of a comprehensive network of ground stations distributed all over the globe to provide Telemetry, Tracking and Command (TTC) support to Satellite and Launch vehicle missions.

Multi-mission operations support at ISTRAC includes

1. TTC network operations
2. Spacecraft operations
3. Scheduling Operations
4. Flight Dynamics Operations
5. Computer network support
6. Communication network support
7. Facilities support

1. TTC network operations

ISTRAC has a network of S-band TTC stations to provide Telemetry, Tele command and Tracking support for low earth orbiting satellites. ISTRAC provides multi-mission support with a network of TTC stations established at Bangalore, Lucknow, SHAR (Sriharikota), Thiruvananthapuram, Port Blair, Brunei, Biak (Indonesia) and Mauritius. Apart from these stations, ISTRAC takes support from external agencies like KSAT (Norway) and SSC (Sweden) stations at Svalbard, Tromso, and Troll and at Kiruna Station.

The functions to be performed by TTC network are:

- Telemetry data reception, recording, conditioning and transmission to Mission computers
- Transmission of commands to the satellite in S-band
- Tracking the satellite and collection & transmission of tracking data to SCC
- Reception and transmission of various health keeping data like DW, HK-PB, SS-PB, TC-PB, SPS-PB etc.

To efficiently use the TTC station network for operations in multi-mission scenario, following features are implemented

- Remote monitoring and Control of all ground station equipment from ISTRAC Network Control Center (INCC), Bangalore
- Schedule based automated operation of the ground station.
- Remote operation of ISTRAC Network stations from a centralized INCC.

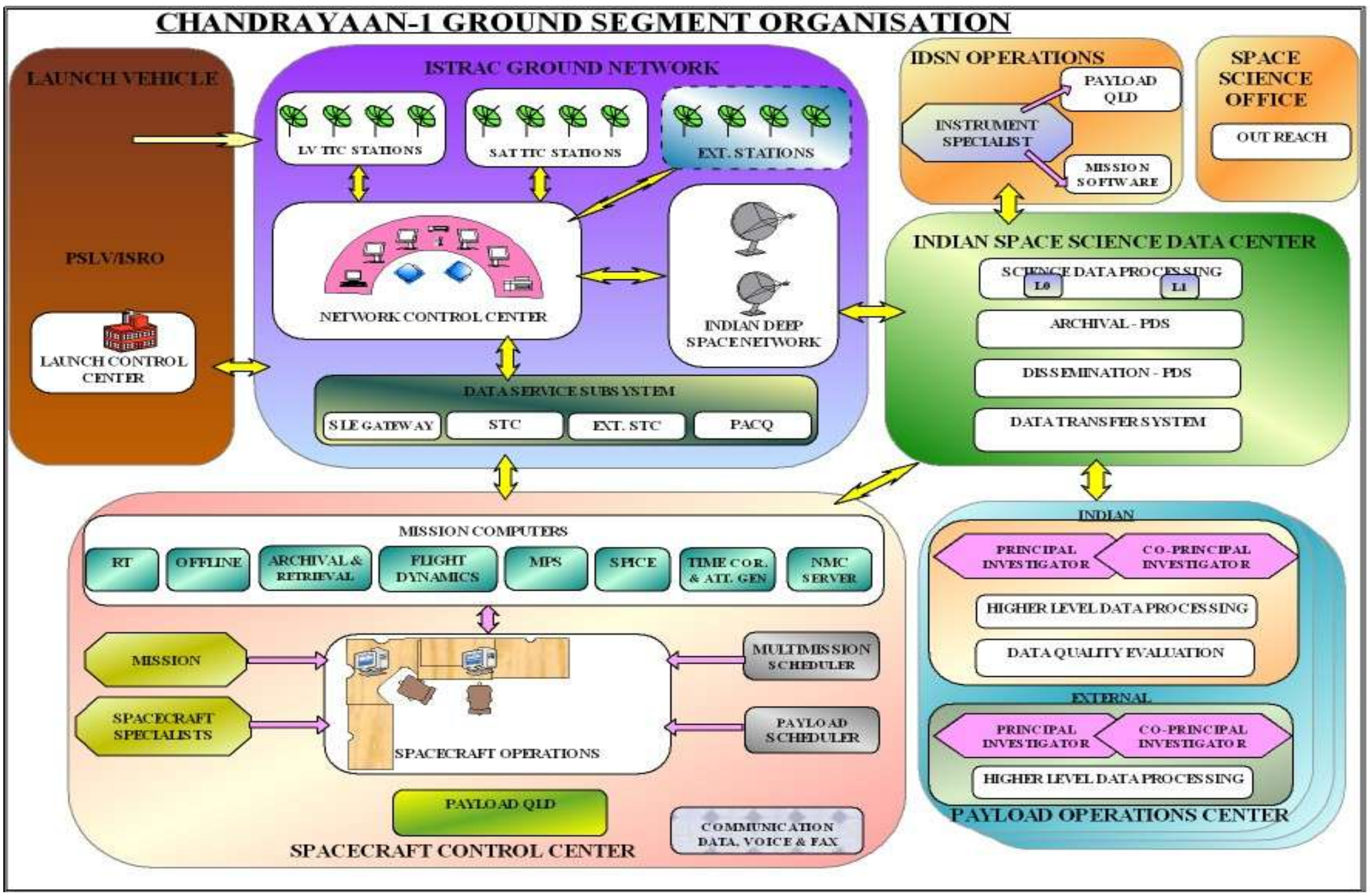


Fig2: ISTRAC Ground Segment Organization

2. Spacecraft operations

ISTRAC provides support for various phases of the mission during the life time of the LEO satellites. Presently, *fourteen* satellites namely RISAT-1 & 2, Resourcesat-1 & 2, Cartosat-1, Cartosat-2/2A/2B, Oceansat-2, TES, Youthsat-1, IMS-1 and HAMSAT are being controlled from ISTRAC. The various mission operation phases are Pre-Launch Phase, Launch and Early orbit phase, Initial Phase, Normal Phase and Terminal phase.

Pre-Launch Phase activities involve

- Ensuring all hardware and software elements of ground segment are in place as per the mission requirement
- Test and evaluation of all ground elements involved
- Training for operations team to understand the spacecraft subsystem functioning and familiarize with the command sequence for various operations

- Prelaunch simulations to check the interface and compatibility of all the ground H/W and S/W elements involved, to exercise the initial sequence of operations, to check the time adequacy for different operations.

Launch and Early Orbit Phase activities involve

- Spacecraft initialization commands after power on
- Lift Off
- Monitoring spacecraft injection and solar panel deployment
- Monitoring spacecraft HK data and commanding
- 3-axis attitude acquisition

Initial Phase activities involve

- 3-axis earth/sun Pointing attitude stabilization with reaction wheels and magnetic torquers
- Subsystem performance validation
- Payload commissioning
- Orbit acquisition and phasing
- Star sensor, Gyro and Payload Calibration exercises

Normal Phase activities involve

- Routine spacecraft health monitoring and commanding operations in 24x7
- Payload programming to meet the user request on daily basis
- Special operations like Orbit maneuver operations, gyro drift corrections, slope and offset corrections for onboard clock etc.
- Contingency handling operations like loss of lock, solar panel non tracking, and processor hang up etc.

Terminal Phase

3. *Scheduling operations*

- *Scheduling for TTC operations*

To fulfill the multi-mission support requirements, the ground network resources need to be shared optimally among the satellites. Scheduling the network resources for telemetry, tele-command and other operations involves visibility clash resolution for the ground stations taking into account the mission constraints and station capabilities. A software based system using genetic algorithm is implemented and is operational to meet the above requirements.

For Multi Satellite Scheduling, inputs from Scheduling Guidelines, Visibilities of TTC network from Flight Dynamics Division and any special operations requests from operations team are taken and clash free schedules are prepared on weekly basis starting from Monday ending on Sunday. The weekly schedule forms the basic building block for generating of operation schedule and commands for the spacecraft. Figure3: provides the flow of scheduling procedure for the TTC and Mission Control Centre operations.

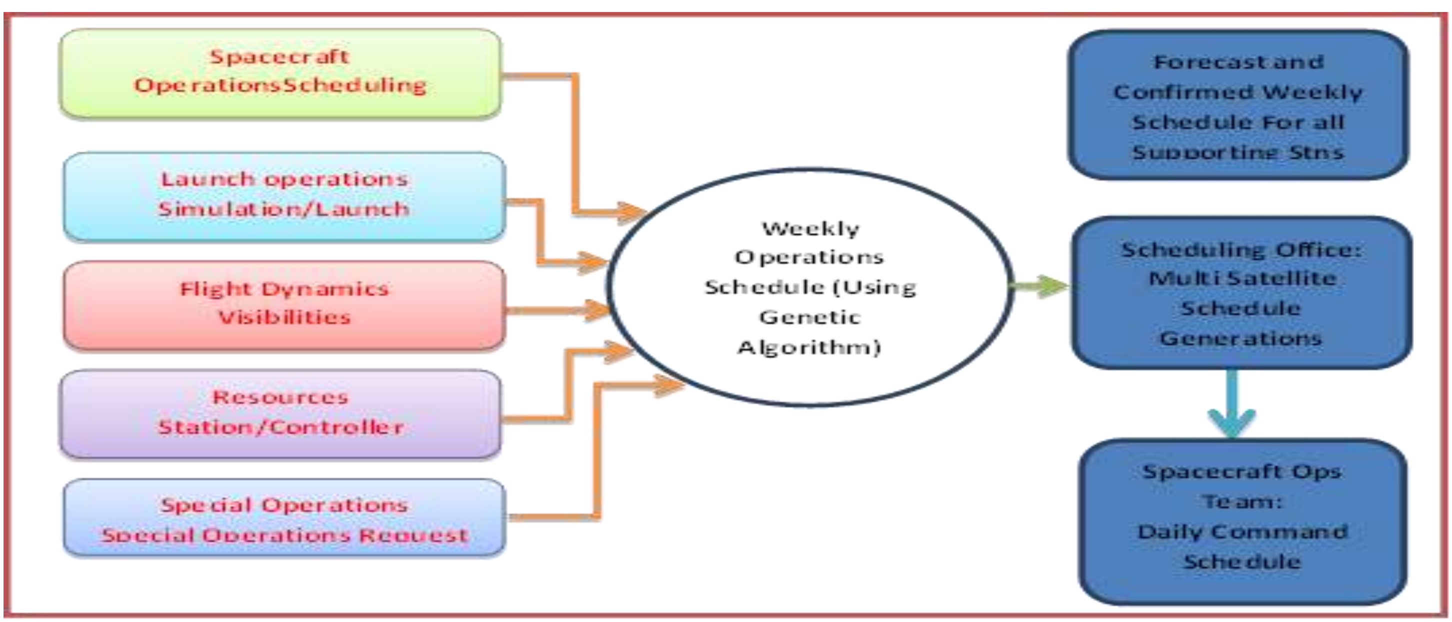


Fig3: Flow diagram of scheduling process

- *Payload programming operations*

The demands of multiple users for payload data have to finally culminate into command sequences that are to be uplinked to the satellite for payload operations. Payload programming is implemented using Payload Operations Planner (POP) software consisting of three modules namely User Order Processing System (UOPS) implemented at user end, Payload Programming System (PPS-NDC) implemented at NDC/NRSC, Hyderabad and Command Sequence Generator (CSG) implemented at SCC/ISTRAC, Bangalore. The payload requested are serviced based on criteria like priorities for different users, spacecraft constraints etc.

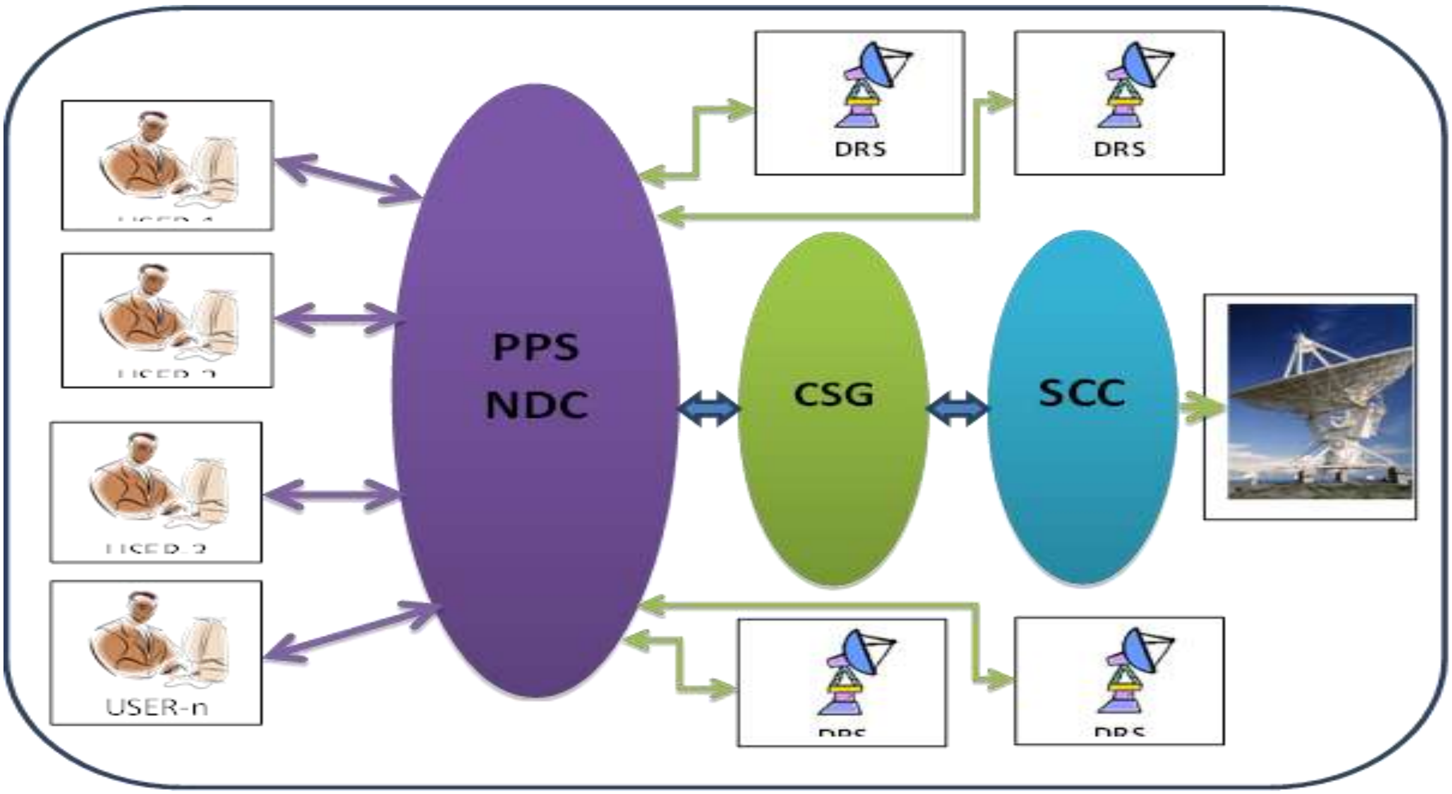


Fig4: Payload Programming Architecture

4. *Flight Dynamics operations*

In order to keep track of the orbit of a satellite, it is essential to compute orbital parameters on daily basis, using the tracking data provided by TTC ground station network or using the SPS data downloaded from spacecraft.

Flight Dynamics Operations include

- Orbit determination using S-band tracking data or SPS data
- Visibilities generation for ground stations for tracking purpose
- Orbital Events prediction such as Eclipse entry/exit times, Pole crossing times etc.
- Orbit maneuver planning for ground track maintenance, local time maintenance and phasing requirements

The S-band tracking data contains the satellite's slant range from the station, range rate and look angles at different times. This information is collected and accumulated for a period of 60 hours (2.5 days) and orbit determination is carried out daily. For SPS based orbit determination, GPS measurements data stored onboard for around two orbits is downloaded and used.

5. *Computer Network support*

Distributed computer architecture has been implemented at Control Center in client server architecture configuration. The computer system will support all the missions in the multi-mission environment. Computers will provide prelaunch phase, initial phase, on-orbit phase and terminal phase support services for all LEO missions.

The computer configuration for a satellite comprises of:

- Work stations for health processing and display of spacecraft data
- File servers/Data base servers for data management
- Routers for interconnecting control center to ground stations

- Gateway systems for interconnecting control center with external agencies
- Virtual LANS for LAN connectivity of all the work stations, communication processors, file servers, Layer-3 switch / routers etc.,
- TCP/IP Data network is used to connect control center with other Ground stations

On these systems, a unified software system will run consisting of a set of layered software products catering to the functions of data communication, data management and data flow monitoring.

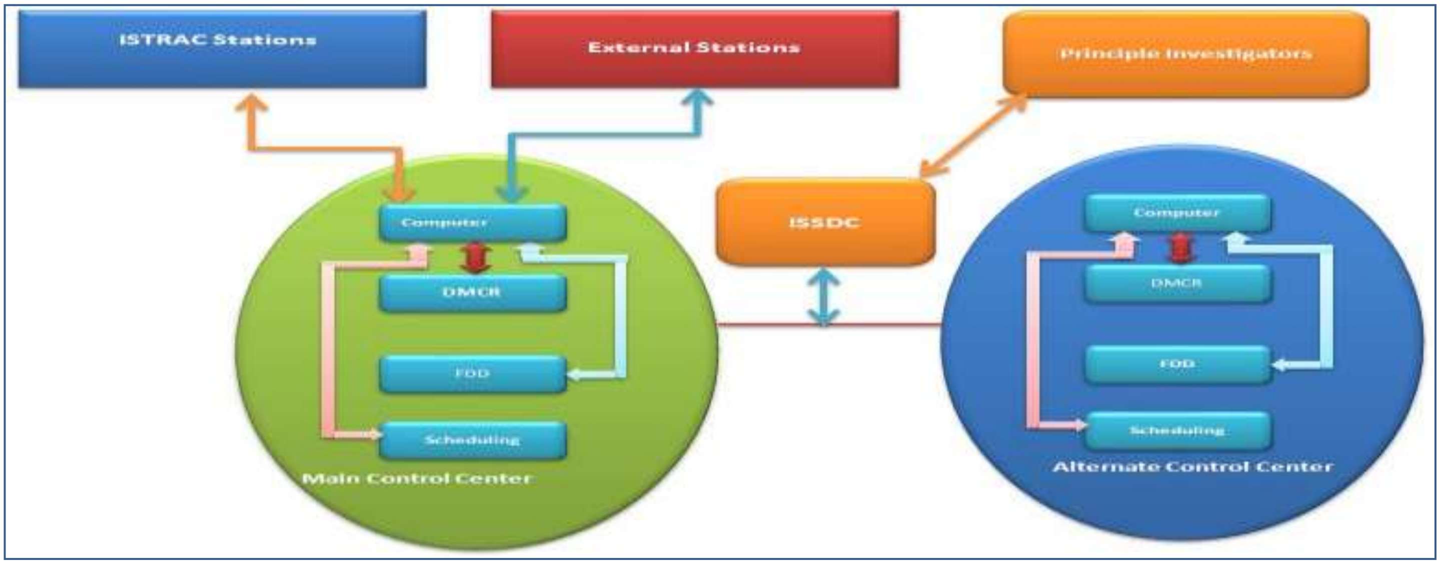


Fig5: Computer Architecture

6. Communication Network Support

ISTRAC Communication Network provides real time voice/data/fax connectivity for TTC operation between Spacecraft Control Center (SCC), Bangalore / Vehicle Control Center (VCC), SHAR and other Network Stations both in India and abroad, supporting Launch Vehicle & Satellite during its launch phase, early orbit and normal phase of missions.

Sky Links: All the communications are provided with 128/256/384/512/768 kbps digital direct satellite links. Communication Links with Network stations within India are established by using INSAT-3E. Port Blair redundant link is established using INSAT-3A satellite. Biak station connectivity is through INSAT-2E Satellite.

Terrestrial links: The terrestrial links are hired from the communication providers (BSNL, VSNL, and MTNL). Terrestrial links are planned for redundancy wherever sky link exist. Two terrestrial links (main and redundant) are planned in an alternate route to avoid single point failures between VCC/SCC and TTC network stations not having connectivity through sky link. ISDN links are also established between BLR-MAU used as backup link.

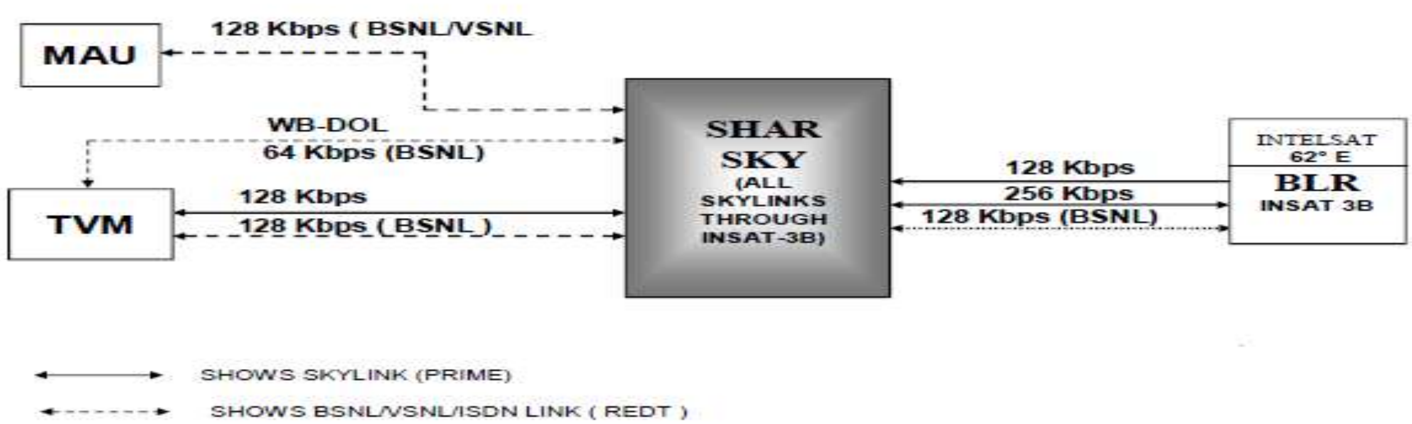


Fig6: COMMUNICATION LINK CONFIGURATION FOR PSLV LAUNCH

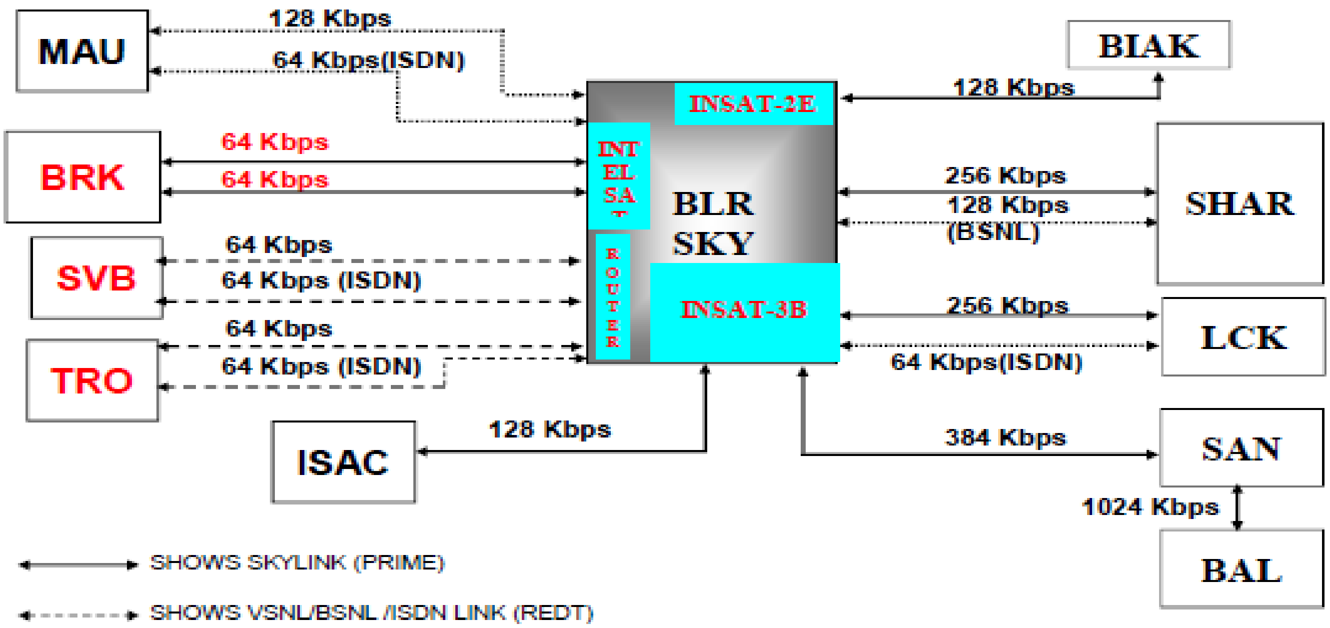


Fig7: COMMUNICATION LINK CONFIGURATION FOR SATELLITE SUPPORT

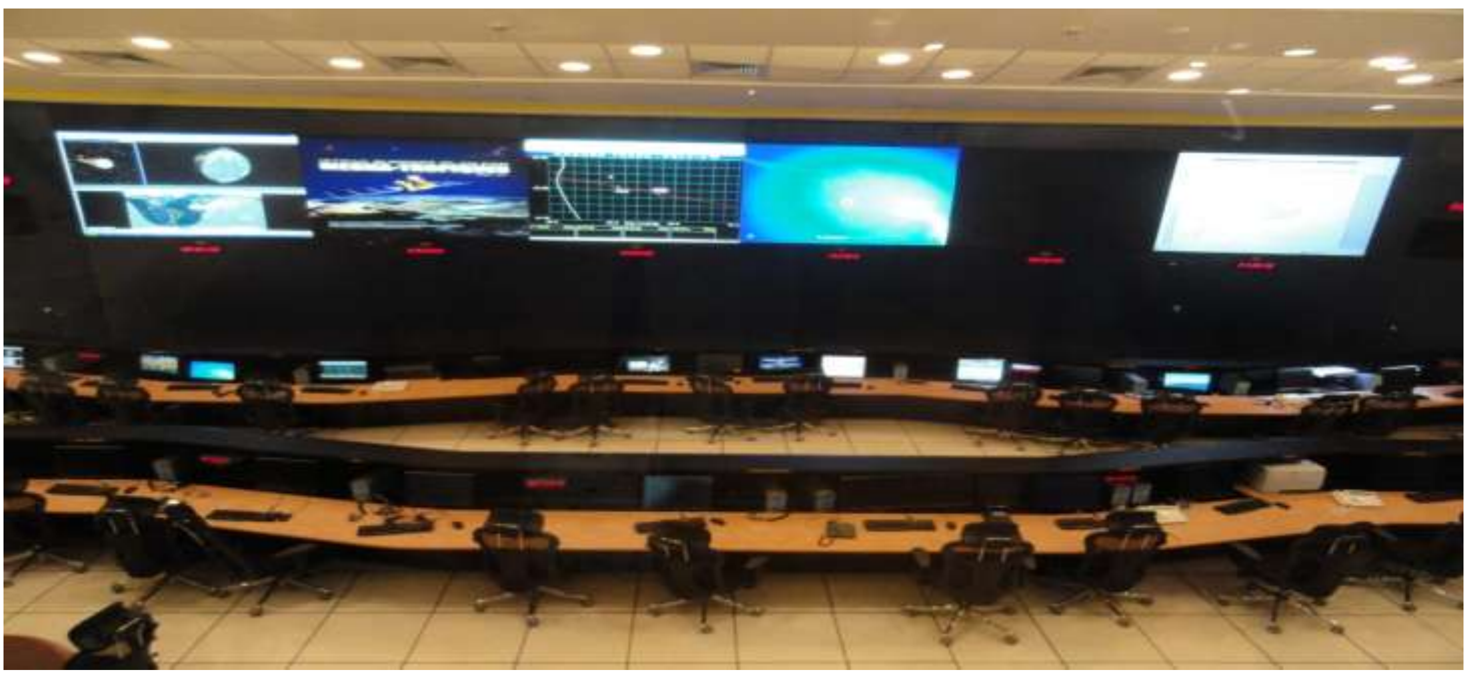


Fig8: MOX-2 Mission Analysis Room (MAR)

7. Facilities Support

To support dual spacecraft mission launch and initial phase operations, two Control Centers (MOX-1 & MOX-2) are established in the Mission Operations Complex. Both MOX-1 and MOX-2 are integrated with each other.

Mission control facilities at MOX-2 comprises of:

- A Mission Control Room (MCR) to support Launch and Early Orbit Phase (LEOP) operations.
- A Mission Analysis Room (MAR) to support launch and early orbit phase (LEOP) operations.
- Dedicated Mission Control Room (DMCR) to support Normal Phase operations along with ongoing missions.
- Conference Hall

Fig9: MOX-2 Mission Control Room (MCR)

Mission control facilities at MOX-2 comprises of:

- A Mission Control Room (MCR) to support Launch and Early Orbit Phase (LEOP) operations.
- A Mission Analysis Room (MAR) to support launch and early orbit phase (LEOP) operations.
- A Dedicated Mission Control Room (DMCR) for normal phase operations of all LEO missions
- FDO area for supporting Flight Dynamics operations during the initial phase operations.
- Scheduling Office area to plan Payload and TTC operations.
- Conference hall and Seminar hall.

Fig10: MOX-2 Mission Analysis Room (MAR) full view

Fig11: MOX-2 Dedicated Mission Control Room (DMCR)

CHALLENGES IN OPERATING RISAT-1

RISAT-1 is first of kind not only because its microwave RADAR features but because of some new operational challenges it poses to operations team, as RISAT-1 is the first satellite launched in 6 AM local time condition.

TRANSPORTABLE TTC TERMINAL FOR VEHICLE SUPPORT:

The first and the foremost demand that RISAT-1 created was during its launch for a transportable terminal. Since RISAT-1 weighed about 1858 Kg, PSLV-19 XL was able to take it to 476 Km orbit only. Rocket trajectory created a small data gap between Trivandrum and Mauritius visibility. Hence, as per the PSLV project requirement, S-Band TT was deployed at RODRIDGE island of Mauritius. This is the first time; ISTRAC had deployed a TT terminal in another country. This started from site selection to TT transportation to Operationalization with on orbit satellites to establishing new communication links through Intelsat to dismantling and bringing back safely after the launch support. TT support was excellent and served all its purpose intended for **Eclipse effect.** ISTRAC has the experience of operating satellites in three kinds of orbits. First one is polar sun synchronous where in TES, RESOURCESAT-1 &2, Cartosat-1; Cartosat-2/2A/2B etc. are placed. Their local time varies from 09:30 am to 12:00 am. The second one is the 45 deg. inclination orbit where in RISAT-2 and HAMSAT are placed. Third one is the 20 deg. inclination near equatorial orbit of MT1. All these satellites experience eclipse from earth shadow on the orbital arch in every orbit. The shadow duration is nearly constant. Although power is not a constraint during these eclipses, optical payloads are operated in sunlit only whereas SCATEROMETER of OS-2, all four payloads of MT1 and X-band RADAR of RISAT-2 are operated in eclipse also.

In the case of RISAT-1, its orbit is eclipse free for nearly 9 months and acquires eclipse from June to August in a triangular pattern with eclipse duration starting from few seconds to 22 minutes in July and vanishing in August.

Further, RISAT-1 demands about 4000 W of power during the payload operation. About 2000 W is provided by the solar panel and about 2000 W is drawn from Battery. As Battery cannot support such a load, payload is restricted to sunlit only.

Its thermal condition follows a yearly pattern as against orbital and seasonal pattern of other constant eclipse bound satellites.

Power Generation: The power generation pattern of RISAT-1 is entirely different compared to other satellites. In all other satellites, constant power is generated during sunlit and zero power is generated during eclipse. Constant power is proportional to the full power of the panel for normal incident sun rays multiplied by Cos (LTA) where LTA is the local time angle. In the case of RISAT-1, peak power is available at the poles and a nominal power is available near the equator about the sun latitude. Further the nominal power varies day to day as the sun transverses from -23.5 deg to +23.5 deg over one year. Power generation will be at the highest level throughout the orbit only on two days when the sun is at -7.5 deg. latitude in a year.

This pattern is new for the operations team. Real time care and background prediction program will be run to ensure any power anomaly accounting for the variable nature of power generation.

Payload command operations: Although the concept of payload request collection, command generation and payload operation using the on-board payload sequencer is old and existing; monitoring of payload sequencer start up daily at 00:00 UT happens over BIAK G/S tracking at about 02:00 am Indonesian local time and at 05:30am for India.

New Elements on-board RISAT-1: Power system of RISAT-1 is entirely new for ISTRAC team. It consists of 70 V Bus and was controlled by a new F2S4R regulator for maintaining the bus at 70 V and also for charging the battery. A new BDR was introduced to control the discharge from battery during the peak power demand. New types of buses like ABR, UBR and EED are derived for support of different systems on different requirements. First time Ni-Hydrogen battery is used in the low earth satellite. ISTRAC team has to get familiarization in this new concept of monitoring and control.

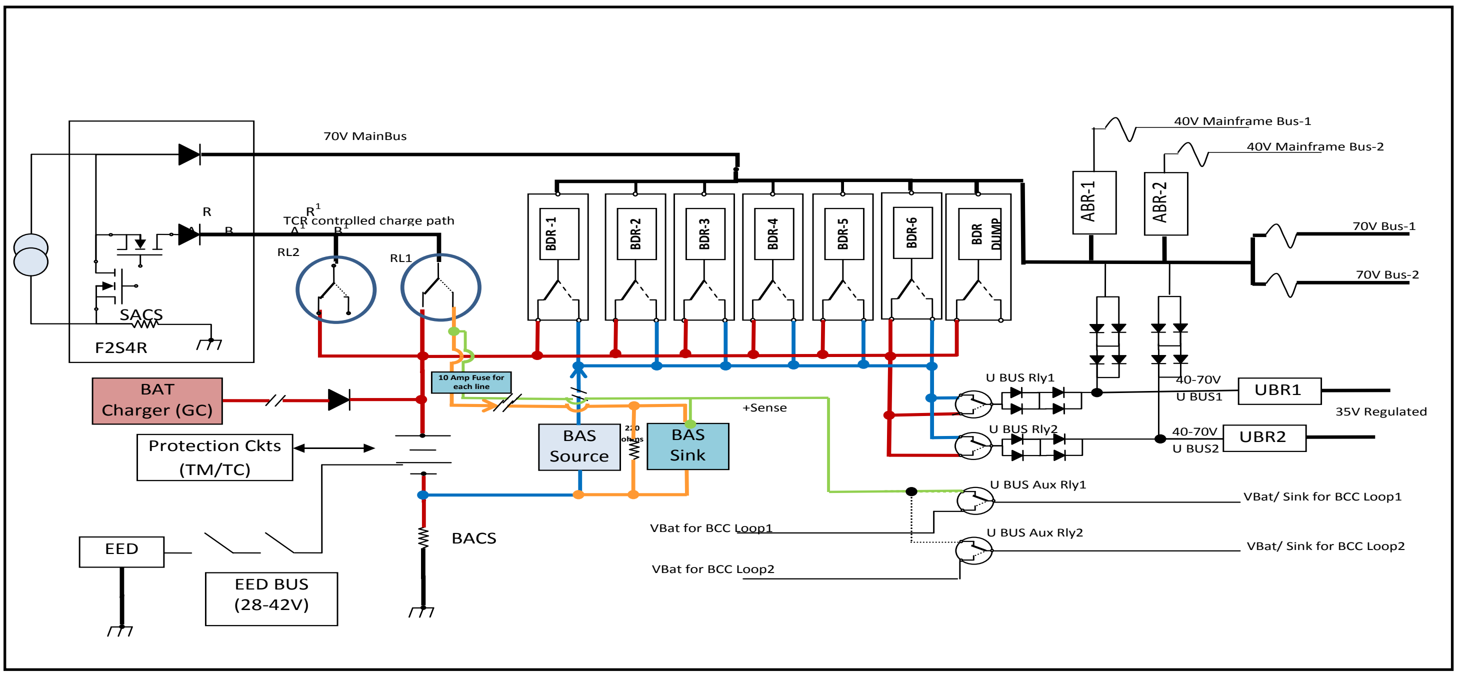


Fig12: New Power system configuration of RISAT-1

Payload systems: ISTRAC had some experience of operating active Scaterometer of OS-2, X-band SAR of RISAT-2 and Mini-SAR of Chandrayaan-1. But for the first time, it is exposed of a C-band active SAR with side looking condition. RISAT-1 SAR is so versatile that it has many modes of operations like FRS-1, FRS-2, MRS, and CRS in linear single polarization and dual polarizations also all the modes in circular polarizations. All these modes were tested during the initial phase during commissioning time. Only HRS mode is yet to be tested. So many modes of operation in a microwave P/L is new to ISTRAC. It will face the challenges effectively.

Conclusion: RISAT-1 is a great satellite and every operation is going smoothly from operation center at MOX. It has all the redundancies intact for any contingency. All the program executes are transferred to 'oa' area and normal phase operation is going on.

Shadnagar Ground Reception and Processing System

D.S. Jain, NRSC, Hyderabad

National Remote Sensing Centre (NRSC) has implemented the state-of-art 'Integrated Multi-mission Ground segment for Earth Observation Satellites' (IMGEOS) Facility at Shadnagar Complex. It features automation of entire process from Payload programming, data acquisition, data processing to data dissemination with multi-mission approach, a world class data centre with 3 tier SAN, secured networks, scalable architecture to meet current and future Earth Observation missions and enhanced user services with a turn-around-time of 1 hour for an emergency products and 24 hours for a normal products. The IMGEOS facility was inaugurated by Chairman, ISRO on Nov 4, 2011.

The configuration of RISAT-1 systems is worked out in

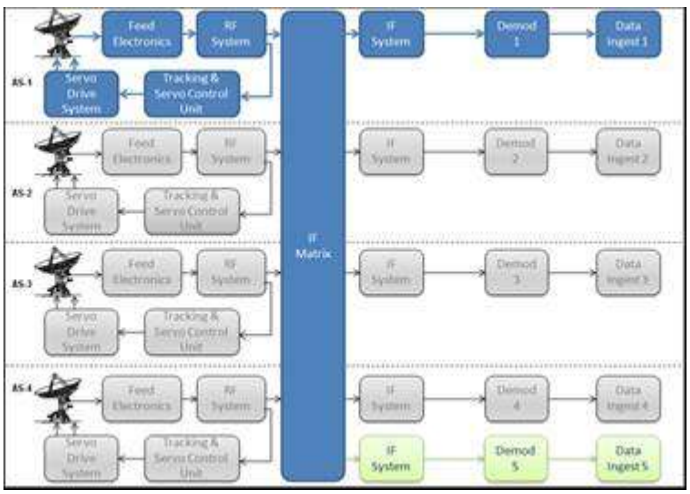


Fig-1 IMGEOS Data Reception System Configuration

Some RISAT-1 Data Reception System features are listed below:

a) 320 Mbps data rate in LHCP carrier and RHCP carrier.

b) Each RF carrier is QPSK modulated at 320 Mbps with 160 Mbps in I & Q channels.

c) New 7.5 m Cassegrain Antenna system with G/T of 32 dB/deg K @ 5º EL.

accordance with the IMGEOS objective of integrated automated process flow of data acquisition, processing and dissemination to users.

1. Data Reception Systems (DRS)

The data reception system comprises of four 7.5 meter antenna systems, all with dual polarization, configured in multi-mission mode to track and receive data from all remote sensing satellites. It is equipped with the state-of-art bore-site facility to validate the data reception chain both in local loop and radiation mode, an IF matrix to facilitate automation and enhance operations efficiency, high data rate digital demodulators to support RISAT-1 data reception. One 4.5 meter Antenna is also configured to support the low data rate missions like NOAA, MODIS etc. The DRS system configuration is shown in Fig.1.

d) Simultaneous RHC and LHC polarized signal reception @ 8212.5 MHz with dual polarized S/X-Band composite Feed using the frequency re-use technique.

e) Feed and front-end system realizes single channel mono pulse tracking.

f) Two data reception chains at 720 MHz IF, each with 320 MHz bandwidth

g) X-Band Auto Track either through RHCP or LHCP carrier

h) Synthesized Up/Down Converter with additional channels

i) IF link for transfer of high data rate modulated IF spectrums.

j) High data rate Demodulators at 320 Mbps (I+Q) data rate

k) High Data Rate Simulator

The RISAT-1 DRS, shown in Fig.2, comprises of Antenna & Tracking Pedestal, Dual Polarized Feed & RF systems, Digital Servo & Automation system, IF & Base-Band system and Data Ingest System as major sub-systems. The station has multi-mission capability with built-in programmable features to cater for the wider range of satellites. The composite S/X feed, shown in Fig.3, is dual circularly polarized in both S & X bands with the capability to receive LHC and RHC polarized signals simultaneously. The X-Band data is received through

RHCP and LHCP simultaneously using frequency re-use technique.

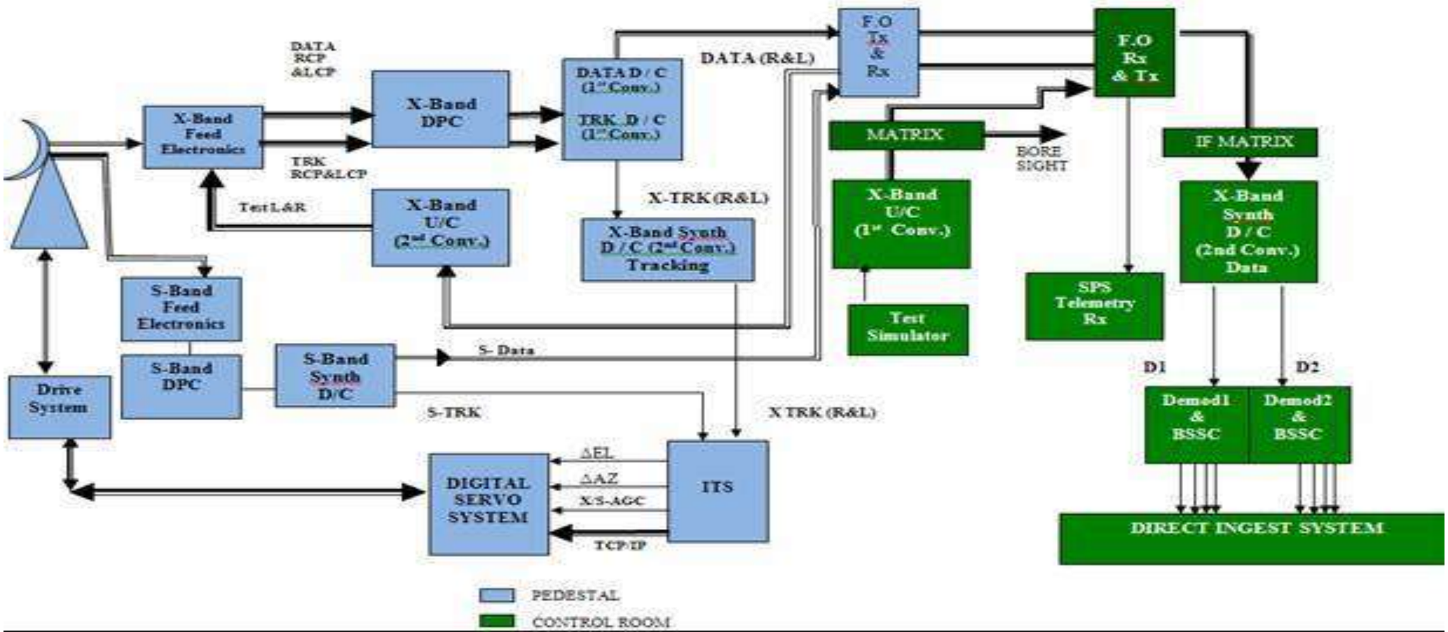


Fig-2 Configuration of RISAT-1 Data Reception

The S-band Telemetry Data and Tracking signals are down converted to 70 MHz IF. The down converted X and S band tracking IF signals are fed to a three channel Integrated Tracking system (ITS). The IF outputs from first data down converter (2 carriers) and S band data IF are driven to the control room through a multi-core optical fiber cable and fed through programmable IF Matrix to the second down converter and then to High data rate digital demodulator. The data and clock signals from demodulators are driven through LVDS interface to Data Ingest System for further processing and product generation.

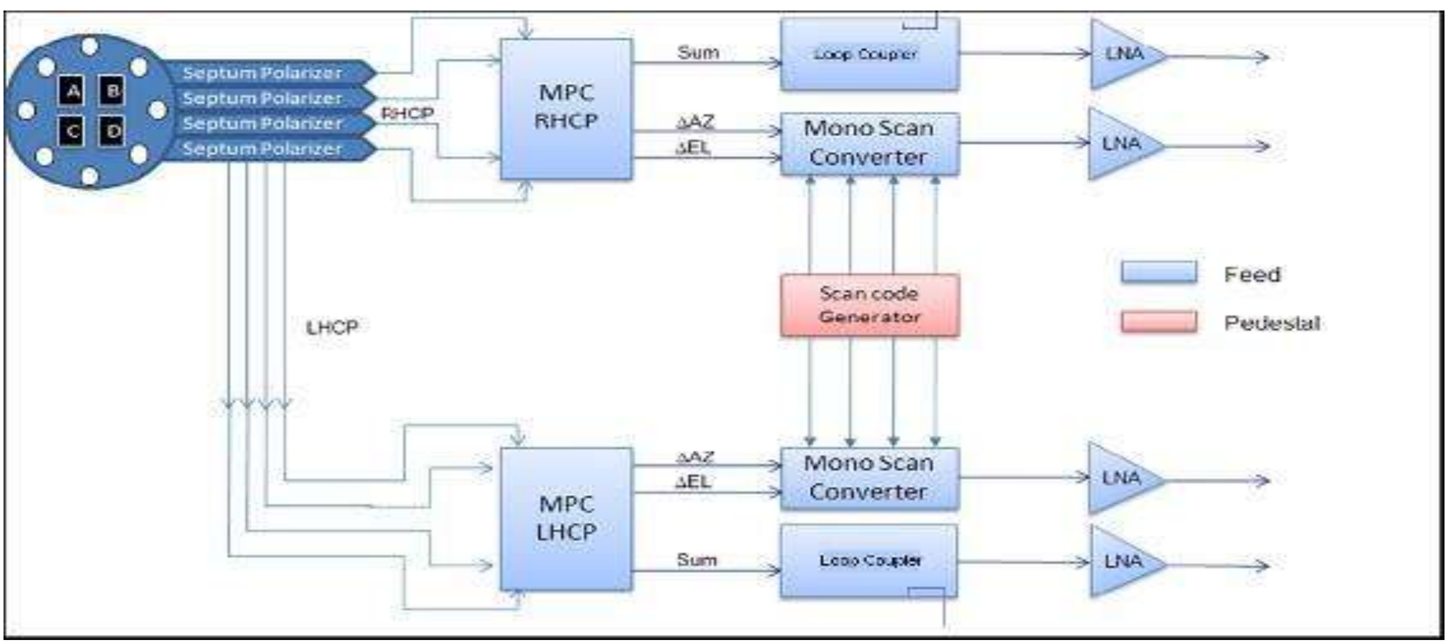


Fig-3 Configuration of Dual Polarized X-band feed

2. Data Ingest System: The data ingest systems, shown in Fig.4, consists of PC servers with RAID for real-time data ingest and PCI Front end Hardware (FEH) cards which are connected to the demodulators. SAR data is acquired onto RAID in real time at 320Mbps in each stream and transferred to SAN in near – real time for

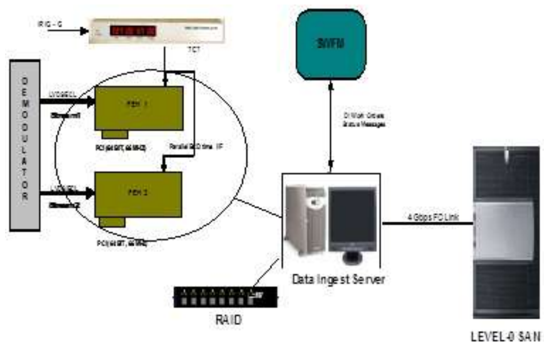


Fig-4 Configuration of Data Ingest system

The PCI-FEH card features:
1) Two Channels at 160 Mbps each ECL input interface
2) 127 bit frame synchronization
3) Parallel data interface to quick look processor
generation of Level-O products.

4) BCD parallel time interface
5) 256K x 16 bits FIFO buffer
6) PCI bus for host independent interface

3. Data Processing: In IMGEOS, the data processing schedulers are classified into three categories - Optical, microwave and non-imaging. A set of servers are configured for each category and are operated in multi-mission mode for optimum resource utilization. The data centre features a state-of-art 3-tier SAN storage repository configured with high reliability & redundancy to facilitate online data archival & retrieval. All the processing systems are connected to SAN by FC and Gigabit networks for instant access and processing as shown in Fig.5.

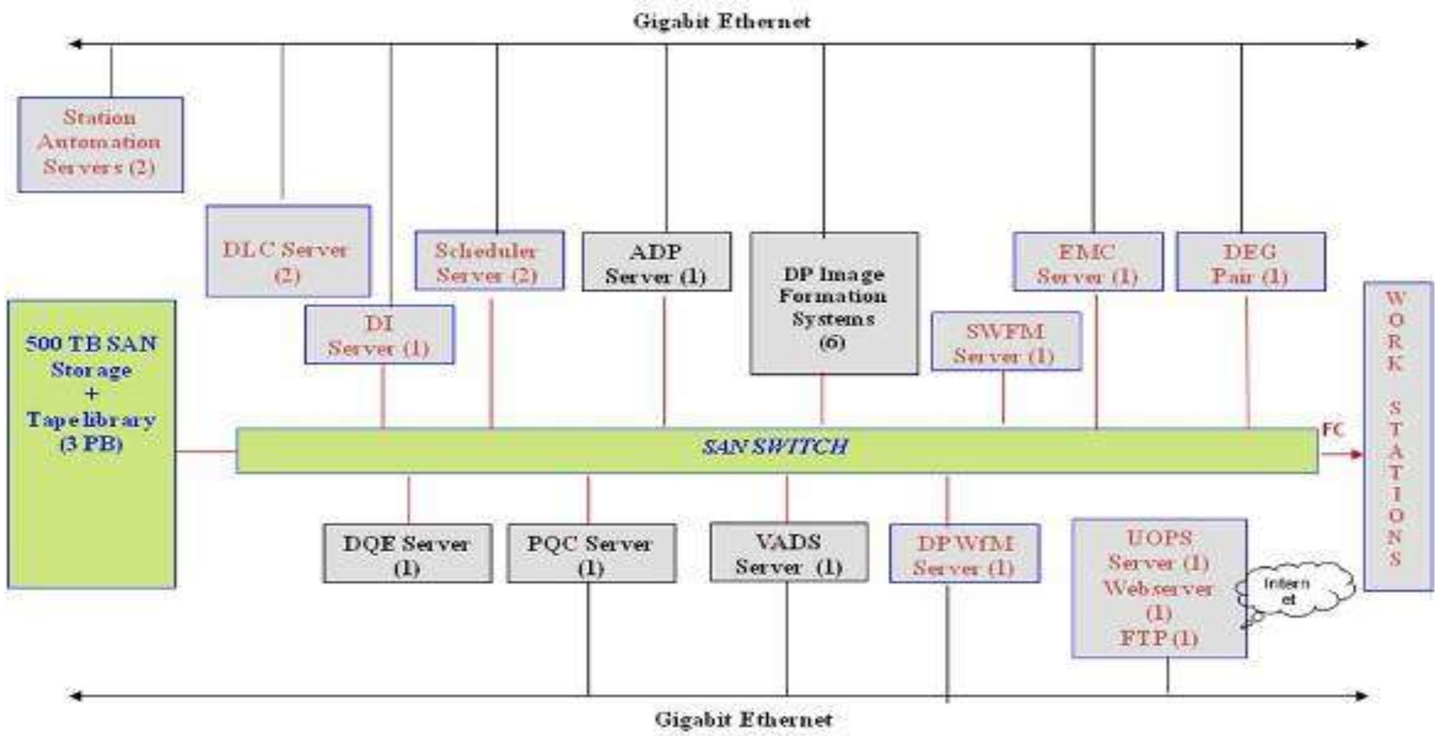


Fig-5 Configuration of Data Processing Systems

The RISAT- 1 products are routed to Microwave DP scheduler. The high end multi core & multi CPU systems are sized and configured keeping in view the complex processing, storage and throughput requirements of RISAT-1. A set of work stations are configured for handling different functions like DI, ADP, VADS,DQE, PQC, PPS, UOPS, media generation and Work flow manager. The standard products with UTM projection / WGS 84 datum are generated and archived for all the passes in default mode. The user products are generated based on user requests.

4. Software Architecture: Combination of different types of software applications on heterogeneous systems and architecture is deployed for product routing and dissemination. *Component based three-tier Architecture is* used for data ordering, payload pass scheduling, request processing and information management services incorporating the following:

a) Automation in all possible enterprise operations
b) Data Centric Processing – SAN storage for online access of Data
c) Improved Quality Assessment of Data
d) Security between Networks

The Station Workflow manager S/w provides centralized scheduling of all the antenna reception systems, event monitoring and control functions for station operations with appropriate interfaces for User Order Processing Systems.

A Centralized Event Monitor & Control (EMC), shown in Fig.6, is integrated in the production chain for monitoring all the events to perform following tasks:

1) Alerts whenever a pre-defined critical event takes place
2) Facilitates to monitor Level-0 processing chain and DPGS processing chain
3) Allows to monitor critical enterprise resources and network peripherals
4) Features various performance and analytical reports.

5. Data Dissemination & User services: The user services provided through UOPS are browsing and data ordering of required area of interest. In case of RISAT-1, the Meta information is populated to enable the user to verify coverage. Different options including Map based, AOI, Path and Date are provided for searching the image catalogue and data ordering. The UOPS is integrated with multi-mission payload programming system (MMPPS). The data is disseminated thru FTP. The products are classified into:
1. Raw Data (Level-O)
2. Geo-tagged Products (Level-1)
a) SLC products from FRS-1 & FRS-2
b) Ground range products from all modes
3. Ellipsoid Terrain Geo-coded products
a) Standard product
b) Shift along Track product.

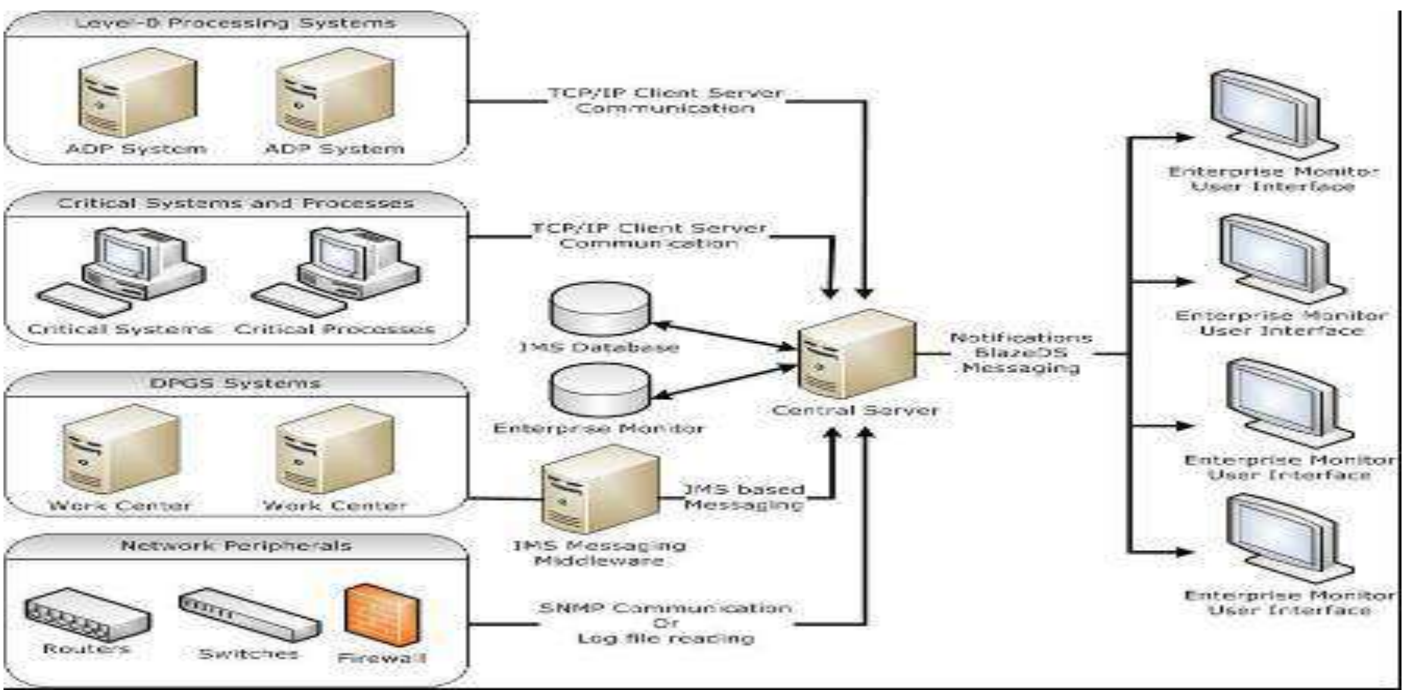


Fig-6 EMC Configuration

Section 2 - New Technology Development and Industry Contribution

Multilayer Antenna System for Radar Imaging Satellite-I

Rajeev Jyoti,SAC, Ahmedabad

1. Abstract: This article presents the salient features of the design and development of active phased array antenna system for Radar Imaging Satellite. It elaborates the issues related to the RF design of a large size planar multilayer microstrip antenna tile of size 1mx1m meeting stringent requirement of sidelobes, gain & cross-polarisation over large bandwidth. The realization aspects including making of large size films, chemical etching and bonding of the layers followed by accurate assembly and bonding has been touched upon in brief. The characterization of this antenna system has been discussed with special emphasis on microwave holographic technique which is a non-destructive diagnostic tool.

2. Introduction: The successful design and development of active phased array antenna system for Radar Imaging Satellite-I (RISAT-I) at C-band paved the way for the evolvement of a number of new technologies in terms of electromagnetic design, realization and characterization of a large size multilayer printed array antenna. Broadband dual polarized multilayer microstrip antenna technology for space-borne application were developed for the first time and none of the contemporary SAR system reports this type of antenna system catering to the stringent requirement of cross-polar isolation better than -30 dB & high gain over 5% bandwidth at C-band.

Single layer micro-strip antenna of size 10.74mx2.16m for 19MHz bandwidth at L-band was the first space-borne micro-strip antenna flown by JPL/NASA for SAR payload on SEASAT 1978. The next space-borne SAR mission in which micro-strip antenna array was used is the J-ERS-1 of NASDA in 1992 and the bandwidth in this case was 15 MHz at L-band. In 1994, JPL/NASA developed separate microstrip antennas at C and X-Band for SIR-C. For this SAR system, the bandwidth at C-band was 10MHz while that at X-band was 20MHz. In 1997, dual polarized coplanar fed stacked micro-strip patch array antenna at C-band was designed and developed for RADARSAT-2. The achieved bandwidth is 100 MHz and antenna is distributed in 20 element sub-array connected with T/R modules. In 2002, ESA developed the C-band annular slot antenna array for ENVISAT mission. The achieved bandwidth was 2% at 5.3 GHz. In 2010, X Band electromagnetically coupled patch antenna array was designed and developed for SEOSAR/PAZ SAR payload. The antenna bandwidth for this mission was around 34 MHz. In the same year, L-band dual polarized probe fed micro-strip patch antenna array was designed and developed for ALOS PALSAR. The obtained bandwidth was 14 MHz. This short and complete review of micro-strip antenna technology for space-borne SAR applications reveal that RISAT antenna had the highest bandwidth using micro-strip antenna technology and that is 225 MHz at 5.35 GHz. The important specifications of the antenna are shown in Table 1 and the bandwidth performances of various international space-borne SAR systems are shown in Table 2.

Table 1: Specifications of RISAT-1

Parameter	Specifications
Size	6meter x 2meter
Frequency	5.35 GHz±112.5MHz
Antenna Beamwidth	0.5 deg X 1.5 deg
Beam Scanning Elevation	± 15 deg
Gain	44.5dB
Gain bandwidth	1.0 dB
Panel size	2m x2m
Cross-Polarization	-23 dB
Polarisation	Dual Linear

As there were no heritage available at that time when the antenna design and development was initiated in 2001 to meet the above specifications, all the aspects of design and development were new. In order to meet the specified gain and beamwidth requirement, the estimated aperture size of the antenna was found to be 6 meter x 2 meter. The antenna was configured as three deployable panels of size 2 meter X 2 meter. Each panel consists of four tiles of size 1 meter x 1 meter. In order to scan the beam in elevation plane, an active phased array concept was employed in which all the 24 linear arrays are fed at the center by T/R modules with digital amplitude and phase control. The following paragraphs describe how the challenges in terms of RF design, realization, qualification and characterization were met. It was a wonderful journey through which the design and development team traversed over a period of seven years to deliver successfully 13 FM tiles and no minor cases of failure observed during the elaborate test and evaluation of the SAR payload systems.

Table 2: Antenna Bandwidth performance of other international missions

Mission	Space Agency	Year	Type of Antenna	BW
Seasat	**JPL/NASA**	**1978**	**L Band Microstrip array Antenna**	**19 MHz**
J-ERS – 1 L Band SAR	**JAXA/NASDA**	**1992**	**L Band Microstrip Antenna**	**15 MHz**
Shuttle Imaging Radar (SIR) – L/C/X	**JPL/NASA**	**1994**	**L and C Band Microstrip Patch Antenna**	**10 and 20 MHz**
ENVISAT	**ESA**	**2002**	**C Band Dual Polarized Annular Slot Array Antenna**	**2%**
RADARSAT-2	**Canada/CSA**	**2007**	**C Band Microstrip Patch Array Antenna**	**100 MHz**
X-band SAR SEOSAR/PAZ Satellite	**ESA/Estec,**	**2010**	**Circular Microstrip patch array antenna.**	**34 MHz**
ALOS PALSAR	**NASDA**	**2010**	**Probe Fed Microstrip Patch Antenna**	**28 MHz**

3. RF Design Challenges: The challenges in this new development were to achieve high gain, dual polarization with low cross polar radiation over a bandwidth of around 5% at 5.35 GHz with constraints of antenna configuration being low profile and relatively light weight. Microstrip antenna was the only configuration which could be conceived at that time. Conventional single layer direct or proximity fed microstrip antenna could not be a natural choice and broadband antenna element was the only choice. Various broadband microstrip antenna elements like stacked SSFIP (Strip slot feed inverted patch), microstrip antenna elements loaded with u-slots etc. were simulated, designed and developed and the configuration which was finalized considering all the RF parameters like gain, bandwidth, cross-polarization and its performance at array level was electromagnetically coupled stacked patch antenna (EMC stacked patch) with inverted upper patch. The configuration of the inverted patch is shown in Fig. 1. In this configuration of single radiating element, stacked patches was used to enhance the bandwidth by stagger tuning. Upper patch was printed effectively on foam material to increase return loss bandwidth and gain of the antenna. RT duroid material RT 6002 was selected for printing feed line, lower patch and upper patch.

The size of the tile antenna was 1mx1m consisting of planar array of 20x24 elements, 20 elements in azimuth and 24 elements in elevation. The inter-element spacing in azimuth plane was 0.89λ and that in the elevation plane was 0.74λ. In the initial phase of design 24x24 elements planar array was considered for tile with uniform spacing of was 0.74λ in both the direction. However, this array topology was changed in order to improve the SLL and wider bandwidth performance.

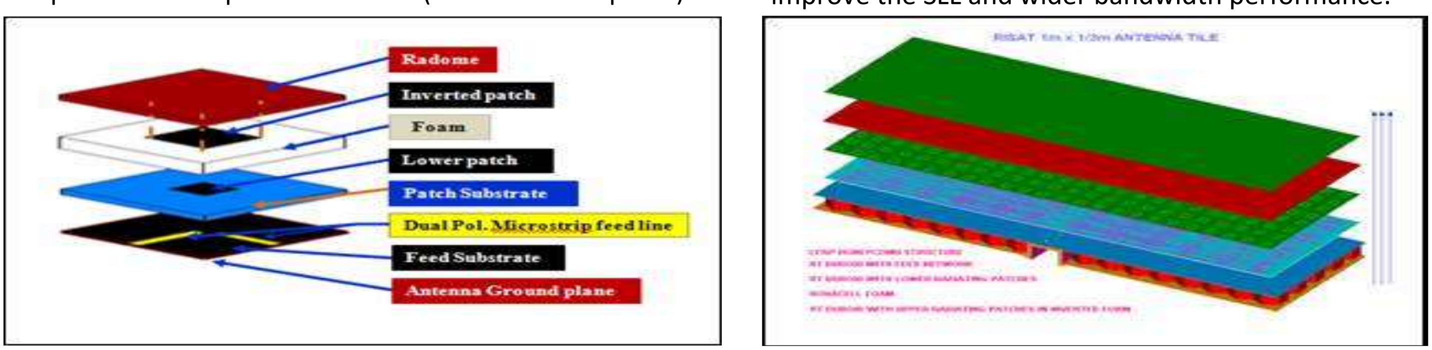


Figure-1: Different layers of multilayer EMCP antenna and the model of sub-tile (1/3rd tile)

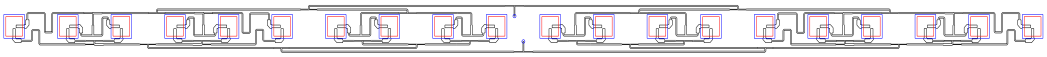


Figure-2: Simulation model of dual polarized linear array

In the tile, the 20 elements in the azimuth plane were combined for both the polarization to give output at both H and V-ports. Since, the inter-element spacing in the azimuth plane was only 0.74 λ, the accommodation of feeder network in the limited inter-element spacing was very challenging. For linear array of length 1 meter (≈ 18λ at the design frequency 5.35 GHz), a series parallel hybrid feed network using microstrip transmission line was designed on a thin substrate of height 0.381 mm. The feed network was optimized for equal amplitude and phase distribution for all 20 elements in azimuth plane. Feed network for twenty element linear array consists of two half portions of 1:10 feed network designed on the substrate of 15 mil RT Duroid in the form of microstrip lines as shown in Fig. 2. Cross polarization suppression technique was used to suppress cross polarization in horizontal plane in each linear array as compared to cross polarization of single element. The photo of printed feed layers of the optimized dual polarized feed network is shown in Fig. 3 depicting both vertical and horizontal polarization for eight linear arrays. The measured radiation pattern of a FM tile at horizontal polarization port is shown in Fig. 4.

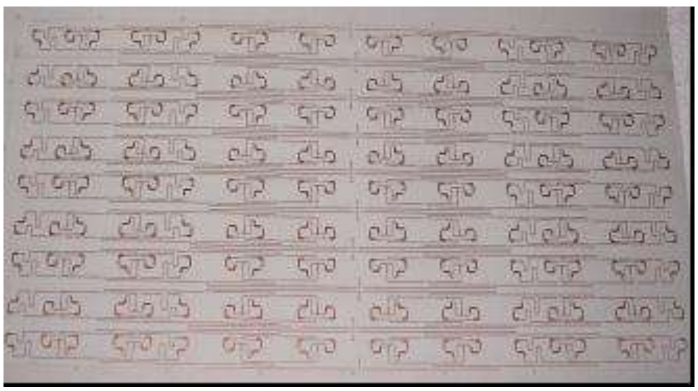


Figure-3: Dual polarized feed of sub-tile (1/3rd tile)

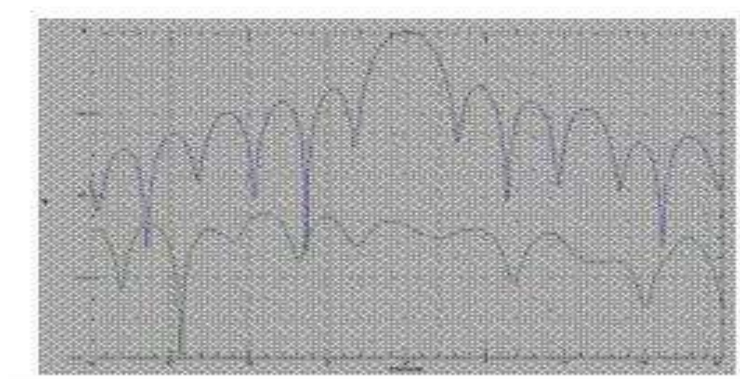


Figure-4: Measured Azimuth plane pattern of FM tile at 5.35 GHz

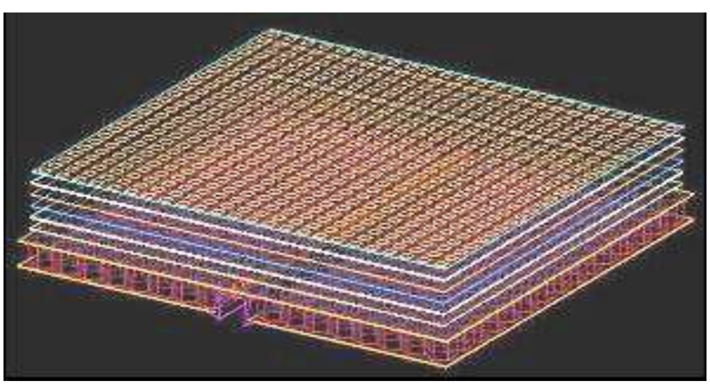


Figure-5: different layers of tile antenna

Figure-6: FM Tile antenna under test in SAC, CATF

4. Realization aspects: The development of multilayer micro-strip patch antenna involved new materials, fabrication & qualification processes without having any space heritage. Besides this, large size multilayer antenna imposed stringent constraints on film making, chemical etching, mechanical assembly/bonding that required the development of vendors and facilities for film making and chemical etching and automated precision assembly station. The realization of the multilayer antenna with required tolerance, assembly and alignment of various layers, vacuum bagging and curing of multilayer antenna were of paramount importance.

Thus, the major challenges for the realization of antenna included film development, chemical etching, inspection, development of jigs and fixtures for developing large size array. During the process of realization and qualification of the tile antenna, the facilities that were established through outside vendors are (i) Clean room facility at Atlantic circuits, Hyderabad for chemical etching through ASTRA Microwaves, Hyderabad (ii) Photo film fabrication at Image tooling, Hyderabad, through ASTRA Microwaves, Hyderabad (iii) Circuit system, Gandhinagar for photo film and chemical etching and (iv) Automated assembly fixture at Sahjanand Laser Technology (SLT), Gandhinagar.

This development called for the evolvement of new qualification processes and through which various anomalies like de-bonding of layers, shorting of connector pins, adhesives curing, post-bonding connector repairing, handling of very thin substrate

Figure-7: Automated assembly fixture designed and developed by SAC through SLT, Gandhinagar

materials, flatness issues of tiles were resolved. The layout and the photograph of one of the developed tiles are shown in Fig. 5 and 6 respectively. The photograph of the automated assembly fixture is shown in Fig. 7.

5. RF Characterization And Fault Diagnosis: Characterization of large planar array antenna tile was carried out using the 6mx9m planar Near Field (PNF) and Compact Antenna Test facility (CATF) of SAC. The electronic scanning performance of the antenna was

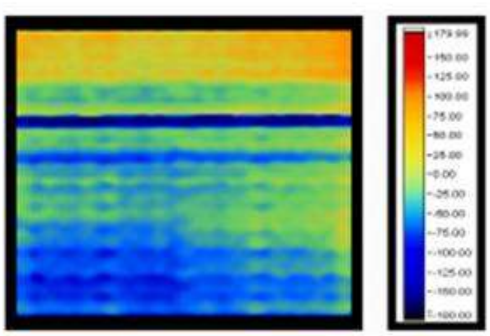
Figure-8: Planar Near Field Test Facility at SAC

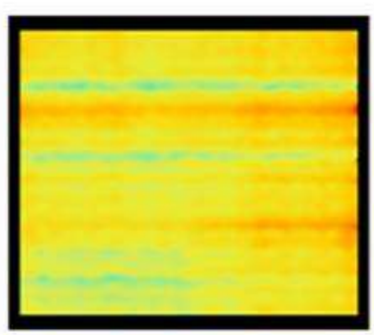
checked with 48 receive only modules for both polarizations and digital controller unit to control the phase and amplitude of the receive modules at PNF. The photograph of the SAC PNF installed in building No. 37 is shown in Fig. 8.

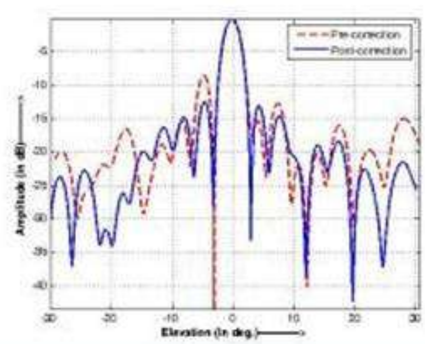
Fig.9 Holography Pre-correction

Fig.10 Holography Post-correction

Fig.11 Pre and Post correction V-port radiation pattern of RISAT antenna tile







A notable development in the characterization phase of the antenna was the development of Microwave Holographic Technique (MHT) using PNF. In this technique far field data is back projected using inverse Fourier transformation to compute amplitude and phase at the aperture. The transformation gives a 2-dimensional aperture distribution plot as shown in the Figures 9 & 10. This aperture distribution may be compared with the given amplitude and phase distribution to locate the faulty element. The low intensity line in the aperture distribution plot clearly shows a faulty linear array. Thus this technique is very useful to locate faulty elements of the larger arrays. Asymmetry in the side lobe level is observed in measured pattern for some of the linear arrays. From the back projected data it was seen that the phase asymmetric distribution causes side lobe asymmetry. The pre and post corrected radiation pattern is shown in Fig. 11.

6. Conclusion: During the process of development of various models of antennas like bread-board, qualification and flight models of antennas, a number of teething problems in terms achieving the specified RF parameters, space qualifications, RF characterization of the antenna, fault diagnosis etc. were faced which in turn gave a very good insight to solve the technical problems and to achieve a very important milestone of developing 13 space-worthy multilayer printed antenna. One of the most notable aspects of this antenna project was to motivate and make a few Indian Industries suitable to take up various jobs to development the flight model of tiles.

The future trend in planar antenna technology is towards ultra light weight antenna technology using unfurlable and inflatable antenna technology. High efficiency broadband dual polarized slotted waveguide array up to 15% bandwidth using light-weight CFRP material will be very attractive in future missions.

7. References:

- RISAT SAR Payload, DDR document, SAC/RISAT/DDR/01/2004
- RISAT SAR Payload, DDR document, SAC/RISAT/DDR/01/2009
- Y T Lo and S W Lee, “Antenna Handbook: Theory, Applications, and Design” Springer; 1 edition (June 30, 1988)

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures*, related to the specific theme “Megha-Tropiques Mission- Radiometers for the Tropics”.

The deadline for inclusion in the next issue is **Sep 30, 2012.**

- Editorial Team

RF and Microwave Subsystems for RISAT-1 SAR Payload

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1. Introduction: The core architecture of RADAR comprises of various diverse Microwave constituents working in tandem to accomplish the entire chain of microwave signal flow; Carrier generation, Carrier signal modulation and up-conversion, signal amplification, signal transmission and reception and finally signal down-conversion and demodulation. RISAT-1 Synthetic Aperture Radar (SAR) payload being an electronically steerable active antenna based RADAR, consists of a number of complex microwave sub-systems, as shown in Figure-1. These microwave Sub-systems can be divided into two main categories -

- Array Electronics
- Central Electronics

The Array RF Electronics form the backbone of the electronically steerable active SAR antenna while Central Electronics Sub-systems are involved in RF Carrier generation, modulation, up-conversion and amplification during transmission and Low noise amplification, down-conversion and demodulation during reception of the SAR signal. RF signal flow within SAR payload starts from Frequency Generator (FG) and ends up in the Central Receiver (Rx).

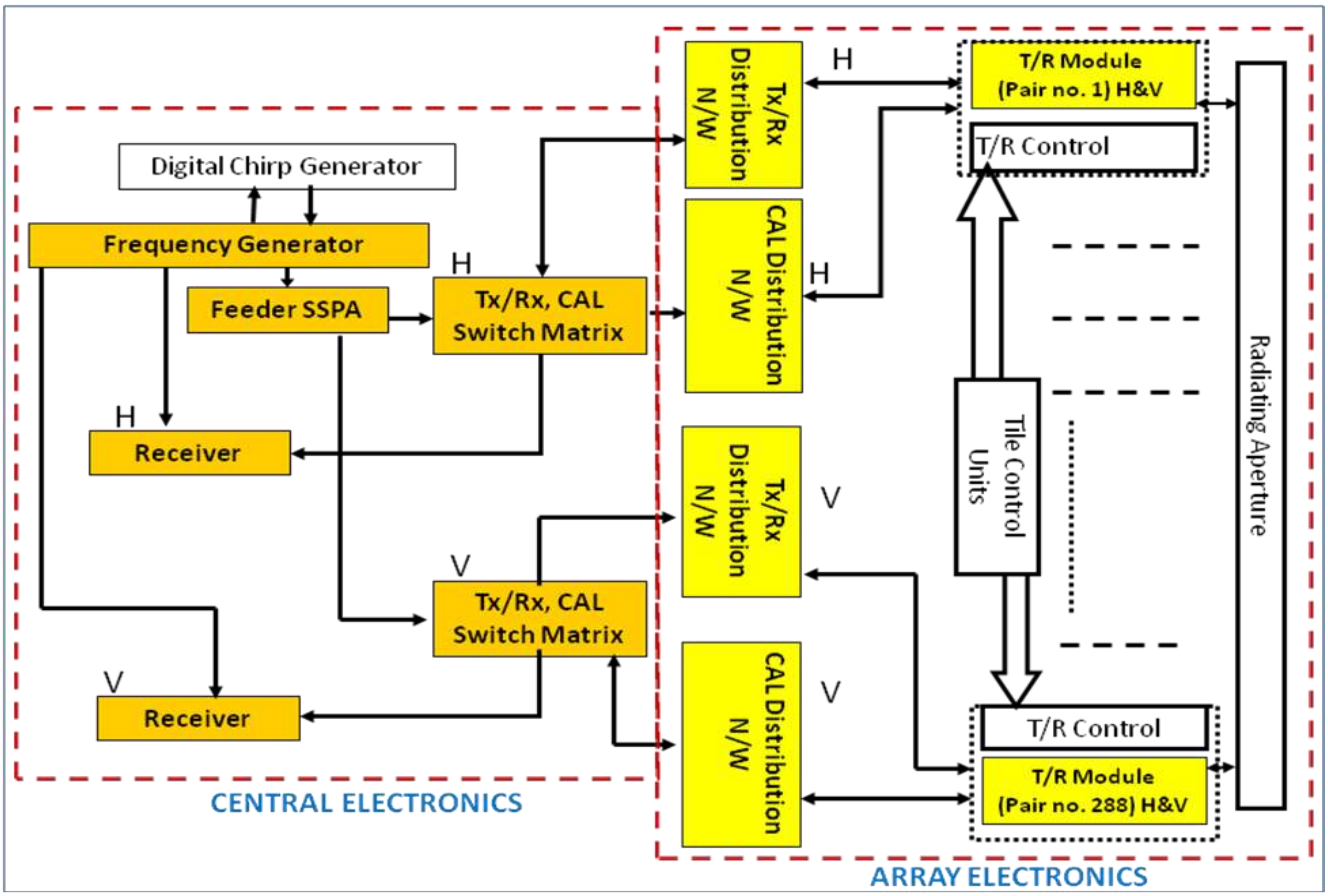


Figure-1: RF & Microwave Sub-systems of RISAT-1 SAR Payload

FG modulates a self generated carrier with an incoming digitally generated baseband chirp signal and up converts it to a desired SAR transmit frequency after frequency multiplication. Solid State Power Amplifier

(SSPA) amplifies the chirp signal to a high power RF level. The SSPA output is fed to the Tx/Rx & Calibration Switch Matrix (CAL SM) which routes the RF signal for Calibration or signal transmission & reception. When working in transmit mode, the output of the SSPA is fed to the Array Electronics section where after passing through an RF distribution network, the signal reaches the individual Transmit Receive Modules (TRM) which amplify and set the phase of the signal, facilitating electronic steering of antenna beam. In receive mode, an incoming signal from the Antenna Array gets fed to the respective TRM for low noise amplification of the weak echo signal. The contribution from each TRM output during reception gets added up in the RF distribution network, from where the summed up signal is fed to the central receiver. The central receiver amplifies the received echo signal, down-converts it to IF and finally demodulates it to generate the baseband I-Q signals for further processing in the digital domain.

The SAR payload operates in linear as well as in circular polarizations. Table-1 gives the break-up of different RF & Microwave units, including redundant units for RISAT-1 SAR Payload. The sections below describe these units.

2. Transmit Receive Modules (TRM): The active antenna of RISAT-1 SAR is driven by 288 TRMs in each of the Vertical (V) & Horizontal (H) Polarization operations of the SAR system. The ability to set the phases and amplitudes of each individual TRM gives electronically steered looking capability to the payload, making the TRMs analogous to human eye.

TR Modules carry out the following functionalities:

- To act as active distributed RF sources and distributed receivers behind the radiating patches.
- To provide power amplification for transmit drive signal and low noise amplification to the receive signal.
- To provide amplitude and phase control for both transmit and receive paths.
- To select either transmit or receive path by proper switching of input and output TrReceive switch.

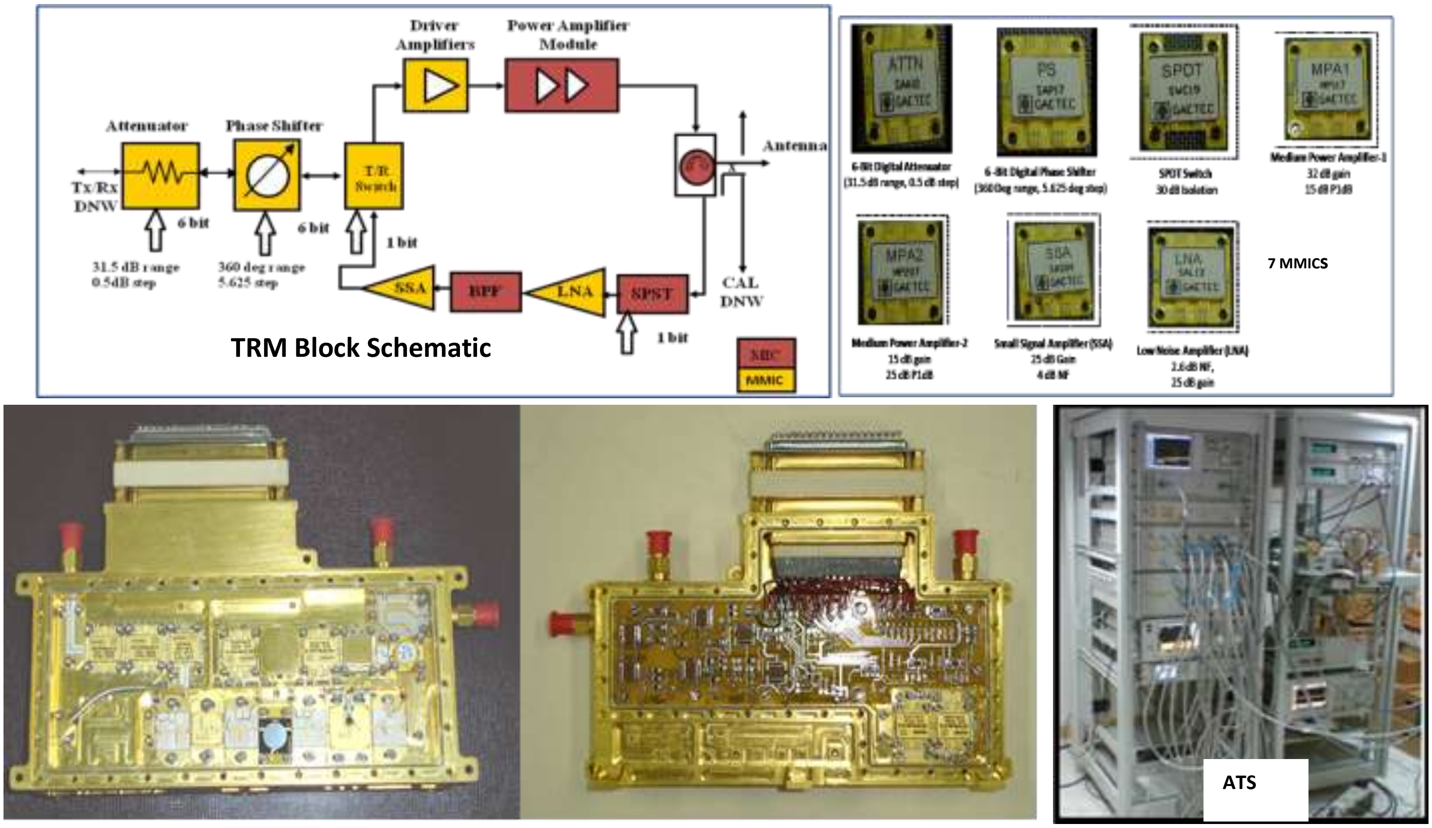
Both V & H TRMs are functionally identical but are mechanically configured as mirrors of each other for addressing the issue of efficient heat removal from SSPA portion of TRM. To meet the requirements of small size and lighter weight, it was decided to realize the individual circuits of TRMs as MMICs, wherever possible. Only those RF circuits which could not be realized in MMICS, like high power Amplifier modules (PAM), High power SPST & Low loss Couplers with high power handling capability were designed in MIC configuration. Two stage integrated PAM in transmit path was designed using industrial grade upscreened internally matched discrete power FETs. It was consciously decided to utilize the indigenous Gallium Arsenide Foundry house, GAETEC, Hyderabad for fabrication of 770 sets of 7 MMICs (Total 5000 MMICs) as per SAC design. The G7 process of GAETEC foundry was also qualified by SAC, Ahmedabad. Also, considering the mammoth efforts & time required to produce such a large quantity of space qualified units, it was necessary to involve indigenous industry in these developments. Thus, T/R Module MIC components like PAM were produced in the two Indian industries - M/s AMPL, Hyderabad & M/s. BEL, Ghaziabad. TR Modules fabrication, assembly, testing and characterization was done at AMPL, Hyderabad. The assembly line of M/s AMPL was also qualified as per ISRO PAX 305 for MIC assembly by SAC. 701 Nos. each of SPST switches, Couplers & Band Pass Filters (BPF) were also developed at M/s AMPL, Hyderabad. Figure-2 gives the block diagram & photographs of MMICs & TR Module while Table-2 gives the major specifications of T/R Modules. Thus the major highlights of TRM development were the development of miniaturized but EMI/EMC compliant and thermally well behaved compact TR Modules using highly precise repetitive fabrication and assembly processes and the utilization of Indigenous Indian Industries to the maximal extent with active participation and guidance from SAC design teams. The complete characterization of 701 T/R Modules required measurements of more than 17 parameters in the receive and transmit modes, over 8 temperature ranges from -10° to +60°C for 128 control states of phase shifter and attenuator. This was necessary to enable On-board real time correction and calibration of TR modules against temperature variations. For these measurements, two units of Automated Test System (ATS), shown in figure-2, for TR module testing were developed by M/s. Agilent India, Hyderabad, as per SAC design & guidance. ATS can test maximum 8 T/R modules at a time in sequence.

Table-1: RF Subsystems in RISAT-1 SAR

Central Electronics	
Subsystem	**Units**
Frequency Generator	2
Feeder SSPA	2
Central Receiver	4
Tx/Rx & CAL Switch Matrix	2
Array Electronics	
Subsystem	**Units**
TR Modules	576
1:12 Power Dividers	96
1:4 Power Dividers	12
1:2 Power Dividers	48

Table-2: Major Specifications of TR Modules

PARAMETER	**SPECIFICATIONS**
Frequency	5350 GHz
Bandwidth	225 MHz
Phase Control	6 bits, 360 deg range/ 5.625 deg step
Gain Control	6 bits, 31.5 dB range/0.5 dB step
Coupling of Cal coupler	20 dB
Transmit Path Characteristics	
I/P power	-10 dBm
Peak o/p power	10W
Transmit pulse duration	20μs, 10% duty
Receive Path Characteristics	
Noise Figure	4 dB
Gain @ 0 dB attenuation	30 dB
SPST Isolation	35 dB
Size	173 mm x 99 mm x 30 mm
Power	5.7 W (Avg. Pd)
Weight	420 gms.



Top View Bottom View

Figure-2: Block Diagram & Photographs of MMICs, TR Module & TRM Automated Test Set-Up

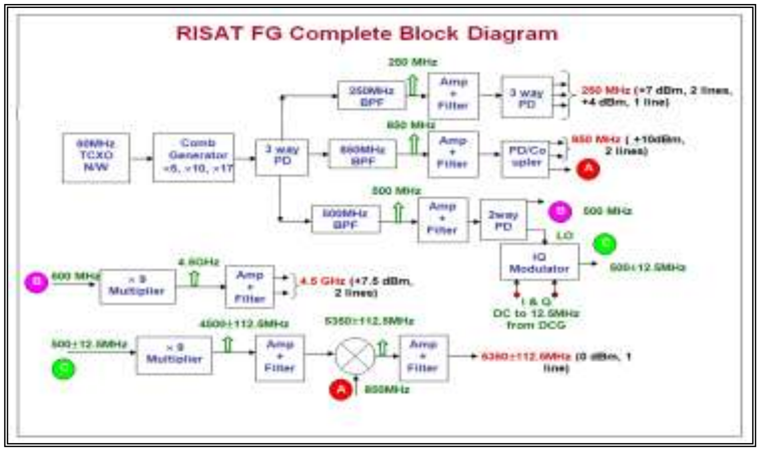
3. Frequency Generator: Frequency Generator (FG), which is the heart of the RISAT-1 SAR Payload, generates all the frequency signals required by various RF& Digital subsystems coherently from a single stable source. FG carries out the following tasks:

- Coherent multiple carrier Generation i.e. Local Oscillators for receivers and clocks for the digital subsystems
- Carrier signal modulation, Chirp bandwidth multiplication & final transmit signal generation

The major specifications, block schematic and photographs of the FG unit are given in Figure-3.

FG system is based on frequency multiplication and mixing technique. The 50 MHz highly stable TCXO sinusoidal signal output is fed as input to the comb-generator which generates the harmonics of 50 MHz at its output. The 5^{th}, 10^{th} and 17^{th} harmonic of 50 MHz are tapped by passing through a 250 MHz, 500 MHz and 850 MHz channel respectively. Each of these channels consist of respective filtering and amplification stages to get spurious free 250 MHz, 500 MHz and 850 MHz respective outputs. The 500 MHz channel is utilized to generate 4500 MHz LOs for the two receivers as well as for vector modulation and up-conversion of I/Q baseband chirp to generate the 5350 ± 112.5 MHz signal for feeding to feeder SSPA. FG consists of 64 MICs and 8 glass-epoxy based circuits housed in four aluminum packages stacked on each other with an in-built EPC, resulting in a volume of 230X230X120 cubic mm. Since the FG handles many frequency stages from DC to 5350 MHz ranging from CW to bandwidth signals, to avoid internal RF interferences within & outside packages, proper care has been taken in design by using two-sided structures, line filters, walled partitions, EMI-gasket & absorber laden covers.

PARAMETER	DESCRIPTION	SPECIFICATIONS		
		Nominal Power	**Phase Noise**	**Freq. Stability**
Input Signal	*DC to 12.5 MHz, I&Q Chirp Signals*	630 mV (p-p)	-	-
Clock & LO O/P Signal	*250 MHz Clock (3 lines)*	+2- +6dBm +5 -+9dBm	**-106**	**± 250 Hz**
	850 MHz LO-1 (2 lines)	+10 dBm	**-95**	**± 850 Hz**
	4500 MHz LO-2 (2 lines)	+8 dBm	**-81**	**±4.5KHz**
Transmit O/P signal	*Chirp modulated 5350±112.5 MHz*	0 dBm		
	Flatness	2 dB (max)		
Spurious	*All Output signals*	-50 dBc Max.		



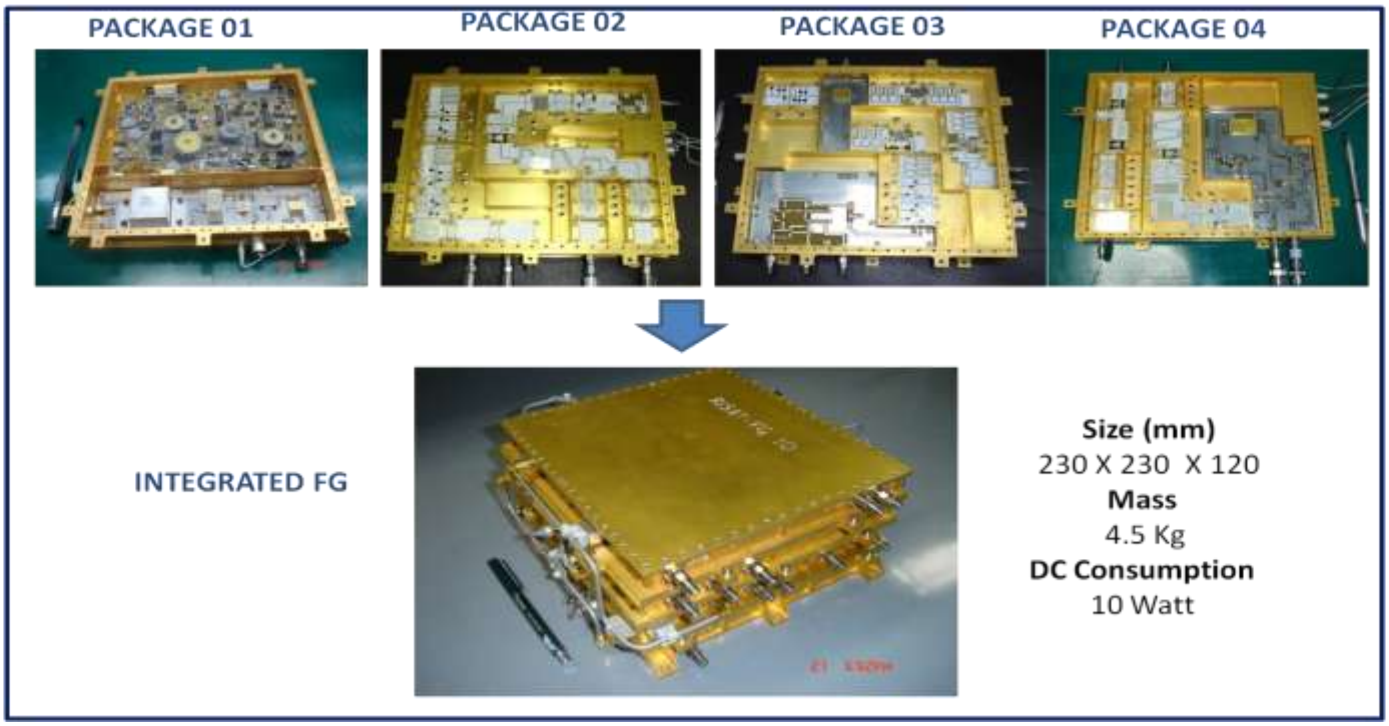
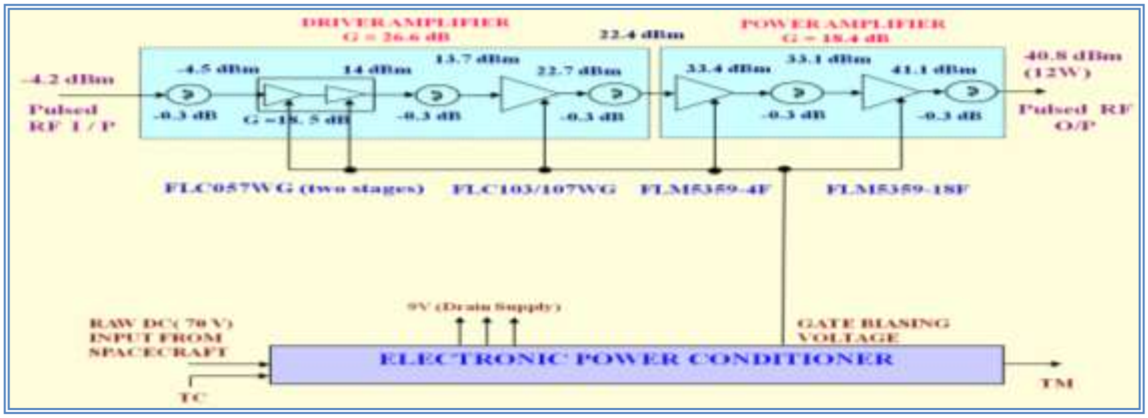
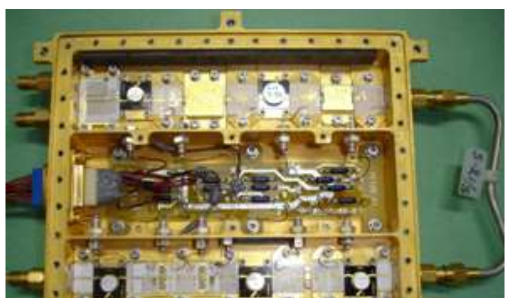


Figure-3: Specifications, Block Schematic & photographs of RISAT-1 SAR Frequency Generator

4. Feeder Solid State Power Amplifier (SSPA) : The feeder SSPA amplifies the transmit chirp signal coming from FG and feeds high level RF power to the distribution network of RISAT-1 SAR payload, from where it gets fed to the 288 pairs of TR-Modules. The power amplifier section of this SSPA also forms the transmit section of TR-modules. Pulsed Feeder SSPA operates at a centre frequency of 5.35 GHz with 225 MHz bandwidth and provides an output power of 12 Watt with a gain of more than 48.5dB. It consists of three driver stages based on MESFET devices and two power amplifier stages. Non-linear EEHEMT models were used for the design of power amplifier stages apart from EM and thermal analysis for all the amplifier stages to take care of the coupling effects and power dissipation. All the stages of SSPA are pulsed to reduce thermal stresses and to reduce raw power requirement. Yield analysis and subsequent design centering was done to ensure high yield. Figure-4 shows the block schematic, specifications & photographs of feeder SSPA.



Parameter	Test Results
Sat. Gain at 5.35 GHz	48.74 dB
Sat. Power at C.Freq.	41.44 dBm
Gain flatness (dB)	±0.15
Pulse Width (µs)	20.1
Duty Cycle (%)	7.41 %
Input Return Loss	~-13.027 dB
output Return Loss	~-19.1 dB
Raw Input Voltage (V)	70.2
Raw Input Current (A)	0.095
Spurious (Out of band)	~-51.5 dBc
Droop (dB)	0.33



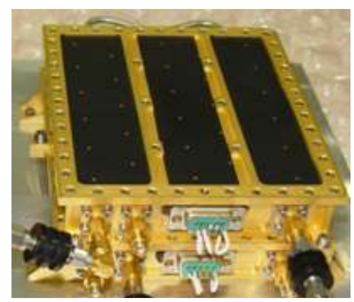


Figure-4: Block Schematic, Specifications and photographs of Feeder SSPA

5. Calibration Switch Matrix: Though the TR modules are characterized extensively on-ground, their performance onboard may drift over time and with other operating conditions including temperature. Hence, an on board calibration is employed to know the actual differential phase and amplitude variations across the array of 288 pairs of TR-RF sub-modules. Calibration switch matrix is used during this on-board calibration to route the Feeder SSPA Coupled output power to the cal port of Receiver, to feed a calibrating input to cal port of TR Module and to route power from the cal port of TR module to Receiver. CAL distribution network, similar to the signal distribution network, is used to route the calibration signal from & to the individual TR modules during the Transmit & receive path calibration, respectively. TRM Transmit paths are switched ON one by one and the coupled output of each TR module is fed to the central receivers through Cal matrix. Similarly, TRM receive path are switched ON one by one and the power from the coupled port of feeder SSPA is fed through CAL network and routed to the coupled port of each V & H TR modules. The calibration signals are subsequently demodulated and digitized. Achieved calibration uncertainty in the gain and phase measurements is approximately 0.5 dB & 6^o respectively. Cal switch matrix weighs just 634 gms. and dissipates 1.9 Watts power. Figure-5 depicts the block schematic and photograph of calibration switch matrix.

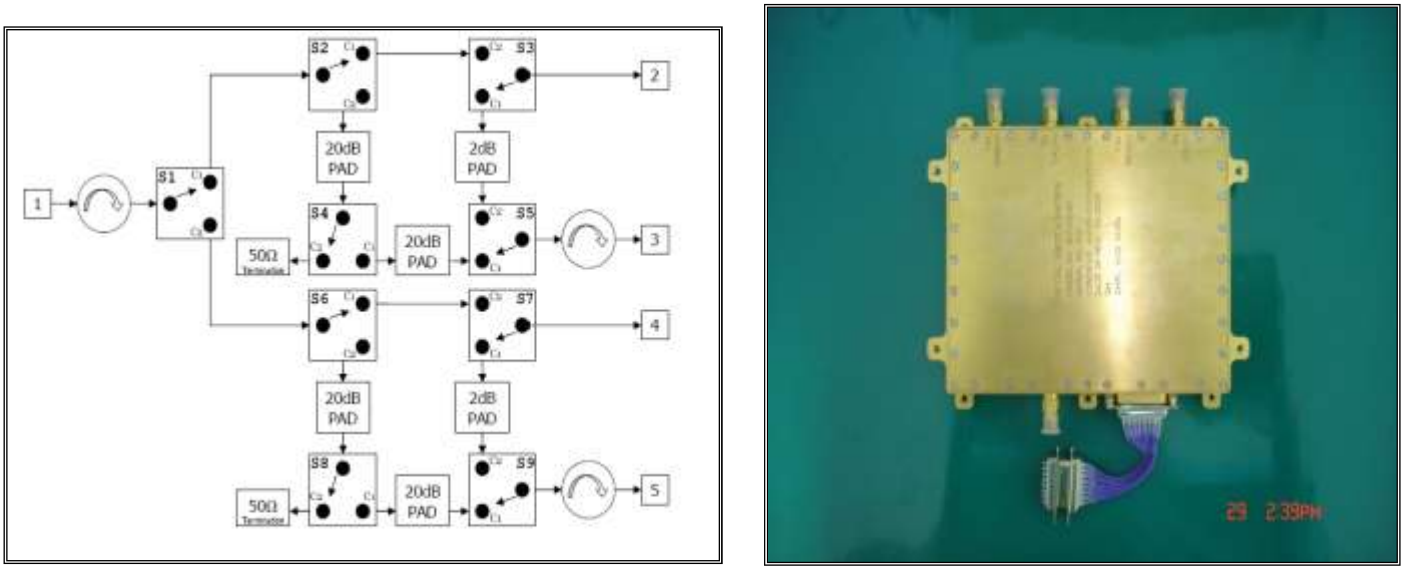


Figure-5: Block Schematic and photograph of Cal Switch Matrix

6. RF POWER DISTRIBUTION NETWORKS: Tx/Rx signal distribution network distributes the power generated in the feeder SSPA to all the TR modules and combines the received signal from all the TR Modules spread across the antenna array. An identical distribution network, which is the CAL signal distribution network, is employed for taking out the sampled o/p of each TR module and for feeding a reference input to the TR module, during the Calibration mode. The distribution network is a passive corporate feed network made up of power dividers and equal length coaxial cables. In each tile, for one polarization, two 1:12 distribution networks feed to two sets of 12 TR-Modules. Similar feeding scheme is there for other polarization. Figure-6 shows the major specifications and photographs RF/CAL distribution network. All the power dividers are designed on 6010 RT duroid in Wilkinson configuration and fabricated at M/s AMPL, Hyderabad.

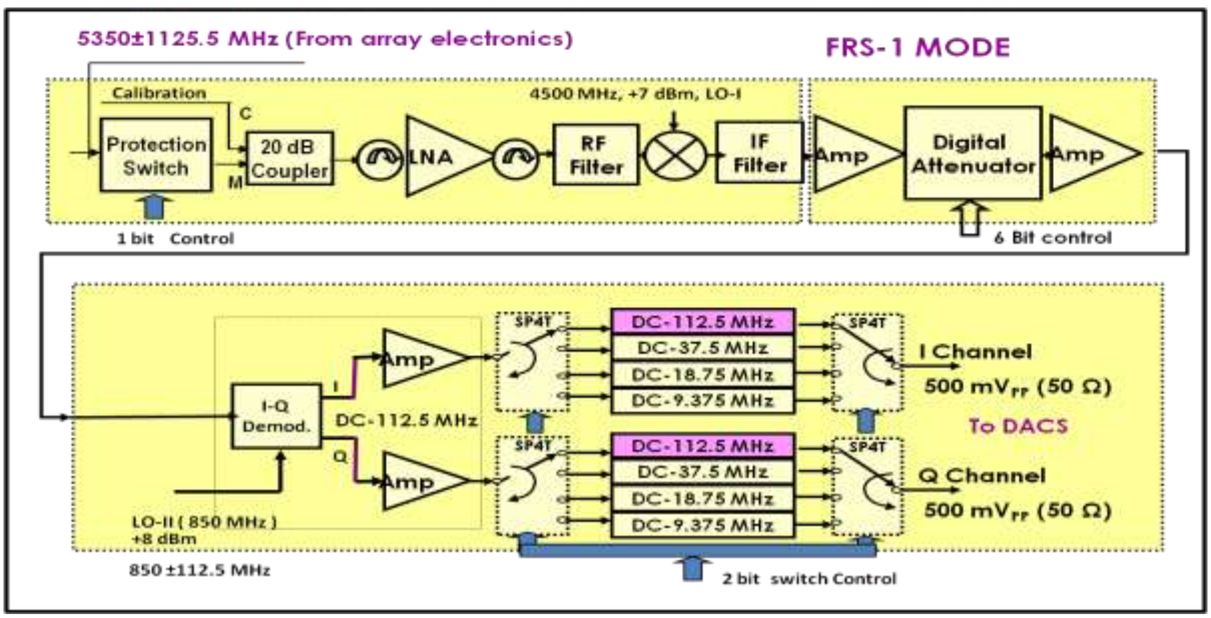
7. CENTRAL RECEIVER: The central receiver of RISAT-1 SAR payload has a coherent heterodyne configuration with a maximum signal bandwidth of 225 MHz and a complex demodulator. It carries out the following major functions:

- Low noise amplification and Gain control
- Demodulation of (I-Q) base band components with tight phase & amplitude balance
- Mode dependent delay equalized anti-aliasing filtering

The receiver employs direct down conversion to baseband frequencies using one stage of down conversion to IF followed by direct I-Q demodulation. The received signal of 5.35 GHz is amplified with a low noise amplifier of noise figure 1.0 dB with input and output isolators to provide better isolation from reflected signals at both ports. It also has an absorptive PIN diode based SPST switch with a minimum isolation of 35 dB to provide protection to LNA from high transmitted power during transmit period and a 20 dB microstrip backward coupler for onboard calibration. The amplified signal is down converted to Intermediate Frequency (IF) of 850 MHz using single balanced schottky diode passive mixer, which is amplified using two IF amplifiers to provide suitable signal level to IQ Demodulator chip. A 6-bit digital attenuator with manual gain control facility helps avoid any gain compression and achieve wider dynamic range. Amplified IF signal is I-Q demodulated to DC-112.5 MHz baseband in a I-Q mixer using 850 MHz LO signal.

Parameters	Type of Power Dividers			
	1:2 Way	1:3 Way	1:4 Way	1:12 Way
Operating Frequency	5350 ± 112.5 MHz			
Ins. Loss for	0.3 dB max.	0.4 dB max.	0.5 dB max.	1.75 dB max.
Input & Output Return Loss	18 dB min			10/ 15 dB min.
Amp. Imbalance across ports	± 0.25 dB max.			
Ph. Imbalance across ports	± 1.5 deg max.			± 10 deg max.
Port-to-port Isolation	20 dB min.			12 dB min.
Nominal input Power	40 dBm			20 dBm
Size	39x30x18	62x50x18	71x42x18	604x62.2x75
Weight	52 gms.	85 gms.	90 gms.	2000 gms.

Figure-6: Major Specifications and photographs of RF Power Distribution Networks



Parameters	Specifications			
Centre Frequency	5.35 GHz			
Bandwidth	225 MHz/ 75 MHz/ 37.5 MHz/ 18.75 MHz			
Input Signal Range	-70 dBm to –45 dBm			
Noise Figure	4 dB (max.)			
Coupling	17 dB (nominal) , ± 1 dB			
Input Return Loss	15 dB min.			
Protection Switch Power handling capability	12 W pulsed RF (10% duty at 3.5 KHz PRF)			
Rx Gain Control 0	30 dB range / 1 dB step / 6 bits			
Rx I-Q Output channel specifications				
	HRS	**FRS-1**	**FRS-2**	**CRS/MRS**
Frequency (MHz)	± 0.02-112.5	± 0.02-37.5	± 0.02-18.75	± 0.02-9.375
Power	0 dBm (nominal), ± 2 dB			
I-Q Amplitude balance	1 dB rms (max)			
I-Q Phase balance	6 ° rms (max)			
Rejection	20 dB (min.) @ 225 MHz	20 dB (min.) @ 75 MHz	20 dB (min.) @ 37.5 MHz	20 dB (min.) @ 18.75 MHz

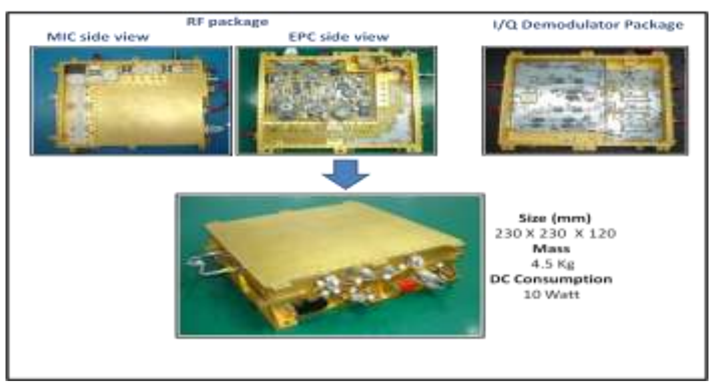


Figure-7: Block Schematic, Specifications and photographs of RISAT-1 SAR Receiver Unit

8. CONCLUSIONS: Microwave and RF subsystems are the main building blocks of any RADAR system and RISAT-1 SAR payload is no exception. Since RISAT-1 SAR payload has an active antenna, the role of RF &

microwave technologies is more critical here considering the usage of a large number of RF Transmit / Receive Modules. Rigorous and enormous efforts have been put in for the design, development & qualification of all these Microwave subsystems. All these collective efforts are bearing fruits with successful in-orbit performance of RISAT-1 SAR payload. One of the major off-shoot of these efforts has been the development and coming of age of various indigenous, both public and private sector Indian industries, in the field of aerospace electronics. These industries will hopefully remain important contributors in all future ISRO programs of similar nature.

Article in Indian Express (26/4/2012)

After RISAT 1 success, ISRO announces 2 new missions

Buoyed by the successful launch of all-weather radar imaging satellite RISAT-1, ISRO today announced it would launch two GSLVs and a PSLV this fiscal and the second Indian moon mission of Chandrayaan 2 in 2014 on board a GSLV.

"The launch of Chandrayaan-2 will be in 2014. We are working towards it. It would be on a GSLV, after we launch two GSLVs within an interval of six months," ISRO chief K Radhakrishnan told reporters here soon after the launch of RISAT-1. T K Alex, Director, ISRO Satellite Centre said ISRO is working with Russian scientists on Chandrayaan 2. "We will discuss on site selection like where we have to land," he said, adding other related works are progressing well.

On launch of two Geosynchronous Satellite Launch Vehicle (GSLVs) and Polar Satellite Launch Vehicle (PSLV) this fiscal, Radhakrishnan said ISRO has studied the reasons for the failure in 2010. "Now GSLV will undergo an endurance test of 1,000 seconds and a vacuum test at a special facility at the Liquid Propellant System Centre at Mahendragiri in Tamil Nadu, where a Rs 300 Crore facility for vacuum test has been made," he said.

"Once we get the green signal from the Ground Testing Team, we would be ready for the GSLV launch,'' he said.

P S Veeraraghavan, Director, Vikram Sarabhai Space Centre, who was present, said ISRO will launch a low cost communication satellite GSAT-14 on board GSLV D5 in September/October 2012.

PSLV C-20 with Indo French satellite SARAL and four small satellites would be launched in October, 2012 and PSLV C-21 with a commercial payload SPOT, a French satellite on earth observation this August, he said.

On GSLV Mark III, he said various subsystems of engines are being tested and it would take two years for it to be completed. "After all the tests, the experimental flight without cryogenic engines could be in 2012-13," he said.

Radhakrishnan also said ISRO had spent over Rs 20,000 Crore in 29 missions in the 11th five year plan against Rs 13,000 Crore in 20 missions in the 10th five year plan. Much of the amount was spent on procuring six to eight Russian cryogenic engines and equipment for remote sensing programmes, he said.

RISAT-1 cost Rs 488 Crore, with Rs 110 Crore spent on the launch vehicle and Rs 378 Crore on the satellite, he said.

ISRO earns over Rs 45 Crore from vending images through its satellites, he added.

Alex said many colleges and universities are now keen on launching satellites made by their students through ISRO. "Many colleges have approached us for sending their satellites made by their students. We have many more such proposals in the pipeline," he said.

Asked about the present status of Indo French satellite Megha Tropiques, launched during the last PSLV mission, he said, "The satellite is sending good images. They are giving details on the clouds and water content, etc. Earlier, we did not get so many details from the earlier satellites," he said.

Onboard Digital Subsystems for RISAT-1 SAR

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1. Introduction: RISAT-1 carries a C-band Multi-mode SAR operating in Stripmap, ScanSAR and Sliding Spotlight modes and mainly caters to civilian land applications related to agriculture and Soil moisture analysis. Considering the multi-mode and multi-resolution requirements of RISAT-1 SAR, onboard programmability and flexibility in SAR payload as well as autonomous operation have been the major mission requirements. The onboard digital subsystems play a major role in fulfilling these essential requirements. The necessary intelligence and sophistication have been built into these onboard digital systems apart from intelligent control and coordination of active antenna of RISAT-1 SAR payload. For C-band SAR payload of RISAT-1, onboard digital subsystems have to cater to data acquisition, raw data compression, buffer storage, formatting and onboard transmit chirp requirements apart from control, timing and coordination of SAR Payload and active antenna elements. It also performs embedded control, command and coordination of the activities of the total radar payload including the active antenna electronics and also provides the necessary flexibility in configuration and overall operation of radar instrument.

The various onboard digital elements of SAR payload are as follows:

- **Baseband Digital Subsystems**
  - ➢ Digital Chirp Generator (DCG)
  - ➢ Dual Channel Data Acquisition (DACS) Subsystem
  - ➢ Block Adaptive Quantization (BAQ) based Data Compression Subsystem
  - ➢ Radar Payload controller (PLC)

- **Tile Electronics (Digital)**
  - ➢ Tile control Unit (TCU)
  - ➢ Transmit / Receive Control (TRC) Unit

Figure-1 shows the overall block schematic gives the major specifications of the onboard Digital subsystems for RISAT-1 SAR. It consists of four Data Acquisition and compression subsystems (DACS), each containing return signal Digitizer, De-multiplexer and FPGA based Block Adaptive Quantiser (BAQ) Compressor and Formatter with buffer memory storage and associated Control and Timing logic. An FPGA based Digital chirp generator synthesizes the digital I/Q chirp signal of different bandwidths, which is low pass filtered, vector modulated, multiplied by appropriate factor and subsequently up-converted in the RF segment to the desired transmit carrier frequency. The Distributed embedded controller for the active antenna array for RISAT-1 SAR is implemented as a three-stage hierarchical system consisting of PLC, TCU & TRC. An onboard Payload Controller (PLC) is a critical element controlling the local multi-drop bus among the multiple distributed tile control units and the T/R module control units of the active antenna. It also performs the overall control and coordination tasks for the various payload subsystems and interfaces with the spacecraft Onboard Controller (OBC)/ Bus Management Unit (BMU). The Payload controller unit interfaces with and controls 12 tile control units. A single Tile Control Unit in turn controls the 24 TR Control units, which in turn control 48 H and V T/R RF modules.

One of the salient features of these complex digital subsystems is the usage of various new and advanced digital technology elements like Field Programmable Gate Arrays (FPGA), Application Specific Integrated Circuits (ASIC), ultra high speed Data Converters and other VLSI devices for the first time in such a big way to implement compact control and signal processing systems, which are also successfully qualified for space use. The sections below describe these onboard digital subsystems in detail.

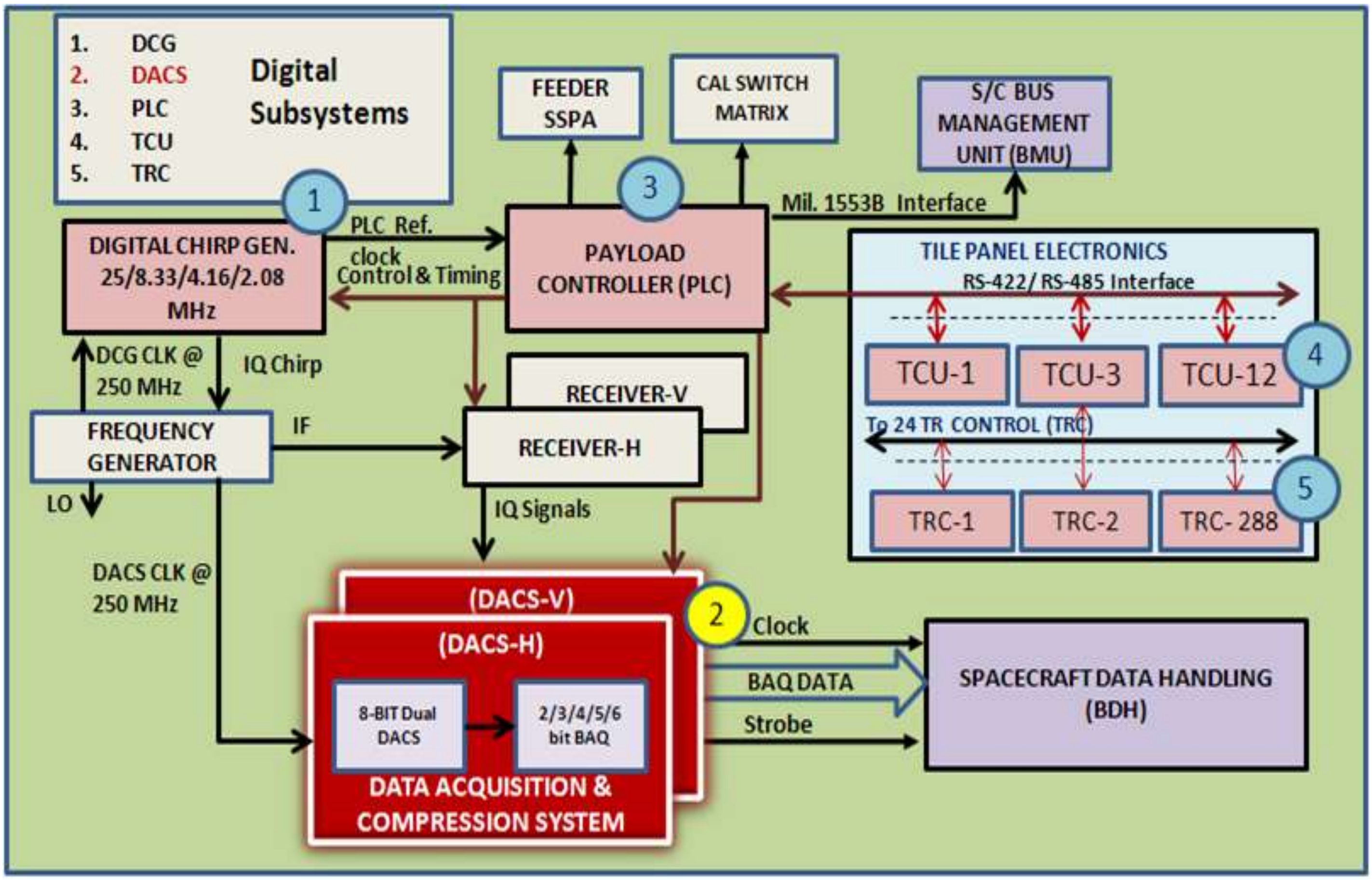


Figure-1: Block Schematic of Onboard Digital Subsystems for RISAT-1 SAR

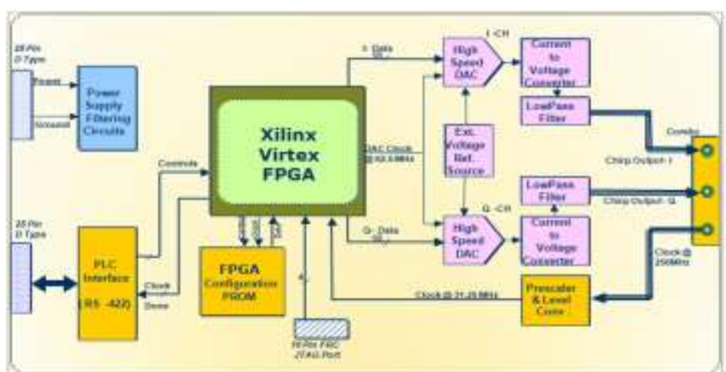
2. Digital Chirp Generator (DCG): RISAT-1 SAR is an active microwave sensor which uses pulse compression technique to achieve better range resolution without compromising on Signal to Noise performance. This necessitates onboard generation of the transmit modulation signal like Linear Frequency Modulated (LFM) signal, also known as chirp signal, during pulse expansion. Traditionally, Surface Acoustic Wave (SAW) devices were used for chirp generation. However, design and fabrication of SAW devices for large time-bandwidth product chirp signals, as required by RISAT-1 SAR, is very complex and expensive. Also RISAT-1 SAR has got multiple SAR operating modes, which require programmable chirp generation with selectable bandwidth and pulse-width values. Hence, digital techniques have been employed for onboard LFM signal generation which offers obvious advantages of programmability, flexibility, better stability, accuracy and repeatability. During the transmission time, **Digital Chirp Generator (DCG)** generates baseband chirp of bandwidth corresponding to the selected SAR and chirp mode of operation. In **Frequency Generator**, this signal is multiplied, modulated and up-converted to the carrier frequency (5.35 GHz). This RF signal is amplified by the **Feeder-SSPA**, and fed to each TR-Module on the active antenna, through the **Distribution Network** (for Signal-V and Signal-H).

DCG hardware consists of a single Xilinx Virtex FPGA (XQVR600) and associated serial PROM for storing the FPGA configuration data, two high speed 10-bit D-to-A converters (DAC), appropriate Current-to-voltage converters, and post-DAC filters for both I/Q channels of DCG. Direct Digital Chirp Synthesis (DDCS) algorithm, utilized for chirp generation in DCG, is a technique of digitally synthesizing high fidelity, long duration chirp waveforms, offering advantages like simplified logic, less memory requirement and better chirp characteristics like flatness, spectral purity, fine frequency resolution (in micro hertz), phase offset capability etc. DDCS module consists of control logic, register-latches for latching programmable waveform parameters, two cascaded N-bit frequency and phase accumulators and an output sine/cosine look-up table of programmable size. Waveform parameters (delta frequency, start frequency & phase, etc) for various SAR operating modes are stored in parameter selection logic and depending on mode, parameters are loaded in register-latches. DDCS phase accumulator output is used to address the internal Sine/Cosine LUT to generate 10-bit

I/Q amplitude data, which are fed to external DACs for baseband chirp generation at 62.5 MHz clock rate. DDCS is implemented in Xilinx Virtex radiation-tolerant FPGA with resource utilization of 20% logic and 75% internal memory and power dissipation of about 1.9Watts. Triple Modular Redundancy (TMR) SEU mitigation technique has also been implemented in FPGA for all the logic elements. The limited bandwidth digitally synthesized I/Q chirp is subsequently vector modulated, multiplied by appropriate factor and up-converted in Frequency Generator (FG) to the required RF transmit frequency. A detailed characterization of baseband I/Q chirp has also been also carried out. Figure-2 shows the Block schematic, specifications, photographs and test results for DCG unit of RISAT-1 SAR. DCG package consists of identical Main and Redundant units, along with respective Electronic Power Conditioner (EPC) modules and is mounted on EP01-IN i.e. Vertical Panel of Triangular Structure (SAR Module)–EV Panel of RISAT-1 satellite.

3. Data Acquisition and Compression System (DACS): Echo signals received from all the TR-Modules are combined and fed to the central **Receiver (V/H)** on the deck. This signal is amplified, down-converted to baseband and filtered within the central receiver. The base-band I&Q signals are sampled and digitized (to 8-bit) at 250 MHz rate by high speed digitizers in **Data Acquisition and Compression System (DACS)**. The digitized 8-bit I/Q data are subjected to Block Adaptive Quantization (BAQ) compression (2-6 bits) to reduce the data rate and volume. The raw data (BAQ-encoded) is then sent to satellite **Baseband Data Handling (BDH)** system. BDH consists of 240 Gbit **Solid-State Recorder (SSR)** where the payload raw-data may be recorded. **X-band Data Transmission System** capable of 320Mbps (for single polarization) / 640 Mbps (for dual-polarization) will beam the satellite data to ground-station, in either real-time or playback mode, depending on the data-rate corresponding to selected SAR mode of operation. On ground, the payload raw data will be extracted and BAQ-decoded to get back the 8-bit I/Q data. This data is processed in real or near-real time to obtain SAR images.

Parameter	DCG Specification
Chirp type	I/Q baseband
Chirp Bandwidth	25.0 MHz (HRS Mode) 8.33 MHz (FRS-1 Mode) 4.16 MHz (FRS-2 Mode) 2.08 MHz (MRS/CRS Mode)
Chirp Duration	20 µsec.
Freq./phase Resolution	~15-bits
Amplitude Resolution	10-bits
I/Q Imbalance	0.5 dB (Amplitude) 2° rms (Phase)
Power	8.5 Watts (Maximum)
Package Size	261mmx210 mmx 147 mm
Weight	4.1 Kgs. (M+R)



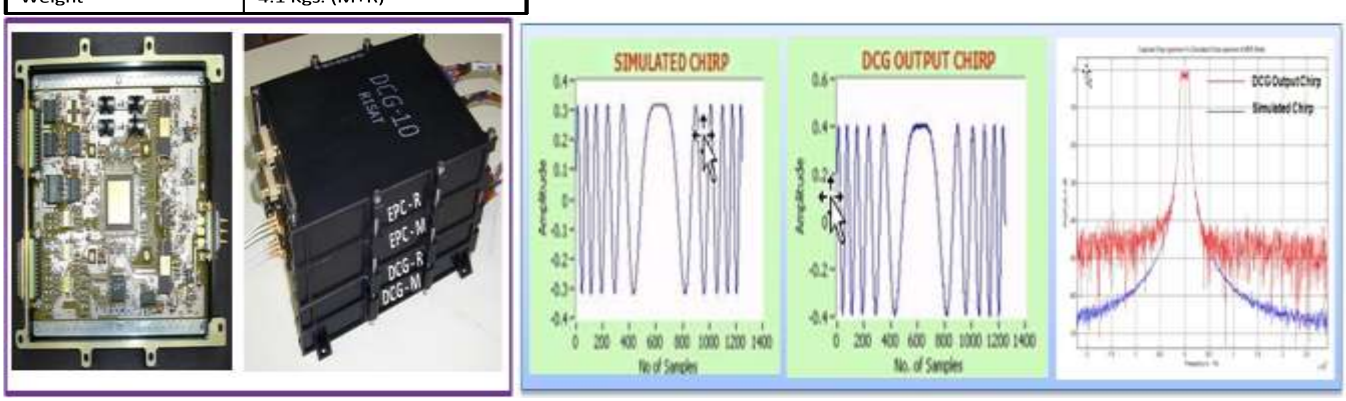


Figure-2: Specifications, Block Schematic, photographs & test results of RISAT-1 DCG Unit

RISAT-1 C-band SAR payload necessitates ultra-high speed data acquisition to meet 1-50 meter resolution requirements for SAR operating modes like Sliding Spotlight, Stripmap and ScanSAR. Moreover, data demultiplexing into multiple channels and suitable data compression approach is also necessary to limit the resultant data rates and overall SAR data volume within the capabilities of spacecraft Data Handling unit (BDH). Considering the multi-mode nature of C-Band SAR operation, incorporating different swath coverage and resolution modes, and resultant very high data rates and in order to optimally utilize the onboard storage and data transmission links, separate I/Q data acquisition channels have been implemented for both the receiver chains. DACS hardware consists of two digitizer chains consisting of ultra-high speed Analog-to-Digital Converter (ADC) operating at 250 MHz, companion 1:4 Demultiplexer to lower down the data rate, Xilinx Virtex FPGA (XQVR600) based flexible Block Adaptive Quantizer (BAQ) data compressor & variable-rate data formatter and BDH interface. The 250 MHz clock from Frequency Generator (FG) unit is utilized to generate I/Q sampling clocks, which along with I & Q analog Output signals from Receiver unit are dc-coupled to respective I & Q digitizer chains. The onboard radar payload controller provides the necessary RS-422 timing and control signals and also controls and configures the various constituent elements of data acquisition unit. The BAQ compressed data from the different data blocks and their respective average values are packed into 16-bit boundaries in the output packet. The BAQ encoded, packed and formatted data for both I & Q channels, are converted into three LVDS data streams (@218.75 MHz) and fed along with LVDS clock to spacecraft BDH unit through very high speed LVDS Serializers.

A detailed characterization of digitizer chains along with BAQ encoder has also been also carried out. Figure-3 shows the Block schematic, specifications and photographs of DACS unit of RISAT-1 SAR. DACS package consists of DACS tray along with an EPC module. Four such identical packages were utilized to cater to the Main and Redundant Co-Pol and Cross-Pol receiver chains. All the four DACS Packages are mounted on EP01-IN i.e. Vertical Panel of Triangular Structure (SAR Module)–EV Panel of RISAT-1 satellite.

Parameter	DACS Specification
ADC Quantization	8-bits (ENOB >6.5 bits)
Input Signal	Max. -2.4dBm (500 mVp-p)
Receive Window	56.832-184.32 μsec.
PRF	2800-3700 Hz
ADC Sampling Freq.	250 MHz
No. of I-Q data / PRI	1280-37000
BAQ Compression	Clock Freq. – 31.25 MHz 2/3/4/5/6 bits & 8-bit Bypass
Data Rates	50-1400 Mbps
Power	36.0 Watts (Max.)
Package Size	283 mm x 255 mm x 83 mm
Weight	3.3 Kgs.

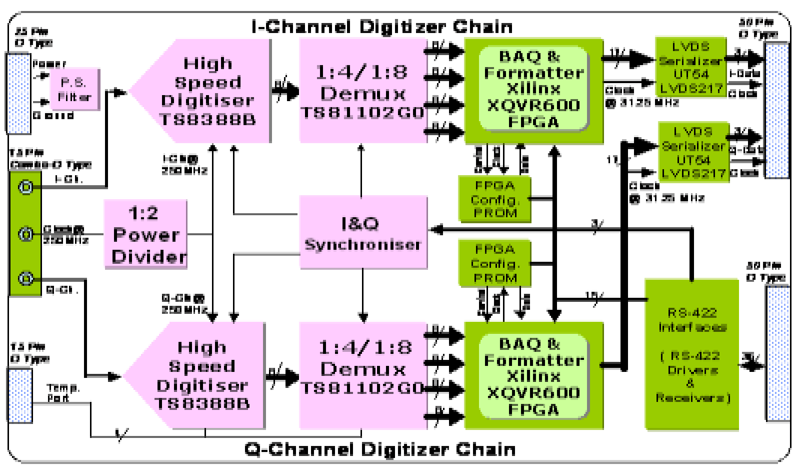


Figure-3: Specifications, Block Schematic & photographs of RISAT-1 DACS Subsystem

4. BAQ Data Compression: The onboard memory available in the spacecraft is limited and the amount of SAR data volume is enormous, so block Adaptive Quantization based data compression technique has to be implemented at the same time preserving most of the signal characteristics. This compression technique assumes that SAR signal has zero-mean Gaussian distribution with slowly varying standard deviation and it aims at minimizing the mean square error between the original and reconstructed SAR data. For the onboard BAQ encoder, two approaches were considered viz. comparator based and multiplier based design and multiplier approach was finalized considering the uniform implementation for any no. of BAQ bits and lesser storage requirements for scale-factor Look-UP Table (LUT).

The input data at 62.5 MHz rate from each of the 4 de-multiplexed channels from 8-bit digitizer is fed to Flexible BAQ, which carries out the following tasks:

- ADC offset correction and de-multiplexing
- Input data decimation and signed magnitude conversion
- Block data Average computation
- Derivation of scale factors from LUT ROM as per BAQ compression mode
- Multiplication of input data sample with suitable scale factor
- Quantization of the data as per BAQ mode:2/3/4/5/6 or 8 bits
- Data packing and Formatting for every PRI frame
- Transmission of the formatted data through spacecraft BDH to Ground

Since the output compressed data have variable rate depending on the selected compression mode (2/3/4/5/6/8-bit bypass), an appropriate formatting scheme, suitable for all the operating modes, has been implemented. For both I&Q Channels, each PRI frame consists of a preamble of 128 bytes containing FSC/PRBS of 4 Bytes (32 bits), 124 bytes of payload and spacecraft auxiliary data, which include, frame/PRF count, sensor ID etc., No. of samples, chirp type, PRF, beam details, BAQ mode etc., followed by BAQ compressed data words frame and final 2 bytes of DACS footer. Each BAQ data frame consists of a one word BAQ header and BAQ data corresponding to one input block of 128 bytes. The BAQ header and compressed data from the different data blocks are packed into 16-bit word boundaries in the output data packet. Many such BAQ frames constitute one SAR P/L frame, which contains the BAQ encoded and formatted data for the data samples received in a data window every PRF, corresponding to the swath. The sample size in swath varies as per the SAR operating mode and the location of the imaging area (near or far swath), thereby resulting in variable number of BAQ frames and overall variable data rate. The on-ground decoder utilizes the BAQ header information and an inverse scale factor LUT to reconstruct the original data samples from the BAQ compressed data. BAQ encoder-decoder SNR performance was analyzed at different White Gaussian noise input levels. Figure-4 shows BAQ encoder-decoder algorithms, FPGA implementation scheme for BAQ encoder and typical test results for FRS-1 mode for RISAT-1 SAR.

The onboard flexible block adaptive quantizer data compression and variable data rate formatter algorithms are implemented in Xilinx Virtex (XQVR600) radiation-tolerant FPGA with resource utilization of 95% logic and 100% internal memory and power dissipation of about 2.2Watts. Triple Modular Redundancy (TMR) SEU mitigation technique has also been implemented in FPGA for all the logic elements.

5. Radar Payload Controller (PLC): The multi-mode nature of RISAT-1 SAR operation, incorporating different swath coverage and resolution modes, necessitates independent and autonomous payload control. Thus, a separate Instrument Control Unit, independent of spacecraft controller, for a complex payload like SAR has been envisaged and implemented for the first time in ISRO’s space history.

Radar Payload Controller (PLC) is thus an intelligent and programmable master controller and heart of RISAT-1 SAR Payload. It performs embedded control, command and overall coordination tasks for the total radar payload including the active antenna electronics and also provides the necessary flexibility in configuration and overall operation of radar instrument. PLC is a critical element controlling the local multi-drop bus among the multiple distributed tile control units and the T/R module control units of the active antenna. It interfaces as a Remote Terminal (RT) with the satellite Onboard Controller (OBC)/Bus Management Unit (BMU) through Mil-Std-1553B bus and decodes & interprets the tele-commands issued by ground segment. BMU passes on SAR operation command sequence for imaging (received from ground Tele-command) to the PLC, which is utilized to set various payload parameters, generate various timing and control signals for SAR payload subsystems and also update payload telemetry information. It also configures the beam parameters of the active antenna and other payload subsystems onboard, based on these tele-commands. In essence, PLC forms the gateway for the payload operations.

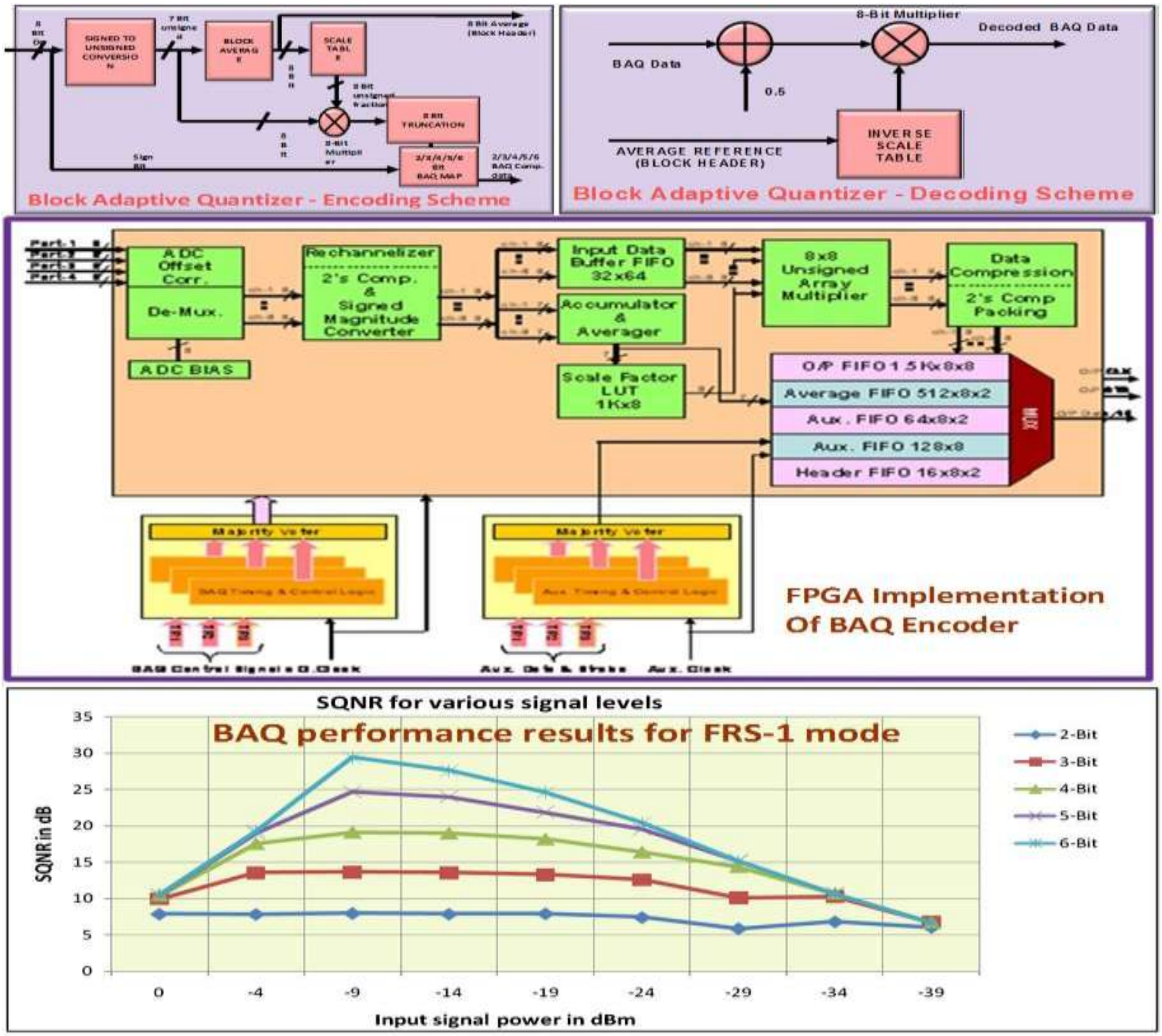
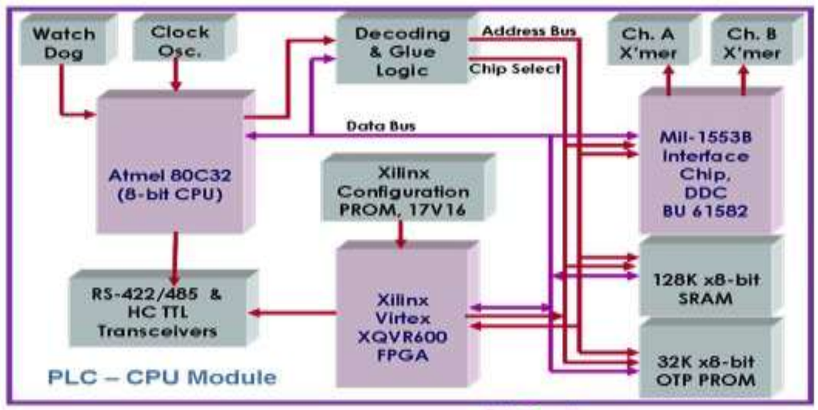


Figure-4: BAQ algorithms, implementation scheme and test results for RISAT-1 SAR

RISAT-1 SAR PLC is an embedded system designed around 80C32-an 8-bit microcontroller, Xilinx Virtex (XQVR600) FPGA and MIL-STD-1553 interface chip. PLC flown onboard RISAT-1 SAR has a motherboarddaughterboard configuration consisting of one PLC-CPU module, three Input/Output (PLC-IO1-2 & IO3) modules for interfacing with SAR Tile electronics, RF and base band subsystems, one EPC module and a motherboard. PLC operates with 24 MHz clock with an effective execution speed of 2MIPS and contains 48 Kbytes onboard PROM and 32Kbytes SRAM. A MIL-STD-1553 interface chip is utilized to configure it as a Remote Terminal (RT) and interfaces to Spacecraft OBC/BMU with dual redundant MIL-STD-1553 channels through a coupling transformer. After power on, default configuration data which are stored in PLC's PROM, are loaded into radar timing registers. During operation, new set of configuration data can be uploaded at any time, which would be transferred to PLC by spacecraft OBC/BMU and utilized on the fly by PLC from the next PRF, without the requirement of MAP OFF and MAP ON commands.

Parameter	PLC Specification
Reference Clocks	3.90625 MHz (Timing) 24 MHz (Microcontroller)
Nominal PRF	2700 – 3800 Hz
Transmit Pulse Width	20 / 10 µsec.
Spacecraft BMU Interface	Mil-Std-1553B @ 1 Mbps
Payload Base band & RF System Interface	RS422 / CMOS
Tile / Panel Interface	RS-422 / RS-485
SAR Payload Power On/Off Time	20 Seconds Power On 10 Seconds Power Off
Active Antenna Configuration Time	15 Seconds
Power	16.0 Watts
Package Size	284 mm x 234 mm x 181 mm
Weight	6.7 Kgs.



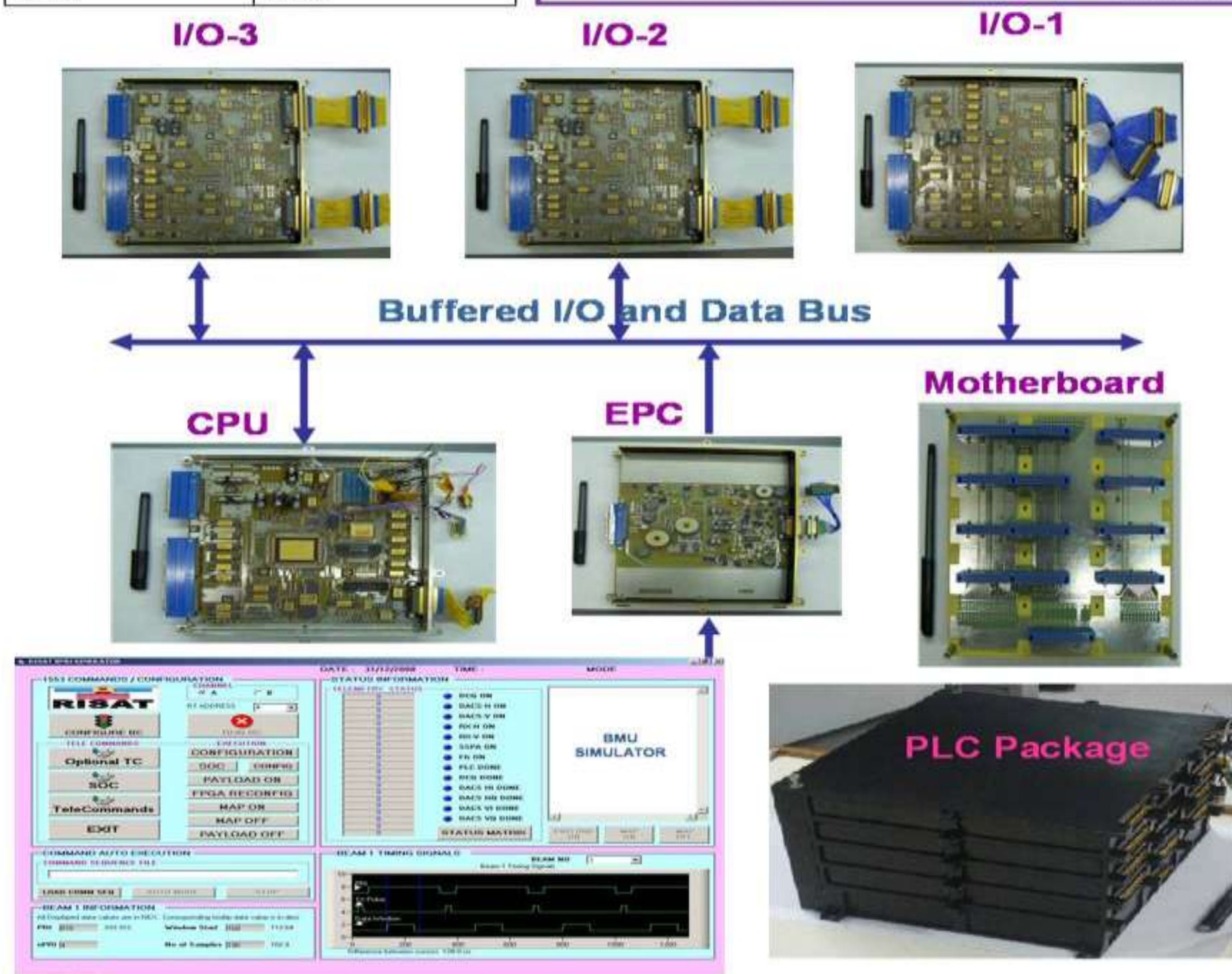


Figure-5: Specifications, Block Schematic & photographs of RISAT-1 PLC Subsystem

All the programmable control and timing signals for various SAR payload subsystems are implemented in Xilinx Virtex (XQVR600) radiation-tolerant FPGA with resource utilization of 60% logic and 37% internal memory and power dissipation of about 0.3Watts. Triple Modular Redundancy (TMR) SEU mitigation technique has also been implemented in FPGA for all the logic elements.

Radar Payload Controller is having two software/firmware elements on-board: Microcontroller and FPGA. Application Programming for Microcontroller followed the ISRO Software Process Document (ISPD) guidelines while the FPGA design guidelines were scrupulously followed for PLC FPGA design & verification. PLC unit was thoroughly tested with BMU simulator and ground check-out unit. Figure-5 shows the Block schematic, specifications and photographs of PLC unit of RISAT-1 SAR. PLC package consists of five daughter boards and a motherboard. Two such identical packages are required for Main and Redundant payload chains. Both the PLC Packages are mounted on EP01-IN i.e. Vertical Panel of Triangular Structure (SAR Module)– EV Panel of RISAT-1 satellite.

RISAT-1 SAR payload control and synchronized operation is achieved with the help of a three level distributed controller hierarchy. The salient features of this Distributed controller with PLC as main arbiter, which carries out Control, Management and status monitoring of the RISAT-1 SAR active antenna array for digital beam-forming and beam switching in elevation direction, are as follows:

- It has been implemented as a three-stage **hierarchical system consisting of :**
  - ➢ Top level: One Payload Controller Unit (PLC)
  - ➢ Middle Level: 12 Tile Control Unit (TCU)
  - ➢ Bottom level: 288 Transmit / Receive Control Unit (TRC)
- PLC interfaces with 12 TCUs through RS-422 multi drop configuration, with a separate multi-drop chain each for main and redundant PLC
- Each TCU interfaces with to 24 TRCs in 4 groups, (6 TRCs per group)
- 24 TRCs of each tile are divided into 4 groups of 6 TRCs each with all 6 TRCs of a group connected in multi drop configuration
- Each TR Control units, interfaces with a pair of H and V T/R RF modules.

Figure-6 shows the complete interface hierarchy starting from PLC to TCU to TRC to TRMs & PCPU.

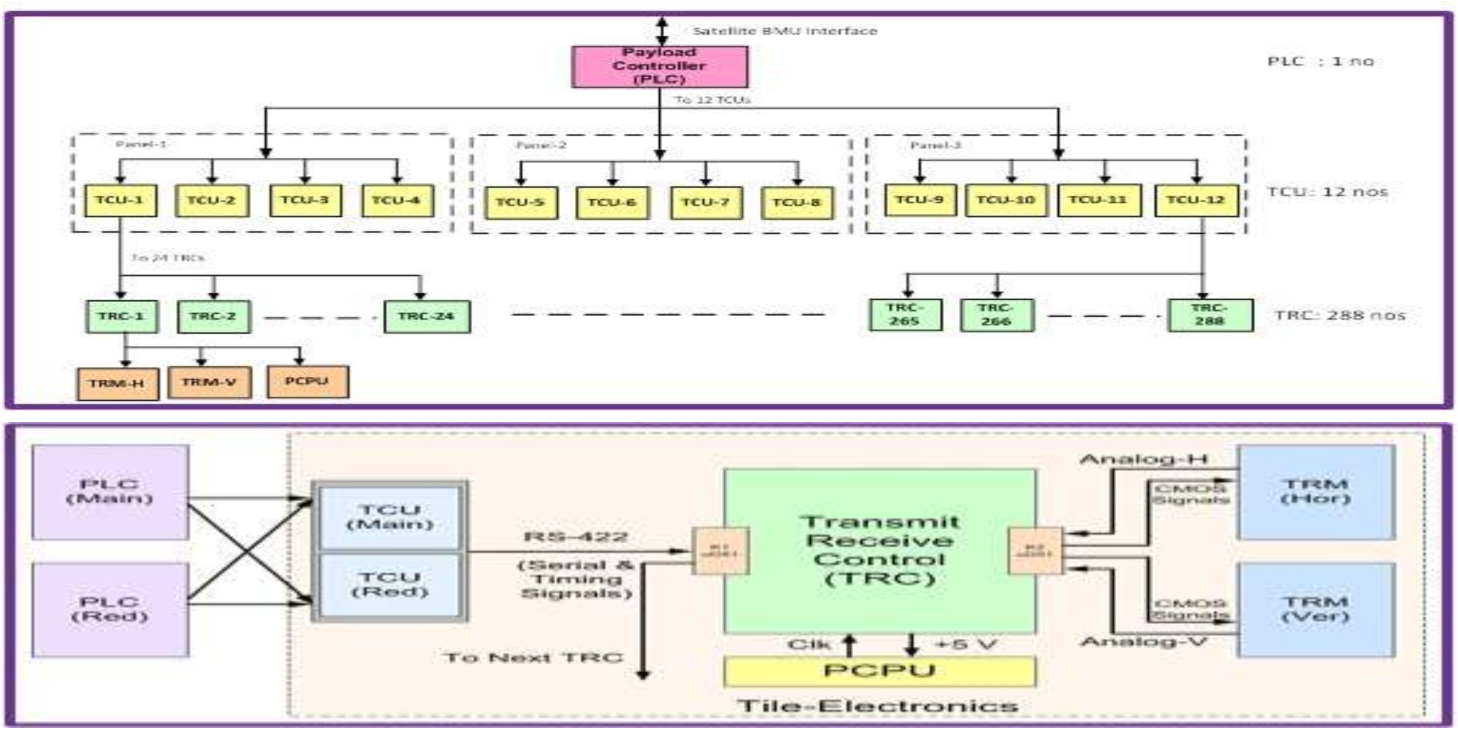
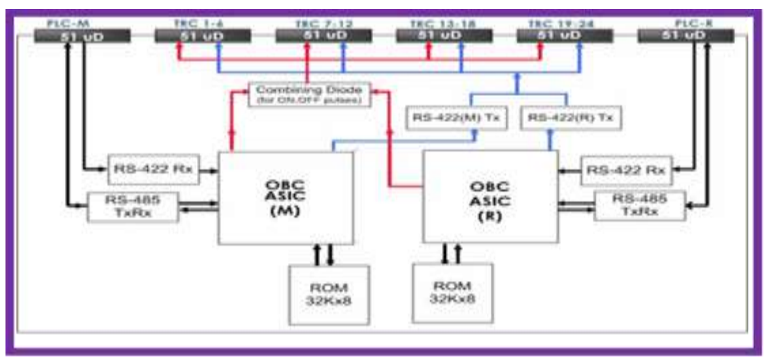


Figure-6: Distributed Controller hierarchy for RISAT-1 SAR Active antenna array

During initialization or SAR mode configuration, the beam-forming information (beam number and Polarization) for maximum 12 beams is transmitted from PLC to the **Tile Control Units (TCUs)** residing on each of the 12 tiles. The TCUs contain look-up tables to convert the beam-numbers to amplitude and phase information required for 24 TR-Module pairs of the respective tile. The information for a total of 128 different beams is pre-programmed and stored into this TCU PROM to cover the 100-650Km swath on either side of the flight direction. This information is transmitted to respective 24 **TR-Control Units (TRCs)** of each tile. TRC is required to derive the requisite temperature compensated amplitude (attenuation) and phase information for the respective TR-RF module pair from the characterization Look-up Table (LUT) PROM and load it to the TR-RF module pair during transmit and receive cycles during SAR imaging operation. These look-up tables have been derived from the temperature characterization of the respective TR-Modules. Each TR-Module contains 6-bit digital attenuator and 6-bit digital phase-shifter in a path common to transmit and receive chains.

3. Tile Control Unit (TCU): Tile Control Unit (TCU) controls, commands and co-ordinates the activities of an individual tile having 24 pairs (24H & 24V) of TR modules and other electronics. TCU carries out the powering On/Off and control of 24 TRCs and 24 PCPUs on the same tile. TCU is designed and built around Rad Hard Onboard Controller (OBC-1) ASIC containing 8-bit 80C32 Microcontroller IP Core and other logic for various functionalities like Serial/Parallel Data communication, Timing Signal Generation, Event Programmable Peripheral Interface etc. TCU operates at 3.90625 MHz external clock provided by PLC and has suitable external 32Kx8-bit PROM interface. The RS-422 differential receivers and RS-485 Transceivers provide command/data, control and timing interfaces with PLC while RS-422 differential transmitters and internal ASIC CMOS buffers are utilized to interface the control, command and timing signals with four groups of 6 TRCs each. The RS-485 serial communication between PLC and TCU is also through UARTs implemented inside OBC ASIC. TCU hardware is optimally designed in such a way that there is a 1:1 passive redundancy built into the same hardware PCB, thereby reducing the overall weight and volume. Figure-7 shows the Specifications, Block schematic and photographs of TCU of RISAT-1 SAR. TCU package consists of TCU tray along with an EPC module. Twelve such identical packages are mounted, one on each tile of antenna array of RISAT-1 SAR. The fabrication, assembly and testing of FM units of TCU has been carried out through an external vendor, M/s. Astra/Komoline, Hyderabad.

Parameter	TCU Specifications
PLC Interface	RS422 Differential for timing/control signals RS485 @ 10172 baud rate for serial comm..
TR Control Interface	RS422 Differential for timing/control signals RS422 @ 10172 baud rate for serial comm..
TCU EPC Interface	HCMOS EPC Clk @ 195.31 KHz, 10% duty Cycle
PCPU Interface	HCMOS PCPU On/Off signal @ 100 msec. pulse Sequentially Time staggered 24 PCPU On/Off
No. of Elevation Beams	128 (100-650Km swath) (on either side of flight direction $\pm$ 36°)
Tile E/c Power On/ Off Time	6 seconds
TCU Config./Re-config. Time	6 seconds
No. of TRCs controlled	24 (Four groups of 6 TRCs each)
Power	2.0 Watts (Maximum)
Package Size	380mm x 84 mm x 92 mm
Weight	1.65 Kgs.



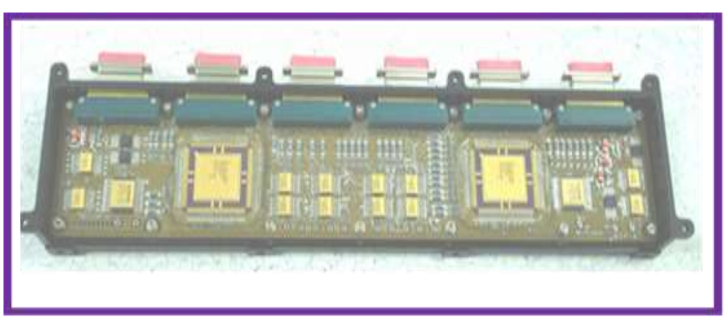
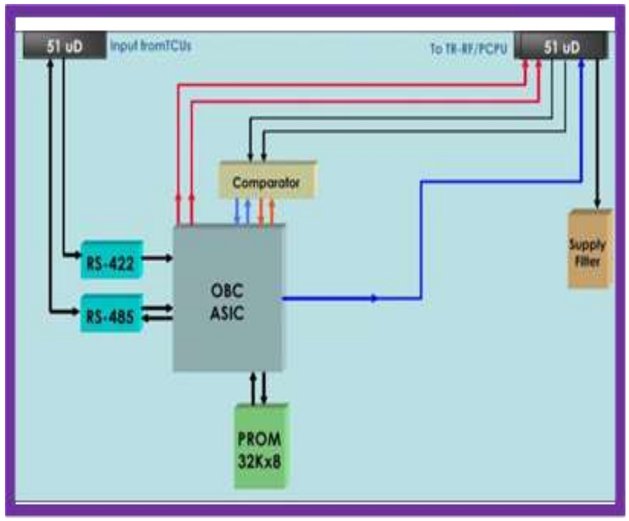


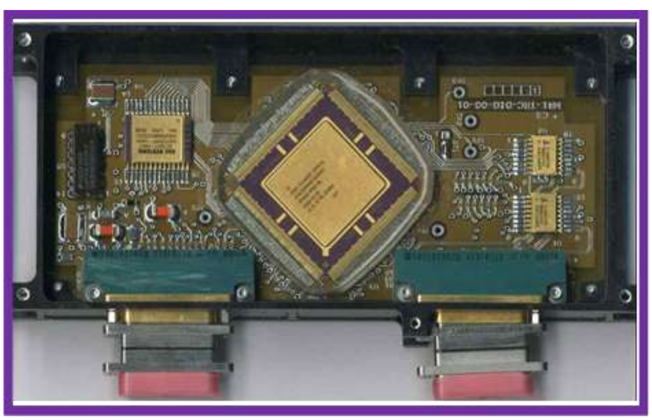
Figure-7: Specifications, Block Schematic & photograph of RISAT-1 Tile Control Unit

4. Transmit Receive Control (TRC) Unit: Transmit-Receive Control (TRC) unit resides at the bottom of the three level control hierarchy and generates the dynamic timing and control signals for individual Transmit Receive Module pair (TRM-H&V) and Power Conditioning & Processing Unit (PCPU). Each TRC is sandwiched between two TR-RF Modules catering to V & H polarizations and the three together are powered using PCPU.

Like TCU, TRC is also designed and built around Rad Hard OBC-1 ASIC, operating at 3.90625 MHz external clock provided by TCU and contains 32Kx8-bit PROM to store application program and LUT data for the relevant TRM pair. The RS-422 differential receivers provide control and timing interface with TCU while internal ASIC CMOS buffers are utilized to interface the phase and amplitude data, control, command and timing signals with two TR-RF modules. The RS-422 serial communication between TCU and TRC is also through UARTs inside OBC ASIC. The delta-sigma A/D converter inside OBC-1 ASIC is utilized for A-to-D conversion of SSPA temperature data, which is utilized to carry out temperature compensation of phase and amplitude data fro TR-RF modules pair. Figure-8 gives the Specifications, Block schematic and photographs of TRC of RISAT-1 SAR. In all, 288 Flight Model TRCs are assembled on 12 different Tiles, with each tile containing 24 nos. of TRCs. The fabrication, assembly and testing of FM units of TRC has been carried out through two external vendor, M/s. Astra/Komoline, Hyderabad and M/s. Centum Solectron, Bangalore.

Parameter	TRC Specifications
TCU Interface	RS422 Differential for timing/control signals RS422 @ 10172 baud rate for serial comm.
PCPU Interface	HCMOS for Timing & Control signals HCMOS for PCPU Clk @ 195.31 KHz, 10% duty
TR Module Interface	CMOS
TRM Phase/Amplitude Compute & Update Rate	100 msec (min. available time) 0.5 µsec @ PRF (update rate)
TRM Smooth Power On/Off Time	3 seconds
No. of TR Modules controlled	Two (Pair of H & V)
Power	0.6 Watts (Max.)
Package Size	173mm x 18.5mm x 81mm
Weight	158 gms.





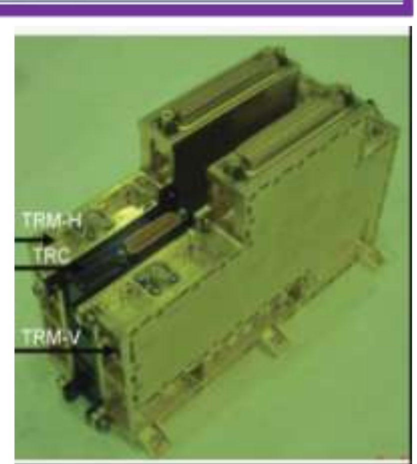
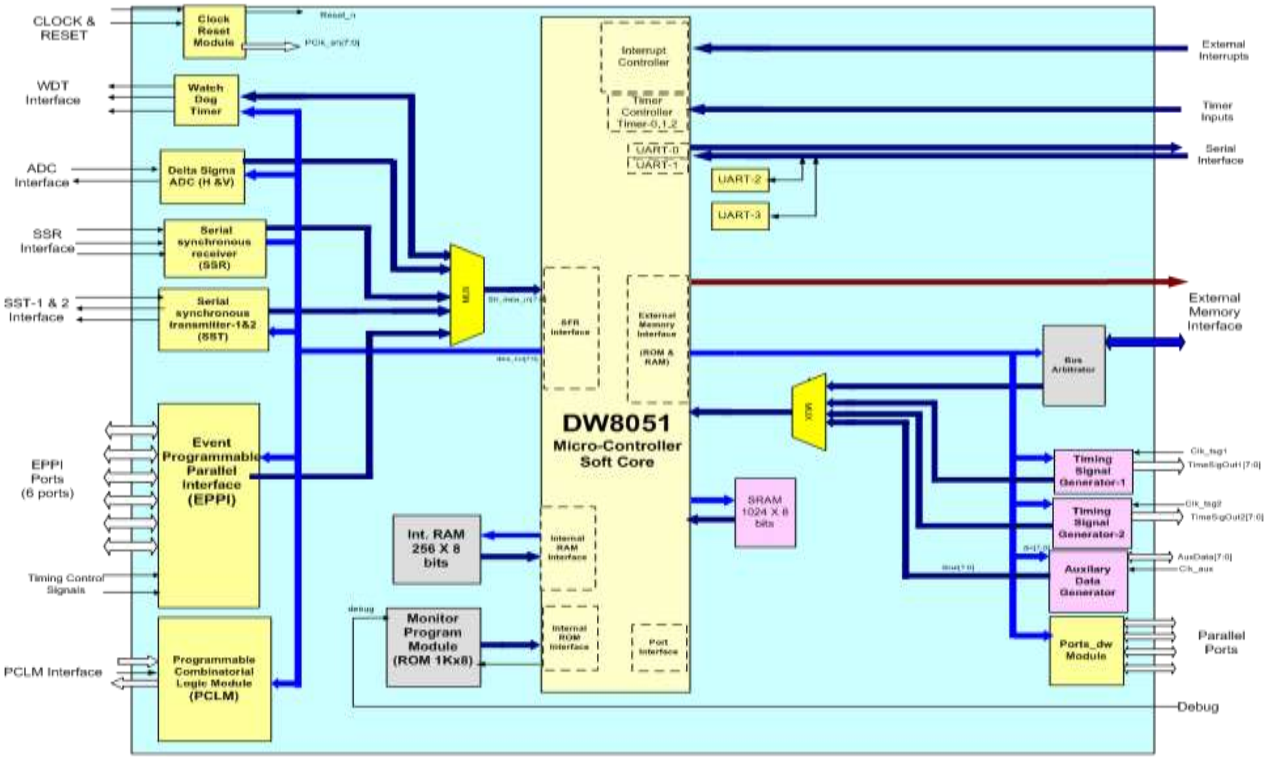


Figure-8: Specifications, Block Schematic & photographs of RISAT-1 TR Control Unit

5. Onboard Controller ASIC: The Onboard Controller-1 (OBC-1) digital ASIC has been extensively used for fabrication of Tile Electronics (TCU & TRC) for RISAT-1 SAR. Figure-9 gives the specifications, block schematic and photographs of OBC-1 ASIC. There are total 312 OBC-1 ASICs used onboard RISAT-1 SAR (288 in T/R Control and 24 in Tile Control Units). OBC-1 ASIC architecture is based on DW8051 microcontroller core, which is interfaced to peripheral modules through SFR or memory bus.



Type	**Digital ASIC, 0.6µ CMOS RadHard Gate Array Technology**
Features	8 bit DW8051, 3 Timers and 5 Interrupts 4 UARTs, 3 SST/SSR, 10 I/O ports Two 8 bit Delta Sigma ADC modules Watchdog Timer, 16 prog. Timing gen.
Supply	Single +5V supply
I/Os	Total 224 I/Os with 5V CMOS compatibility and 4ma/8ma drive
Memory	256 Bytes RAM (8051 Internal) 1024 Bytes RAM (8051 External)
Clock Freq.	16 MHz (System clock) 30 MHz (Peripheral clocks)
Gate count	300K NAND2 equivalent gates (~900K Transistor Pairs)
Package	256 pin CQFP
Radiation Performance	TID ≥ 100Krad (Si), SEL LET ≥ 125 MeV-cm2/mg, SEU rate (FF) ≤ 1.6×10^{-10} err/bit day QML-V Qualified, ESD sensitivity: 2KV

OBC-1 FM ASIC

OBC-1 FM DIE

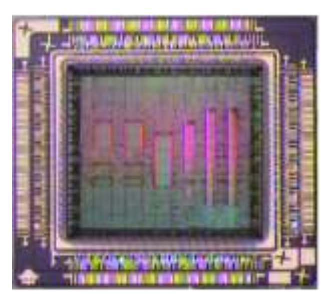


Figure-9: Block Schematic, Specifications & photographs of OBC-1 ASIC for RISAT-1 Tile Electronics

OBC -1 ASIC contains a rich set of serial interfaces (4 UARTs, 2 modules of 3-wire serial I/O using clock, strobe & data). It contains 10 parallel ports (total 80 bits). OBC-1 ASIC contains a unique feature of event programmable parallel I/O (EPPI), which makes I/O deterministic and reduces load of software for I/O task. OBC-1 ASIC has been fabricated at AMI foundry, Italy using 0.6μ CMOS RadHard Digital Technology. The front and back-end design and fabrication, assembly and testing of Proto and Flight Model OBC-1 ASIC have been carried out with the help of two external vendors, M/s. CG-Coreel, Bangalore and M/s. Aeroflex, USA.

6. Conclusions: The onboard digital subsystems were technologically new and perhaps the most challenging elements in C-band SAR payload of RISAT-1. Apart from the realization of the large volume of hardware and complex technologies, the major challenge was the synchronized and coordinated execution of the various onboard tasks for RISAT-1 SAR payload. The roles of onboard payload controller and the distributed tile controllers based on OBC-1 ASICs were therefore very crucial. This apart, realization and successful operation of ultra-High speed dual-channel digitizers along with 2-6 bit programmable BAQ-encoding scheme and digital waveform synthesis have also been significant achievements. Another significant achievement has been the successful realization of space qualified Onboard Controller-1 ASIC and its usage in such a large number, in a coordinated fashion for elevation beam-forming for active phased array SAR onboard RISAT-1.

It is envisaged that these digital and mixed signal technology developments are significant steps in standardization of onboard digital hardware for ISRO's future spaceborne SAR missions like L-band SAR and X-band SAR. This apart, the involvement of indigenous Indian industries during the DVM and Flight model digital hardware development has also been a significant achievement, which will help ISRO in faster execution of spaceborne missions of similar complexity, nature and volume.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures*, related to the specific theme "Megha-Tropiques Mission- Radiometers for the Tropics".

The deadline for inclusion in the next issue is **Sep 30, 2012.**

- Editorial Team

Hardware Quick Look SAR Processor for RISAT-1 SAR

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1. Introduction: SAR has an unique role to play in mapping and monitoring of large areas affected by natural disasters especially floods, owing to its unique capability to see through clouds as well as all-weather imaging capability. For the various civilian and strategic applications, the utility of SAR sensor is primarily governed by its capability to generate radar images of the terrain under observation, in real or near-real time with very fast turn around times. Since SAR processing is characterized by enormous data volume, very high computing power and difficult control requirements, the generation of off-line SAR data products through standard software-based precision data processing (DP) chain involve considerable product turn around time.

Considering the growing user demand and inevitable necessity of real or near-real time SAR data processing, the design and development of a Hardware Quick Look SAR Processor (HWQLP) / Near Real Time SAR Processor (NRTP) was pursued as one of the mission goal of RISAT-1 Ground segment. This HWQLP/NRTP has been built, to the extent possible, using only Commercial-Off-The-Shelf (COTS) Digital Signal Processor (DSP) and other hardware plug-in modules on a Compact PCI (cPCI) platform. Thus, the major thrust for this HWQLP has been on working out Multi-DSP architecture and algorithm development and optimization. For RISAT-1 mission, this HWQLP is currently installed at Shadnagar, NRSC ground receive station with system configuration as shown in figure-1 and is mainly used for data archival, SAR sensor performance evaluation and real / near real time browse product generation. The two-dimensional SAR processing tasks are performed by DSP boards and the processed image data is displayed on the monitor screen as well as stored on a suitable recording media. A cPCI Pentium P3/P4 Single Board

Computer (SBC) performs the overall control and co-ordination tasks for the various DSP processors and other interfaces. Once operationalized, HWQLP/NRTP will also provide an alternative emergency SAR product generation chain. One major objective of this endeavor had also been to identify critical technology elements for SAR processing and gain necessary expertise and experience in optimizing SAR processing algorithms for configuring onboard real / near real Time SAR processing systems for ISRO's future SAR missions. The sections below give the salient features & specifications and hardware architecture of this HWQLP/NRTP system.

2. HWQLP/NRTP Features and Configuration: RISAT-1 SAR image generation throughput requirements are of very high order and involve Block Adaptive Quantiser (BAQ) data de-compression, two-dimensional complex signal compression based on radar matched filtering algorithms (Range-Doppler or Deramping) along both the range (Compression Ratio, CR=400-5000) and azimuth directions (CR=200-12000), as well as motion sensing and compensation tasks like Doppler Centroid Estimation and AutoFocus, and image mosaicing on display monitor screen as well as storage of processed SAR images on suitable recording media.

Table-1 gives the major specifications of HWQLP/NRTP system for RISAT-1 SAR. The major functions performed by it are as follows:

- Dual channel 8-bit I/Q data reception from Front End Hardware (FEH)
- Extraction of SAR data from BDH frames
- Online Block Adaptive Quantizer (BAQ) decoding
- Raw data extraction from formatted SAR data and distribution to other processing units
- Digital Range compression using Digital Signal Processors (DSP)
- Data distribution from Range processor to Azimuth processing units along with auxiliary data for further processing
- Azimuth processing and post processing tasks using DSPs
- Real time display of processed images on multiple monitors
- Online recording of the image to an appropriate storage device

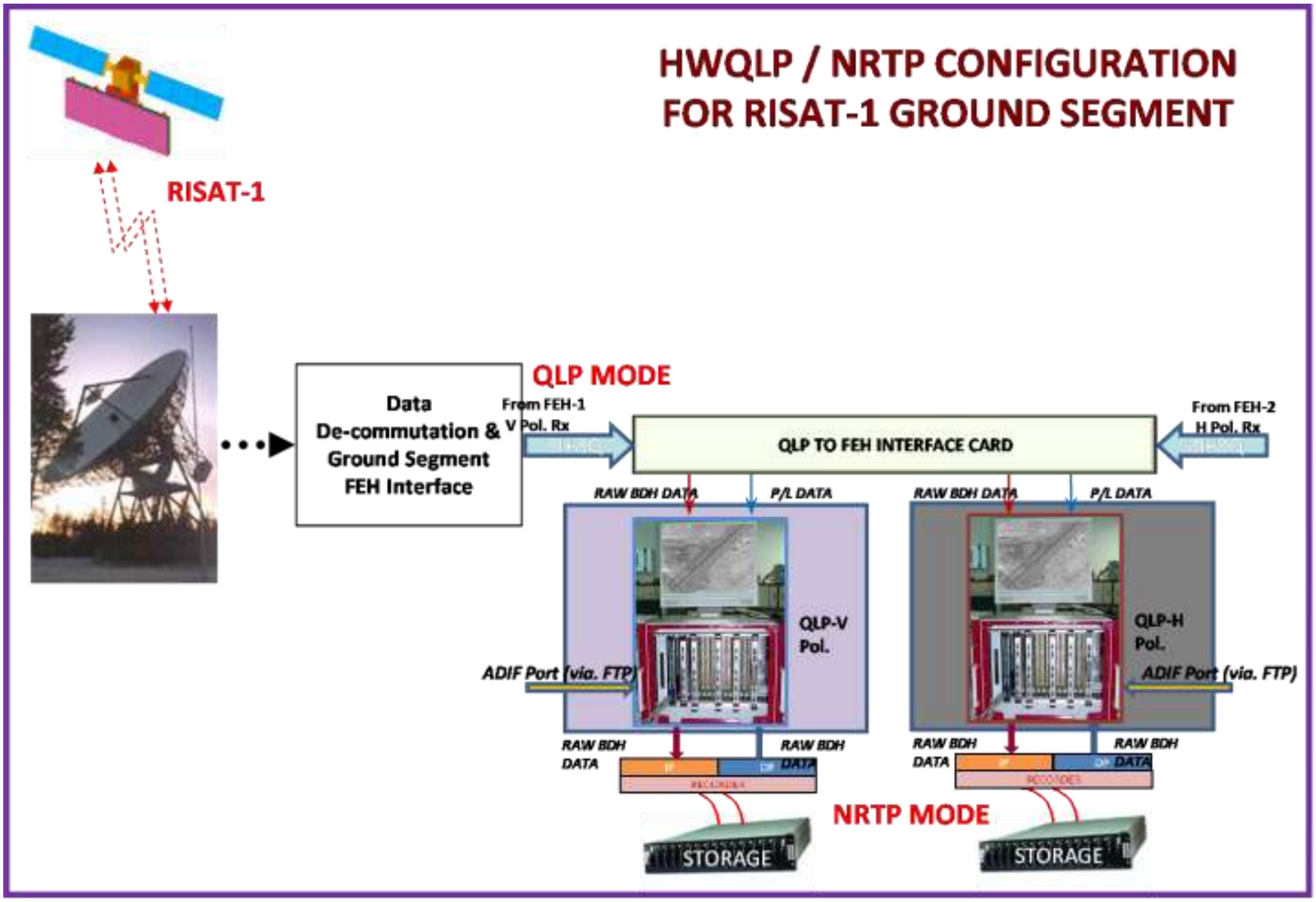


Figure-1: HWQLP/NRTP system configuration for RISAT-1 ground segment

Table- 1: Major Specifications of RISAT-1 SAR HWQLP/NRTP System

Parameter	RISAT-1 SAR Operating Mode		
	Spotlight Mode	Stripmap Mode	ScanSAR Mode
Range Pulse Compression Ratio	5000	1667-834	417
Resolution (Ground Range x Azimuth)	1m x 1m	(2.4–9.4 m) x 3m-FRS1 (4.9-18.8 m)x 9m-FRS2	(9.8-37.7m)x21m -MRS (9.8-37.7m)x52m- CRS
Hardware Quick Look Processor (HWQLP)			
Input Data	Two Chains of 16-bit (8I + 8Q) LVDS @ 20 MHz each		
Swath Coverage	-	12.5 Kms	25 Kms (One sub-swath in real time)
Product Turn Around Time	-	Real Time	Real Time
Sustained Throughput	-	3 GFLOPS	3 GFLOPS
Near Real Time SAR Processor (NRTP)			
Input Data	Two Chains of 16-bit (8I + 8Q) LVDS @ 1-2 MHz each		
Swath Coverage	Full Swath		
Standard Scene Size	10 Kms x 100 Kms	25 Kms x 25 Kms	113 Kms x 113 Kms 225 Kms x 225 Kms
Product Turn Around Time	45-90 Min.	Less than a 1 Min.	6-12 Min.
Sustained Throughput	4 GFLOPS	4 GFLOPS	4 GFLOPS

HWQLP / NRTP Hardware Configuration	
Host Computer and Housing	Intel Core2 T7400 @ 2.16 GHz SBC – PC cPCI @ 33 MHz, 64-bit, 500 GB or Higher HDD,16 Slot cPCI Chassis
Multi-Processor DSP	FIM: 16 TigerSHARC (TS201S) DSPs @500 MHz HWQLP/NRTP-V : 112 TigerSharc (TS201S) DSPs @500 MHz HWQLP/NRTP-H : 112 TigerSharc (TS201S) DSPs @500 MHz
Additional Storage for NRTP	RAID or JBOD, 7200 rpm or Higher Capacity : 2 TBytes, Fiber Channel interface External Housing capacity 16 disks
Display Monitor	21” SVGA / TFT / LCD
Weight and Power	30 Kgs, 2000 Watts (HWQLP/NRTP) 15 Kgs, 500 W (Recorder)

HWQLP/NRTP system can be configured to operate in the following modes:

(a) Quick Look Processor (QLP) and Data Archival Mode: QLP mode is exercised during the satellite pass over India. In this mode, RISAT-1 raw SAR data available from the Ground segment Front End Hardware (FEH) is directly received by HWQLP & archived on dedicated JBOD/RAID recorder and SAR image generation is accomplished in real time.

(b) Near Real Time Processor Mode (NRTP): Here, the data archived during the satellite pass is played back from the archival system to the NRTP at a slower rate. In this mode, NRTP may utilize the ADIF/OAT files available from the ground segment processing chain to generate precision SAR images.

(c) Payload Performance Evaluation (PPE) Mode: In this mode, HWQLP/NRTP system is used to evaluate the performance of the RISAT-1 SAR payload, operating in Calibration (CAL) mode. The payload performance evaluation includes BDH and DACS data format verification, raw data statistics, antenna performance evaluation etc. It is possible to perform payload performance evaluation both online (i.e. during a satellite pass) and offline (i.e. after the satellite pass). In online mode, the HWQLP performs real time range compression on the received data and displays the processed data along with the auxiliary parameters on a sampled basis. For full fledged payload performance analysis the raw BDH data stored in the archival system is transferred to the host. The host application performs full-fledged performance analysis on the data and the results are displayed on the HWQLP display screen.

3. Hardware Architecture and SAR processing

Conventional Stripmap SAR data processing necessitates matched filtering along both the range and azimuth directions. The range compression involves linear chirp matched filtering or complex correlation individually for each pulse return. The corner-turning operation follows range compression where in, the range-compressed data are to be re-ordered from range sequential to pulse-sequential order. This is followed by azimuth compression, which also involves matched filtering individually for each range gate, across all the pulses in the synthetic aperture. High-resolution SAR imaging also suffers from the Range Cell Migration (RCM) effect during the synthetic aperture time, which includes the range walk and range curvature. The range curvature effect due to long integration time is required to be compensated during azimuth processing. These tasks will be performed by frequency domain interpolation and complex multiplication. This apart, ScanSAR and Spotlight SAR processing has its own demanding requirements like mosaicing, time and frequency domain RCM corrections and interpolations. Among all the SAR processing algorithms reported in literature like Time domain convolution, Range-Doppler, Spectral analysis (SPECAN), Step Transform, Polar processing, Wave number domain algorithm, Chirp Scaling algorithm and its variants etc., the frequency domain Range- Doppler and SPECAN algorithms only are suitable for real time implementation.

For FRS-1 stripmap mode, frequency domain Range-Doppler algorithm is employed in HWQLP/NRTP, with the following processing tasks:

- Range compression involving Range FFT, complex multiplication and range IFFT,
- Azimuth FFT, Doppler Centroid Estimation, Range cell migration correction,
- Azimuth matched filtering and IFFT
- Slant to ground range conversion.

For MRS/CRS conventional ScanSAR imaging modes, presently Range-Doppler algorithm only is employed in HWQLP/NRTP. Individual sub-swaths of MRS/CRS are processed by zero-padding in the burst gaps in azimuth direction. All the bursts are processed at once using a full-aperture matched filter. Therefore, the compression algorithm is similar to that of continuous case and additionally includes Scalloping removal and Range Mosaicing. SPECAN or Deramping algorithm is also being implemented in HWQLP/NRTP for MRS/CRS and FRS-2, which is quad polarization and burst mode SAR imaging mode.

Spotlight or Sliding Spotlight SAR processing algorithm for HWQLP/NRTP is a variant of the Range Doppler algorithm. The major processing steps therein are as follows:

- Range compression involving Range FFT, complex multiplication and range IFFT,
- Time domain Range cell migration correction followed by phase compensation.
- Azimuth FFT, Range Cell Migration Correction to correct target trajectory
- Second Interpolation in azimuth direction
- Azimuth matched filter generation, Azimuth matched filtering and IFFT
- Reverse range cell migration correction
- Geometric corrections for residual squint

As shown in Figure-1, the overall system consists of two HWQLP/NRTP units corresponding to V and H receive chains of RISAT-1 SAR payload. Each HWQLP/NRTP system is configured around an 16-slot cPCI chassis with a host SBC and Analog Devices' 112 TigerSHARC, TS201S DSP processors (@ 500 MHz). Additionally, each HWQLP/NRTP has its own archival system consisting of a cPCI recording blade along with a RAID based disk array. HWQLP/NRTP system caters to various RISAT-1 spacecraft data transmission modes namely Real time (RT) transmission mode, Stretch mode and SSR playback mode. In RT mode, V/H-pol. SAR data available from FEH-1/2 is acquired by the FEH interface module (FIM) and the pre-processed and raw data is transferred to the HWQLP/NRTP processing system for Quick Look SAR image generation and archival. When the RISAT-1 SAR operates in dual polarization mode, both the HWQLP/NRTP systems will generate corresponding V & H pol. images. In stretch mode, only a single SAR P/L receiver (either H or V receiver) is ON. The SAR P/L data down linked in real time is distributed in all the four receive (i.e. I1, Q1, I2 & Q2) chains. In this mode, FEH-1 receives the I-channel of P/L data and FEH-2 receives the Q-channel of P/L data. The FIM receives the distributed data from both the FEH systems and internally combines the I-channel and Q-channel P/L data and transfers the same to one of the HWQLP/NRTP system for further processing and archival. Figure-2 shows the various processing elements, architecture and data distribution scheme for HWQLP/NRTP system. HWQLP/NRTP set-up consists of the following major hardware units :

(a) FEH interface module (FIM): It consists of 16 TS201 DSP based COTS module housed in a 4-slot CPCI chassis along with an SBC host, used to control and configure the DSP COTS modules. The BDH formatted raw SAR data from the two onboard SAR (V & H) receivers is available to the two FEH systems in four serial chains, namely I1, Q1, I2 and Q2 at 160 Mbps. The FEH system receives the serial data from the ground segment data de-commutation system and after pre-processing, sends the data to FEH interface system in 8-bit I and 8-bit Q format @ 20 MHz per receiver. The major operations performed by FIM are:

- FEH data ingest, BDH frame sync detection and subsequent data transfer to DSP's
- Parallel data transfer of raw BDH to DSP processors for archival
- De-randomization of BDH frame, BDH data extraction and SAR PL data reconstruction
- Transfer of extracted SAR P/L frame to HWQLP/NRTP for real time SAR processing & raw data archival

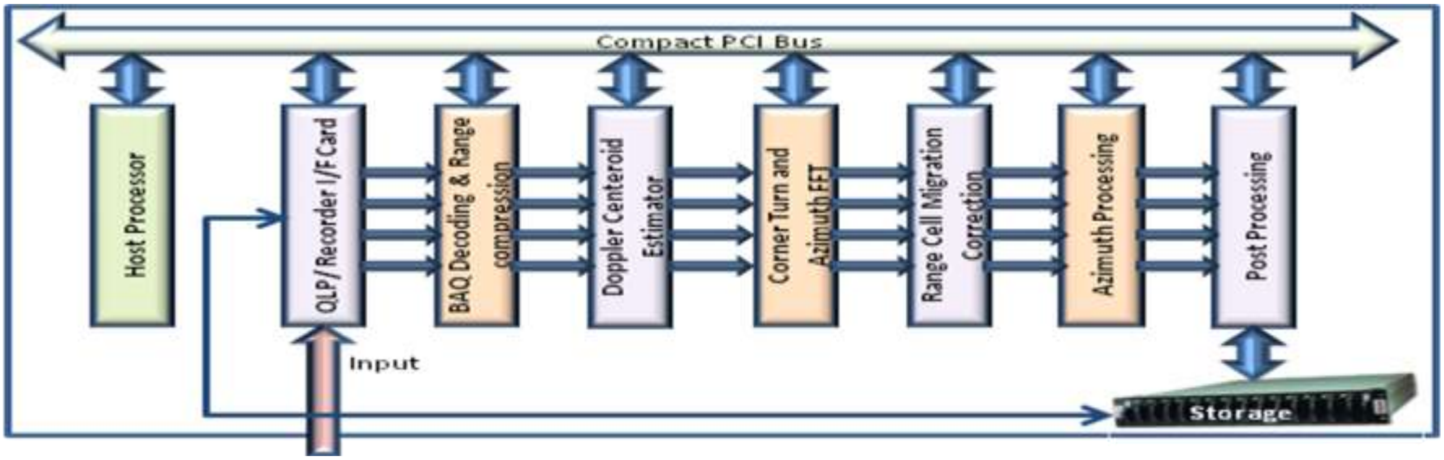


Figure-2: Architecture and data distribution scheme for HWQLP/NRTP

(b) **HWQLP/NRTP SAR Processing system:** It has the following major hardware constituents:

(1) QLP/NRTP Recorder interface: In QLP mode, this 16-DSP module receives I/Q SAR data from FIM module and transfers the same to DSP modules. It also receives the raw SAR data and transfers it to the archival unit for recording using FPGA's DIO port. In NRTP mode, it performs BDH sync detection, de-randomization and SAR P/L data extraction. These data are fed to DSP modules for BAQ decoding and range compression.

(2) BAQ Decoding and range compression modules: It carries out Payload auxiliary data extraction and BAQ decoding as per BAQ mode followed by Range compression using fast convolution with stored replica. Range processed SAR data along with auxiliary information are fed to Doppler Cetroid Estimator (DCE) module. Two 16-DSP modules are utilized for this real time processing.

(3) Doppler Centroid Estimator module: One 16-DSP module is utilized to perform Doppler centroid estimation on range processed data. The estimated Doppler centroid values are embedded in aux. data and transferred to Azimuth Processor.

(4) Azimuth Processor modules: The azimuth Processors receive the range compressed data and perform corner turning operation, complex 8K FFT, Range cell migration correction using DCE and frequency domain fast convolution for each range gate. DCE and other aux. parameters are utilized to generate the appropriate azimuth reference functions for azimuth compression. Suitable overlap is maintained between two azimuth blocks for image continuity. The azimuth compressed data is the sent to the host SBC for real time display of a scrolling image. Three 16-DSP modules are utilized for this azimuth compression and post processing.

(c) JBOD/RAID based Recording system: The Compact PCI based recording system consists of a high speed recording blade and an associated JBOD/RAID based storage unit. The recording blade consists of two high speed 32-bit I/O ports with a maximum record rate of 50 MHz. The two ports can be configured independently to act as an input or output port. During QLP mode of operation port-1 is utilized to record the raw SAR data. During NRTP mode of operation, port-2 is utilized to replay the recorded SAR data back to HWQLP/NRTP processing system. Two separate recording units are used to store V and H –polarization SAR data.

4. First Results of HWQLP/NRTP

The hardware configuration of HWQLP/NRTP for RISAT-1 ground segment is totally based on COTS Multi-processor DSP and other plug-in I/O boards on a Compact PCI (CPCI) platform. Major efforts were directed towards algorithmic studies, simulations, DSP coding and implementation aspects. The working out of a common and generic architectural design based on these DSP accelerator boards, which is amenable for all the RISAT-1 SAR operating modes was a major challenge. Moreover, it has to meet the input ingest and processing requirements for both real time on-line quick look and near real time playback mode of operations. SAR processing algorithm and other software utilities for HWQLP/NRTP has been coded using VC++, Visual DSP++, Matlab and DSP assembly language. One of the challenging aspects in the design and development of the HWQLP/NRTP system is the development of real time DSP software for inter-processor communication between processing modules without the use of any centralized Real Time Operating System (RTOS). Figure- 3 shows the photograph of the rack-mounted HWQLP/NRTP system at Shadnagar, NRSC and some of the early results of RISAT-1 SAR images generated using this HWQLP/NRTP system.

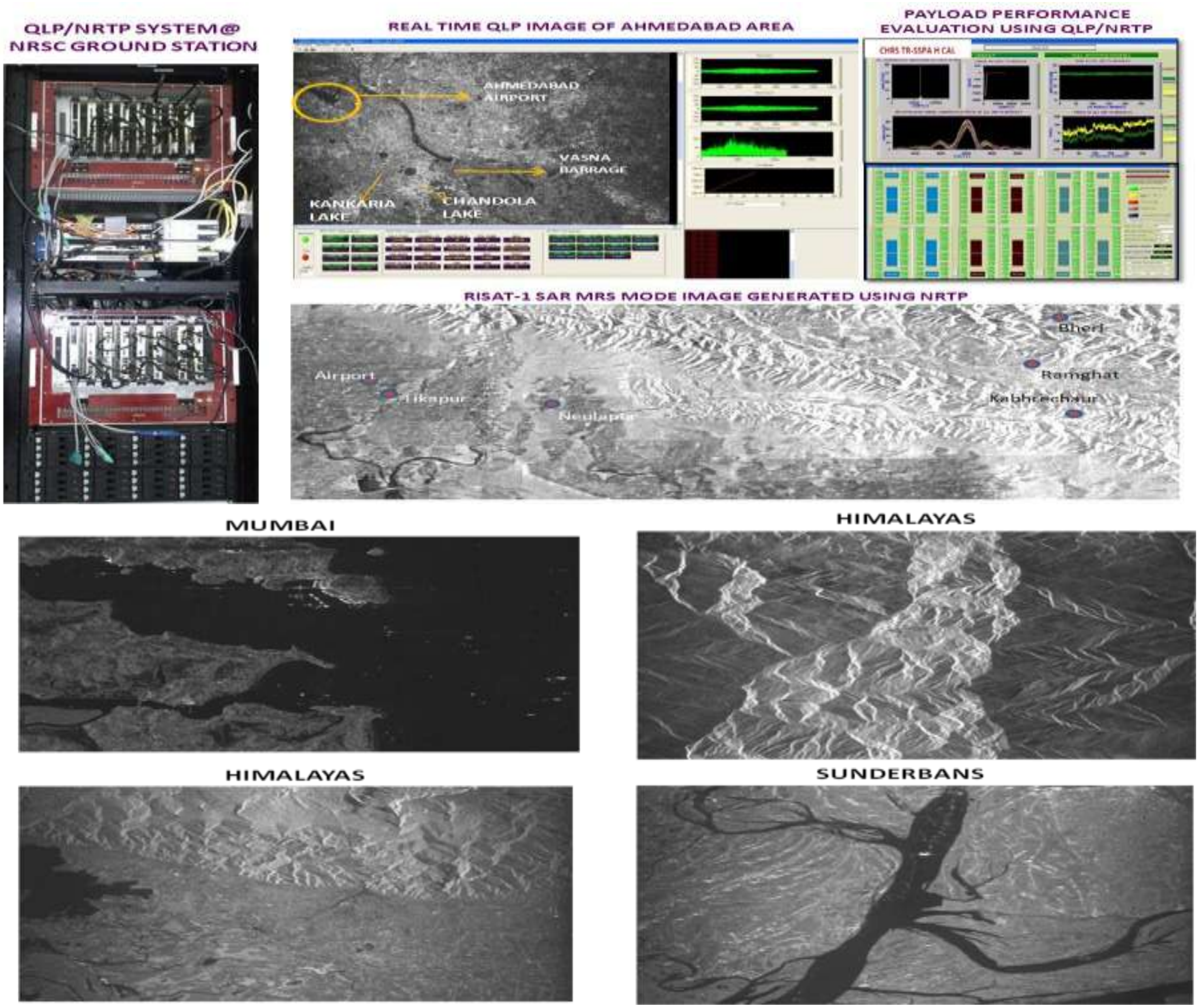
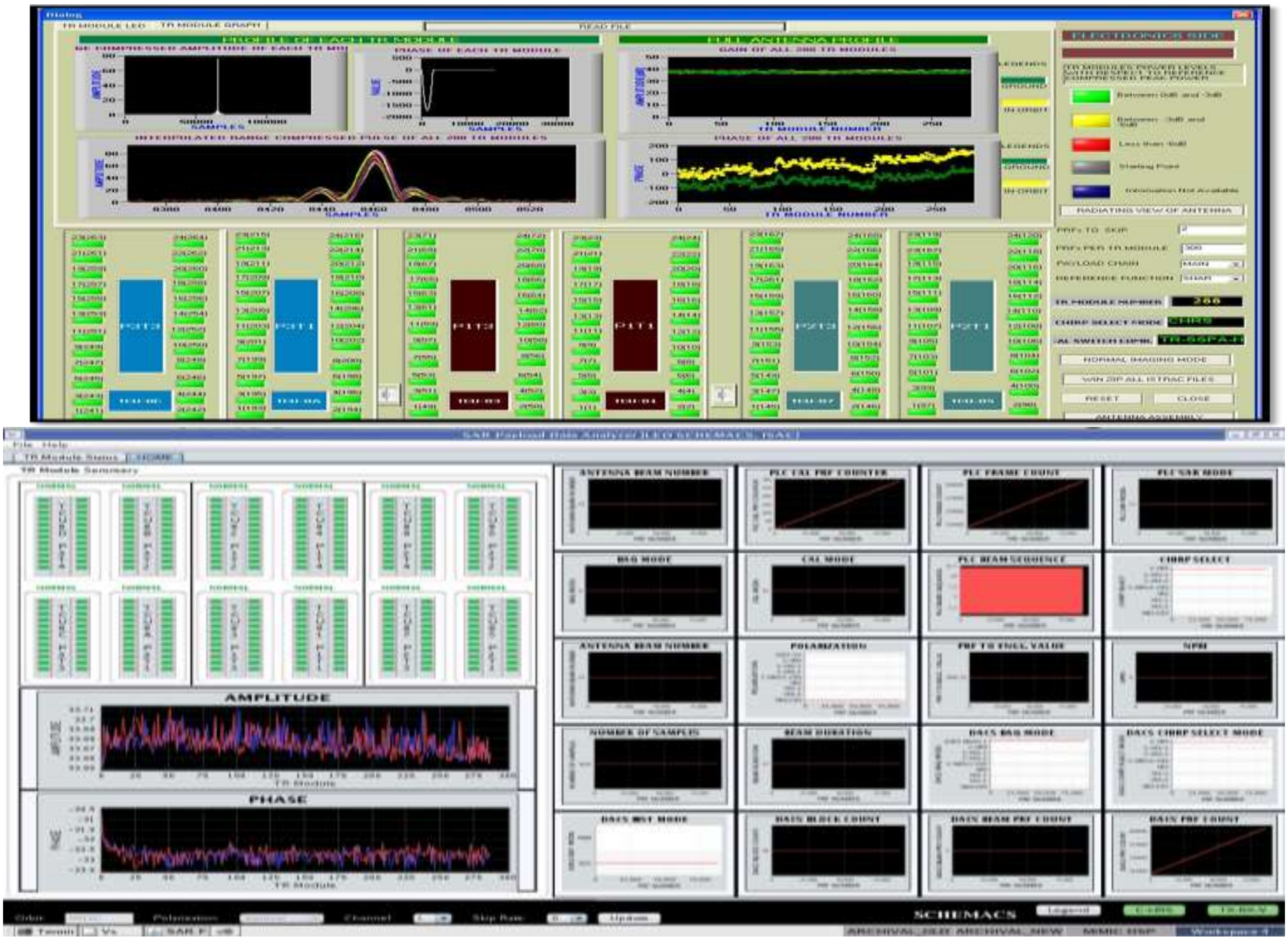


Figure-3: RISAT-1 SAR HWQLP/NRTP system and First Results

As mentioned earlier, the other off-line application of this HWQLP/NRTP is for evaluation of the sensor performance of the RISAT-1 SAR using Calibration (CAL) mode data. A Graphical User Interface (GUI) based software package called "RISAT-1 SAR Payload Performance Evaluation (QLP/NRTP)" in VC++ has been designed and developed. This software evaluates major auxiliary parameters related to Payload subsystems like Data Acquisition and Compression Subsystem (DACS) & Payload Controller (PLC) and Spacecraft subsystems like Baseband Data Handling System (BDH) and Bus management Unit (BMU). It also measures the quality of video data received in each of the receive chains and monitor the health and performance of 288 pairs of Transmit-Receive (TR) Modules used in the RISAT-1 SAR active antenna by computing the gain and phase response of each TR module. The In-Orbit gain and phase response of each TR module is then compared with the previously stored ground reference to observe deviations, if any. This Dialog based software has different pages and tabs for displaying health of different subsystems over the entire satellite pass data.

Depending on the gain and phase values deduced from the actual received data, the TR module status is displayed on screen. Figure-4 shows the first day CAL results of RISAT-1 SAR (Orbit No. 69, 30th April, 2012) along with the transmit Gain and Phase responses of 288 TR modules (Horizontal Polarization) for CHRS (Circular High Resolution Mode) comparted with the reference (gain and phase) measured at Sriharikota (SHAR). As evident from the figure, the In-Orbit gain and phase patterns are matching with ground reference very closely. This software also generates twelve different files containing information about the health of TR modules and overall SAR payload. These files are then transferred from NRSC, Shadnagar over a dedicated link (2 Mbps) to ISTRAC, Bangalore, after the satellite pass is over for Offline display and further analysis at Mission Control Centre during the Initial Operations Test (IOT). For this purpose, this software was also integrated with RISAT-1 mission software "SCHEMACS" at ISTRAC, as shown in figure-4.

Figure-4: Payload Performance Evaluation using HWQLP at NRSC & SCHEMACS, ISTRAC



5. Conclusions : The real/near time SAR signal processor had been technologically new and challenging element of RISAT-1 SAR mission. HWQLP/NRTP system is currently installed at NRSC, Shadnagar, Hyderabad and is being regularly utilized to record raw SAR data and for browse image generation for FRS-1, MRS and CRS modes. Presently efforts are underway to make it operational in an automated manner as per Pass Schedule File. The spotlight SAR mode image generation will be tested once RISAT-1 SAR is operated in HRS mode. This HWQLP/NRTP design and development strategies are derived from similar efforts for the development of HWQLP/NRTP for ISRO's C-band Airborne SAR for Disaster Management (DMSAR). It is also envisaged that these developments would be significant first steps in the direction of configuring real time onboard SAR processors for ISRO's future spaceborne SAR missions. It will also enable real time generation of Information products and help reduce data transmission requirements.

Electronic Power Conditioners (EPC) for RISAT-1 Active Antenna and Payload Subsystems

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1. Introduction: The power supplies perform the function of conversion of DC power from spacecraft bus to the Conditioned and regulated DC power for various payload subsystems and are broadly known as Electronic Power Conditioners (EPCs). A state-of-the-art microwave payload like active phased array antenna based Synthetic Aperture Radar (SAR) would require hundreds of such EPCs. For pulsed RADAR like SAR, many of these EPCs have to deliver pulsed power, which could be several times higher than the average power. Moreover, EPC being a closed loop system, such pulsed EPC designs necessitate extreme care regarding the stability aspects under all operating and environmental conditions including EMI/EMC.

RISAT-1 development was initiated a decade back and at that time spacecraft heritage power bus was of 26-43 V and high voltage bus (70V or higher) related development activities were just beginning. The active antenna of RISAT-1 SAR was envisaged to require >3 KW DC power distributed across the 6m x 2 m area. To minimize the voltage drop in wires over such a long distance and also to reduce the harness weight to the possible extent, the high voltage spacecraft bus was found mandatory. Also, High voltage bus reduces the current through the wire and allows the use of thinner wire, thereby resulting in lesser stiffness and ease of antenna deployment in space. All these requirements resulted in selection of 70 V regulated bus for RISAT-1spacecraft and payload.

As in other spacecrafts, RISAT-1 spacecraft main power is generated by solar array strings on solar panels. Solar Array is regulated by F^2S^4R (Fixed frequency Sequential Switching Series and Shunt regulator) for powering the bus at 70V and to charge the battery. Battery Discharge Regulator (BDR) supports power to bus when load demand exceeds the array generation during the payload operation and also during eclipses by regulating the 70V. All SAR payload subsystem EPCs are designed for the 70$\pm$2V regulated input supply voltage.

The following two categories of EPCs were identified for development of RISAT-1 SAR Payload:

1) EPCs for the active antenna Tile Electronics
2) EPCs for deck mounted RF & Baseband Subsystems

The sections below describe the features and developmental challenges.

2. EPCs for RISAT-1 Tile Electronics: The active phased array antenna of C-band SAR of RISAT-1 is divided into 3 panels with 4 tiles each. Each tile contains one Tile Control Unit (TCU) and 24 T/R Module (TRM) pairs (V & H polarization) resulting in overall 288 TRM pairs. Thus separate power supply module is required for each TRM pair as well as each TCU.

Multiple output EPCs having pulsed and continuous power outputs for the T/R modules as well its TR Control (TRC) unit, are named as **Power Conditioning and Processing Units (PCPU).** These units condition the power output as well as provide relevant pulsed outputs as per the control inputs provided at the input of pulse modulator. Thus PCPU consists of an EPC and pulse modulator circuit. Each PCPU provides power for both H & V TR Module pair. Thus 288 PCPUs are required to power 576 T/R modules on RISAT-1 active antenna. Table-1 gives the major specifications of PCPU.

PCPU is a highly complex EPC and its design necessitated utmost care in terms of stability, EMI/EMC, weight and volume. Initially import option was also considered, but considering the responses received against our international survey and the exorbitant costs quoted by reputed vendors, it was consciously decided to go ahead with indigenous development with the target goals of minimum possible weight and volume. In 2002 A.D., PCPU design and development was initiated in-house using discrete components.

Table-1: Specifications of Power Conditioning and Processing Unit (PCPU)

Parameter	O/P- 1 / 2	O/P- 3 / 4	O/P- 5/ 6	O/P- 7 / 8	O/P- 9	O/P- 10
O/P V-I	9.2V-5.8A	6V-0.7A	5V-0.25A	5V-0.275A	+5V-0.34A	-5V-0.15A
Duty Cycle	8.2%	8.2%	8.2%	65%	100%	100%
Pulse width	22	22μs	22μs	175μs	-	-
Line & Load Reg.	1.5%	1.5%	1%	1%	1%	1%
O/P Droop	500mv	200mv	200mv	200mv	-	-
Rise time	0.75μs	0.75μs	0.75μs	0.75μs	-	-
Fall time	0.75μs	0.75μs	0.75μs	0.75μs	-	-

PCPU Design Verification Model (DVM) was configured with an EPC having three basic outputs (+9.2V, +5V, & -5.0V). The EPC of PCPU was designed using Single ended Flyback current mode converter operating at 100 kHz frequency. Power MOSFET switches were used as pulse modulators to generate the pulsed output, along with appropriate drive circuits on output line to modulate the voltage from zero to nominal voltage. The energy needed during pulse operation must be provided by large energy storage capacitors at the output of EPC to avoid unacceptable current ripple at raw spacecraft bus and keep the voltage droop low within the transmit pulse duration. Droop compensation circuit designed around the same MOSFET switch reduces the droop with reasonable capacitor size. This PCPU DVM, developed using discrete components weighed 650grms. The 68% efficiency achieved was at par with the offer received from a reputed international vendor but size and weight needed to be reduced, hence it was decided to hybridize the PCPU with the help of Indian industries. Considering the large quantity requirements and repeatable performance of magnetic components, it was also decided to use planar magnetics in PCPU. Based on SAC design, 30 DVM hybridized PCPUs were fabricated by M/s Solectron Centum (SCEL), Bangalore. SAC and SCEL team worked together to solve various problems faced during this challenging developmental phase. This Hybridized PCPUs utilized three Hybrid Micro-circuits (HMC), planar magnetics and two PCBs. After thorough performance evaluation and testing of DVM PCPUs, the fabrication order for FM PCPUs was placed on given to M/s SCEL. It included delivery of 16 sets of CTQ HMCS + 16QM + 16LAT + 350FM PCPUs.

Figure-1: DVM and FM PCPUs and EPC for TCU

To power the tile control units for 12 tiles on the active antenna, 24 EPCs (12 Main + 12 Redundant) with +5V - 0.6A output are required. In order to reduce the size and weight of these EPCs, it was decided to hybridize this EPC as well using one of the HMC (PWM HMC) of PCPU. Due to large quantity requirement and need of qualified HMCs, this EPC development was also carried out through outsourcing to M/s SCEL, Bangalore. Figure-1 gives the photographs and comparative details of DVM and FM PCPUs as well as EPC for TCU.

3. EPCs for RISAT-1 RF & Baseband Subsystems: Apart from EPCs for Tile Electronics, deck mounted RF, Baseband and digital packages like Digital Chirp Generator (DCG), Data Acquisition and Compression Subsystem (DACS), Payload Controller (PLC), Receiver, Frequency Generator (FG) and Integration Block & Cal Switch Matrix (IB & CSM), were also indigenously designed. All these EPCs were developed in-house and qualified for space usage.

The EPCs for Receiver, FG and IB & CSM were designed using single ended discontinuous Flyback Current Mode PWM topology as it is quite amenable for such multi-output low power designs. In view of relatively high output power and low output voltage requirements, the EPCs for of digital subsystems were designed using current mode push-pull converters. In-house developed low drop regulators were used at the outputs to meet the stringent ripple and regulation requirements of digital devices like FPGAs and data Converters. Figure-2 shows the FM EPCs of various RF, baseband and digital subsystems of RISAT-1 SAR payload.

SAR being a high power pulsed RADAR, good EMI/EMC performance was a major design goal. Also, fast switching of voltage and current within the EPCs give rise to severe electromagnetic interference which may hamper the performance of the other subsystems. To meet the CE102 requirements as per MIL-STD-461E, proper EMI filters were used at the input of the converters within the EPCs. Extreme care was also taken while making the PCB layouts & package designs to minimize the EMI. Also, opto-isolators, isolation transformers and appropriate snubber circuits were utilized at suitable places to reduce EMI generation and radiation.

Figure-2: Flight Model EPCs for RF & Baseband Subsystems of RISAT-1 SAR

4. Conclusion: A large number of Electronic Power Conditioners for deck subsystems with passive redundancy and Pulsed **Power Conditioning and Processing Units (PCPU)** for active antenna without any redundancy were developed for RISAT-1 SAR payload. Many of these designs were very challenging considering the pulsed mode of operation and the need of multi-output EPCs. During these EPC developments and Integration with respective subsystems as well as during Payload and satellite level integrated testing, many problems were faced by the design team, which were resolved amicably. All these EPCs and PCPUs have exhibited very good EMI/EMC performance and have worked very satisfactorily during on-ground testing. The in-orbit performance of all these EPCs have been found very satisfactory as evident from RISAT-1 SAR Payload telemetry data available till now, after the launch of RISAT-1 on 26th April, 2012.

The other major achievements had been the design of EPCs for high voltage (70V) spacecraft bus, fabrication and qualification of three types of Hybrid Micro-circuits (HMC), use of planar magnetics for these developments as well as identification and qualification of M/s. Solectron Centum as a qualified EPC and HMC vendor.

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1. Studies at (http://www.coloradotrees.org/) have shown that, over a 50-year lifetime, a tree generates

1. $31,250 worth of oxygen,
2. provides $62,000 worth of air pollution control,
3. recycles $37,500 worth of water,
4. and controls $31,250 worth of soil erosion.

Other than this, trees also remove other gaseous pollutants by absorbing them with the leaf surface and thus Planting trees improves the air quality. Thus by investing Rs 50 a year a person can expect to have made donation of around Rs. 10 million (one crore) in 50 years. A total of 300 trees can counter balance the amount of pollution one person produces in a lifetime.

NEAR FIELD Measurement and Calibration of RISAT-1 Active Phased Array Antenna in Pulse Mode Using Matched Filtering and TIME GATING Method

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1. Abstract: Radar Imaging Satellite (RISAT) is a multi resolution/multi-swath/multi-polarization system and carries an Active Array Antenna on-board. Multimode agility of the system demands complex system architecture. RISAT system is configured with a dual polarized active antenna with 288 radiating elements. 6mx2m antenna is configured in three identical panels. Each of the panel consists of 4 tiles of size 1mx1m each. TR modules, each with maximum pulse power capacity of 10 watts, are mounted on the back side of the antenna. Active phased array antenna normally operates in pulsed mode and the requirement for the near field measurement is the precise measurement of amplitude and phase front at a least distance of 10λ (λ-wavelength) and most distance of $2d^2/\lambda$ from the antenna aperture. Measurement of signal phase and amplitude is a critical process and classically Vector Network Analyzed (VNA) performs this job of measuring input and output signal parameters. Antenna aperture data collected in 2D format is then synthesized to develop far-field pattern.

RISAT-1 Antenna Pattern was measured with a new technique called "pulsed mode antenna testing" which is based on match-filtering and time gating of signal. Test set-up requirement are two channel signal sampler of sufficient bandwidth, antenna input signal generator, Probe Antenna, 3D/2D Scanner and master timing Controller. Requirement of microwave absorbers is reduced by the use of FMCW pulsed signal, as compression filter time domain output response resolves the signal reflected from all the targets. Range bin sampling of the data is done here to select true antenna response and rejecting all other unwanted target reflections.

2. RISAT-1 System and Active Array Antenna: Radar Imaging Satellite (RISAT-1) is a multi resolution/multi-swath/multi-polarization Synthetic Aperture Radar (SAR) which was launched on 26th April 2012 and has been performing with highest data quality since launch. This satellite is multimode SAR which operates from a sun synchronous orbit at a nominal altitude of 536kms. Basic imaging modes are Coarse Resolution ScanSAR(CRS) with 50m (12 beam) resolution operation, Medium Resolution ScanSAR (MRS) with 25m (6 beam) resolution operation, Fine Resolution StripMap (FRS) with 3m and 6m resolution (single beam). All these modes can be operated in Linear as well as Circular Polarization. There is also a special operation mode called High Resolution Spotlight Mode (HRS) which has been kept as an experimental mode of operation and provides a sliding spotlight image of 10 km x 10 km with better than 2m resolution. RISAT-1 is configured on a dual receiver concept providing identical resolution and swath in co- and cross-polarisation. The system is configured around a dual polarized active antenna with 288 radiating elements. 6mx2m antenna is configured in three identical panels of which the central one is fixed and rest two are deployable. Each of the panel consists of 4 tiles of size 1mx1m each. The earth viewing part of the antenna is a printed microstrip patch array. TR modules, each with maximum pulse power capacity of 10 watts, are mounted on the back side of the antenna. RISAT-1 Active Array Antenna Specifications are shown in table-1 below.

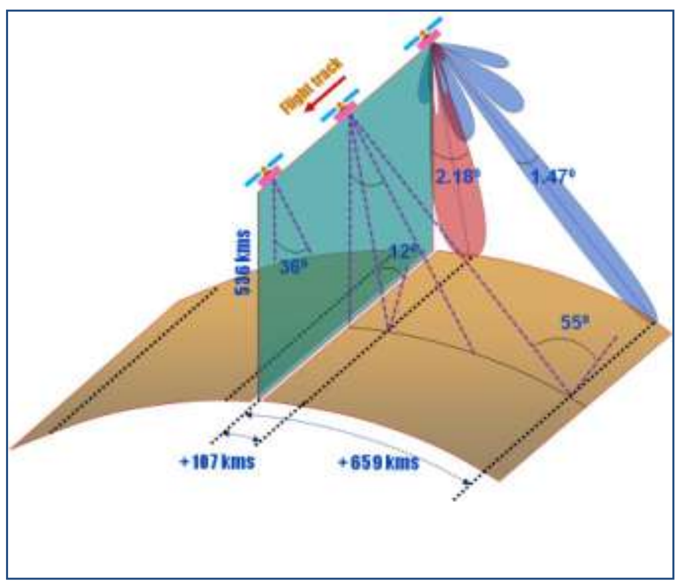


Fig.-1: RISAT-1 Antenna Beam Pointing

Table-1: RISAT-1 Antenna Specifications

Size and No. of T/R Modules	**6m x 2m, divided into 12 Tiles 1mX1m, 288 T/R Modules (H & V)**
Type	**Multi layer micro strip Patch Array**
Operating Frequencies / Band	**5.35GHz ± 112.5MHz (bandwidth)**
Polarization	**Dual/ Linear (H &V)**

3. Testing and Characterization of Active Array Antenna: RISAT antenna operates in pulsed mode and characterization of the same needs a special technique where array electronics can be excited for antenna pattern measurement. A new technique called "pulsed domain antenna testing" has been developed in SAC to measure near field pattern of RISAT antenna. This technique works on the principle of pulse compression and range bin sampling. Baseband electronics has been used here as basic signal source for the excitation of RISAT antenna. As seen in Fig.-2, antenna testing configuration utilizes all the payload electronics except signal compression and near field processing (which is part of signal; processing software).

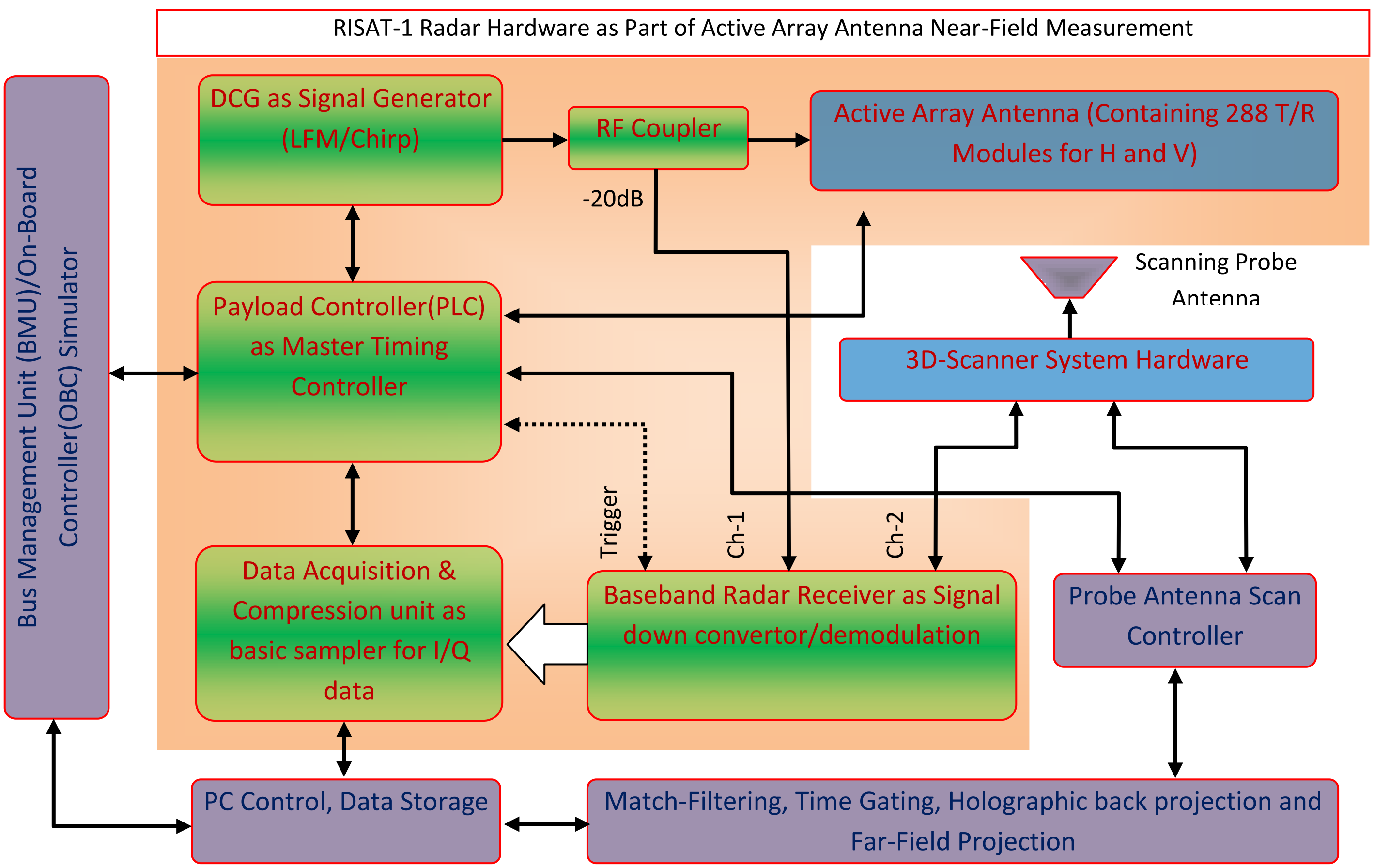


Fig.-2: Active Array Antenna Measurement Set-Up

Near Field Facility (PNF) for RISAT-1 Antenna Testing has been developed indigenously by SAC-ISRO which includes development of Scanner (Mechanical Hardware), Control mechanism and communication protocol, Near-field Signal capturing, Holographic Back projection software and Far-Field Pattern evaluation software.

4. Pulsed Domain Antenna Measurement: RISAT-1 Active phased array antenna works in pulsed mode which also applies to all other Synthetic Aperture Radars existing in world. Requirement for the near field measurement is the precise measurement of amplitude and phase front at a least distance of 10λ (λ is wavelength of operating antenna frequency) and most distance of $2d^2/\lambda$ from the antenna aperture. Measurement of signal phase and amplitude is a critical process and classically Vector Network Analyzed (VNA) is used to performs these measurements. Antenna aperture data collected in 2D format is then synthesized to develop far-field pattern.

A new technique was developed by SAC-ISRO for the measurement of Near-field which involves Match filtering and Time gating to eliminate unwanted reflections so that true antenna signal can be selected. Testing set-up requirement are two channel signal sampler of sufficient bandwidth, antenna input signal generator, Probe Antenna, 3D/2D Scanner and master timing Controller. Requirement of microwave absorbers is reduced by the use of FMCW pulsed signal, as compression filter output response resolves the signal reflected from all the targets. Match filtering is a standard technique utilized in imaging radars for range compression.

5. Range Compression and Time Gating: Match filter compression output for an FMCW (chirp) signal is a sinc pulse with a beam width of 1/BW (BW is the bandwidth of chirp). Match filter response of time delayed chirp is a shifted sinc function as shown in Fig.-3 and Fig.-4. Match filter response for multiple chirp signals with different time delays is compressed output corresponding to each input chirp signal, although time domain signal seems to be random in nature.

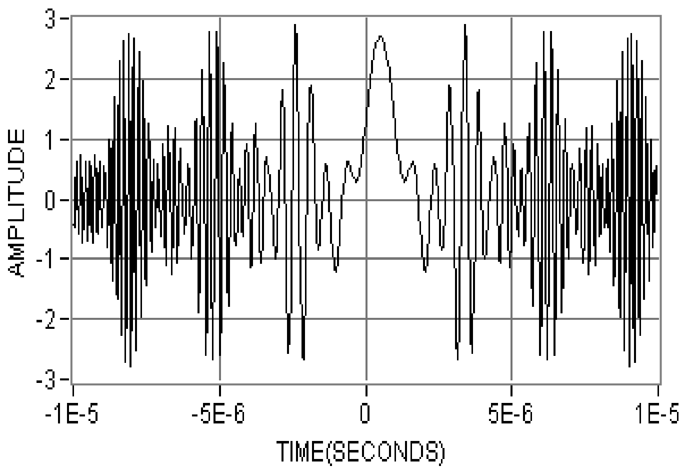


Fig:-3: Real Part of Multiple Reflected Signals

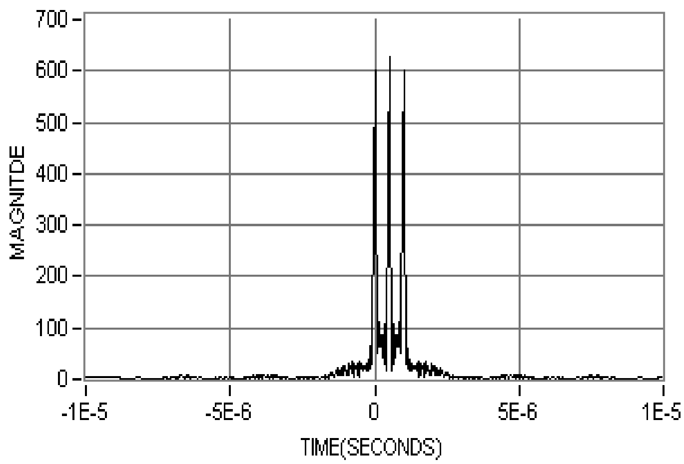
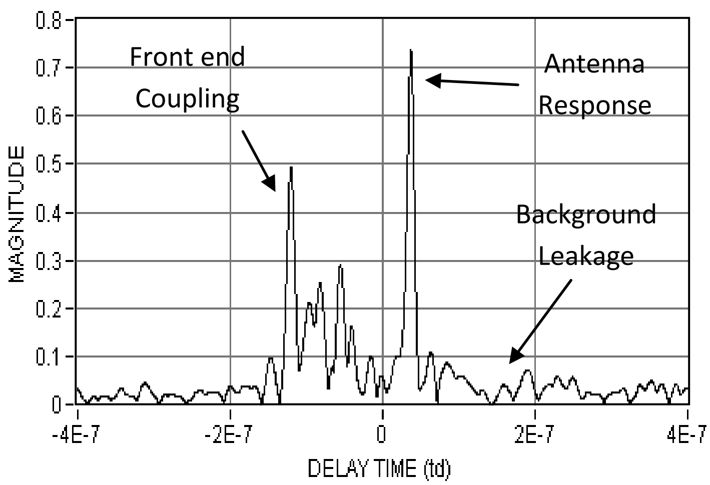


Fig.-4: Compressed Response of Multiple Targets



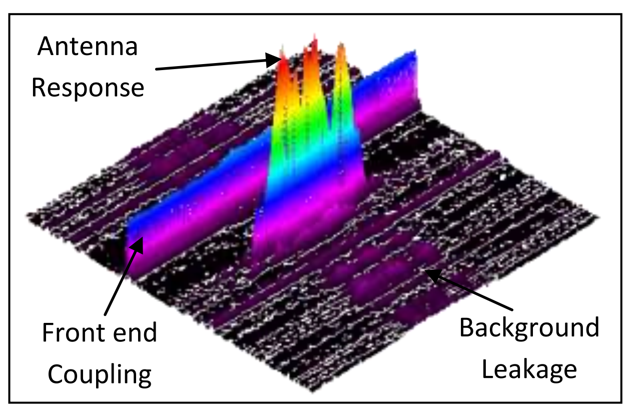


Fig.-5: Compressed Match Filter Output of 1mX1m Active Array Antenna Tile

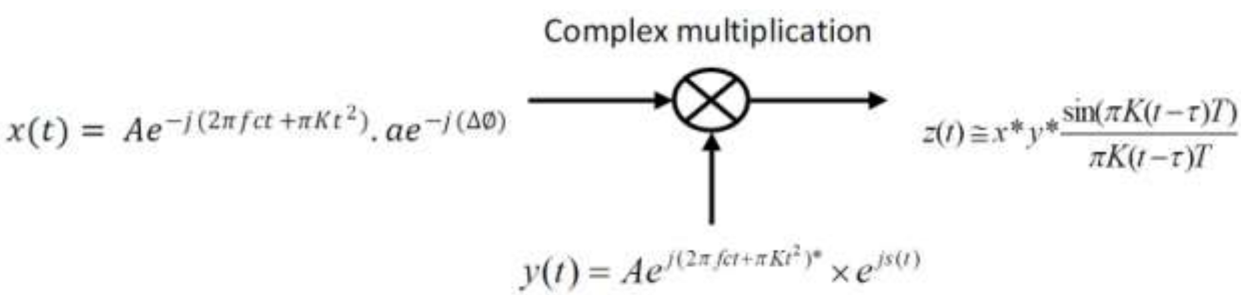
With the knowledge of distances of different targets, proper output response corresponding to particular target can be selected from the compressed match filter output. Time resolution of compressed out is same as sampling frequency (fs). Targets distances which correspond to time resolution less the 1/Sampling cannot be separated so that choice of sampling frequency becomes a critical part of the measurement.

As the distance of the targets from the DUT antenna increase beyond 1/fs period, absorbers can be avoided. Fig.-5 shows the responses of background leakage coming directly to the receiver and front -end reflections which are separated out in time after match filter compression. As the antenna probe approaches antenna front end, match filter response increases sharply, although other responses remain at the same level as shown in Fig.-5.

Match filtering and Time gating has made it possible to test more than one antenna simultaneously with different path lengths so that returns from each antenna can be separated out after match filtering. Fig.-5 shows single patch row antenna (1m long) illumination pattern, for 3m^2 scan area, after match filter compression. Antenna response is clearly visible within the antenna width of 1m although background leakage and front-end reflections are maintaining constant level.

6. Match Filter Errors and Equalized Match Filter: Antenna Near Field testing requirement is to measure Antenna true amplitude and phase response and nullify all other signals. Match filtering detects the signal response in terms of time delay, we can pick-up a sample corresponding to a specific range-bin and reject all the responses corresponding to unwanted reflections. This takes care of reflections from the surrounding areas. Probe response can be compensated by correcting Far-Field with probe characterization data. Signal mainly contains signal generator and coaxial cable characteristics and de-convolving these responses with main antenna signal becomes a tedious job because calculation of characterization data for these devices is a very difficult process. Instead of finding a de-convolution function for the correction of input signal, simplest way of achieving the required output response is to design a match filter which carries characteristics of transmitted signal. This technique nullifies all the errors due to above mentioned devices and yields a true antenna compressed response.

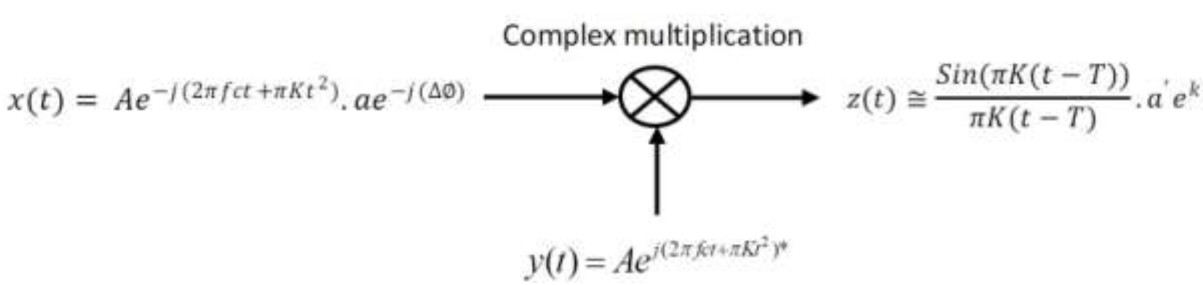
6.1. **Normal Match Filtering:** Signal received from the antenna probe is match filtered with a mathematical function to get a compressed time domain signal. Mathematical function doesn't contain true characteristics of signal generator, coaxial cable/microwave guide and receiver probe.



$ae^{-j(\Delta\emptyset)}$ = amplitude and phase deviation in the input signal due to transmitter and path.

$a'e^{k}$ = corresponding amplitude and phase deviation factor

6.2. Equalized Match Filtering:



$e^{js(t)}$ =Equivalent time function to cancel out $a'e^{k}$ term in the output

7. Near Field Facility Based On Pulsed Domain Antenna Measurement Concept:

7.1. **Near-Field Scanning System:** Near Field Antenna Measurement Setup based on Pulsed Domain Measurement concept for RISAT-1 Active Array Antenna consists of a 3D-Scanner, Controller and antenna fixture/holding mechanism. As hardware setup of this newly built facility is similar to general PNF facility, difference remains in the measurement principle, as mentioned earlier, involving Pulse Compression and Time Gating of Signal. Fig.-6 shows antenna Scanning column and (a) antenna fixture with single antenna tile of RISAT-1 Antenna and (b) RISAT-1 fully deployed Antenna of 6mX2m being scanned in near-field.

Fig.-6: 3D Scanner System with DUT as (a) Antenna Single Tile (b) Fully deployed Antenna

As depicted in Fig.-7, radar RF and Baseband Hardware is being used as signal receiver for antenna measurement.

7.2. **Pre- and Post Data Processing:** Testing of RISAT-1 Active Array Antenna was done in pulsed domain which involves transmission/reception of linear frequency modulated (LFM)-Chirp of 225MHz bandwidth for each scan sample across antenna aperture. Baseband signal passes through radar digital chain which does data encoding. Digital encoded data needs pre processing to decode original data and Pulse compression (match filter) to perform time gating to evaluate Gain/Phase characteristics from the pulsed LFM-Chirp signal. Post processing of data involved holographic back-projection, filtering and weighting. Fig.-8 shows near field raw data for phase and gain of single antenna tile of RISAT-1 for 0^0 pointing where Fig.-9 shows compressed holographic data for the same.

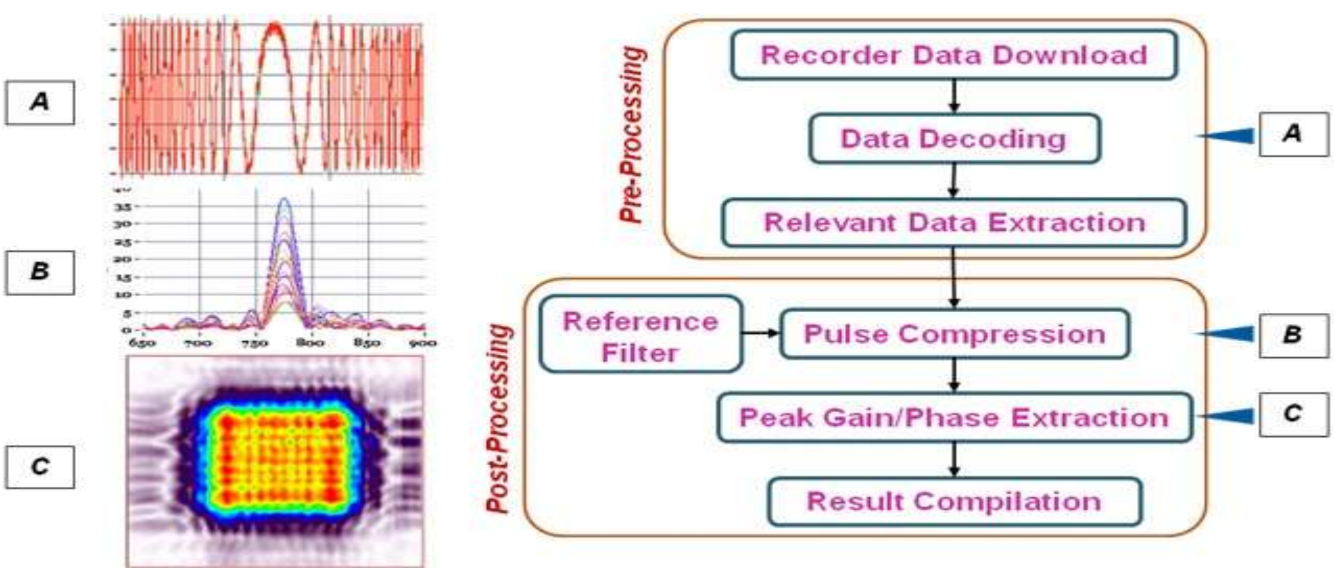


Fig.-7: Near-Field Antenna Raw Data Pre Processing

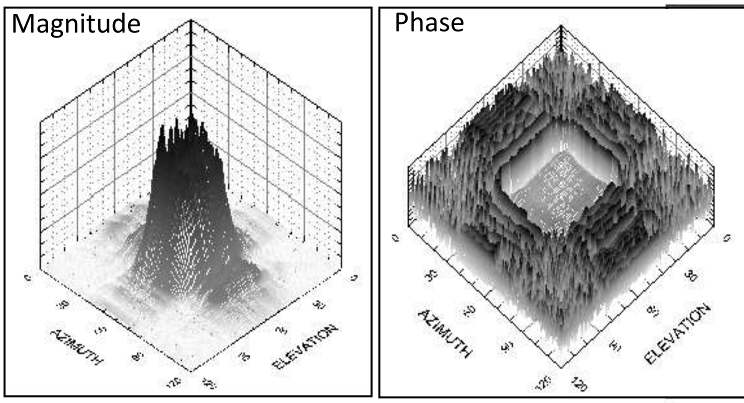


Fig.-8: Raw Data of RISAT-1 single antenna tile for 0^0 Pointing

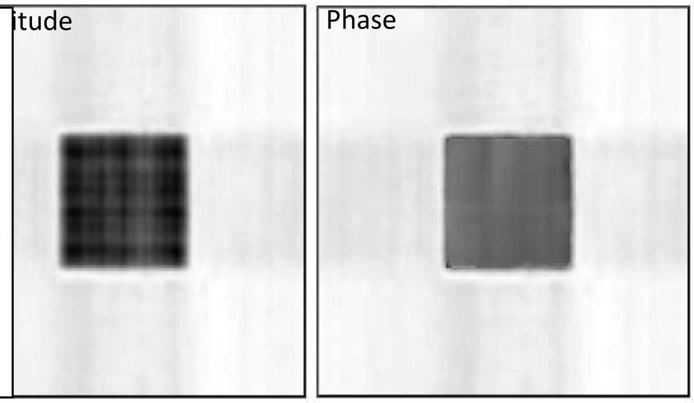


Fig.-9: Near Field Hologram of RISAT-1 single Antenna tile for 0^0 Pointing

7.3. Active Array Antenna Elements Phase and Gain Collimation: Array (Active/Passive) antenna requires proper collimation, i.e. maintaining desired amplitude and phase distribution across antenna aperture to achieve maximum gain and desired pointing. All the active/passive elements (T/R Modules) are fed through corporate distribution network to achieve maximum bandwidth. In order to maintain constant phase front of all the patch elements of active array antenna, under broadside i.e., zero degree pointing condition, all the RF path lengths including active and passive elements upto the antenna radiating element are supposed to be same. Because of small mismatch in the fabrication of RF electronics and integration elements including RF cables and corporate feed network, phase front of all the elements of active array antenna may distort which results in constructive and destructive amplitude and phase fronts and breaks far-field pattern of antenna. Mismatch of Phase and Gain for RISAT-1 Active Array Antenna has been measured with a special technique which involves measurement with a single linear scan in the near-field of antenna. Each element of the array is illuminated sequentially and gain/phase history of the same is measured in the Near-Field for fixed probe position.

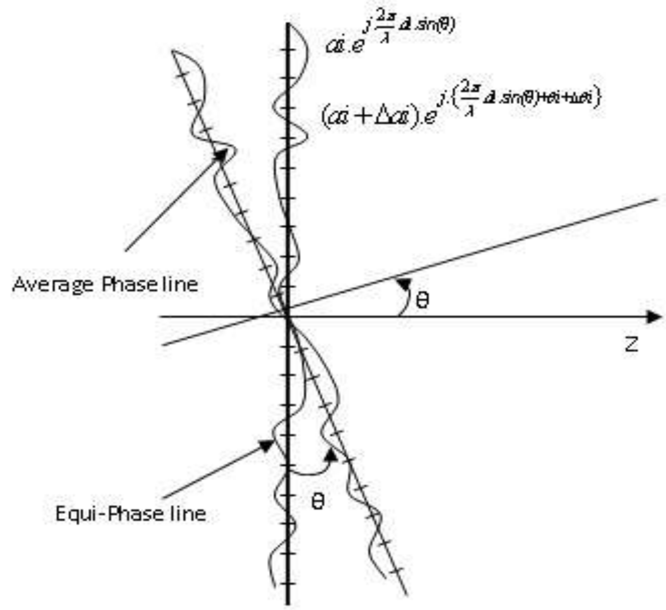


Fig.-10: Phase errors over antenna aperture

With Collimation Errors **Without Collimation Errors**

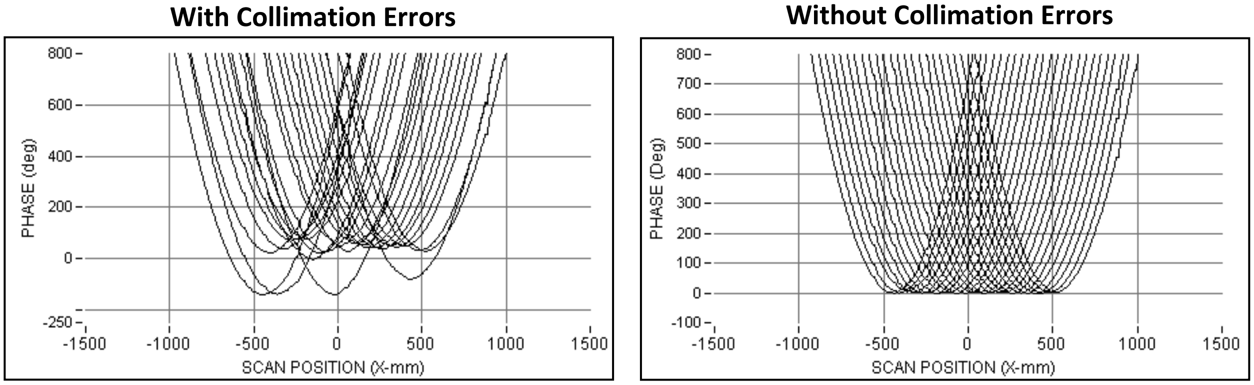


Fig.-11: Insertion phase error of 24 T/R Module corresponding to single antenna tile

This process is repeated for each probe position in the Near-Field while the probe is linearly scanning the aperture of antenna. Collimation of antenna elements is achieved by adjusting digital phase/gain control of each array element.

With Collimation Errors **Without Collimation Errors**

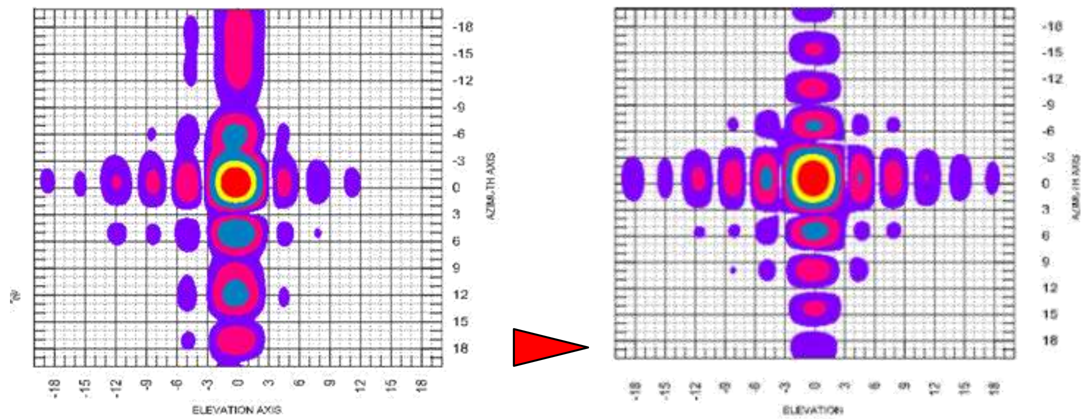


Fig.-12: Far-Field response of single antenna tile for 0^0 Pointing

8. Validation Of RISAT-1 PNF (Custom Built) Antenna Testing Facility: RISAT-1 PNF antenna test facility carries custom built hardware for scanning and software for control, data capture, pre-processing and post processing. Although radar hardware was used as receiver, data processing involves lot transformation. Instead of absolute calibration of test facility, relative calibration was an easy option. RISAT-1 PNF facility was validated by comparing test results of a single passive antenna tile of 1mX1m with a standard CATF facility results. Table-2 shows test result comparison of both the facilities. As CATF facility measures antenna pattern in far-field, RISAT-1 PNF facility data output was processed to compute far-field which involves Match filtering and time gating, Holographic back-projection and far-field transformation.

Table-2: Antenna Parameter Comparison of RISAT-1 PNF with standard CATF

Measurement Facility	**Azimuth**	**Elevation**				
	Left Peak Sidelobe (dB)	**Right Peak Sidelobe (dB)**	**Beam Width (deg)**	**Left Peak Sidelobe (dB)**	**Right Peak Sidelobe (dB)**	**Beam Width (deg)**
CATF (Standard)	**-13.6**	**-13.9**	**2.82**	**-11.3**	**-16.2**	**2.83**
RISAT-1 PNF Facility	**-13.7**	**-14.07**	**2.85**	**-11.91**	**-16.17**	**2.85**

Results show a close match for Peak sidelobe and beamwidth. ISLR and gain could not be compared as CATF facility has limited scan beyond second sidelobe and for PNF facility, in general, absolute gain measurement contains errors. Active antenna tile (24 T/R Modules), in transmit mode, was also validated for near-field holographic accuracy by "RISAT" mask, as shown in Fig.-13. width of mask characters is as close to λ (wavelength) at C-band.

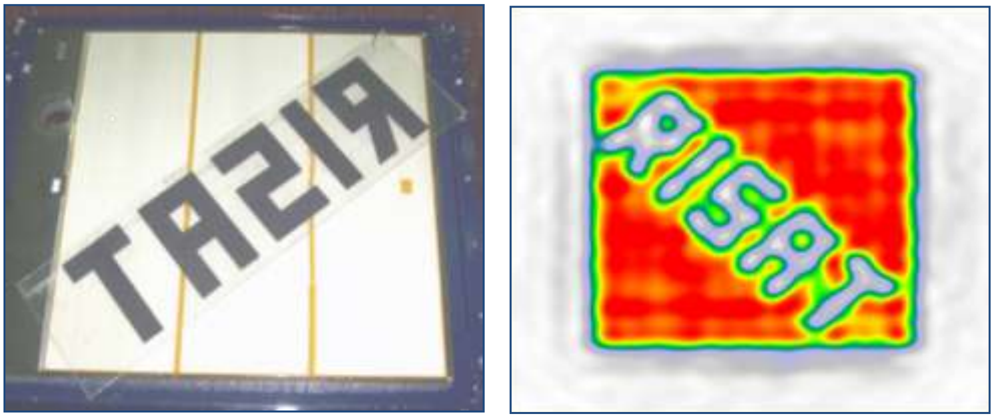


Fig.-13: RISAT-1 PNF facility results for "RISAT" mask in front of antenna tile aperture

9. Measurement Of RISAT-1 Tiles, Panels And Full (6mx2m) Antenna Pattern: RISAT-1 Antenna was tested at three levels namely (a) Tile testing for 12 tiles of 1mX1m (b) Panel testing for 3 panels of 2mX2m and (c) Full antenna testing of 6mX2m. Correction factor for all 288 T/R Modules was measured and fused into Payload Controller (PLC) PROM. Active array antenna is not reciprocal by hardware design, separate transmit and receive calibration and testing is required. RISAT-1 Antenna was tested for 24 beams out of total 128 (64 left side looking and 64 right side looking). All these patterns were calibrated for transmit and receive pattern, as correction coefficient of each T/R Module is different for transmit and receive paths.

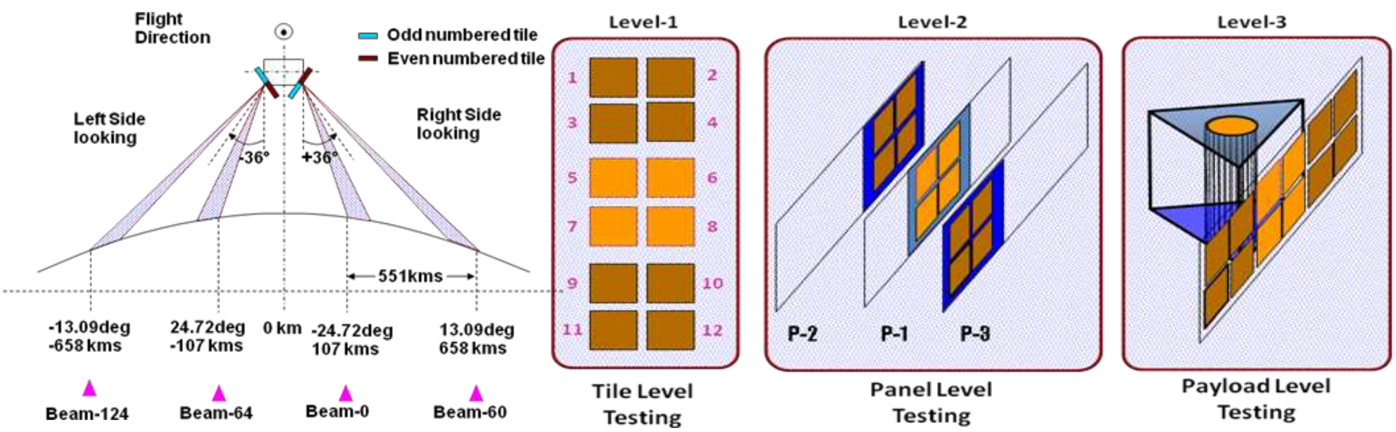


Fig.-14: (a) RISAT-1 Antenna field of View (b) Tiles, Panels and Full Antenna Testing

As RISAT-1 PNF test facility is capable of measuring 12 beams simultaneously, two sessions of scanning antenna aperture were carried out. Fig.- 15 shows typical results of near field hologram and computed far-field of RISAT-1 antenna panel with zero-pointing and 24.5 degree pointing.

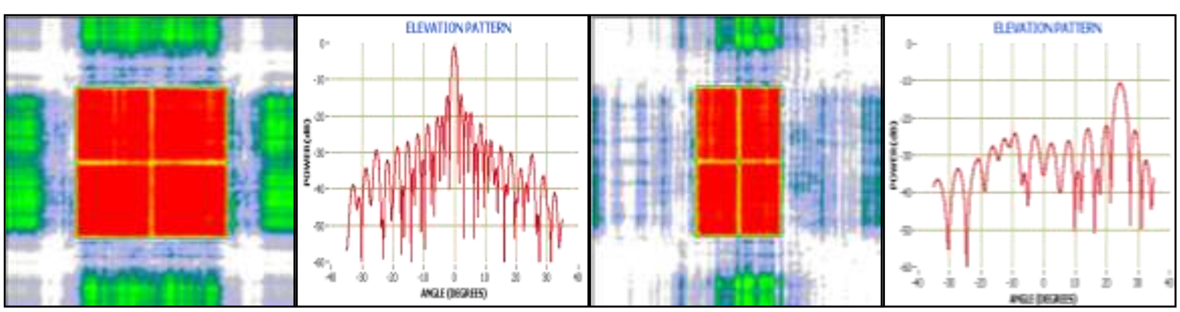


Fig.-15: Hologram & Far-Field pattern of RISAT-1 Antenna Panel 2mX2m for 0^0 and 24.5^0 Pointing

Fig.-16 shows deviation of Transmit and Receive patterns and Fig.-17 shows typical antenna patterns for left side look direction of antenna computed from measured near-field antenna pattern.

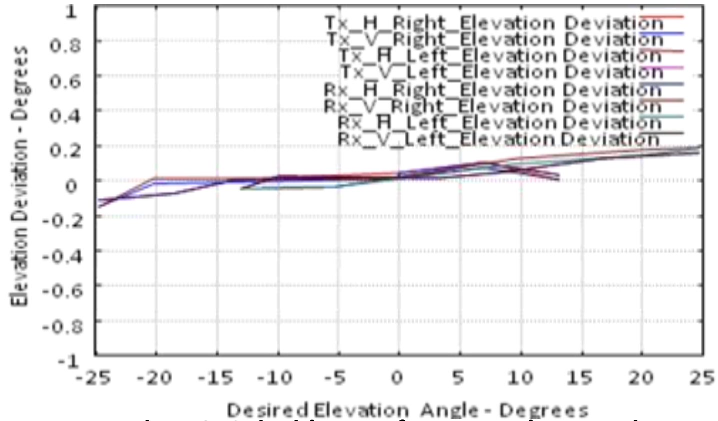


Fig.-16: Coincidence of Measured Transmit and Receive beams for RISAT-1 Antenna

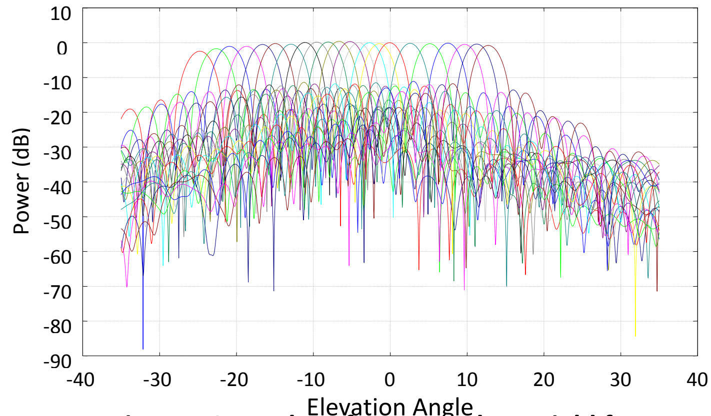
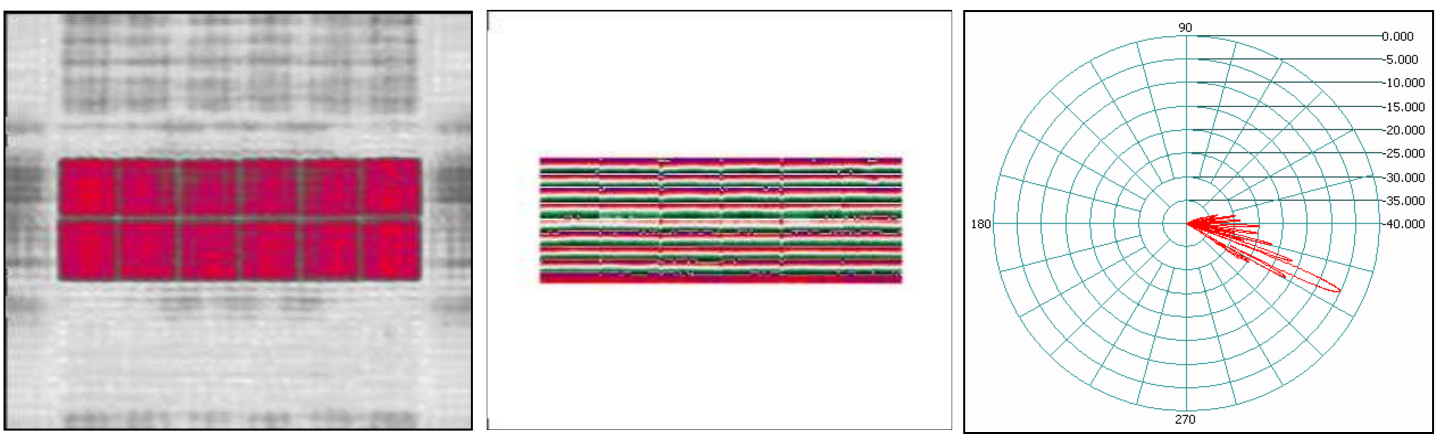


Fig.-17: Over plot of computed Far-Field for Left side look direction of RISAT-1 Antenna

RISAT-1 Antenna aperture hologram for Gain and Phase was analyzed for extreme pointing with 24 discrete steps, where rest 104 (128-24 = 104) patterns were predicted by software modelling. Validation of prediction was done by comparing derived results with practically measured results. Fig.-18 shows Magnitude and phase hologram of full antenna 6mX2m with zero-degree pointing and Fig.-19 shows Magnitude and phase hologram of full antenna 6mX2m with -24.5 degree pointing.

Fig.-18: (a) Magnitude Hologram (b) Phase Hologram (c) Computed Far-Field Pattern for 0^0



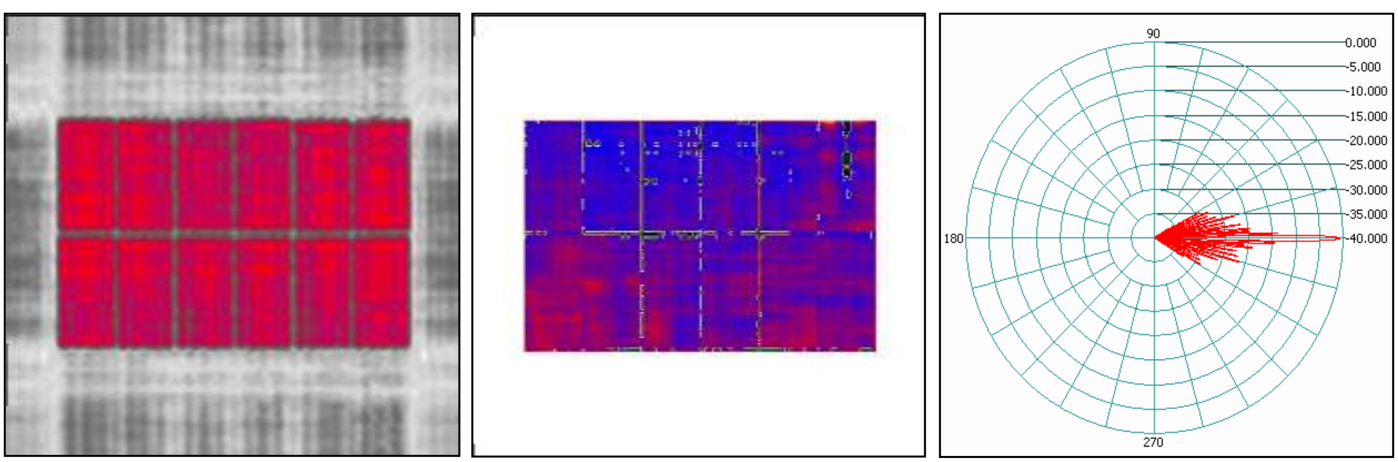


Fig.-19: (a) Magnitude Hologram (b) Phase Hologram (c) Computed Far-Field Pattern for -24.5^0

Table-3 shows typical results of Transmit-H pattern of 6mX2m antenna and comparison of desired and achieved pointing. Results show a close match of pointing with errors in 1/200th part. Elevation and Azimuth pointing error contains mechanical alignment error as major contributor and computational error as minor part. Scan loss contains antenna aperture illumination (electrical width change to keep ground swath same) as major contributor and antenna patch pattern convolution as minor contributor.

Table-3: Typical results of RISAT-1 Antenna for Transmit-H-Left Side Pointing

Desired Elevation (deg)	Achieved Elevation (deg)	Achieved Azimuth (deg)	Elevation Beam Width (deg)	Azimuth Beam Width (deg)	Azimuth Side lobe (dB)		Elevation Sidelobe (dB)		Scan Loss (dB)
					Left	Right	Left	Right	
-13.09	-13.05	-0.04	1.44	0.48	-11.72	-12.87	-13.87	-12.59	-0.85
-5.41	-5.38	-0.01	1.41	0.45	-11.87	-12.91	-13.06	-13.02	-0.44
9.60	9.48	-0.04	2.07	0.48	-11.74	-13.18	-11.88	-12.27	-3.96
20.24	20.07	-0.04	2.43	0.48	-11.59	-13.45	-12.13	-11.62	-4.91
24.72	24.54	-0.04	2.73	0.48	-11.35	-13.03	-11.80	-11.52	-6.05

10. Conclusion: RISAT-1 Antenna testing and characterization has created a new standard of PNF testing in Pulsed Domain. Although validation of RISAT-1 PNF Facility was time consuming but it has opened doors for new and effective methods of Active Array Antenna Testing.

Pulsed domain antenna testing ensures measurement of antenna pattern over full bandwidth of operation while using radar hardware as transmitter and receiver for near-field measurement. This type of antenna testing results in cheaper antenna testing and eliminates need of anechoic chamber by using time gating technique to eliminate unwanted reflections.

As discussed in section 7.3, collimation correction coefficient measurement of an active array antenna in the near field facility by single linear scan of probe, has eliminated the inaccuracies in the measurement due to the overlapping of Impulse response of individual array elements and has greatly enhanced the time span of calibration of an active array antenna.

Challenges of RISAT-1 SAR Integration and Testing

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ABSTRACT: Radar Imaging Satellite (RISAT-1) is a multi resolution/ multi-swath /multi-polarization synthetic Aperture Radar (SAR) which was launched on 26th April 2012 and has been performing with highest data quality since launch. This satellite is multimode SAR which operates from a sun synchronous orbit at a nominal altitude of 536kms. Basic imaging modes are Coarse Resolution ScanSAR(CRS) with 50m (12 beam) resolution operation, Medium Resolution ScanSAR (MRS) with 25m (6 beam) resolution operation, Fine Resolution StripMap (FRS) with 3m and 6m resolution (single beam). All these modes can be operated in Linear as well as Circular Polarization. There is also a special operation mode called High Resolution Spotlight Mode (HRS) which has been kept as an experimental mode of operation and provides a sliding spotlight image of 10 km x 10 km with better than 2m resolution. RISAT-1 is configured on a dual receiver concept providing identical resolution and swath in co- and cross-polarisation. The system is configured around a dual polarized active antenna with 288 radiating elements. 6mx2m antenna is configured in three identical panels, of which the central one is fixed and rest two are deployable. Each of the panel consists of 4 tiles of size 1mx1m each. The earth viewing part of the antenna is a printed microstrip patch array. TR modules, each with maximum pulse power capacity of 10 watts, are mounted on the back side of the antenna.

RISAT-1 SAR being first space borne radar with active array antenna, demanded lot of new engineering techniques and technological development in Integration and Checkout, so that radar is characterised to its full performance in time effective manner. New techniques of testing which evolved during integration and testing are (1) Pulsed Domain Antenna Testing (2) Sleek and light weight PNF Antenna testing facility with customized in-house hardware and software development (3) Equalized near-field holographic software algorithm (4) Customized Far-Field software development for customized PNF test facility (5) Efficient technique for active array antenna collimation coefficient estimation, measurement and correction (6) Accurate Antenna Pattern estimation algorithm and software development.

As RISAT-1 antenna of 12mX6m was developed in 12 parts of 1mX1m each called antenna Tile, each tile was tested in sequence, so that integration of next tile was time overlapped with the testing of previous one. This staggering of integration and testing operations was repeated for antenna Panels (3 No.'s) of 2mX2m size. One antenna tile was also subjected to sun-simulation test to get confidence of thermal balance during operation.

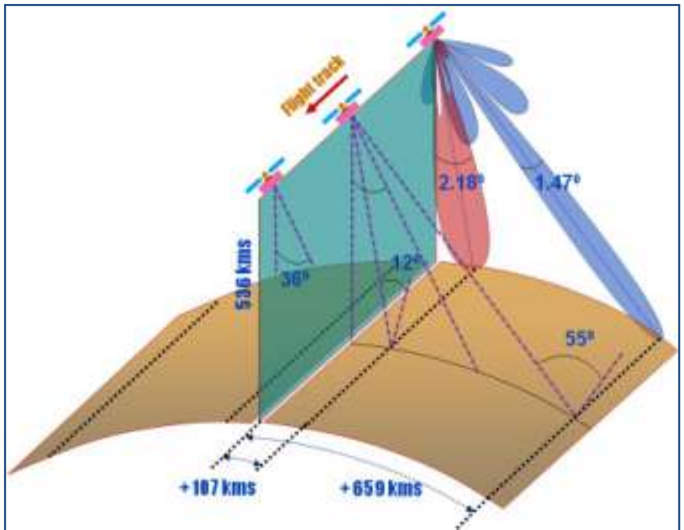


Fig.-1: RISAT-1 Antenna Beam Pointing

RISAT-1PAYLOAD NTEGRATION PHILOSOPHY: In order to facilitate integration and testing, RISAT-1 antenna having 12mX2m size was divided into 12 parts of 1mX1m each. Payload was integrated in phases to coincide the activities with hardware delivery to integration lab. Integration sequence of antenna tile and panel was validated on dummy wooden model and one DVM tile was also integrated validate integration and testing sequence. Tile and Panel antenna fixtures were designed and developed in-house. Fig-2(a) and 2(b) shows integration and testing sequence of RISAT-1 payload.

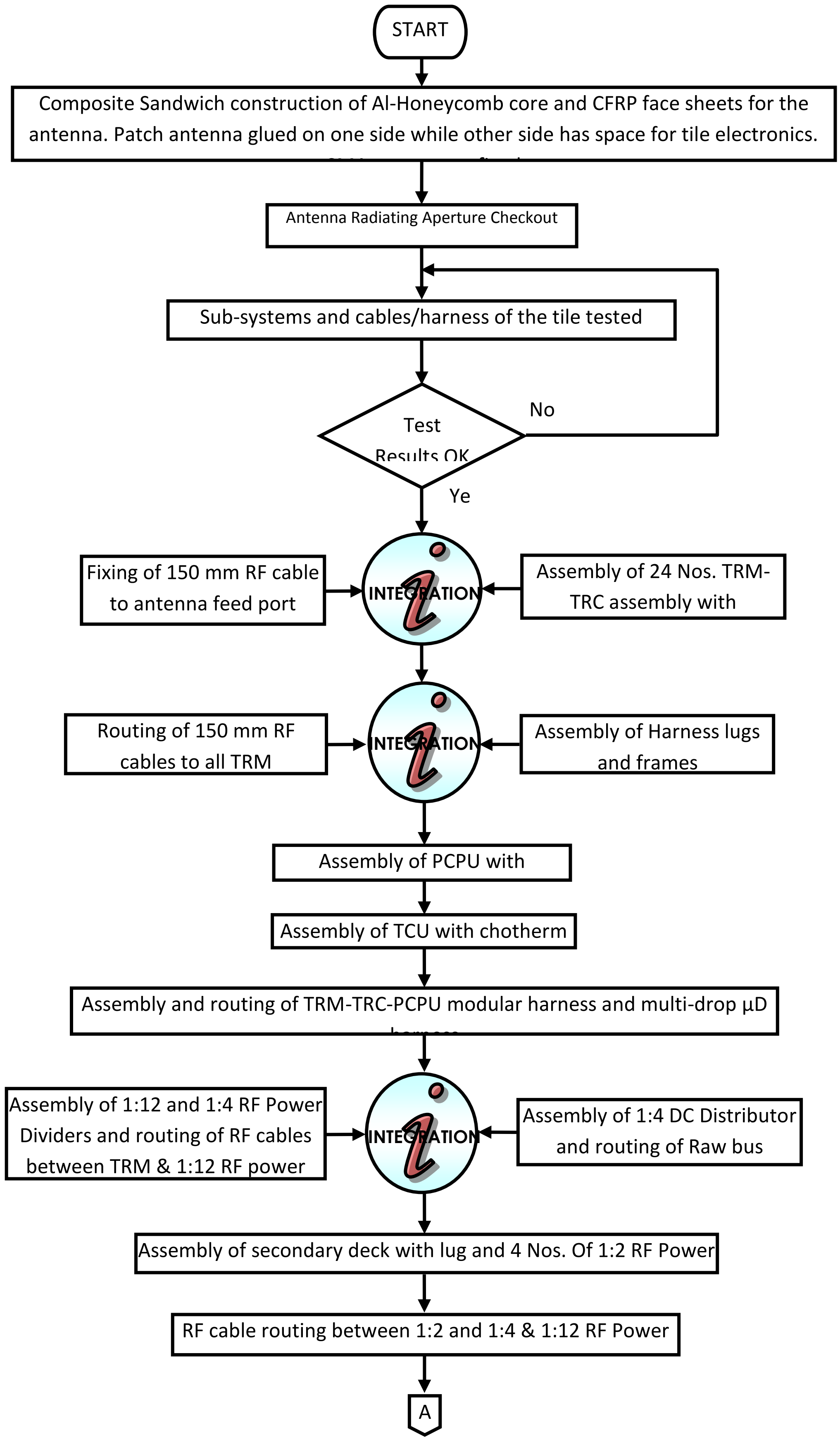


Fig.-2(a): RISAT-1 Integration and testing Sequence

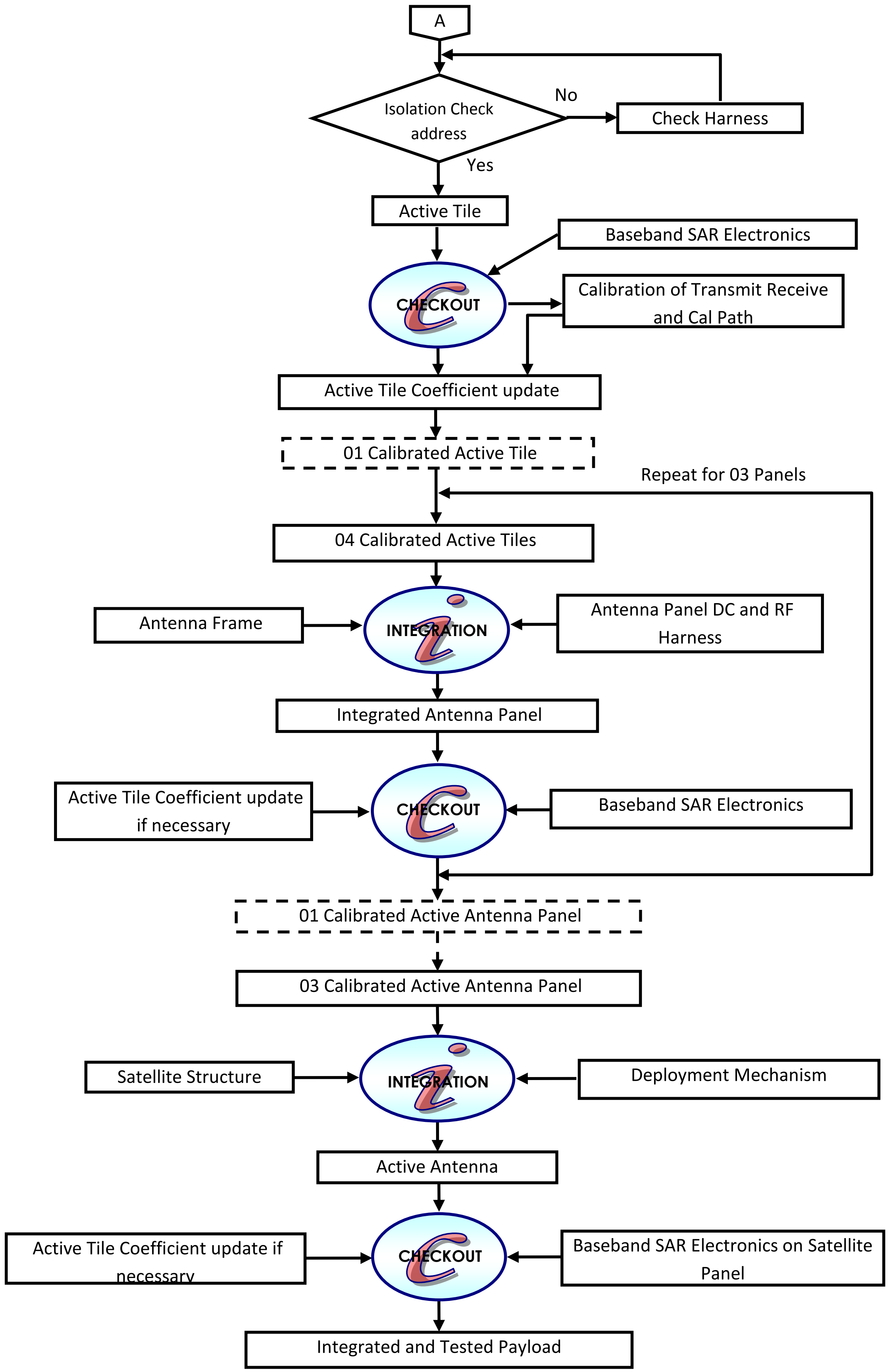


Fig.-2(b): RISAT-1 Integration and testing Sequence

RISAT-1 DVM AND FM INTEGRATION & TESTING: RISAT-1 payload DVM electronics was integrated for deck elements and one antenna tile of 1mX1m size carrying 24 TR Modules in V and H. Although DVM antenna tile was not subjected to thermovac and sun-simulation, antenna measurement was carried out in PNF (custom built RISAT PNF Facility) for pattern evaluation. Fig.-3 shows integrated DVM antenna tile without harness routing. Purpose of DVM integration of RISAT-1 deck elements was to understand and validate:

a. PLC Software Validation - Finalization of Correction data format, Communication Protocol Validation and Signal Integrity

b. DACS Software Validation - BAQ Validation, Data Format Verification

c. DCG Software Validation - Chirp Rate and IQ Imbalance for Phase and Gain.

d. Receiver Hardware and Interface Verification - IQ Imbalance and Noise Figure(NF)

e. FG Hardware and Interface Verification - Frequency, IQ Modulator Parameters

f. Solid state power amplifier (feeder-SSPA) Hardware Interface, Gain flatness over bandwidth and droop Verification.

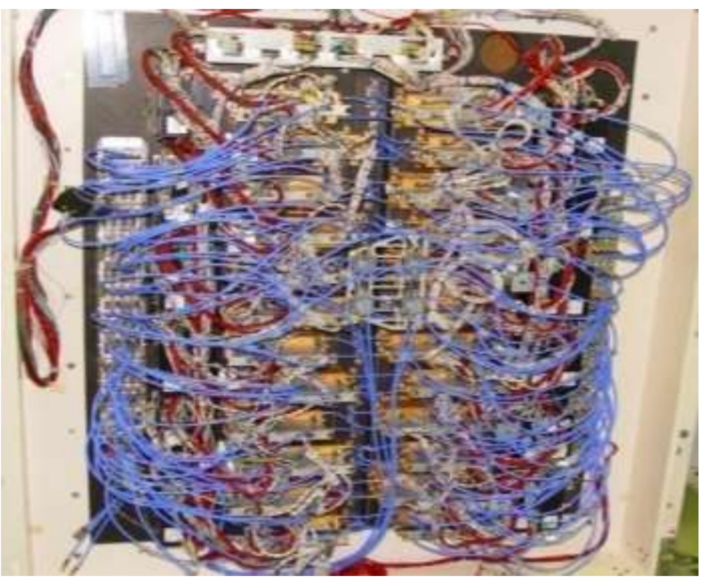


Fig.-3: DVM Antenna Tile of RISAT-1

Purpose of DVM integration of RISAT-1 deck elements was to understand and validate:

a. TR Module Hardware Interface and operation qualification

b. Tile controller and TR Controller Hardware Interface and software qualification

c. TR Module Power Supply (PCPU) performance qualification.

Hardware and software changes were done multiple times to achieve final performance. Subsequent to DVM integration and testing, RISAT-1 FM deck elements were

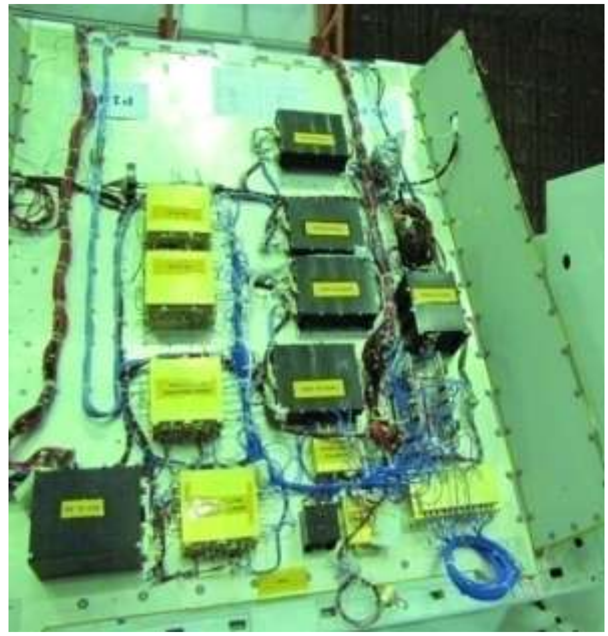


Fig.-4(a): RISAT-1 SAR Deck Elements Integrated on Dummy Panel

Fig.-4(b): RISAT-1 SAR Deck Elements Integrated on FM Panel

integrated and tested on Dummy FM panel received from ISAC Bangalore. Fig.- 4(a) shows SAR deck electronics integrated on Dummy Panel, while Fig.-4(b) shows SAR deck electronics integrated on FM Panel. Integrated SAR-Deck electronics was tested in loop-back (without active array antenna) to evaluate system-noise-figure, data integrity and other related parameters.

Fig.-5 shows partially integrated antenna tile of 1mX1m size with 24 TR Modules for V and H. Modular harness was designed to interconnect TR Module V, TR Module H and TR Control along with Power Supply (PCPU).

Fig.-6 shows fully integrated antenna tile with 48 antenna feed elements rows connected with MF141 cables, eight 1:12 RF power dividers and four 1:2 RF power dividers. Each tile after integration was subjected to characterization in RISAT-1 PNF. Testing process included,

1) CAL mode testing to evaluate Collimation correction coefficients
2) Validation of collimation coefficients
3) Full Near Field scan to evaluate H and V Patterns
4) Hologram Computation and Evaluation for Antenna Aperture Phase and Gain flatness
5) Far-Field pattern computation and PSLR/ISLR evaluation.

PAYLOAD SYSTEM CHECKOUT PHILOSOPHY

RISAT-1 spacecraft level testing can be broadly categorized as three activities, of which, payload testing and characterization is single part as:

1. Payload Integrated Level Test
A. Payload Functional Testing
a. Digital Timing, Data integrity and communication
b. Analog/RF Level (I/Q Imbalance, Noise Figure)
B. Antenna Integrated Patten Measurement
2. Space-Craft Level Testing
3. Thermovac Level Testing

RISAT-1 system was sub-divided into two major parts, namely (1) Active array antenna and (2) Deck sub-systems, as far as system checkout and characterization is concerned. Checkout instrumentation, automation and software development was carried out in-house. As RISAT-1 active array antenna needed testing and characterization at each level of integration, Tile and Panel level testing was staggered with integration sequence. since RISAT-1 antenna testing was carried out with the help of baseband transmitter as signal source and receiver as signal capturing system, deck elements were integrated first and tested in a standalone fashion (loop-back) so that baseband electronics is ready for antenna testing. There was no-use of VNA or any external instrument for active array antenna testing. Fig.-8 shows stages of RISAT-1 payload testing; shaded cells indicate testing at spacecraft level.

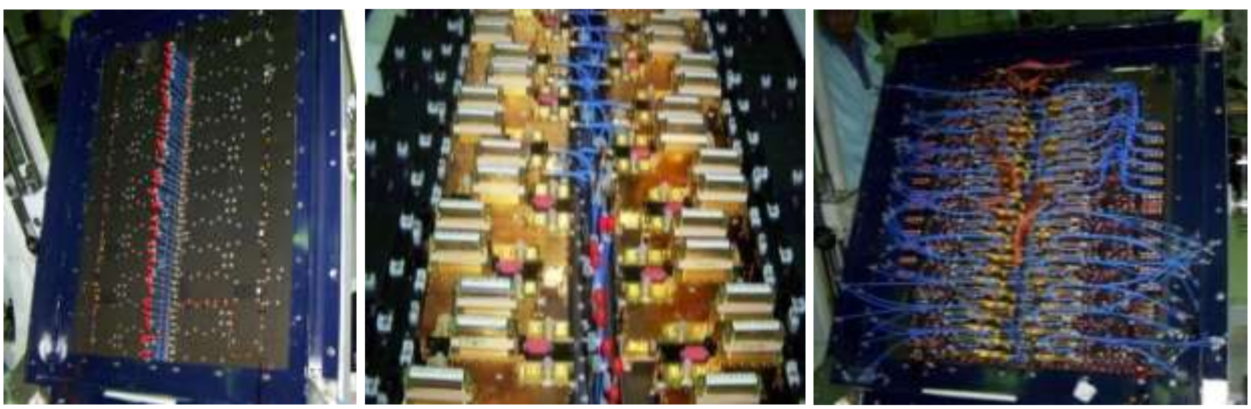


Fig.-5: Partially integrated RISAT-1 SAR Antenna tile on FM CFRP structure

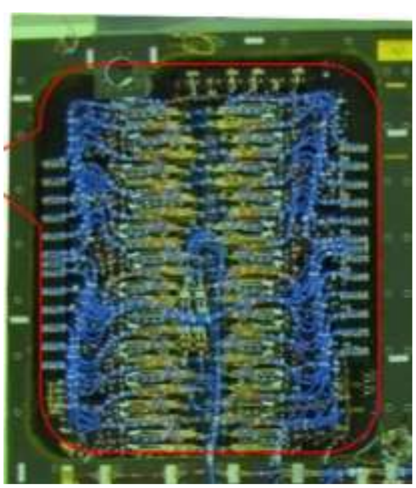


Fig.-6: Fully Integrated Antenna tile 1mX1m with 24 TR Modules for H and V

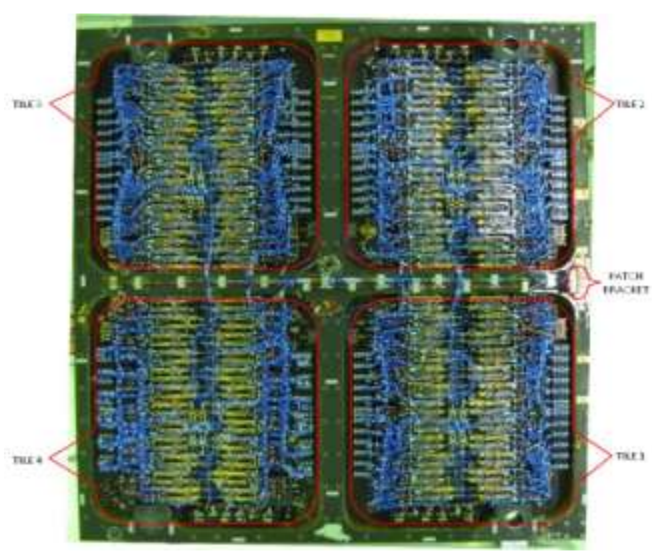


Fig.-7: Fully Integrated RISAT-1 SAR Antenna Panel 2mX2m with 96 TR Modules V and H

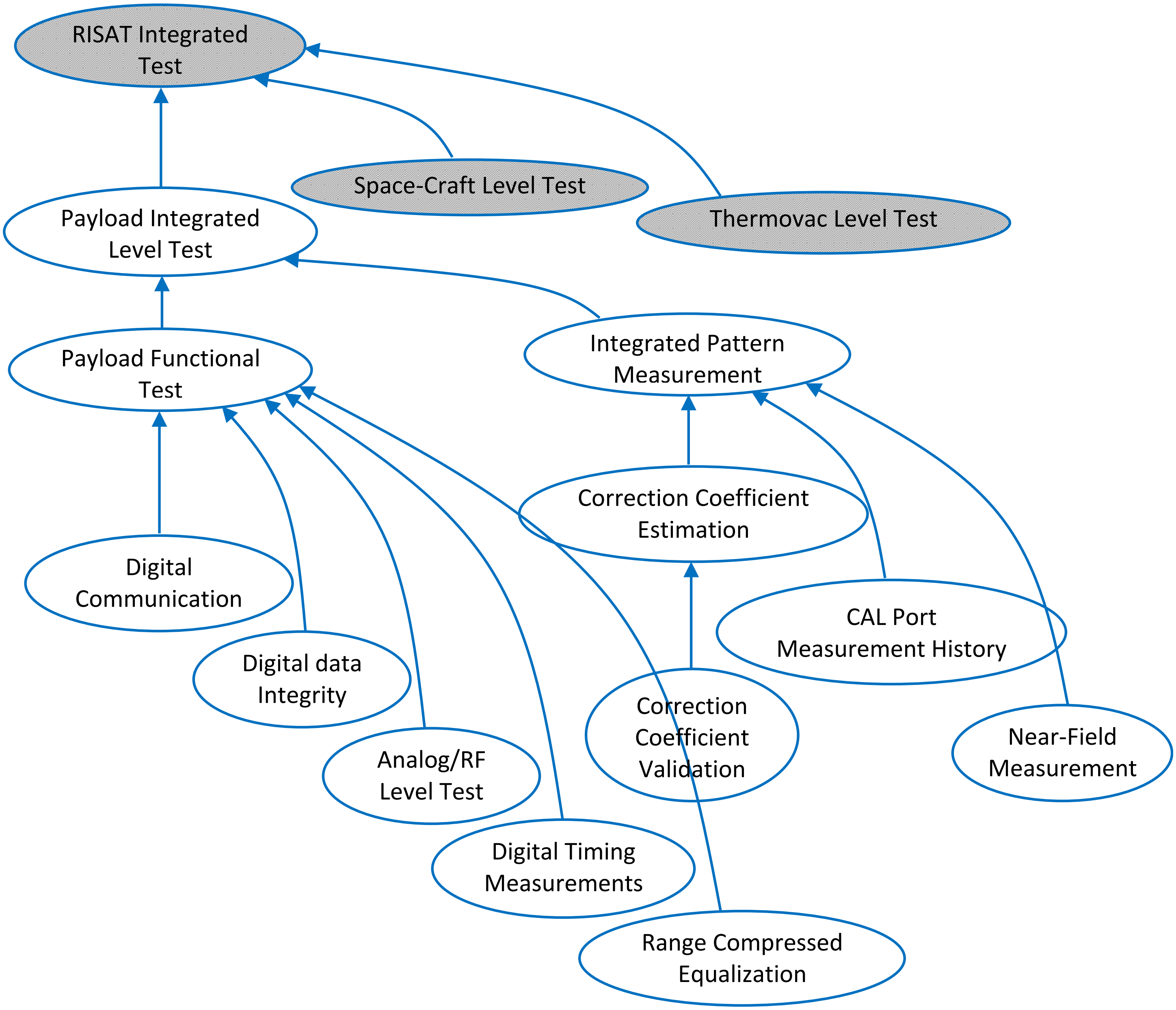


Fig.-8: Stages Of RISAT-1 Payload testing

Level-1 testing, as mentioned above, was completed at SAC, where other two levels were completed at ISAC, bangalore. RISAT-1 Payload Functional testing includes measurement of performance for Analog/RF and Digital elements of all the payload elements in integrated mode for main and redundant elements on the deck and antenna. Although RISAT-1 systems were tested in integration lab on individual basis, T&E was carried out separately for integrated payload. Fig.-9 shows interleaving of integration and checkout activities for RISAT-1 Payload.

RF-CABLE FABRICATION AND MEASUREMENT

Active array antenna of RISAT-1 required group-delay matched cables for each radiating element (TR Module). Distribution of RF signal to each antenna element goes through equal path delay (group delay) in the present corporate feed network incorporated in RISAT-1 design. Since total signal path to each antenna element, measuring to 10mts (approximately), goes through four RF power dividers and seven interconnections, maintaining equal path length (group delay) for each antenna element becomes a difficult task. Since group delay is a function of path length of cable, each cable (segment) was cut in equal length and SMA connector soldering was handled by skilled persons to avoid any change in the quality of cables.

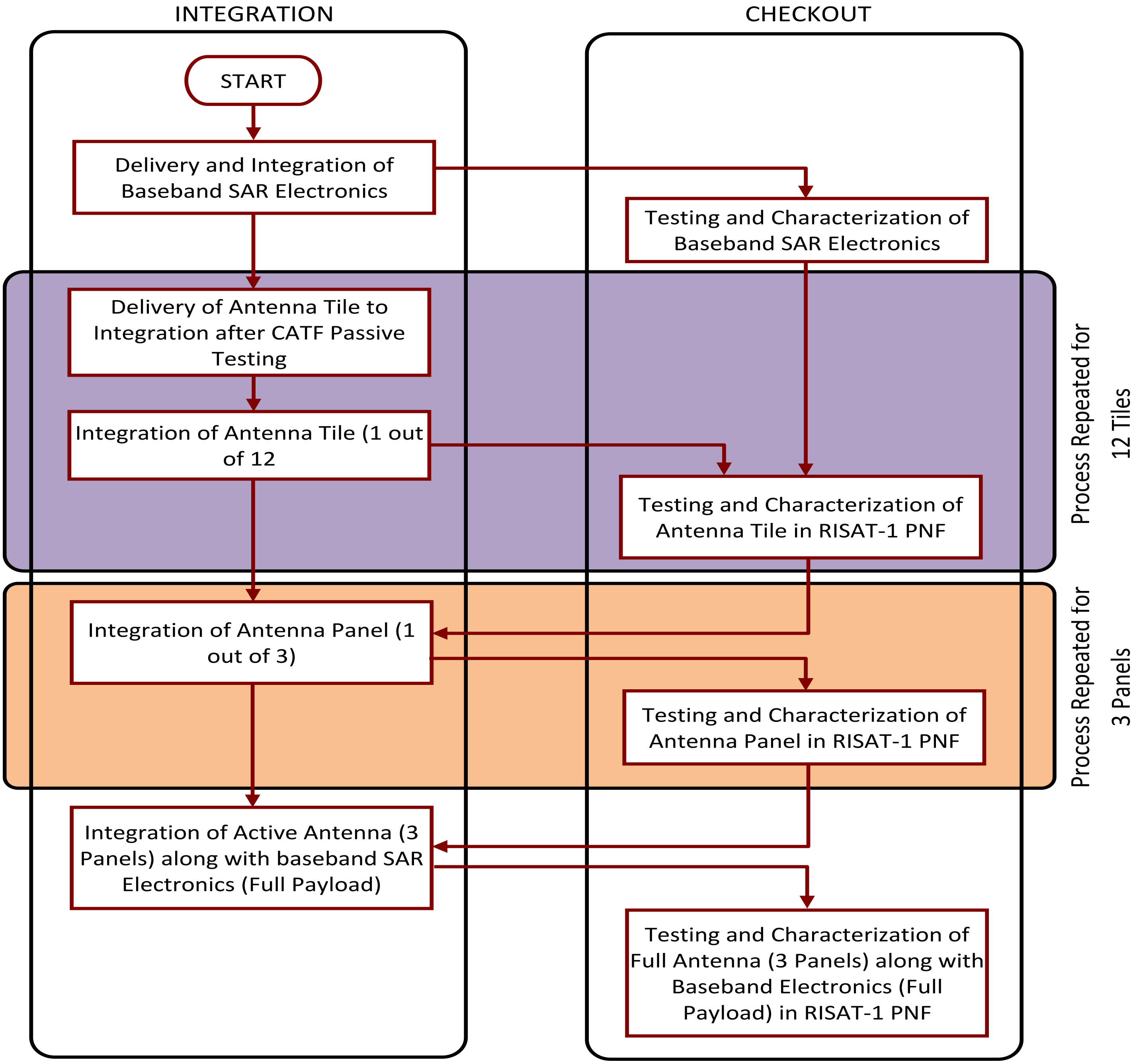


Fig.-9: Interleaving of RISAT-1 Integration and testing activities

Group delay matching requirement of cables was computed as 4e-9sec over the total length of 10mts. Cable and connector selected were based on the ISRO experience of TES phased array antenna, developed by ISAC. Due to stringent delay matching requirements, the fabrication process adopted by ISAC was further improved and sample assemblies were made and tested. As the requirement of the number of RF cables was very large, it was decided to carry out the fabrication partly in-house and partly at the vendor's site. Fabricators from the vendor's company were trained for this precision fabrication at SAC. A special tool was designed indigenously for precision cutting of the RF cables. During this entire fabrication period, coordination was maintained between SAC Fabrication facility, vendor and R&QA, SAC at various stages.

A new test method to measure cable delay with pico-sec accuracy was developed by SAC-ISRO and copyright was obtained for same. The standard VNA (HP8510C-Aglient make) was being used for the cable measurement and software was developed to suitably filter data and analyze it in terms of delay. The measurement process was rigorously tested for its consistency.

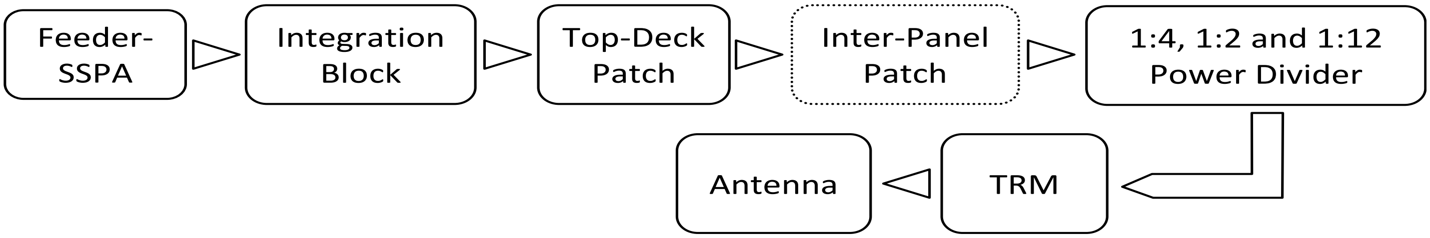


Fig.-10: RF signal (cable) distribution for active array antenna

<u>MODULAR HARNESS FABRICATION FOR ACTIVE ARRAY ANTENNA</u>

RISAT-1 flight model (FM) antenna harness design consisted of 1260 D-sub connectors and 648 micro-D connectors. Realization of this involved a tremendous amount of effort and man-power. Looking into the project schedule, it was planned to off-load the modular harness fabrication between TR Module, TR Control and Power Supply to outside industry.

Fig.-11: Precision cutting tool for RF Cables

Although Fabrication was managed by a contract between SAC and a vendor, measurement of fabricated harness was carried out at SAC. A customized test jig was designed and developed for the same. To visualize the problems associated with such complex and high density harness, 1:1 flight model dummy tile was fabricated which was used for flight model harness fabrication and layout finalization. RISAT-1 flight model harness layout routing, anchoring and flattening plan was finalized on dummy model. Fig.-13 shows a set of Modular Harness used on active array antenna between TR Module, TR Control and Power Supply.

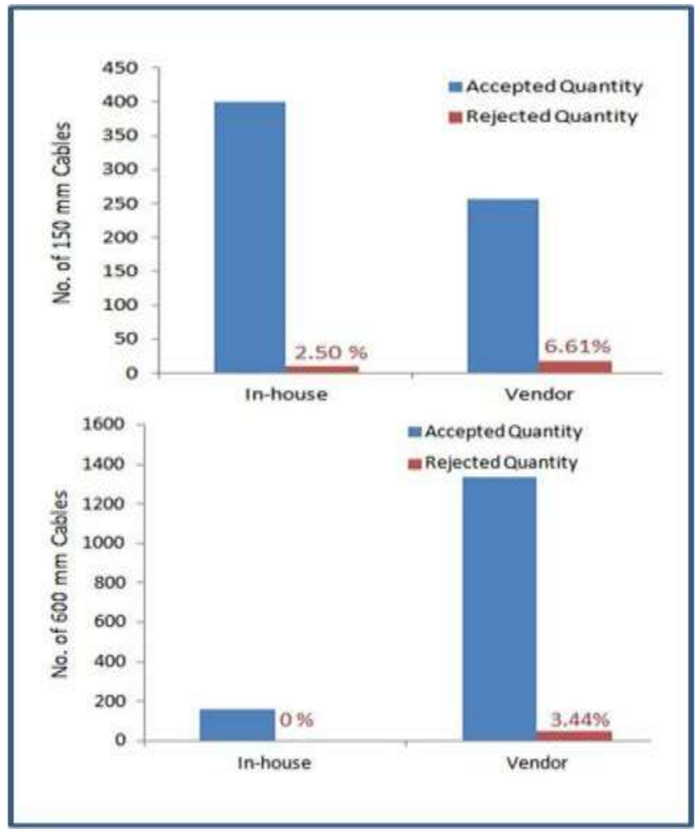


Fig.-12: RISAT-1 RF Cable (MF141) Fabrication Statistics

Fig.-13: Modular Harness for Active Array Antenna

MECHANICAL & GROUND SUPPORT SUBSYSTEMS

In order to carry out the assembly and testing of RISAT-1 Deck and Active Array Antenna, during different phases of integration, numbers of mechanical ground support subsystems were required. Some of them are conventional while few are payload specific. Following specific support subsystems were identified, designed and developed by SAC:

1. Tile/Panel Integration, handling and Testing Fixtures.
2. PNF with 3-Axis Scanner System for Active antenna testing.
3. Tile/Panel Storage Fixtures

Fig.- 14(a), (b), (c) and (d) shows mechanical ground support handling and mounting fixtures to facilitate integration and testing of RISAT-1 payload and active array antenna.

Fig.-14(a): FM-Tile Integration Fixture

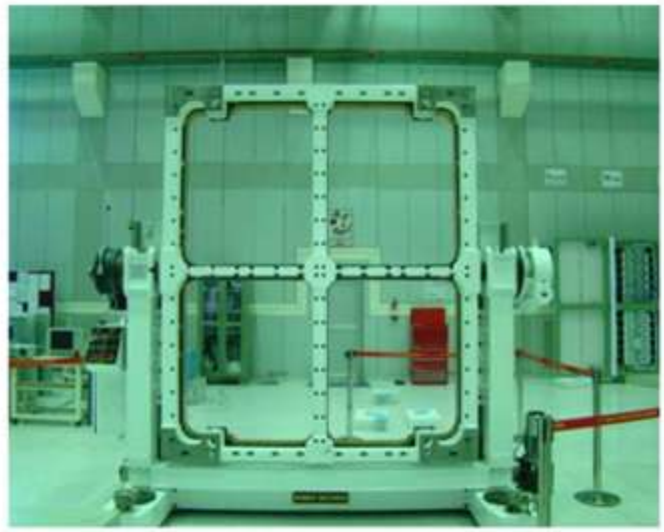


Fig.-14(b): Antenna Panel Integration Fixture

Fig.-14(c): Antenna Tile Storage Fixture

Fig.-14(d): Antenna Tile/Panel Testing Fixture

PREPARATION OF RISAT-1 PAYLOAD (ANTENNA) FOR NEAR-FIELD TESTING

RISAT-1 Payload was integrated in clean room with dummy spacecraft frame for testing and transportation to ISAC-Bangalore. Antenna Panels were hinged across frame and deployed/stowed with the help of air suspension to create zero-gravity effect. Subsequent to integration, payload was transported to PNF chamber for antenna testing which was completed in six-steps as, Step-1: Payload integration in clean-room, panel deployment

Step-2: Antenna Panel Stowing and transportation to PNF Facility

Step-3: Alignment of Payload structure inside PNF facility

Step-4: Deployment of Antenna Panels and support system for antenna panels

Step-5: Near-field scanning of antenna in Transmit and Receive for H/V polarization.

Step-6: Antenna Panel Stowing and preparation for transportation to ISAC, Bangalore

First FM Antenna Tile integration was completed in January 2008. This development was crucial for smooth integration of succeeding tiles. This tile had successfully undergone electrical test at the near-field test facility developed at MRSA, SAC and subsequently, it had also successfully undergone for thermal balance, sine vibration and acoustic tests at ISAC, Bangalore.

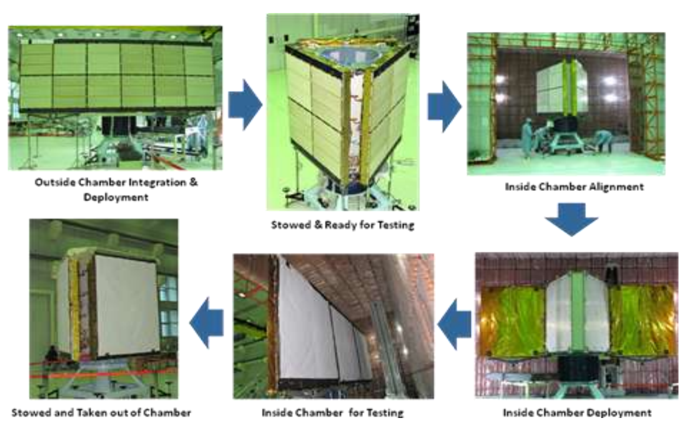


Fig.-15: RISAT-1 Payload Integration and Preparation for Near-Field Testing

Planning of the activities for panel level integration along with spacecraft integration, thermal and mechanism teams required precise sequencing of various activities. This was most crucial during this phase to ensure smooth and scheduled progress of the project. Mechanisms team had carried out the integration of deployment mechanism and subsequent deployment of SAR antenna panels at SAC. Deployment harness, both RF and digital, was realized at this stage. Fabrication and routing of these harnesses were carried out within very strict guidelines from mechanisms. Any error in this stage could have led to failure in panel deployment. At the same time, electrical constraints like equal length of cables etc. were also met while designing this.

In order to take out heat during near-field scanning operation, in absence of OSR, an air-blower mechanism along with feeding pipe structure was custom made. Fig-16 shows deployed antenna (electronics side) along with air-blow pipe structure and Fig. - 17 shows antenna single tile inside thermovac chamber during sun-simulation test at ISAC, Bangalore.

Fig.-16: RISAT-1 Payload inside PNF along with Air-Blow pipe structure

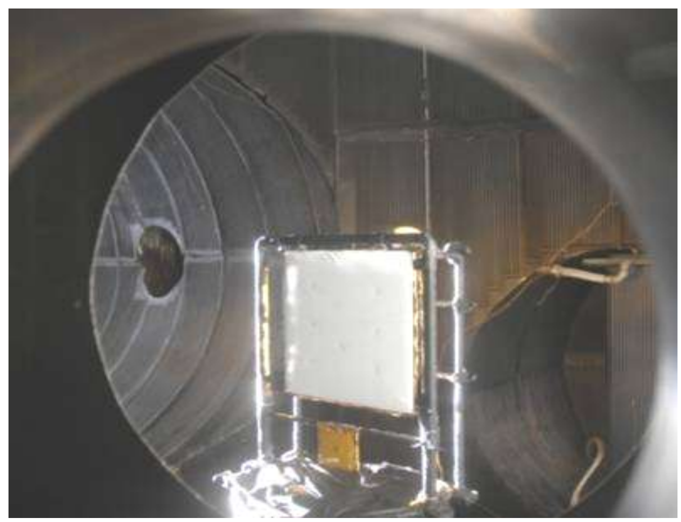


Fig.-17: RISAT-1 antenna tile during sun-simulation at ISAC Bangalore

ANTENNA NEAR-FIELD SCANNING SYSTEM

Near Field Antenna Measurement Setup based on Pulsed Domain Measurement concept for RISAT-1 Active Array Antenna consists of a 3D-Scanner, Controller and antenna fixture/holding mechanism. As hardware setup of this newly built facility is similar to general PNF facility, difference remains in the measurement principle, as mentioned earlier, involving Pulse Compression and Time Gating of Signal. Fig.-18 shows antenna Scanning column and (a) antenna fixture with single antenna tile of RISAT-1 Antenna and Fig.-19 shows fully integrated RISAT-1 antenna of 6mX2m being scanned in near-field. RISAT-1 Baseband Hardware was used as signal generator and receiver for antenna measurement in PNF.

Fig.-18: PNF with Antenna Single Tile

RISAT-1 Active phased array antenna works in pulsed mode which also applies to all other Synthetic Aperture Radars existing in world. Requirement for the near field measurement is the precise measurement of amplitude and phase front at a least distance of 10λ (λ is wavelength of operating antenna frequency) and most distance of $2d^2/\lambda$ from the antenna aperture. Measurement of signal phase and amplitude is a critical process and classically Vector Network Analyzed (VNA) is used to performs these measurements. Antenna aperture data collected in 2D format is then synthesized to develop far-field pattern.

Fig.-19: PNF with Fully integrated Antenna

A new technique was developed by SAC-ISRO for the measurement of Near-field which involves Match filtering and Time gating to eliminate unwanted reflections so that true antenna signal can be selected. Testing set-up requirement are two channel signal sampler of sufficient bandwidth, antenna input signal generator, Probe Antenna, 3D/2D Scanner and master timing Controller. Requirement of microwave absorbers is reduced by the use of FMCW pulsed signal, as compression filter output response resolves the signal reflected from all the targets. Match filtering is a standard technique utilized in imaging radars for range compression. Near-Field PNF measurement was validated by comparing Single Passive tile data with standard CATF Far-Field.

Active Array Antenna Pattern measurement in Near-Field was taken for 48 beams only (out of 512) while rest of the patterns were generated synthetically. Synthesized patterns were generated from zero-degree pointing and compared with practically measured patterns on sample basis. Table 1 shows typical results of practically measured antenna patterns and Fig.- 20 shows comparison of synthesized and practically measured patterns for pointing angle.

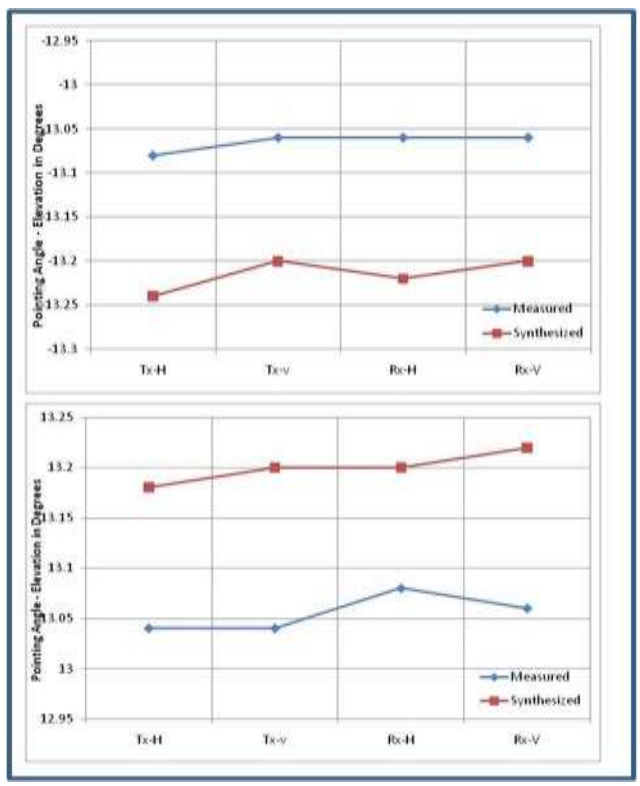


Fig.-20: Comparison of Practically Measured Antenna Patterns and Synthesized Pattern

TRANSPORTATION OF RISAT-1 PAYLOAD TO ISAC BANGALORE

To ensure safe transportation of the payload from SAC Ahmedabad to ISAC Bangalore anti-static cover was designed for the payload, which was grounded at grounding points provided inside the payload container. A convoy of 40 people, 10 vehicles was necessitated during transportation of RISAT Payload from Ahmedabad to Bangalore by road, which was covered in nine days, in most adverse weather conditions.

Fig.-21: RISAT-1 Payload being transported to Bangalore

Post shipment, payload was integrated and tested in ISAC clean room. No change in performance was observed. Following this SAR Payload elements were integrated on Space Craft FM Panel at ISAC, which was tested and cleared for further integration activities with spacecraft. All the interface checks and isolations checks were conducted for tiles, antenna panels and baseband SAR electronics panel, prior to integration of the payload with the spacecraft. Subsequently, payload antenna panels and spacecraft equipment panels were configured for disassembled mode spacecraft tests. This was done in an optimum way keeping losses of RF cables and voltage drop in DC harness in view.

Fig.-22 RSIAT-1 Antenna Panels in dis-assembled mode in ISAC Clean Room

Payload was integrated with the spacecraft stage by stage. In the first stage, Lambda power supply was removed and spacecraft power system was integrated with the payload. Then BMU simulator was removed and onboard OBC was integrated. Finally, recorder was removed and payload was interfaced with BDH unit. All the payload telecommands and telemetry status lines were checked during this phase. Heaters and thermistors on the antenna tiles and panels were also tested.

CONCLUSION

RISAT-1 payload integration and testing was done in an effective and time scheduled manner by sequencing integration and checkout activities. Handling of payload during integration, checkout and transportation was facilitated by innovative mechanical fixtures and handling systems. Results obtained during testing of payload in custom-built PNF facility were encouraging and payload functioning on-board confirms the same.

Mechanical Configuration, Integration and Checkout of RISAT-1 Payload

H. S. Bhalodi, K. R. Dave, SAC, ISRO

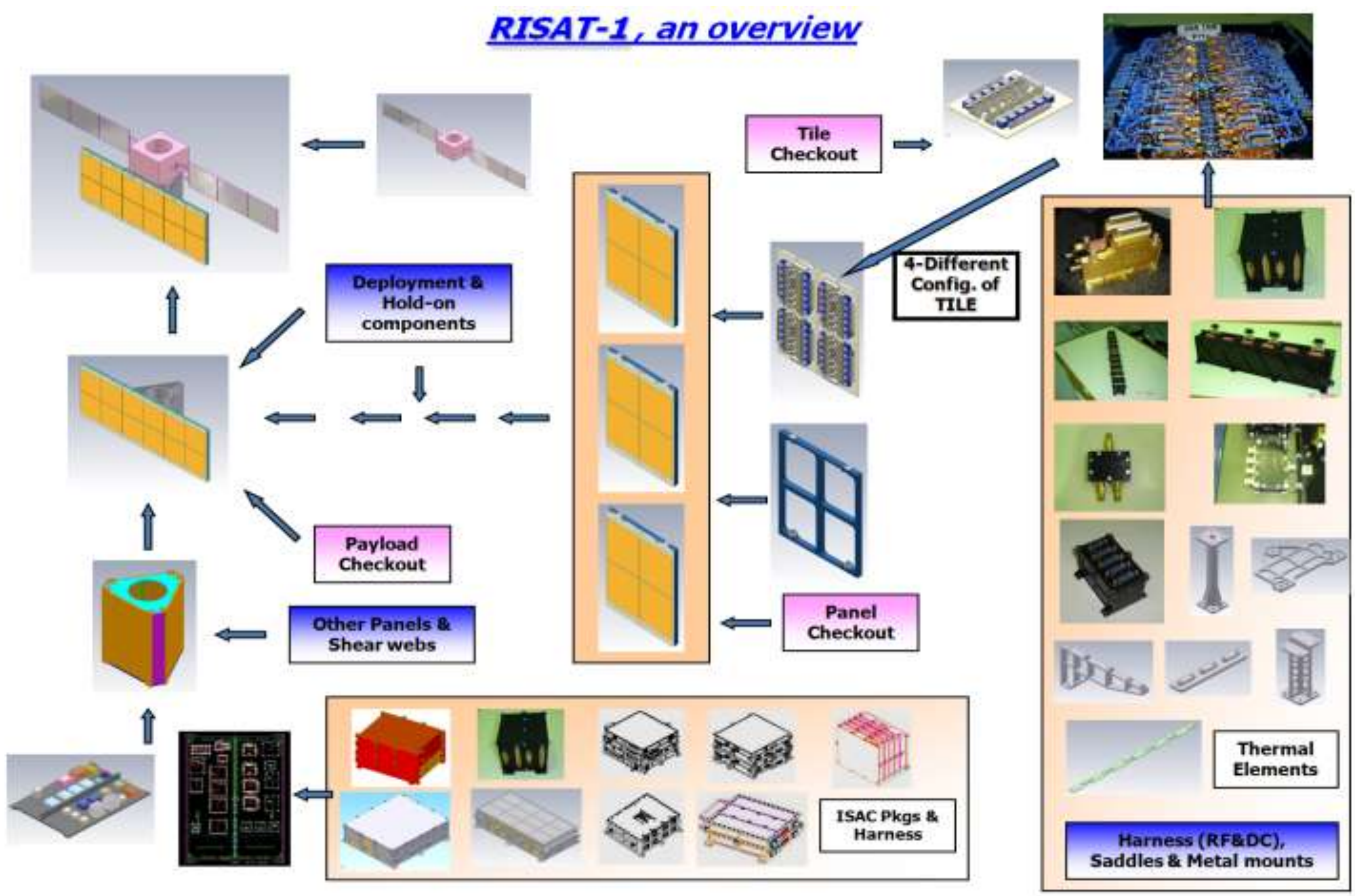
1. **Introduction:** The SAR system with an active phased array antenna is very complex in nature. It is amalgam of antenna, RF microwave and high speed digital electronics and therefore requires a totally different approach for system configuration, integration and testing.

Considering the mission parameters of RISAT-1, to fulfill the system requirements, feasibility of realization of subsystems/components, assembly, integration and launch, it was conceived the antenna of the size of 6 m X 2 m. Antenna was divided in 3 panels in deployable configuration. Further each panel was divided in four TILEs. This each Tile was considered as one base element of the whole antenna. Such 12 Tiles was made to generate whole antenna of 6m X 2 m.
RISAT-1 Payload was consisting of two major components.

- Deployable active antenna with active electronic subsystems on back of it. The active antenna consist multi layered Printed radiating aperture fabricated on one side of CFRP Honeycomb and on other side TR related complete electronics are integrated. This antenna was divided in 12 tile modules distributed in 3 panels in deployable configuration, from which one was fixed of support structure. On each panel, 4 Tiles were assembled on Panel structure made of CFRP Honeycomb. This has also provided electrical and mechanical interface for support structure, deployment mechanism and thermal control.

- RF and base band subsystems mounted on the spacecraft deck panel. The RF and base band subsystems are located on the Deck (EP-01) behind fixed panel of the triangular support frame on the spacecraft. This deck is located at the rear of the central panel of the active antenna to minimize the harness.

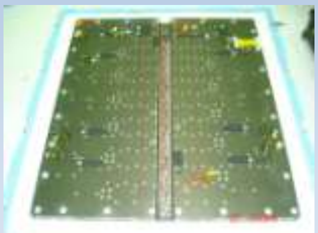
Overview of Configuration, Integration and Checkout activities is shown below schematically.



Configuration is one of the major activities in realization of such a complex Payload. To fulfill the requirements of the different aspects from the areas likes system, structure, thermal, assembly, integration, checkout, mechanism, spacecraft and launch and was required intensive interaction with the project team as well as other facilities/venders involved. It was also required to develop large number of Ground Support Mechanical Hardware like, Near Field Test Facility (NFTF), different types of fixtures (for Integration, testing and storage), Handling systems, containers and other components.

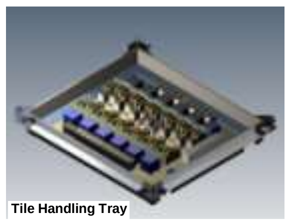
The major activities of realization with the required some of the major ground support mechanical hardware is shown below in order of sequence of the activities.

CFRP Tile Antenna



- **Tile with antenna container**
  - **Made of GFRP, Qty - 06**
  - **Fabricated by M/s Moonlight Fiberglass, Bhavnagar**

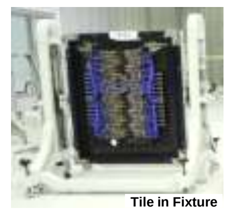
Integrated Tile



Tile Handling Tray

- **Tile Handling Tray, Qty - 12**
  - **Fabricated by M/s Atisha, Mumbai**
- **Tile Integration Fixture, Qty - 06**
  - **Fabricated by M/s Shree Mktg, Vadodara**
- **Tile Handling Systems, Qty - 01**
  - **Developed by M/s Parth, Vadodara**

Tile Handling System

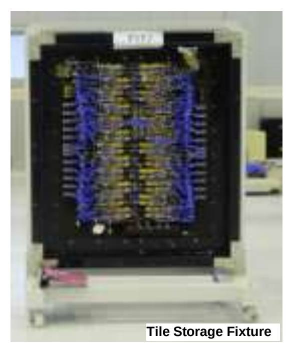


Tile in Fixture

Tile Integration Fixture

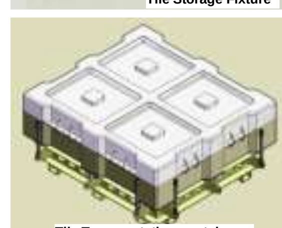
Tile Checkout

- **Tile Test Fixture, Qty - 01**
  - **Fabricated by M/s Atisha, Mumbai & Moonlight Fiberglass, Bhavnagar**
- **Tile Storage Fixture, Qty - 04**
  - **Fabricated by M/s Mahalaxmi, Ahmedabad**
- **Laser Tracker**
- **Near Field Test Facility (NFTF)**
  - **3-Axis Scanner**
    - → **Fabricated by M/s Bombay Machines, Bangalore**
  - **Anechoic Test Chamber**
    - → **Fabricated by M/s S. B. Engineering,, Ahmedabad**



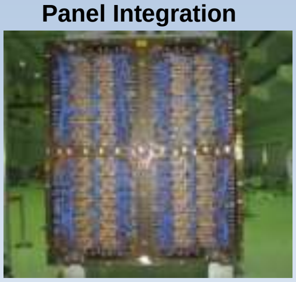
Tile Storage Fixture

- **Int. Tile Transportation container Qty - 02**
  - **Fabricated by Moonlight Fiberglass, Bhavnagar**

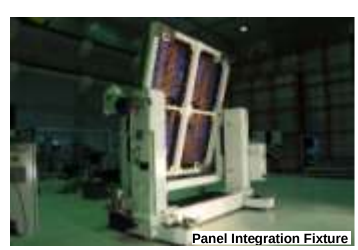


Tile Transportation container

Panel Integration



- **Panel Integration Fixture, Qty - 07**
  - **Fabricated by M/s Bombay Machines, Bangalore**
  - **4 Nos. for SAC and 3-Nos. for ISAC**



Panel Integration Fixture

Panel Checkout

- **Panel Test Fixture**
  - Same Tile Test Fixture is used for Panel Testing
- **Panel Handling System,** Qty - 01
  - Fabricated by M/s Shree Mktg., Vadodara
- **Near Field Test Facility (NFTF)**

Panel Handling System

Tile/Panel Test Fixture

Deck Integration

- **Deck Integration Fixture**
  - Same Panel Inttegration Fixture is used for Deck Integration Testing
- **Deck Handling System,** Qty - 01
  - Fabricated in House, WOC

Deck Handling System

P/L Integration and Deployment

- **P/L Integration Fixture**
  - Developed by ISAC
- **P/L Handling System**
  - Used with four lagged slings
- **Add on Adapter,** Qty - 01
  - Fabricated by M/s Prashant Industries Ahmedabad
- **Granite Tables**
  - Developed by ISAC
- **0-g Equipments**
  - Developed by ISAC
- **Mechanism & Hold down**
  - Developed by ISAC

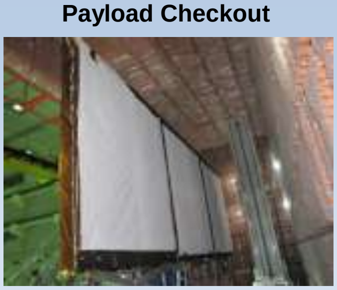
P/L Integration Fixture

0-g Granite Table

Add-on Adapter

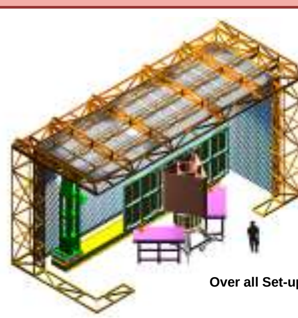
0-g Bracket with Air Brg.

Payload Checkout

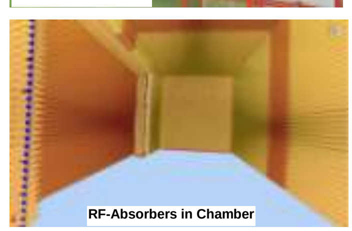


- **Near Field Test Facility (NFTF)**
- **P/L Handling System**
  - Used with four lagged slings
- **P/L cooling System**
  - Developed in-house

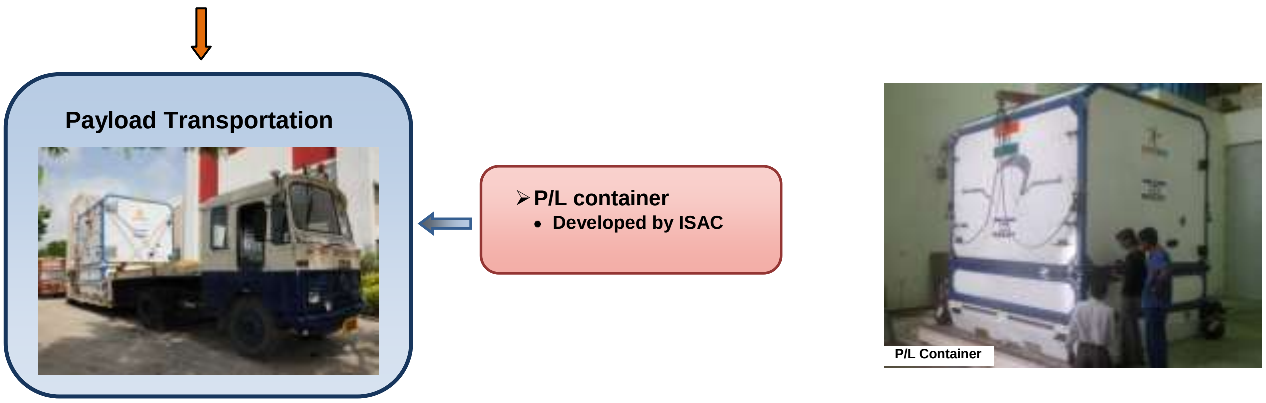
Scanner in Chamber



Over all Set-up



RF-Absorbers in Chamber



Summary:

- 12 Tiles was integrated with very dense harness and tested in NFTF
- Two tier philosophy was adopted to cope up the situation of very dense population of packages/components and harness
- 3 Panels was Integrated and Tested with 4 tiles on each panel and Tested in NFTF
- EP-01 (Deck) was Integrated with 15 Packages with dense Harness for control and interface between Payload and Spacecraft
- Antenna was made of 3 Panels with required mechanism elements and Tested in NFTF
- About 780 packages & components was integrated on P/L Antenna excluding thermal and mechanism elements
- Harness was done with matching of more than 5000 RF and Data connectors
- About 1200 Saddles used on Harness support system for proper routings of harness
- P/L integration was done by using more than 7000 fasteners only for integration of packages/components and harness saddles
- About 3000 helicoils was fitted for harness support system (excluding Tile inserts)
- Different fixtures, handling systems, containers and components were developed in required quantities with help of in-house facility/WOC/external venders
- Special purpose Tools and Extenders was developed
- Extensive Handling at each stage of Integration, Testing, Storage & Transportation
- Demonstrated deployment of P/L with required planarity of antenna (0.5 mm RMS)
- Weight of P/L was about 950 kg out of 1858 kg of total weight of satellite

Abbreviations:

RISAT - Radar Imaging Satellite
SAR - Synthetic Aperture Radar
TR – Transmit Receive
CFRP - Carbon Fiber Reinforce Plastic
GFRP - Glass Fiber Reinforce Plastic
SAC - Space Applications Centre
ISAC - ISRO Satellite Centre
P/L - Payload
S/C - Spacecraft
WOC - Work Order Committee
NFTF - Near Field Test Facility

Design and Development of Payload and Spacecraft Structures

S Dasgupta, Shivanand M. Kamat, ISAC, Bangalore

1. Introduction: Structural configuration and design of RISAT-1 is a challenge in many ways. RISAT-1 spacecraft Lift of Mass (LoM) is 1858 Kg and it is the heaviest remote sensing satellites in IRS class, designed and launched successfully by Indian launch vehicle PSLV-C19. More than 50% of the LoM being payload (largest share of payload) with very large volume has made the configuration more challenging. The planarity and minimum in orbit distortion requirement for RISAT-1 payload has compelled the usage of the carbon composites with their low Coefficient Thermal Expansion (CTE). Inclusion of thermal control elements like heat pipe for handling large power requirement for payload space environments in the composite structure has posed a new technological problem in design/manufacturing of payload structure. The design and development of thermal and mechanism elements do not form the part of this paper; both the systems have constraints on payload design and spacecraft configuration.

2. Structural Configuration: The payload consists of three panels of size 2073 X 2383 mm, each panel weighing 300 Kg. These three panels once deployed in orbit form the main payload of size 6238X2383 X196 mm. The basic structure obviously provides hold down for both fixed and deployable panels. The large size of the payload did not allow the payload module to be placed on mainframe module due to constraint on envelope, stiffness and limitation on spacecraft Center of Gravity. Envelope needed to fold these three panels in a triangular shape is around 2800 mm, which can be accommodated only in the cylindrical region of the heat shield. After several trade-off studies, a new type of configuration is evolved with triangular prism shaped structure **(Figure 1)** supporting payload system around and main frame electronics packages including battery and payload electronics in the central portion. The volume inside the cylinder is used for housing RCS tank and reaction wheels. A small cuboid **(Figure 2)** of size 1010 (Roll) X 1340 (Yaw) X 880 mm (Pitch) is placed on the top of triangular prism for supporting deployable solar panels, sensors and antennae needing clear field of view. The total mass of the cuboid module is around 200 Kg. The gap between these two modules is dictated by the clearance needed between two deployable subsystems namely SAR panels and SOLAR panels. The overall volume of the structure including both modules is 1963 (Roll) X 1757 (Yaw) X 3722 mm (Pitch).

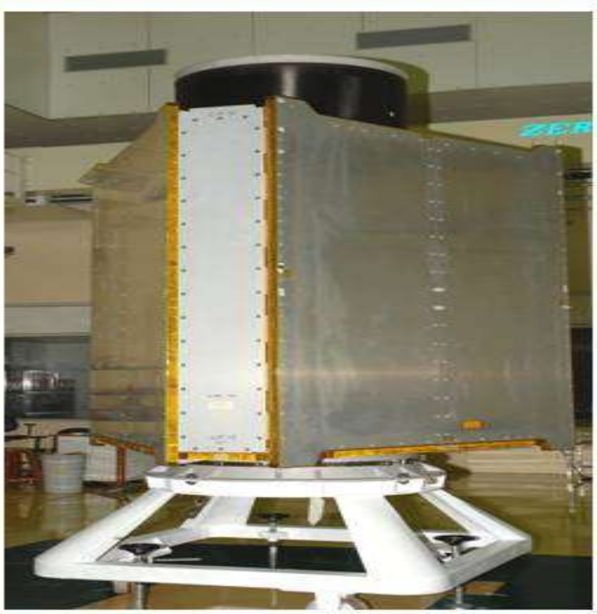


Fig-1: Main Structure (With equipment Panels)

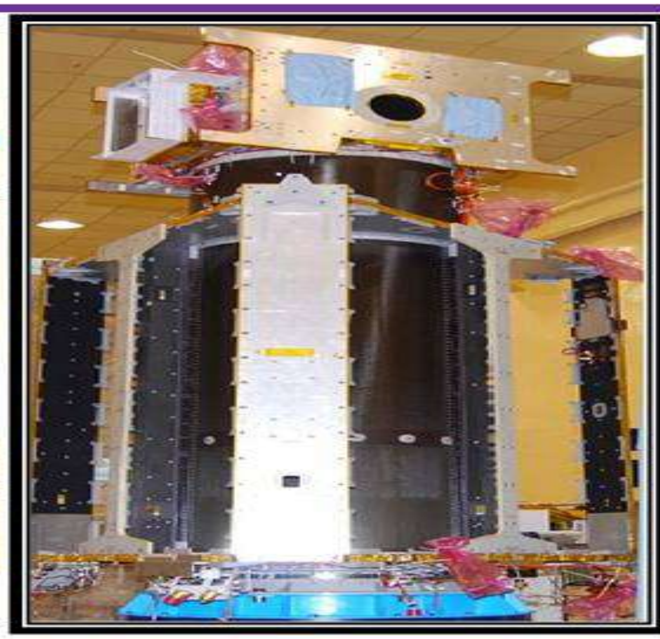


Fig-2: RISAT-1 structure with cuboid module (Equipment decks not shown)

3. Main Structure:

3.1 Design: The main thrust cylinder interfacing with the launch vehicle is made of sandwich construction with aluminium core and **C**arbon **F**iber **R**einforced **P**lastic (CFRP) face sheets and aluminium rings on either side. Three shear webs of triangular prism are also made of sandwich construction with CFRP face skin and aluminium core. All the equipment decks and cuboid structure are made of sandwich decks with aluminium face skin.

The cylinder design is based on a similar structure made for 2000Kg communication satellites. The number of layers is modified throughout the length including interfaces based on the quasi-static loads given by Launch Vehicle (LV).

The frequency constrain of > 40 Hz (longitudinal) and > 15 Hz (lateral) given by LV is dictated primarily by the The estimated frequencies are 36 Hz and 14.2 Hz in global longitudinal and global lateral respectively. As the frequency constraints imposed by LV are not met, it became absolute necessity to carry out Coupled Load Analysis (CLA) at very early stage of the programme. After the clearance through CLA prediction, the design was frozen.

3.2 Fabrication: The components and assembly of the main cylinder followed regular established process and did not pose any problem. The stringent requirement of SAR panel holds down interfaces (100 microns over 1460 X 2183 mm at 23$\pm$ 2^{O}C) and angular tolerance of the three panels interface (within 0.02^{o}) needed special tooling to achieve the same. Utmost care was taken to achieve parallelism, perpendicularity and planarity constraints required for payload assembly. Dimensional inspection was carried out by co-ordinate measuring machine (CMM) to identify deviations, which have been fed back to payload assembly team for necessary corrections.

4. Payload structure

4.1 Configuration: The SAR panel structure consists of frame, which supports 4 panels independently known as tile. The flatness requirement of each tile of size 1035 X

central cylinder. The number of trade off studies and design iterations are carried out to satisfy both stiffness and strength requirements using Finite Element (FE) analysis **(Figure 3)**.

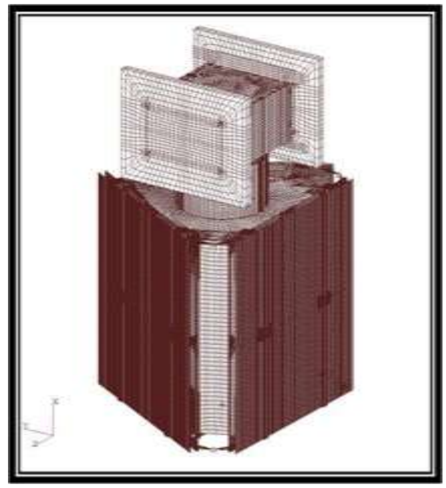


Figure-3: RISAT-1 Finite Element Model

1190 mm and the supporting frame of size 2073 X 2383 mm has lead to the choice of CFRP material due to high specific stiffness and low co-efficient of expansion. The usage of CFRP also will help in minimizing distortion under various in orbit thermal conditions. The target deformation constraint for in orbit thermal environment should be within $\pm$ 1.5 mm, which includes manufacturing, assembly tolerances, spacecraft and SAR panels' deformation.

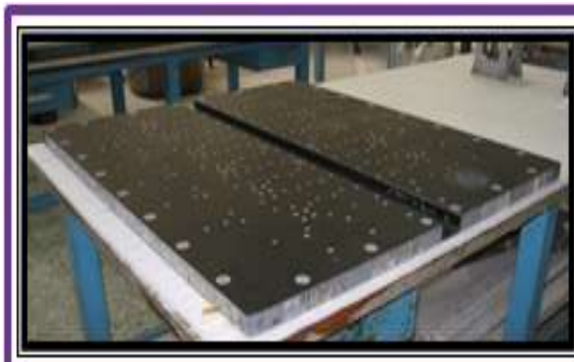
Each tile substrate supports bonded patch antenna of size 1000 X 1000mm on earth viewing surface and TR modules with associated electronics at the back side. The total volume of panel structure is dictated by the above. At the center of the panel a hat section has been provided for mounting connectors. The thickness of connector mounting area is 5 mm for accommodating mounting screws. Due to high dissipation of around 1.3 KW/ Panel, it was absolutely necessary to use heat pipes embedded into the CFRP tiles. The heat pipes will transfer the heat at the extended portions of the panel. Optical Solar Reflectors (OSR) are bonded on the tile substrate on earth viewing face for radiating heat. Considering all aspects the final size of tile substrate is 1035 x 1190 mm including the extended portion for OSR. The configuration of the SAR frame is based on allowable gap between the tiles, mounting configuration and antenna requirement. The frame, which supports all the four tiles, is held onto the base structure at four points for both fixed and deployable panels. The hold-down locations have embedded Aluminium blocks. Based on the minimum edge distance for inserts and other considerations given above, the size of the frame is 2073 X 2383 mm.

4.2 Design: Having finalized the size, the design of tile substrate was carried out based on both stiffness and strength. Here it is important to note that the stiffness of individual tile will dictate the spacecraft modes in launch configuration. The basic substrate is of sandwich construction with Aluminium core and CFRP face skin. As already mentioned earlier, thermal design needs heat pipes made of Aluminium alloys to be embedded in CFRP panel. Due to mismatch of CTE between CFRP (1-2ppm) and Aluminium (23 ppm), interface design posed a problem. The heat pipe thickness being lesser than the panel thickness, it was necessary to use higher density honeycomb core between heat pipe and CFRP skin to improve thermal conductivity. Due to high temperature curing and low temperature in orbit, the CFRP skin above heat pipe experiences high stresses which was taken care with additional layers locally. A detailed Finite Element analysis of tile was carried out with finer mesh size near critical interface to capture the stress pattern. The design of frame is also based on both stiffness and strength. The frame stiffness also has large influence on spacecraft modes and hence lot of iterations has to be carried out before finalizing. The final design of the frame is of sandwich construction with Aluminium core and CFRP skin. Due to smaller width of the beam, thick face is used and the final lay-up sequence was arrived at with FE analysis.

Thermo-elastic deformation of the frame along with the tiles being of prime importance, a detailed analysis was carried out for various in orbit thermal load cases. The deformation estimated on deployed SAR panels (over an area of 6238 mm X 2383 mm) is around 1 mm RMS, for the worst temperature condition. Considering flatness achieved in payload hardware, calculated deformation is around 1.2 mm as against design goal of 1.5 mm.

4.3 Fabrication: Flatness or surface planarity being of prime importance, the bonding fixtures were fabricated with flatness of surface plate specification. Mild steel has been selected as tool material in order minimum difference in CTE with chosen of CFRP face skin. A special curing tool was also developed for manufacturing of CFRP hat section.

The curing temperature of adhesive system of CFRP being 180^{O}C as compared to allowable temperature of 120^{O}C for heat pipes, it was necessary to cure CFRP components separately before converting into sandwich for tile substrates. Due to large thickness of hat section, the curing cycle was modified for achieving better temperature distribution leading to a better product. The final curing of all the components was carried out in a suitable bonding fixture to produce the tile substrates **(Figure 4)**. All the 12 tile substrates were cured using the same process. The flatness (in mm, RMS) measured using laser tracker is given in **Figure 5.**



P2T2	P2T4	P1T2	P1T4	P3T2	P3T4
0.3	0.08	0.04	0.09	0.06	0.20
P2T1	P2T3	P1T1	P1T3	P3T1	P3T3
0.09	0.1	0.11	0.12	0.05	0.14

Figure-4: SAR tile substrate with embedded heat CFRP Channel

Figure-5: Measured flatness pipes and values of tile substrates

Special curing fixtures were designed and fabricated for curing thick face skins of the SAR frame as well as the final assembly of the frame along with embedded aluminium blocks. The component being very large **(Figure 6)**, the curing cycle was modified in order to achieve a desired product. All the hold down interfaces was opened to the final dimension in post bonding operation to achieve required tolerances. All the inserts potting and curing for tile/frame as well as subsystem interface were carried out as post bonding operation.

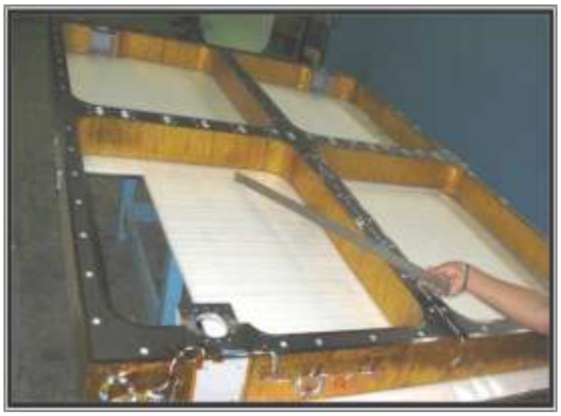


Figure-6: SAR Frame after post bonding of Inserts and Clamps

Thermography technique has been used as non-destructive evaluation of the product. All the tiles and frame were subjected to thermal cycling between –30°C to +75°C before delivery

4.4 Payload Assembly: Mechanical assembly at the level of tile to subsystem and tiles to frame level was carried out without difficulty. All the three frame assemblies have a dual interface namely frame to base structure **(Figure 7)** and between frame to frame through mechanism elements. The complexity further increases as the frame interfaces do not have flexibility and overall mass of the each frame assembly is around 300 Kg.

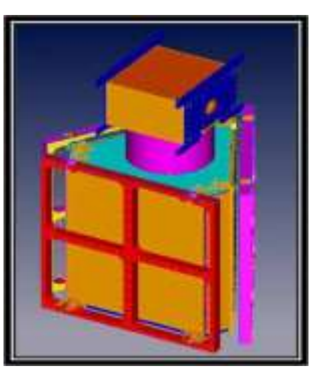


Figure-7: 3D model of Structure with frames attached (tiles are not shown)

In order to gain experience an assembly fixture made of mild steel with welded construction was fabricated simulating all spacecraft interfaces. Due to deviations noticed in the fixture, difficulties were faced during flight model payload assembly. The assembly procedure was subsequently modified and the frames were assembled and deployed successfully. The deviations measured on the flight structure were nominal and the payload SAR panels were assembled onto the flight structure without any difficulty and subsequently deployed on ground successfully. The planarity was around 0.53 mm measured over entire surface area of 6238 mm X 2383 mm after deployment.

5. Qualification: The present structure along with payload system being different from earlier ones, lot of deliberations has taken place regarding qualification philosophy to be adopted for both spacecraft and payload structure. Considering efforts, cost and time, it was decoded to go for a single model philosophy for both spacecraft and payload structures. The static qualification of the central cylinder along with shear webs and horizontal deck could derive the benefit from static qualification test of previous communication satellite of 2500 Kg lift of mass. The tile substrate has been qualified statically through 4-point bending test up to the expected strain level. One single tile system after full integration of patch antenna along with electrical system has undergone both sine **(Figure 8)** and acoustic test at qualification level. This test has not only qualified the tile assembly for dynamics but also helped to correlate mathematical model.

Based on the results thus obtained, a detailed FE analysis was carried to predict major frequencies, mode shapes and expected responses at various locations. Finally the flight spacecraft was subjected to both sine and acoustic tests at proto flight level successfully.

Figure-8: RISAT-1 spacecraft on sine vibration test set-up

The comparison of FE analysis and test results given in Table 1, justifies the maturity of analysis.

Table 1 Comparison of Analysis and test values of RISAT-1

Sl. No	FEA (Hz)	Test (Hz)	Major modes	Sl. No	FEA (Hz)	Test (Hz)	Major modes
1	14.11	14.25	1st Lateral (Z) mode	6	35.7,36.5	36.5	Global longitudinal mode
2	14.27	14.5	1st Lateral (Y) mode	7	40.1,42.7, 46.6	41.5	2nd lateral mode is roll direction
3	22.4, 23.1, 23.3	23.9	SAR panels bending	8	44.58	44.5	SAR 1 In-plane mode and SAR 02 & SAR 03 bending
4	31.3	31.5	SAR panels 2 & 3 anti symmetric bending	9	49.5, 52.5	52.2, 54.0	SAR Tile modes
5	32.6	33.75	2nd Lateral yaw direction	10	62.6,70.3, 77.2	68.8	Cuboid longitudinal

6. In Orbit Performance: The spacecraft has been launched successfully by PSLV-C19 on April 26, 2012 from Sriharikota. Immediately after injection, SAR panels were deployed. The payload performance under various thermal environments faced so far is excellent.

7. Conclusion: The spacecraft and payload configuration, design, analysis and fabrication have been successfully demonstrated the adequacy of mission requirements. In orbit performance of the payload justifies successful design/development and implementation of all mechanical elements – namely structures, thermal and mechanism.

8. Acknowledgment: Authors with great satisfaction acknowledge the support provided by other members of Structures Group, ISAC. Thanks to Dr. T. K. Alex, Director, ISAC for providing support during execution and permission for publishing this paper.

Challenges in Space Electronics and Preview of RISAT Bus Systems

Shri E Vasantha, Outstanding Scientist, Deputy Director, DCA, ISAC, ISRO

"ZERO DEFECT SPACE SYSTEMS" is the buzz word at every space system manufacturing centre, worldwide. To achieve highest reliability and compactness, it is of paramount importance to address system realization at different levels.

Components: Both the active and passive components must belong to highest reliable family. Components used in space may degrade and eventually fail due to different reasons. The stress induced on devices during manufacturing, screening and testing has highest role to play with the life. The latent ESD phenomena, which are predominant in the semiconductor, can lead to a disaster, if precautions are not taken while handling and testing.

Radiation in space and its impact cannot be neglected. The total dose, proton irradiation, and the effects like SEU, SEL and SET (in linear devices) to be analyzed. Generally, the devices must have LeT > 80 MeV-cm2/mg for latch up immune and total dose capacity of > 100 Krad. Radiation shield with tantalum sheet for the devices help to improve total dose. Out gassing, which occur in plastic devices, leads to the cracking of devices and deposition of particles on optical surfaces which in turn causes degraded performance. Obsolescence in the digital devices, miniaturization and also cost effectiveness are reckoning factors which drive the space system designers to embark on new designs using Commercial-Of-The-Shelf devices (COTS). Design innovations are being employed to mitigate faults using modern EDA tools.

System Interface: "Never neglect the interface design between packages". Standard interfaces such as 1553 bus, space wire and multi drop RS 485 are some of the emerging standards for satellite systems. In other cases, consideration for cold sparing, resistor termination to prevent reflections, filtering of control signals at the receiver end by advanced digital techniques are necessary. Addressing voltage level compatibility whenever different logic levels are used across the system is mandatory. Use of twisted pair wires with shield, separating low level signals from high power/ high voltage switching signals in spacecraft harness will help in solving many of the trivial issues occurring during system integration at spacecraft level. Surge current requirements of systems should be recorded and necessary remedies for soft switching features to be incorporated.

System Configuration: Redundancy at system level is vital for many of the systems. Space system must be configured carefully to avoid single point failure and not to jeopardize the complete mission. For example, command distribution from an ASIC should not be connected to both main and redundant system. Similarly, the payload chain which is very critical in IRS mission, where if cross coupling is not included, it is very important to connect all the main to one chain and redundant to other. The power distribution is also coming under the same category. Whenever cross coupling is employed, the cold sparing consideration is necessary to prevent stress on the devices. Hot redundant systems like TM, TC & OBC, the interface between the main and redundant to be designed carefully to prevent fault propagation.

Digital Design: Most of the spacecraft systems belong to digital category with few analog elements. Rules of space system design and the stipulated process must be followed at all stages of realization. Many of the modern systems are moving towards digital implementation using ASICs/FPGAs & mixed signal ASICs. Guidelines from manufacturer such as synchronous design, limiting SSOs, avoiding use of gated clocks, power supply sequencing, decoupling requirements must be followed verbatim. Estimation of power dissipation at the early phase of the design helps in proper thermal design.

Static timing analysis is a major step in most of the FPGA implementation and has to be verified for min/typ./max delays for robustness of the design. Any set up/hold time violation and warnings should be addressed and resolved. The VHDL code implementation of the design follows different life cycles like consolidating design requirements, top level design, design break up, block level implementation, synthesis, verification, place and route, delay extraction, simulation and fuse file generation.

In the board level design, all the system requirements must be addressed. Use of EDAC and refresh of memory, watch dog timer to wake up the system during the stuck faults, fault tolerant features by employing TMR logic for critical elements and graceful degradation feature to remove the faulty devices from the operation (as in SSR design) can be employed to improve the robustness. Signal integrity is another factor not to be neglected in the era of high frequency system design. Most of the modern devices are so fast, and normally overshoot/undershoot beyond the device spec. are seen at the receiver causing undesirable operation. Proper series damping /lower slew option can limit this to within the spec. Termination of high impedance points to either logic supply or ground is also required to reduce the risk of ESD. De-rating of the operating frequency ensures the devices to operate over the life with the radiation absorption and at higher temperature.

Software Design: Deterministic software is an important element of any flight critical system. Following software life cycle process to build the software helps in modular design, traceability, documentation, verification and portability. Modern day systems do permit to upload the software at the launch pad itself enabling last minute changes in the system requirements. The real time software must be checked elaborately by independent team for all boundary conditions to avoid major faults. Code coverage tests to the maximum extent also aides to weed out coding errors.

RF System Design: RF systems for TT&C and Data transmitter design is altogether a new ball game. The RF spectrum availability being limited, it is essential to move to higher frequency bands like Ku and Ka. This opens a new vista of RF designs based on GaAs and GaN high-electron-mobility transistors (HEMTs) devices. The tantalizing modulation schemes like QAM, MPSK with the advanced error correcting codes LDPCM and convolution; turbo coding will soon be a reality. Reception of very low RF signals (-150dBm) and transmission at requisite EIRP is a design parameter. The antenna system along with the feed is required to provide near Omni for TT & C and narrow pencil beam for data transmitter.

Power system Design: Power generation to the tune of 10 KW to 15 KW is not uncommon in both LEO and GEO missions. Sizing of ATJ cell based solar panel and lithium based battery depends on payload and bus. Solar string formation by series and parallel connection, the process of bonding cells on to the honey comb panel must have good heritage and high reliability since panels undergo continuous thermal cycling (-100 ^{0}C to +100 ^{0} C). De-rating of SADA slip rings is also essential for long life. Shunt regulators to condition the power in solar strings, bus formation, optimum battery charging and strict control over battery discharge are some of the design parameters. Battery cell failure and bypass is incidentally part of cell behavior. High power distribution through bus bars is becoming popular to reduce power loss in harness. DC/DC converter for all subsystems, again a compact design with all best features is part of power design.

Testability: DFT, design for testability is essential while designing state of the art systems. Use of scan flip flops, boundary scan etc. in FPGA/ASIC design helps in early detection of fault. Inclusion of diagnostic hardware and software aids the fault location and remedies to be taken during testing and operation.

Thermal Management: Thermal management is very important not only for power systems, but also for rest of the systems. Power dissipation must be estimated for selecting the passive/active components to prevent the hotspot and burn out. Copper pouring below the hot device, use of heat sink and connecting copper braid between the device and chassis are some methods to overcome the hotspot. Partial power down mode or operating in lower frequency, (to minimize switching loss) whenever less activity is envisaged helps to reduce power consumption.

To summarize,

Standardization, reconfiguration, modularity and portability are important factors in space systems. If followed, it will drastically reduce turnaround time of the systems availability for different programs.

PREVIEW OF RISAT BUS SYSTEMS: RISAT bus systems are highly complex and very challenging and many systems are designed new, only few elements have drawn heritage from predecessors. The thermal design is very tough as the payload operation power is ~ 4 KW and quite a large amount of power has to be dissipated in the spacecraft for keeping the temperature of all sub-systems within the operational range.

The OBC for attitude control is a newly developed system with ASICs and MAR 31750 as an embedded processor. The TM/TC functions are also incorporated in OBC. All the features like remote programming, patch upload, event based commanding, time tagged commanding programmable temperature controller are some of the value added functions built in OBC software. The four 0.3 NM reaction wheels are used in spacecraft for attitude control which are driven by OBC in staggered mode (in different timing region of OBC minor cycle) with the one ohm series resistor to limit the surge current demand by wheels while applying torque.

The patch upload software enabled this operation seamlessly. The fail safe features to protect DGA during battery emergency is again through an event based commanding, shows the versatility of the software.

Onboard power is generated by two side solar wings supported by two Ni_H 70 AH batteries. The power output is regulated by different regulators, like UBR, ABR, BDR . ABR, a 400W regulator provides 42Volt bus to many of the bus systems from 70 Volt bus. BDR is a 6 module battery discharge regulator which is connected in parallel to support the payload during imaging operation. Each BDR provides 750 W power.

The switching BDR ON/OFF is managed by voltage sensing mechanism with majority voting logic. Moving from S4R region to BDR region is critical and has to be quite fast in view of the high current requirement of the payload. The response of MVL is tuned to limit the ripple in 70 volt bus within +/- 2 volts. The battery temperature maintenance between -10 ^{0}C to 10 ^{0}C is necessary for highest ampere hour age.

The Rx, Tx, sensors, SADA, DTG, Wheels and propulsion systems are enhanced versions and has heritage from earlier spacecrafts.

Data Handling (BDH), SSR, Data transmitter and PAA are the new high speed systems designed for RISAT. The ser/deser interface between payload and BDH is adopted in RISAT mission which made the interface definition very simple. The BDH system formats the V & H polarized data into four streams .

The formatting rate was adaptive depending on the mode selected (CRS, HRS, MRS, FRS). The data can be transmitted to ground in two carrier of different polarization using the QPSK modulation. The overall Tx rate is 640 Mbps in X band with dual polarization. The parallel to serial conversion in BDH at 160 Mbps is very critical as margin available is very less.

The qualified Data transmitter with QPSK modulation was realized by external contract from M/s. ASTRA microwave. The 300W PAA is a new design with 64 elements. The SSPAs and phase shifters are realized with MMICs for beam forming (70 deg width) . The dual beam is targeted to the station by the onboard S/W of PAA which gets station coordinates from OBC.

The SSR for onboard storage has 300 G bits capacity with 4 Inputs/ and 4 Outputs. The interface is again of ser/ deser type with the BDH. The SSR design is optimized for high speed design to handle input rate of 2.048 G bits per second with pipeline architecture in the memory controller. The power in the system is conserved during retention by operating at lower frequency and power down mode for SDRAMs.

The SPS is a new development for this spacecraft with 8/10 channel GPS receiver in a single system. This configuration is employed to provide the position, velocity and time information to the OBC without break.

All systems have undergone stringent qualification tests as per ETLC before integration with the spacecraft.

Glimpse of new bus elements: Figure-1 shows the various new bus elements which were used in the RISAT-1 mission.

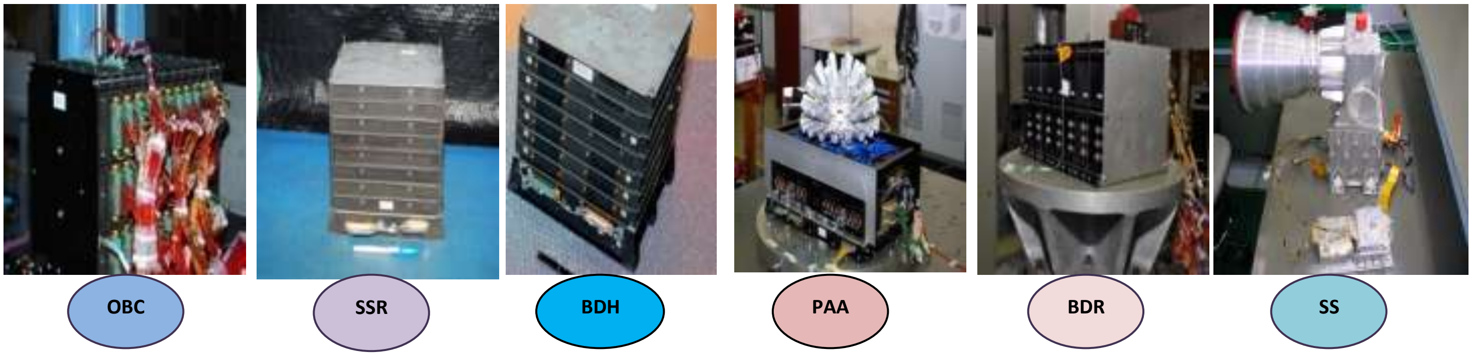


Figure-1: Various new bus elements of RISAT-1

Conclusion:

To wrap it up, RISAT spacecraft configuration has thrown a challenging task to bus system designers and the system designers met all the spacecraft demands. All the bus systems had no hiccups throughout the system realization, depicting maturity of the design and fabrication team. Overall, the journey to **"ZERO DEFECT SPACE SYSTEMS"** realization proved that,

"FOLLOW DISCIPLINE, GUIDELINES AND BE INNOVATIVE" to reach the goal.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures* related to the specific theme "Megha-Tropiques Mission- Radiometers for the Tropics".

The deadline for inclusion in the next issue is **Sep 30, 2012.**

- Editorial Team

High Data Rate (640 Mbps) Reception System for RISAT-1

Padmavathy C.S, M.Satyanarayana, NRSC, Hyderabad

1. Introduction: National Remote Sensing Centre has established several satellite ground stations in S/X Band to receive data from Indian and Foreign Remote Sensing Satellites. Over the past 3 decades, the multi-mission ground station at Shadnagar has envisaged X-Band signal reception occupying spectrum bandwidth for data rates varying from the lowest 5.2 Mbps of IRS-1A towards 105 Mbps of Cartosat and Resourcesat series, depending on enhancement in image resolution. X-Band signals at a combined data rate of 170 Mbps were received from earlier missions.

SAR payload of RISAT when operated in dual polarization imaging mode transmits data at 640 Mbps rate towards a satellite ground station. The allocated bandwidth at X-Band for data reception is 375 MHz and hence reception of 640 Mbps exceeds the allocated bandwidth and calls for frequency re-use system or higher level modulation schemes. Hence, RISAT-1 X-Band QPSK modulated signals at high data rate of 640 Mbps is being received through frequency re-use by polarization discrimination. From the total of 640 Mbps, half the data is received in Right Hand Circular Polarization (RHCP) and remaining half in Left Hand Circular Polarization (LHCP).

The data reception system has been designed and developed to receive RISAT-1 signals data with good quality. This paper describes the design aspects and technology involved in all subsystems required for RISAT-1 data reception.

2. High Performance Dual Polarized S/X Band Feed: A dual polarized X-Band feed has been designed, fabricated and installed to meet the requirements of RISAT-1. The dual polarized feed configuration is shown in Figure 1

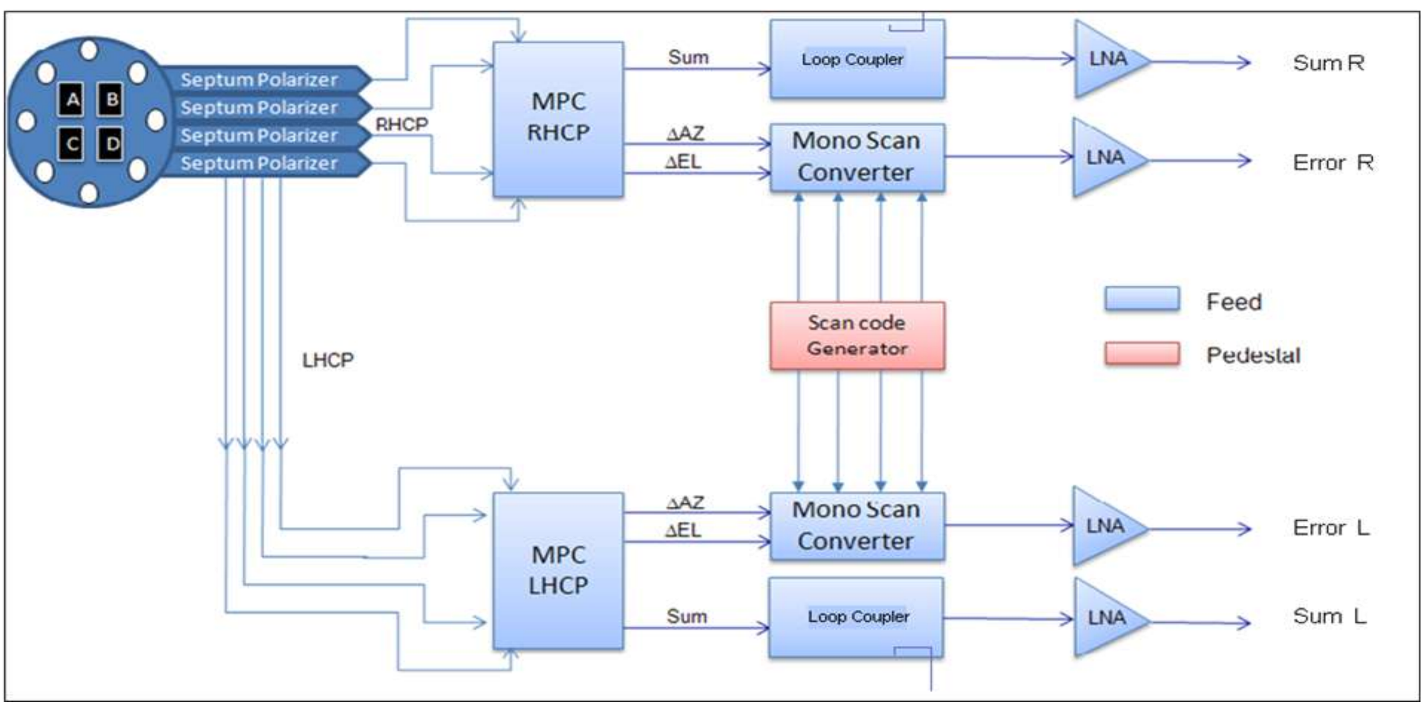


Figure-1: Configuration of dual polarized X-Band feed

The feed is of multi-element Single channel mono pulse tracking type, capable of receiving dual circularly polarized S & X-band signals with the operating frequency band of 8 to 8.4 GHz in X-Band. The feed consists of four high performance Teflon dielectric radiating elements, each with the gain of 16.5 dBi. The feed performance was evaluated in Compact Antenna Test Facility of ISAC, The cross polar isolation measured as 30 dB was sufficient to achieve polarization discrimination between RHCP and LHCP signal reception. Figure -2 shows the LHCP and RHCP Radiation Patterns.

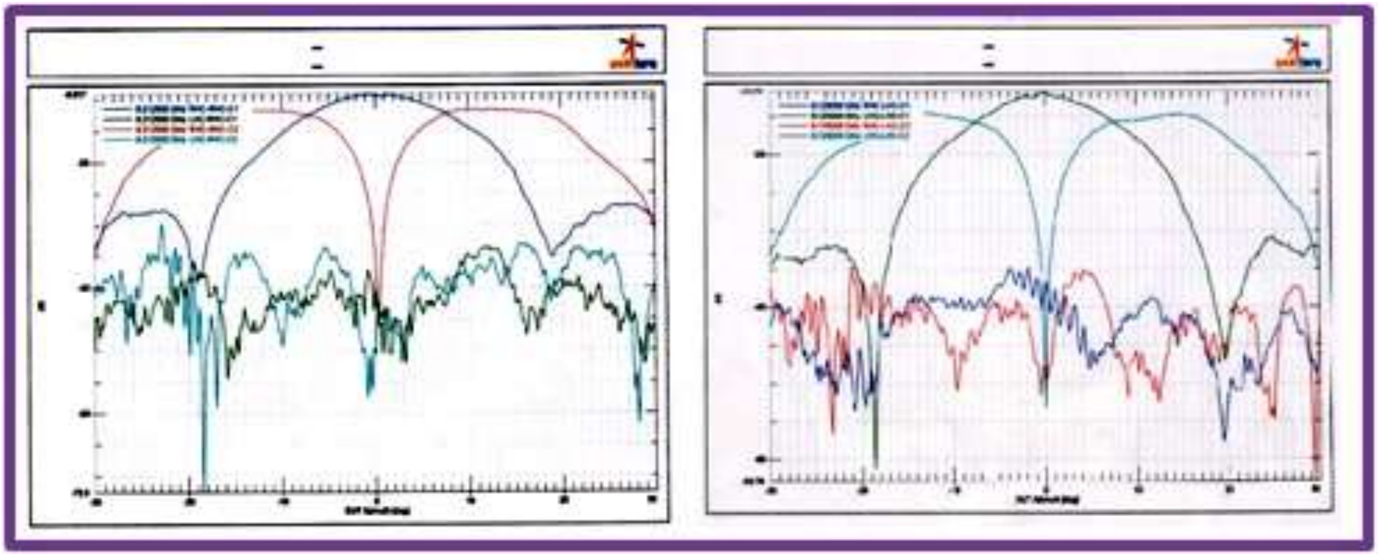


Figure-2: LHCP and RHCP Radiation pattern

3. **High Efficient 7.5 m Antenna System:** The feed is integrated with a 7.5 m dual shaped reflector in Cassegrain configuration. The complete antenna system is characterized for secondary radiation patterns at outdoor test range of BEL, Sohna. The antenna provides a gain of min 54 dBi over the complete frequency band at LHCP and RHCP ports. The antenna along with the state of the art GaAs FET Low Noise Amplifiers provides G/T of 32dB/ºK

4. **Satellite EIRP and Station G/T:** The transmit EIRP of Cartosat and Resourcesat series of satellites for 105 Mbps data is around 19 dBW. The EIRP of RISAT-1 spacecraft is 25 dBW and it is higher than other earlier missions by 5 dB in view of threefold increase in data rate. The data reception system with a G/T of 32 dB / deg K provides a system margin of 4 to 5 dB for RISAT-1 data reception.

5. **Satellite Auto Track:** The Auto Track error required for satellite tracking is generated from the tracking chain. RISAT-1 X-Band signals are received either through RHCP or LHCP or both depending on payload mode of operation. This requirement calls for a three channel tracking receiver with auto diversity feature for Auto Track mode selection based on AGC. Hence, an integrated tracking system has been designed and developed using DSP technique and this has facilitated compact tracking chain in data reception system for satellite Auto Track.

6. **Design Concepts:** RHCP and LHCP signals in X-Band at carrier frequency of 8212.5 MHz are received with a min. isolation of 20 dB from feed. The two QPSK modulated signals, each at 8212.5 MHz are down converted to 2257.5 MHz using a Phase Lock Oscillator of very good phase noise. The low data rate IF signals of earlier missions were driven from antenna pedestal to control room through coaxial cables. Now, this has been replaced by Fiber Optic Link with higher bandwidth and good noise performance to avoid the amplitude tilt in driving RISAT-1 high data rate modulated spectrums. The frequency response of complete data reception system from the feed to demodulation is maintained to be within ±1 dB. The specifications of Band pass filters with flat amplitude and minimum group delay characteristics are used in both RHCP and LHCP receive chains.

7. **640 Mbps Data Receive System:** The receive system comprises of X-Band synthesized down converters, IF Fiber optic link,. High data rate demodulators and Data Ingest System for receiving high volume of RISAT-1 data. The digital demodulators realized using the latest FPGA based technology is used in Data Reception System. The demodulation schemes (BPSK, QPSK, OQPSK and 8PSK) and bit rates (1 to 400) Mbps are programmable to support reception from any satellite in orbit. The unit operates at 720 MHZ IF with the bandwidth ± 200 MHz. The input signal levels of down converter, Fiber optic link and demodulators in DRS are optimized such that the demodulator is operated within its dynamic range from -50 to -10 dBm

This also takes care of the signal level variation that occurs due to path loss advantage from horizon to overhead, The bit synchronization after digital demodulation provides I data, Q data, I clock and Q clock outputs at symbol rate either in ECL and LVDS output interface. The LVDS (linear Voltage Differential Signaling) outputs are interfaced through CAT-6 cable with Data Ingest System to provide good signal integrity and clock synchronization for high data rate signals.

8. Data Ingest System: The Data Ingest systems consist of PC servers with RAID as shown in Figure 3, for real-time data ingest. The PCI based Front End Hardware (2 cards) performs front end processing of RISAT data on serial bit stream. The Frame Synchronizer accepts serial data from BSSC in real-time and performs frame synchronization on the incoming data. The high resolution (10 micro seconds) IRIG-G time code is used for time stamping of RISAT-1 raw data. The high volume data is transferred to RAID through PCI 64 Bit, 66 MHz interface for further processing.

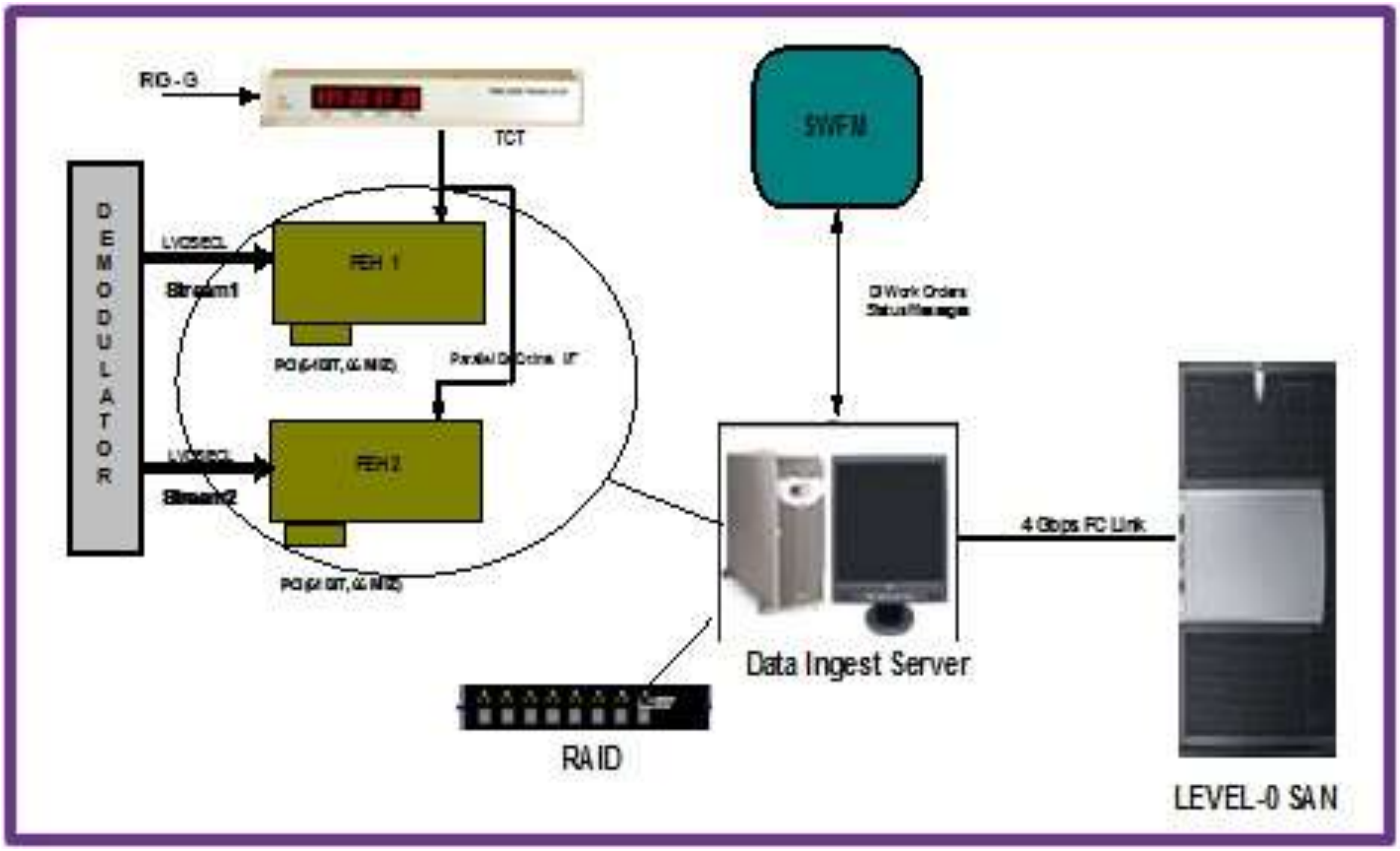


Figure-3: Data Ingest System Configuration

9. Achieved Test Results: The design concepts discussed so far have been realized and achieved the specified and intended performance for high data rate RISAT-1 signals.

The Carrier to Noise density ratio required for 320 Mbps data reception is 98 dBHz. The threshold Eb/No is 12.95 dB. The implementation loss is 2.15 dB including modulator. The spectrums are received without any distortion due to flat frequency response over the complete system. The BER performance of DRS was evaluated through PN sequence transmission from spacecraft and no error bits are observed throughout a satellite pass down upto 3 deg EL. This has confirmed X-Band link margin and the system capability to receive 640 Mbps data of RISAT-1. The LHCP and RHCP spectrum of RISAT-1 orbit -77 data is shown in Figure-4 and the Constellation plot of RISAT-1 QPSK signal @ 320 Mbps is shown in figure 5.

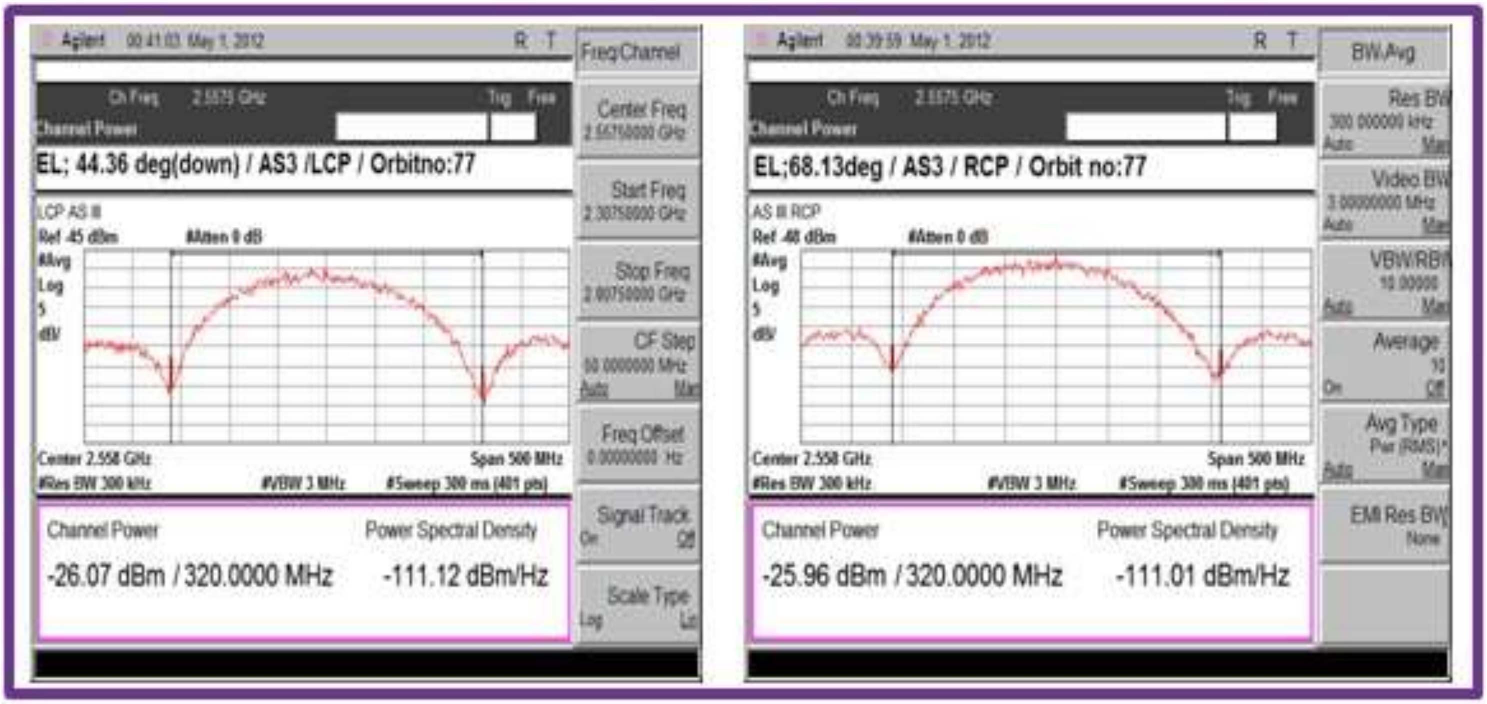


Figure-4: LHCP and RHCP Spectrum @ 320 Mbps Data Rate

Figure-5: Constellation plot of RISAT-1 QPSK signal @ 320 Mbps

Komoline's Proud Contribution to RISAT

KOMOLINE

KOMOLINE'S PROUD CONTRIRIBUTION TO RISAT

Established in 1990, Komoline has had a gradual and steady growth. Transcending different electronics related business areas, it has now oriented itself for a future in aerospace.

Komoline has in-house design, development, test and manufacturing facility of hi-reliability Space and Defence applications. Accumulating almost 15 years of experience in the fabrication of sub-assemblies for Communication and Remote Sensing payloads onboard ISRO's satellites, the Company has an imbibed all skill sets necessary for the manufacture of electronic subassemblies for space and has steadily also invested in the development of infrastructural support. As part of the expansion currently underway, a 30,000 sq ft complex is being developed by the Company to exclusively cater to the hi-rel business. The complex will house a state-of-the art one-roof manufacturing cum test and qualification infrastructure.

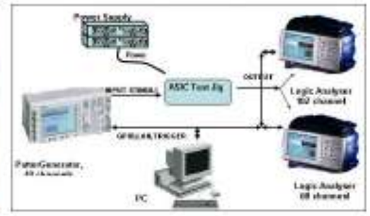
Komoline derives immense satisfaction from having contributed to the latest pride of India in space, RISAT-1, right from the early days of the project. It all started with the custom-built Test Setup and calibration unit for first TR Module (in the days before TR Controller).

An Automated ASIC Tester System (AATS) for OBC-1 ASIC has been a Komoline development; these complex devices were extensively used in RISAT-1 TR Control and Tile Control units (TRC and TCU). Komoline had later contributed to the actual bulk-manufacturing of these two high-density fine-pitch digital subsystems, too (nearly 200 units in all). Another significant Komoline-developed ground-support equipment used extensively in RISAT-1 FM realization is the Ground-Checkout Unit for the TCU, enabling stand-alone testing and qualification of the units. Komoline had also created customized vacuum-curing chambers for addressing the issue of out-gassing in the Dam-and-fill process of fine-pitch high-density devices. Last but not the least Komoline had, under SAC Guidance, mastered the art of producing matched group-delay cables in large volumes with excellent yield.

Komoline had supported with many small and odd jobs along the way as RISAT was taking shape. The company looks forward to more challenges in the future from SAC/ISRO.

TR Module Tester

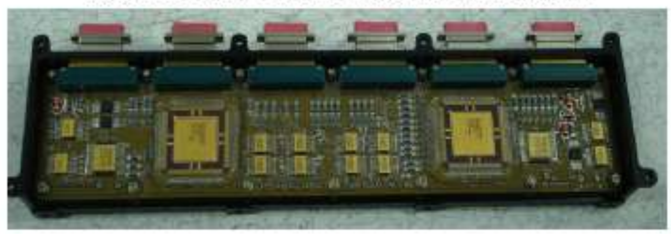
Automated ASIC Test Setup (AATS)



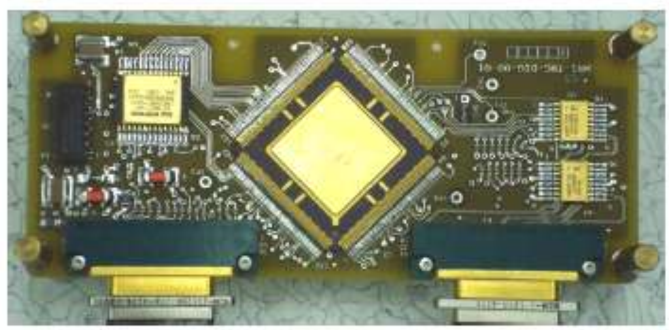
TCU-GCU

Outgassing Chamber

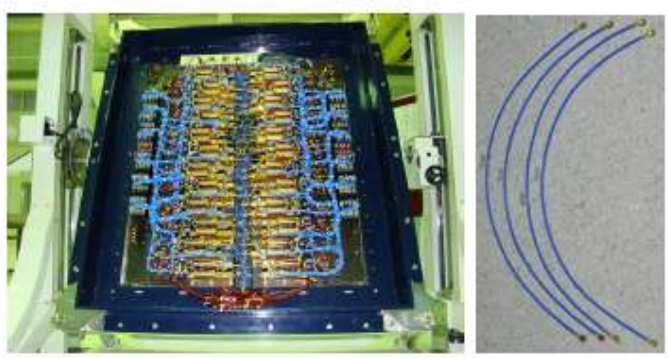
Flight Model Tile Control Unit (21 Nos. Produced)



Flight Model T R Module Controller (168 units Produced)



Group-Delay matched cables for RISAT-1



Section 3 – SAR Processing & Applications Related

SAR Data Processing System

Kirti Padia & Dr. R Ramakrishnan, Data Products Software Group (SIPA), SAC

Introduction: Radar imaging Satellite (RISAT)-1 is India's first space borne active imaging synthetic aperture radar satellite operating in C band. It was launched on 26th April 2012 from Shriharikota through PSLV launch vehicle. An imaging radar transmits pulses of microwave radiation to a target and receives the back scattered radiation from the target in the form of intensity and time delay of the return signal. The time delay gives information about the position of the target and the intensity, when converted into digital numbers after some radiometric corrections, gives a radar image of the target. The advantages of SAR are

(i) All weather imaging capability (penetrating through cloud cover)

(ii) Day and night imaging capability

(iii) Penetration through vegetation and soil is possible to some extent.

For RISAT-1 a polar sun synchronous orbit at 536.38 kms altitude and inclination of 97.554 deg. with repetivity cycle of 377 orbits in 25 days with a descending node local time of 6:00 AM +/- 5 min is chosen . Main guiding parameter for choosing the orbit for RISAT-1 is achieving a global coverage in a systematic way for a given swath. Orbit parameters are planned to be variable as per mission operation requirements for various imaging modes. The satellite can image on both the side with respect to sub satellite track. Various modes available for imaging ground are described in table-1 and viewing geometry is described in figure-1.

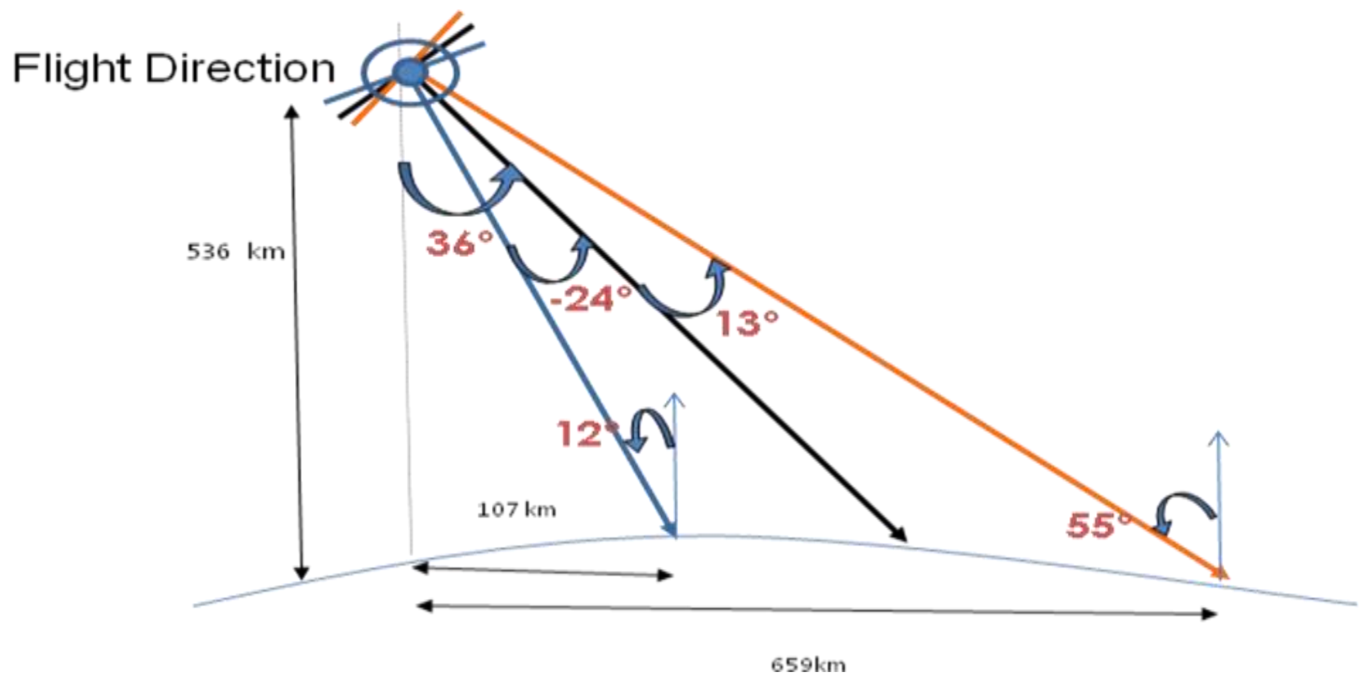


Figure-1 RISAT-1 viewing geometry

Basics of SAR imaging: Synthetic Aperture Radar (SAR) is an active microwave imaging system. An imaging radar transmits pulses of microwave radiation to a target and receives the back scattered radiation from the target in the form of complex samples. The time delay of the return signal gives information about the position of the target. Target history is spread in across track as well as along track direction. Information about target is retrieved through signal processing techniques. The across track direction (fast time) is known as range direction and the along track direction (slow time) is known as azimuth direction.

Table-1: RISAT-1 payload modes, polarization, swath and resolution

Payload modes	No. of beams	Polarisation	Swath *(km)*	Resln (m)
Coarse Resolution (CRS)	12	Singular, Dual, Circular	223	50
Medium Resolution (MRS)	6	Singular, Dual, Circular	115	25
Fine Resolution (FRS-1)	1	Singular, Dual, Circular	25	3
Fine Resolution (FRS-2)	1	Quad, Circular	25	9
High Resolution (HRS)	1	Singular, Dual, Circular	10	1

The transmitted long pulse (say, Chirp (Frequency modulated) signal) views the target for longer duration in the range direction. SAR's principle of synthesizing the aperture to achieve finer azimuth resolution increases the target dwell time. Hence, the target information is spread in both the range and the azimuth directions (Fig. 2 a). The spread is due to the long pulse duration (in range) & the finite azimuth integration time associated with the target. The aperture synthesis is realized in the data processing segment. Coherent SAR image generation involves the compression of the received signal in the range and azimuth directions. The transmitted range signal (chirp) had an apriori frequency modulation. However, the received azimuth signal has a frequency modulation encoded due to the Doppler effect arising from the varying range. SAR focusing basically involves signal compression in both the range and azimuth directions. The target to sensor range changes within a synthetic aperture. As a consequence, a given target is viewed at a varying range instead of a constant range. This range variation spans through multiple resolution cells (Fig. 2b). SAR as mentioned earlier places the target according to the range and not as per the planimetric position. This effect is termed as range cell migration or range walk. The dependence of Doppler modulation and range cell migration as a function of range distance makes the SAR processing a two dimensional problem. This two-dimensional problem can be split into two one-dimensional problems due to the varying chirp propagation times associated. In the range, due to the microwave propagation velocity (c), a fast time is associated. In the azimuth, due to the velocity of the sensor (<<c), a slow time is associated. Also short pulse duration with large bandwidths and long aperture time along with small bandwidth (Doppler) are associated with the range and azimuth chirps.

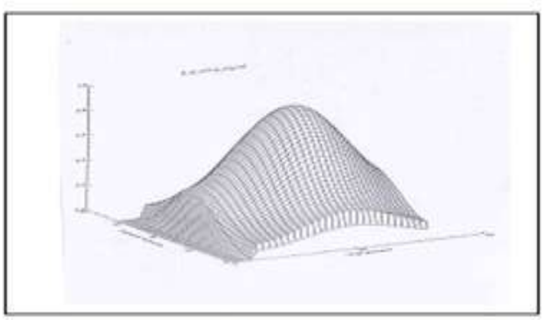


Fig. 2a: Envelope of 2D Chirp Signal

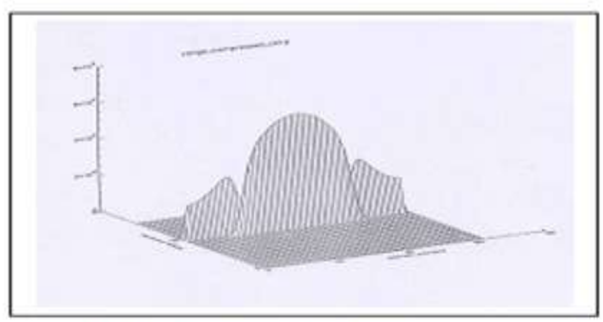


Fig. 2b: Range Compressed Chirp

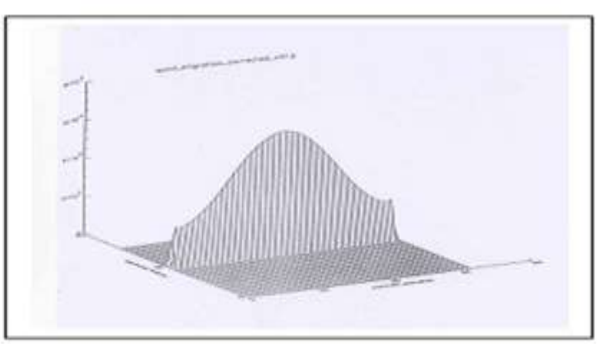


Fig. 2c: Quadratic Migration Corrected

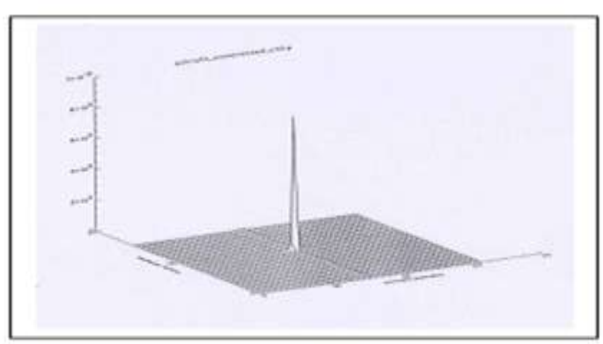


Fig. 2d: Azimuth Compressed

The compression of the range and the azimuth chirps (matched filtering) is effected by the two correlation operations of the chirps with the appropriate reference functions. A matched filter is an optimum filter that increases the signal to noise ratio of the compressed pulse. The range compression is straightforward and is realized by a correlation operation. The received range signal is correlated with the complex conjugated time inverted replica of the transmitted pulse. The azimuth reference filter has to be constructed using the Doppler information. The dependence of the Doppler and the RCM on range complicates the azimuth processor. The Doppler frequency modulation, which occurs as a physical phenomenon needs to be estimated. The curved path (in memory) of the range cell migration is usually corrected (using interpolation kernels) (Fig. 2 c) before azimuth compression (Fig. 2 d). Multilook technique to reduce the speckle noise at the cost of azimuth resolution degradation is done to increase the radiometric resolution for σ_0 measurements. Range & azimuth compressed data is detected and geocoded images can be formed using SAR geolocation algorithm.

The basic steps of SAR data processing can be summarised as

- Block Adaptive Quantisation decompression
- Correction for I & Q imbalance
- Doppler Centroid Estimation
- Range Compression
- Range Cell Migration Correction
- Azimuth Compression
- Single Look Complex or Multi-look data generation
- Slant range to Ground range conversion
- Geocoding

Data processing for RISAT-1 mission is carried out on a cluster of Six SMP nodes each having 4 CPU 8 core configuration under IMGEOS environment with a near real time throughput.

SAR Acquisition Modes for RISAT-1:

Radar Imaging Satellite (RISAT-1) will acquire data in C band with following modes:

- ***Stripmap Mode:*** The antenna pointing angle is kept constant as the radar platform moves. The beam sweeps along the ground at an approximately uniform rate, and a strip of ground is imaged. The azimuth resolution is governed by the antenna length. It provides 2 m slant resolution image over 25 km swath in either single or dual polarisations
- ***ScanSAR Mode:*** The antenna beam is switched in range many times during a synthetic aperture. A much wider swath is covered at the cost of azimuth resolution. There are two scansar modes, namely Medium Resolution (MRS) and coarse resolution(CRS). MRS provides 8 m slant resolution image over swath of 115 km in either single or dual polarisation. CRS provides 8 m slant resolution image over swath of 223 km in either single or dual polarisation.
- ***Alternate Polarization Mode:*** The transmitter polarization is switched a number of times in the synthetic aperture. Rest all conditions are same as in Stripmap mode. It provides 4m slant resolution image over 25 km swath in quad polarisation.
- ***Spotlight Mode:*** Best resolution can be achieved in this mode by steering the beam gradually backwards as the sensor passes the scene. Coverage in the along track direction is a fraction of the along track traversed distance. It generates 1 m resolution image for a spot of 10km (Azimuth) and 10km (ground range swath) for either single or dual polarisation.

Levels of data products:

The various levels of products defined for RISAT-1 are as follows:

Raw Signal Products (Level-0): This product contains raw or unprocessed radar echo data in complex in-phase and quadrature signal (I and Q) format. The only processing performed on the data is the stripping of the downlink frame format, BAQ decoded (optional) and re-assembly of the data into contiguous radar range lines. Each range line of data is represented by one Signal Data Record in the RAW CEOS product. Auxiliary data required for processing is also made available along with echo data.

Geo-Tagged Products (Level-1)*:* The image is geo-tagged using orbit and attitude data from the satellite. This allows latitude and longitude information to be calculated for each line in the image. The earth geometry is assumed to be the standard ellipsoid. Each image line contains auxiliary information which includes the latitude and longitude of the first, mid and last pixels of the line. The raw radar signal data is processed to provide SAR image data pixels. The image pixel data is represented by a series of CEOS processed data records, each record containing one complete line of pixels lying in the range dimension of the image. The product can be obtained as slant range data (16 bit I and 16 bit Q) or ground range data (16 bit) amplitude data. Additionally, an auxiliary file containing a dense grid of geo-locations is associated along with the data file.

Terrain corrected Geocoded Products (level-2): This product contains terrain corrected and geocoded data. There exists provision for UTM (default) and Polyconic map projections. For systematic processing UTM projection is provided. The pixel spacing in the product will depend on mode, no. of looks and look angle. The options for product format are CEOS and GEOTIFF.

Value added products: Beside the above mentioned standard products value added products like merged products and Polsar products (for FRS-2 mode) are also planned.

Following pictures show FRS-1 image (Fig. 3a), colour image generated from CFRS-1 data (Fig.3b) and CRS image (Fig. 3c) of RISAT data.

Acknowledgements: Authors are thankful to Shri Santanu Chowdhury, Deputy Director, SIPA for guidence and encouragement. We also thank RISAT-1 Data products team for providing necessary inputs.

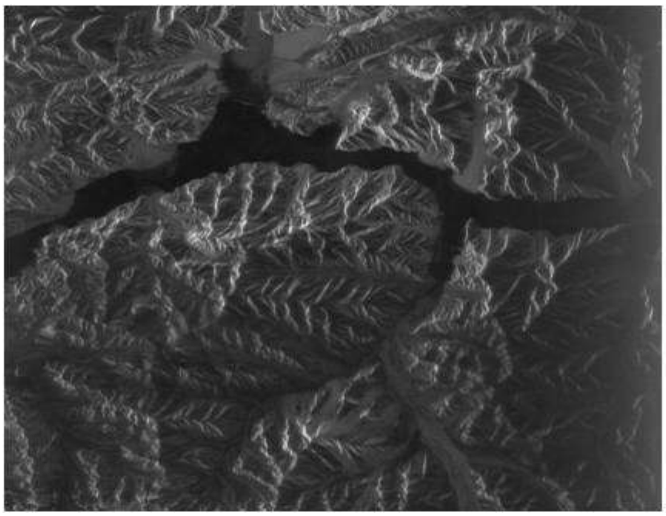


Fig. 3a FRS-1 mode

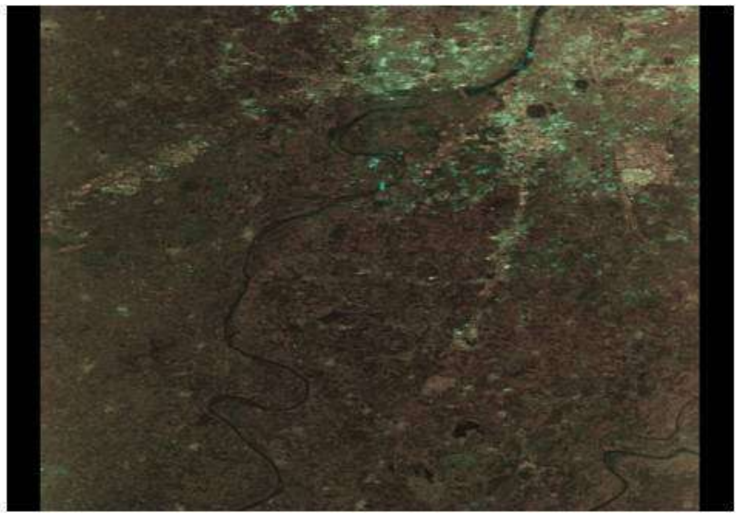


Fig. 3b CFRS-1(RV+RH+diff)

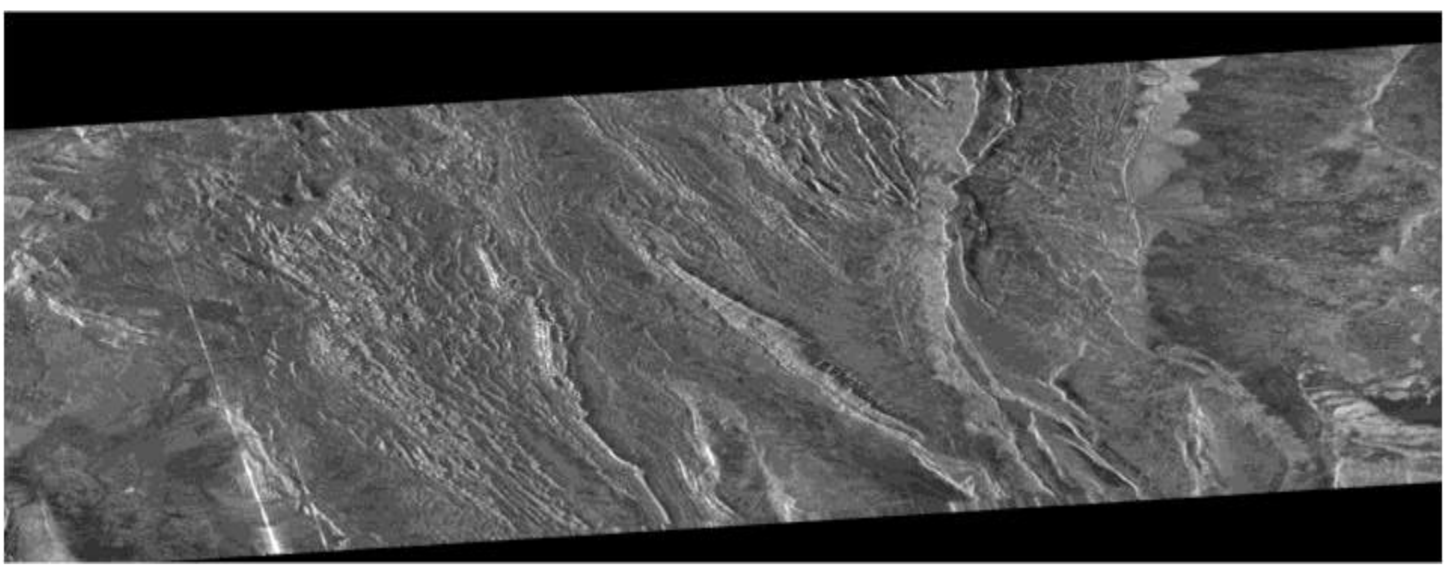


Fig. 3c: CRS image (Geocoded)

Fusion of RISAT-1 SAR Data with ResourceSAT-2 Optical Images

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1.0 Introduction: Satellite Image fusion generates single hybrid image from a collection of input satellite images and helps us to extract maximum information from the remotely sensed datasets to achieve optimal spatial and spectral resolution. Fusion described by Wald [4] as a "formal frame work in which are expressed means and tools for the alliance of data originating from different sources. It aims at obtaining information of greater quality.

The primary attention of this work is to study the improvement and quality of images generated by fusion of low resolution multi spectral data of Resourcesat-2 LISS-III/LISS-4MX; 24m5m resolution and high resolution RISAT-1 FRS mode; 3m resolution [1]. The integration of optical and SAR images from Indian Remote Sensing satellites facilitates better visual and automatic image interpretation.

2.0 Methodology Used: Digital Image Processing techniques are used to generate fused image in different stages. RISAT-1 FRS mode geometrically corrected data is filtered using enhanced LEE Filter in order to suppress speckle effect and improve interpretation capabilities. Resourcesat-2 LISS-3 and LISS-4 MX ortho rectified scenes are used for registering RISAT-1 SAR data to prepare them for an accurate fusion application. Image Registration is done using non-rigid registration technique with adaptive stochastic gradient descent optimizer. All images are resampled to same pixel size using cubic convolution resampler.

After transforming the datasets into same projection system, the images are fused to generate image which have better spatial and spectral characteristics [3]. The fusion technique used here for merging SAR with optical data is Color Normalized fusion which is a variant of Brovery Transform [2].

- **Brovey Transform (BT):** The BT, uses ratios to sharpen the multispectral image. It was created to produce RGB images, and therefore only three bands at a time can be merged . Many researchers used the BT to fuse a RGB image with a high resolution image. The basic procedure of the BT multiplies each multispectral band by the high resolution SAR data and then divides each product by the sum of the multispectral bands.

- **Color Normalized Transformation (CN):** Color Normalized is an extension of the BT. CN transform also referred to as an energy subdivision transform. The CN transform separates the spectral space into hue and brightness components. The transform multiplies each of the multispectral bands by the SAR data, and these resulting values are each normalized by dividing the sum of the multispectral bands.

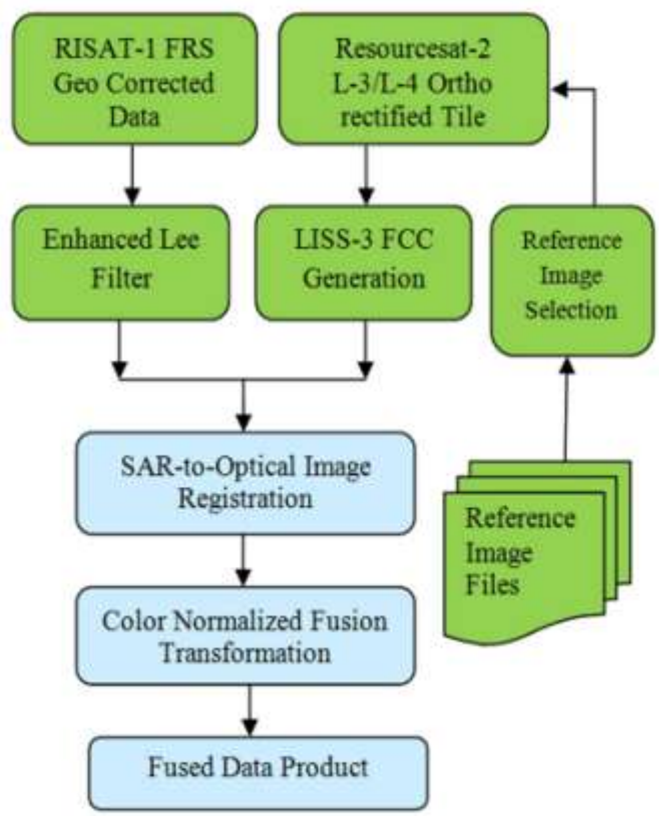
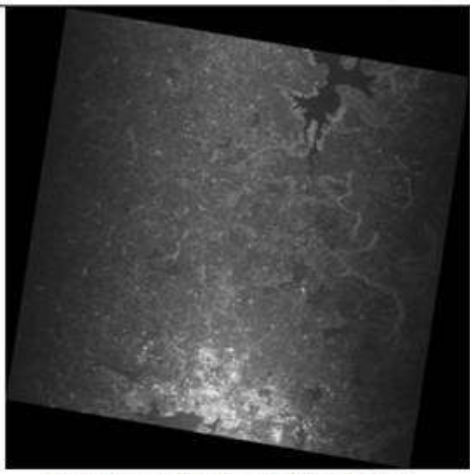


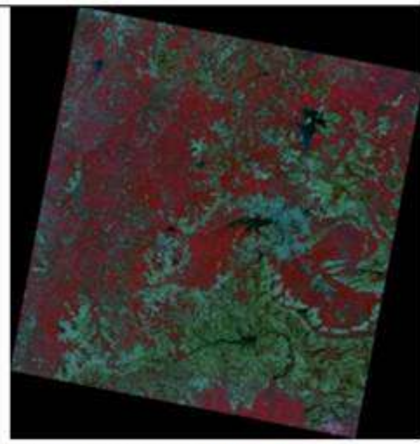
Figure 1: Fusion Data Processing Workflow

3.0 Fusion Processing Workflow: The fusion data processing workflow (as in Figure-1) involves selection of Resourcesat-2 LISS-3 reference image using geographic corner coordinates of RISAT-1 FRS geo corrected data. The speckle noise in SAR data is suppressed using Enhanced LEE Filter, as well as in parallel LISS-3/L-4MX

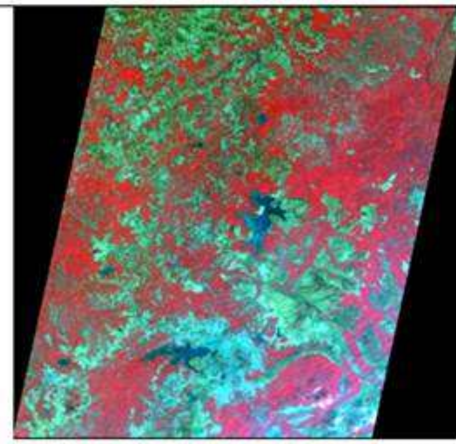
FCC image is generated using combination of BAND4, BAND3 and BAND2 and all the images are resampled to same pixel resolution. The next step is to register RISAT-1 SAR data with LISS-3/LISS-4MX ortho rectified reference to align the SAR geometry with the master image geometry of LISS-3/LISS-4MX. Finally the registered images are fused using color normalized transformation to generate the Fused Data Product.



RISAT-1 SAR L2-GEOREF SCENE

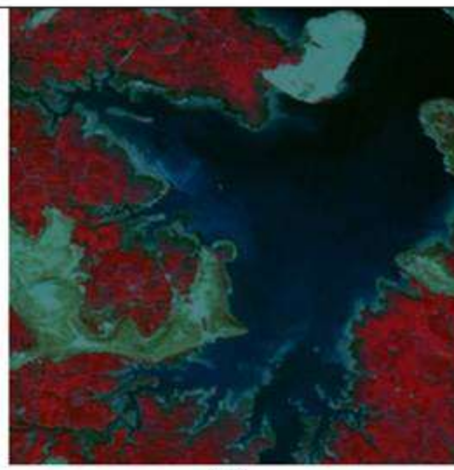


RESOURCESAT-2 LISS-3 FCC SCENE

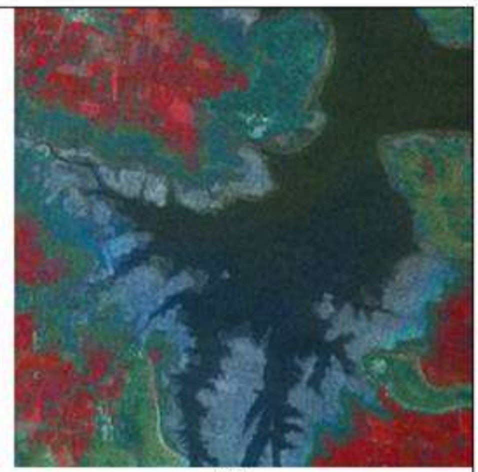


RESOURCESAT-2 LISS-4MX FCC SCENE

(A)



(B)

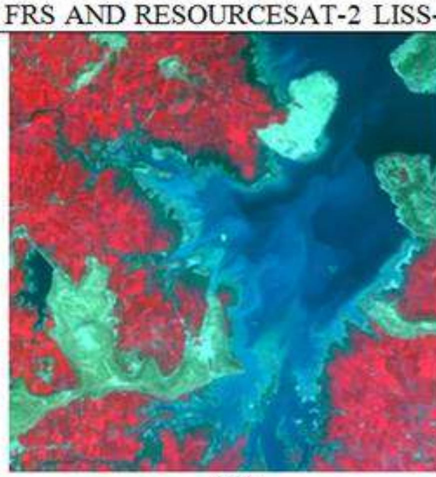


(C)

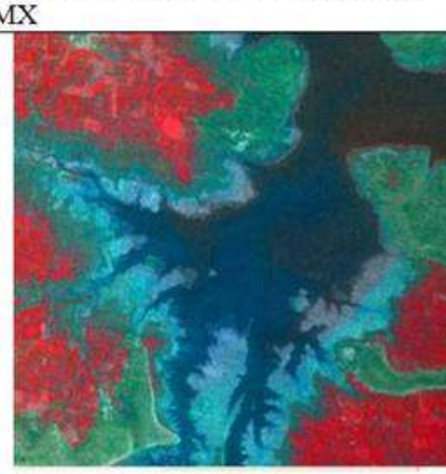
Halali Reservoir, 40 Km Away From Bhopal, India.

(A) RISAT-1 FRS MODE L2-GEOREF (B) RESOURCESAT-2 LISS-3 FCC (C) FUSED DATA PRODUCT USING RISAT-1 FRS AND RESOURCESAT-2 LISS-3 (D) RESOURCESAT-2 LISS-4 MX FCC (E) FUSED DATA PRODUCT USING RISAT-1 FRS AND RESOURCESAT-2 LISS-4 MX

(A)



(D)



(E)

TABLE I: FUSION RESULTS

4.0 Results Achieved: The methodology and processing workflow is exercised at first day RISAT data processing activity. The input RISAT-1 FRS mode geo corrected data (Level-2) is located between 23°12'51.3890"N to 23°33'22.2855"N and 77°17' 06.2876" E to 77° 34'28.1285" E which falls over the region of Bhopal, Madhya Pradesh, India. The Fusion process takes RISAT-1 FRS L2-GeoRef product as input, generates corresponding Resourcesat-2 ortho rectified LISS3 FCC product, register the images using online utility and generates the fused product. The TABLE-I shows the results generated by merging RISAT-1 FRS mode data with Resourcesat-2 LISS-3/LISS-4 MX data.

5.0 Conclusion and Future Work: In this paper, we introduced an efficient fusion procedure for merging RISAT-1 SAR data with Resourcesat-2 Multi spectral data for improving the visual interpretability of the image. Furthermore, land cover/use information can be extracted with more accuracy by classification of fused data. Experimental result shows that fused product is more informative having optimal spatial and spectral characteristics. Brovery transform used is a powerful fusion technique for generating fused product. But the future work includes study of other fusion techniques/methods such as Smoothing Filter-Based Intensity Modulation (SFIM) and Principal Component Analysis (PCA) which can also generate optimal fusion data.

6.0 Acknowledgement: The authors thankfully acknowledge Shri A.S Kiran Kumar, Director, Space Applications Centre, ISRO for giving us support. We thank Shri Santanu Chowdhury, Deputy Director, Space Applications Centre for his technical guidance.

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RISAT-1 SAR Processor from ADRIN

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1. Abstract: Synthetic Aperture Radar (SAR) image formation algorithms convert raw signal data to interpretable detected images and require significant processing after acquisition. ADRIN has developed a SAR processor which has an edge over a readymade SAR processor in achieving flexibility apart from image formation e.g. input data format handling, option of working on a region of interest (ROI), having full control in focusing parameters, special applications like moving target indication, to name a few. The major challenge is to understand the underlying imaging processes and building expertise to address more advanced and agile sensors in future. ADRIN SAR processor is built with a generic "one-fits-all" approach and is sensor independent. It is a multi-mode digital SAR processor capable of handling different modes of SAR acquisitions e.g. STRIPSAR, ScanSAR and SPOTLIGHT. This can be easily tuned for experimental modes as well.

This processor provides phase preserving single-look complex (SLC) images in slant range suitable for interferometric and polarimetric applications. It also provides value addition like geocoding and orthoimage generation. It incorporates multiple processing algorithms such as Range Doppler Algorithm (RDA) and Chirp Scale Algorithm (CSA) for STRIPSAR mode; Range Migration Algorithm (RMA), Polar format Algorithm (PFA) and Extended CSA for spotlight and SPECAN for ScanSAR mode. This is built around C++ and C#. Parallel processing is achieved by applying multithread techniques. It has an option to toggle between throughput and precision processing.

Image quality measure (IQM) refers both to the impulse response properties of a radar/processor combination, and to the response of the system to distributed scatterers, which are evaluated to qualify the SAR processor. The most important set of image quality tests revolve around the impulse response.

In ADRIN, a framework is developed to handle multi-sensor data, from data ingestion to image formation involving all the focusing algorithms mentioned above, also validating with a set of IQM parameters. The framework is also extended for value added product generation including special products and applications.

The focus of this document is to bring out few results of RISAT-1, ISRO's first SAR satellite.

2. RISAT-1: Radar imaging satellite, RISAT-1 carries a SAR payload onboard operating in the C-band at 5.35 GHz [5] which has the capability to operate in multiple beams and multi-polarization mode. It has fine resolution stripmap (FRS-1) and FRS-2, medium resolution ScanSAR (MRS) and coarse resolution ScanSAR (CRS), high resolution SPOTLIGHT (HRS) and two experimental modes e.g. circular polarization and *sliding SPOT*. Imaging is done in various swaths ranging from 10 km to 223 km with spatial resolutions ranging from 1m to 50m.

3. Image Formation Algorithms: SAR image formation can be achieved through various algorithms published in the literature [1, 2, 3, and 4].

RDA uses the large difference in time scale of range and azimuth data and approximately separates processing in these two directions using Range Cell Migration Correction (RCMC). RCMC is the most important part of this algorithm. Since, azimuth frequency is affected by Doppler Effect and azimuth frequency is bonded with Doppler frequency, it is called Range Doppler Algorithm.

The CSA provides accurate SAR processing without an interpolator. In this algorithm, all operations are performed with either multiply or FFT operations. RCMC is done in two steps (a) differential RCMC and (b) bulk RCMC. First the differential RCM is corrected in range Doppler domain which is dependent on the range to the individual target. Bulk RCM is performed in two dimensional frequency domain.

ScanSAR is a particular SAR mode that achieves very wide swath coverage scanning through several range sub-swaths by periodical switching of the antenna pointing based on burst mode of operation. ScanSAR data can take advantage of the algorithm known as SPECtral ANalysis (SPECAN). This algorithm is more efficient and requires less memory than RDA, while producing the image quality required for these moderate-resolution applications.

There are several algorithms for SPOTLIGHT processing. PFA transforms the input raw data from rectangular format to polar format which is more accurate way of representing the raw data on the basis of imaging geometry. Third is a extended chirp scale algorithm (ECSA) for SPOTLIGHT processing which doesn't require any interpolation. Unlike PFA, RMA does not assume that illuminating wave fronts are planar. Hence, RMA images do not suffer from the space- variant defocusing and geometric distortion that wave front curvature induces with the use of PFA. In addition RMA is often competitive with PFA in terms of computational efficiency. These characteristics make the RMA particularly attractive for imaging situations that involve severe differential range curvature over the scene of interest.

The type of algorithm is chosen according to the mode and the requirement of phase retention.

Methodology: The type of algorithm is chosen according to the mode and the requirement of phase retention as depicted in figure 1.

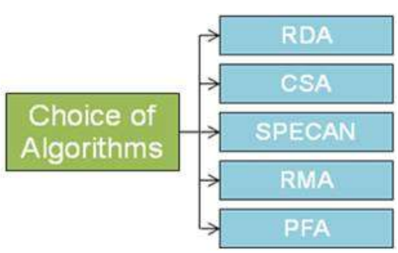

Figure1. Choice of SAR focusing algorithms.

The processing chain of SAR image formation and value addition is illustrated in figure 2. The precision processor handles all the image formation algorithms as shown in figure 1. It handles the raw signal data in either Committee for Earth Observations Satellites (CEOS) or (Baseband Data Handling) BDH format.

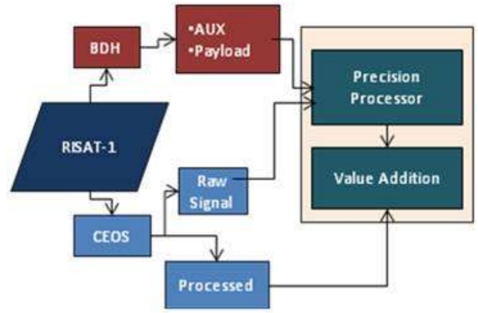

Figure 2. The flow diagram of RISAT-1 data processing chain in ADRIN's framework.

The sub-beams, beams and polarizations are separated and each raw data is prepared with an internal processing parameter file to be ingested into the precision processor.

4. Results & Discussions: Results of the image formation are discussed in this section. All the modes are processed with intra and inter overlaps between sub-beams and beams wherever applicable.

4.1 FRS-1: STRIPSAR (FRS-1) has 3m spatial resolution and 30 km swath and the processed image is shown in figure 3. The circular STRIPSAR (cFRS-1) image is shown in figure 4. Circular polarimetric modes images are acquired with transmit H & V with 90 deg phase and receive as linear (dual-pol). The only change is pulse width is reduced to half.

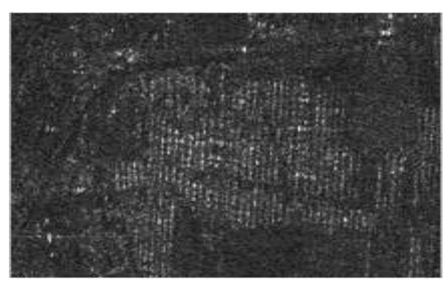

Figure 3. A point target in slant range in the detected FRS-1 mode (actual pixels).

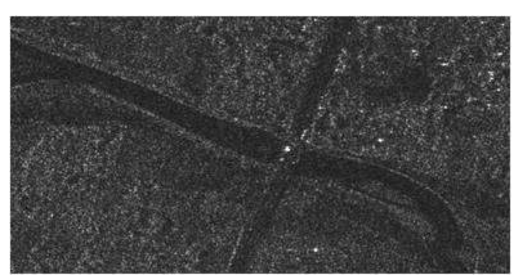

Figure 4: One of the cFRS-1 mode images.

4.2 FRS-2: It is a hybrid STRIPSAR and ScanSAR mode having quad polarizations. A ground area with FRS-2 in orbit 198 is illustrated in figure 5. Here, antenna pattern correction has been applied.

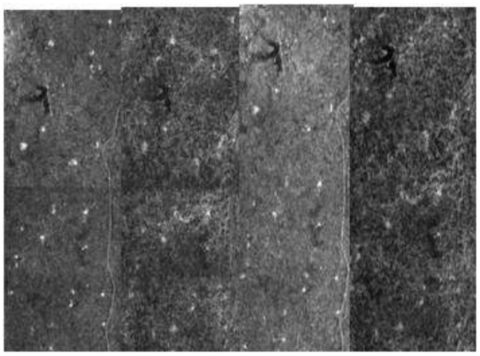

Figure 5. One of the FRS-2 mode images belonging to 198 orbit number having all four polarizations HH, HV, VV and VH respectively.

4.3 MRS & CRS: MRS and CRS are ScanSAR modes of acquisitions with 6 and 12 beams respectively. CRS has a resolution of 50m and swath of 240 km. The ScanSAR mode has a challenge in data processing for intra and inter beam mosaicking with seamless radiometry. Two beams are shown in figure 6 acquired in medium resolution (MRS).

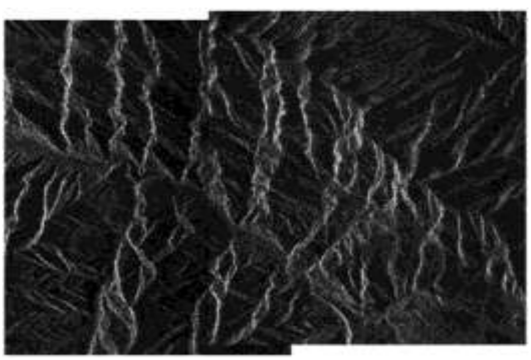

Figure 6. Two beams are shown mosaicked acquired in RISAT-1 MRS mode which also includes sub-beams mosaicking under a particular beam.

4.4 Image Quality Measure (IQM): Parameters e.g. spatial resolution, peak side lobe ration (PSLR) and integrated side lobe ration (ISLR) are measured on point target [6] as in figure 7 and results are illustrated in table 1 and 2. Spatial resolutions are broadened by 20% because of windows applied.

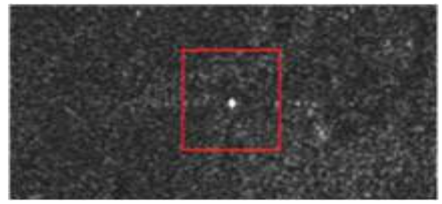

Figure 7. A point target in RISAT-1 (FRS-1)

Table 1. IQM in range (FRS-1)

RES (m)	PSLR (dB)	ISLR (dB)
2.155095	**-18.657425**	**-4.673192**

Table 2. IQM in azimuth (FRS-1)

RES (m)	PSLR (dB)	ISLR (dB)
4.367269	**-25.7545**	**-6.31255**

4.5Value Addition: The processed and detected slant range images are subject to ground range and geocoding. Orthoimages are generated using available DEM such as SRTM and ASTER, shown in figure 8.

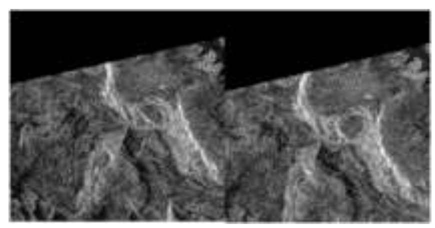

Figure 8. A geocode image (left) and orthoimage (right).

5. Conclusions: ADRIN has built a *one-fits-all* SAR processor capable of handling multi-sensor SAR raw data and is tested on ERS-1, ERS-2, RADARSAT-1, PALSAR and RISAT-1 data. It can handle high squints and tested with squints upto 26 deg. It can also process SPOTLIGHT mode data acquired in high squints with both high and low PRFs. Tons of data sets are processed with all the algorithms. Moreover, the focusing algorithms are evaluated by an expert team [7].

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"Two of the largest, long term, technically advanced projects ever undertaken were the Manhattan Project and the Apollo Program. Both of these marshaled enormous physical and intellectual resources over many years. However, they weren't launched to create new markets, but as a response to a perceived existential threat. For me, therein may lie the answer---"

Richard Yanck

SeaSAT to RISAT - SAR Data Processing Experience

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1.0 Introduction: The Synthetic Aperture Radar (SAR) sensor developed by ISRO for the RISAT-1 mission is an advanced SAR having multi-mode, multi-beam-pointing and multi-polarization capability. The Hybrid polarimetric mode of data acquisition is the first of its kind in the world for an EOS mission. The first Hybrid polarimetric SAR was the MiniSAR which was designed and developed by JPL, and launched in the Chandrayan I. The data available from the RISAT-1 SAR system has a potential to cater to a wide variety of applications for all seasons and throughout the day across the whole globe. As such SAR has a tremendous application potential in land as well as ocean areas.

Unlike optical data, SAR signal processing involves highly compute bound two dimensional operations on large complex data sets, and hence the need for high speed processors arises in order to generate the products in a reasonable time. With the advent of high speed computers, with parallelization capability, the data processing time can be substantially reduced to almost near real time.

However during the 1980s when the spaceborne SAR systems for civilian use were flown as part of EOS missions, computer systems as well as the algorithms for SAR data processing were quite primitive, and very little knowledge was available in this field. In this article, I would like to share my experiences in this venture (of SAR processing) with the readers.

2.0 Seasat SAR Data Processor Development: Seasat-A of NASA/JPL was the first civilian satellite designed for remote sensing of the Earth's oceans with synthetic aperture radar (SAR). The mission was designed to demonstrate the feasibility of global satellite monitoring of oceanographic phenomena and to help determine the requirements for an operational ocean remote sensing satellite system. Specific objectives were to collect data on sea-surface winds, sea-surface temperatures, wave heights, internal waves, atmospheric water, sea ice features and ocean topography. The mission ended on 10 October 1978 due to a failure of the vehicle's electric power system. Although only approximately 42 hours of real time data was received, the mission demonstrated the feasibility of using microwave sensors to monitor ocean conditions, and laid the groundwork for future SAR missions. The major difference between Seasat-A and previous Earth observation satellites was the use of active and passive microwave sensors to achieve an all-weather capability.

The satellite carried microwave sensors such as L band SAR, Ku band Scatterometer, multifrequency scanning microwave radiometer, and Ku band altimeter. The data acquired by these sensors paved the way for a multitude of research activities in the microwave data processing and application areas, all across the world.

Some data sets over Germany and Goldstone(California) area of USA were available with NRSA in CEOS format. The raw complex data was available in CCTs. We, in SAC acquired the data and started developing the algorithm for processing the data over Goldstone, after carrying out the relevant simulation exercises. The computer system available at that time was a VAX-11, 780 with 1.5MB RAM! The processing load being huge, even for a 100Km by 100Km area, with 25m resolution, it used to take about 4-5 hours to just perform a range compression operation in a multi user environment. With the small RAM available, corner turning(of about 40MB range compressed data) was an operation, which had to be carried out using an efficient algorithm called Eklund's algorithm. This is mandatory for performing the azimuth compression, if large memory is not available. This operation also involved a lot of time. The algorithm for SAR signal processing was chosen as the 'Range-Doppler' algorithm, which was the most efficient processing algorithm known at that time. The only SAR software processors for Seasat, during that time, were developed at MDA(Canada) and at JPL (as reported in journals). Our processor was developed during those early phases of digital SAR processor development. The flow diagram of the processing steps is given below in Fig 1.0

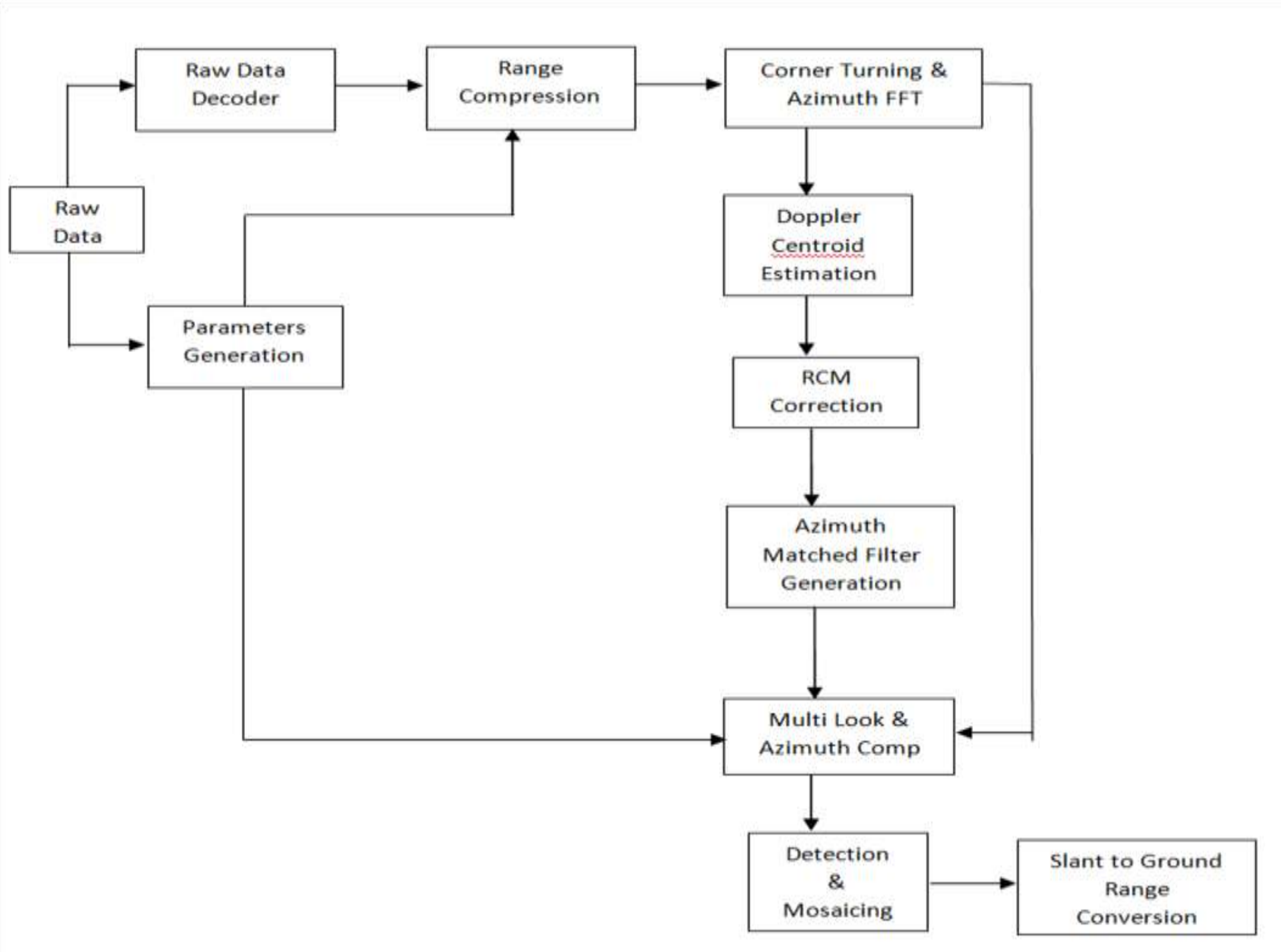

Fig-1: Flow Diagram Of SAR Processing

With the above algorithm, the first data which was processed and which brought out an image of the L band SAR data from the raw signal data, was that of the California's Goldstone Corner Reflector. One sample image for a small area around the CR is given in Fig: 2.0

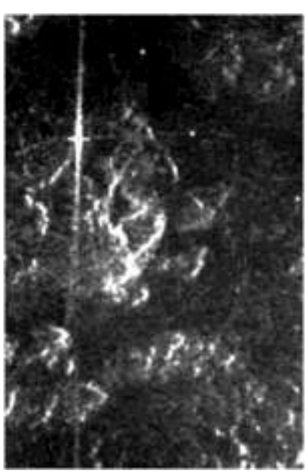

Fig: 2.0 Goldstone Corner Reflector Data (4 look image) ,1987

The algorithm was further fine tuned to perform auto focus. The input data for Seasat-L band SAR was available as single channel real data in baseband. This had to be converted to get the complex in phase and quadrature phase components, for the signal processing operations, mentioned above. Multi-look processing was carried out by look extraction using band pass filtering. Subsequent azimuth compression and mosaicing was performed to get the multi-look, radiometrically superior data. Single look processing gave a radiometric resolution of about 4db. Multi look(4 looks) significantly improved it about 2.6dB. However in the process, the geometric resolution of single look (azimuth) of about 6mt degrades to around 24mt.

As was known, that the highly compute bound SAR signal processing was not conducive to the requirement of high throughput requirements from the user community, and hence several institutes and organizations were toiling hard to come out with algorithms to cater to a feasible and acceptable turnaround time of the product. Thus our mandate was not only to develop the silmulation and processing algorithm to process the data, but also to design the algorithm around available computing systems, in order to optimize the processing time. This was a challenging task, and we took up the challenge of designing systems for faster and faster processors.

PARAM Based SAR Processor: The breakthrough in SAR processing gave a tremendous boost to the development of SAR processing in ISRO, India. At that time this was one of the very few processors in the world(only US, Canada, Italy and USSR were having software SAR processing technologies). However the computing technologies were not sufficient in India to cater to fast turnaround time. Processing a 100Km by 100Km scene in 10-15 hours was a bottleneck. This gave rise to the need for designing the algorithm around multi processor systems, which were being developed by different organizations. Thus, the collaboration for the SAR software development around a super computing machine such as the PARAM(PARAallel Machine) was taken up between CDAC, Pune and SAC, ISRO, Ahmedabad.

Transputers were the building blocks for this super computing technology. 16 node transputer was first used to design and develop the Seasat SAR processor. Using a new language called OCCAM this software was developed, which drastically reduced the processing time to about one hour. This was the first attempt at multi processor based SAR software development in ISRO. It was a matter of pride when this processor earned the 100MFlops PARAM award given by CDAC. Ref [1]

3.0 ERS-1 Operational SAR Processor Development: The success of Seasat processor had earned accolades from not only the ISRO management(then Chairman, Prof U R Rao personally came to see the processed data in SAC), but also from outside agencies. Hence, the task of developing the operational SAR data products for the up coming project of ESA, the ERS-1 also came. This gave a full fledged insight into the development of an end to end system for an operational SAR processing system. First the design was carried out around a MicroVAX computer with a mass memory and an Array Processor, to cater to the highly compute bound jobs. The algorithm was further upgraded for a C band system of ERS-1 to cater to the need for PRF ambiguity estimation and incorporating that in the azimuth compression. Approximate turn-around time was about 7-8 hours. The software was ported to NRSA, Hyderabad and made operational.

PARAM Based ERS-1 SAR Processor Development: By this time the PARAM technology was established. Hence we started design and development of the software around a SUN-PARAM system, with 16 node transputer system. SUN machine was the front end system for this architecture. This design and implementation brought down the processing time to about an hour. This system was also operationalized at NRSA, Hydearabad.

One processed data set is shown in Fig:3.0 (a). The processor architecture is shown in Fig: 3.0(b)

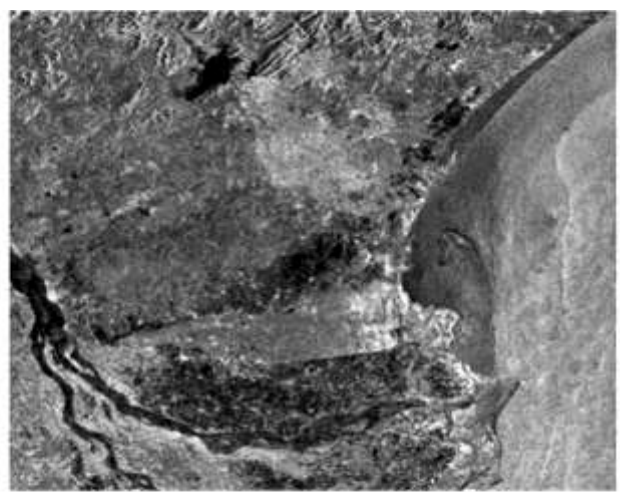

Fig:3.0 (a) ERS-1 SAR Processed Data over Rajamundry area,1991

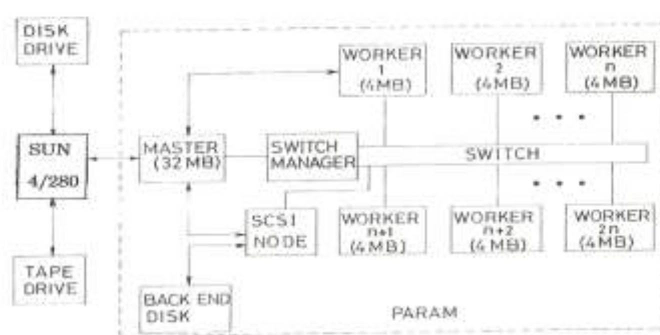

Fig:3.0 (b) Processor Architecture For the PARAM based SAR Processor

4.0 Auxilliary SAR Processor Development: As a spin off to the above activity, we also developed the first

Airborne SAR processor, for ISRO's ASAR systems which were being made during the 90s. This was first done around the PC_PARAM machine, and subsequently upgraded to better computing systems such as the SUN_PARAM systems[Fig 3.0(b))]. To test the algorithm for the airborne sensing, some test data from DLR was processed. One of the processed data of ESAR,DLR is shown in Fig:4.0(a).The ASAR DP(data processing) was different from the spaceborne data processor, due to the additional tasks of motion compensation. Motion errors fuzz out the image, and has to be compensated at various levels. Auto-focus, FDC estimation, and PRF ambiguity algorithms had to be properly implemented to take care of such FDC estimation, and PRF ambiguity algorithms had to be properly implemented to take care of such errors. Some of the processed data sets are shown in Fig:4.0(b) & (c)

Fig: 4.0 (a) ESAR Data of DLR processed by the ASAR_DP (SAC), 1990

Fig:4.0 (b) ASAR Data over Ahmedabad, processed by ASAR processor (SAC), 1996-97

Fig:4.0 (c) ASAR Data near Ahmedabad processed by the ASAR Processor(SAC)

Similarly Interferometric SAR processing algorithm was developed in SAC. In order to do that a proper design starting from SLC(Single Look Complex) product generation was carried out. ERS processing algorithm was augmented by us properly to take care of generation of the SLC data without degrading the phase fidelity. Phase unwrapping technique using residue method, was simulated and tested using ERS-1 interferometric pair of data sets. Registration and correlation methods were tested using actual ERS-1 SAR data. Subsequently this led to the development of InSAR processor.

Another development related to SAR processing, was in the field of Differential Interferometric SAR. The simulation work was carried out in DLR and an algorithm was developed and tested using both simulated as well as actual ESAR data.

5.0 RISAT-1 Processor Development: With the expertise of Seasat, ERS and ASAR processing, the design and development of the RISAT-1 data for FRS-1 was attempted. A generic processor was designed and implemented and first tested using the ERS-1 raw data. The sample image is given in Fig 5.0(a). The processing time of course now came down to only 6 minutes, using a dual core Xeon machine. This of course shows the amount of technological advancement in the world of computing.

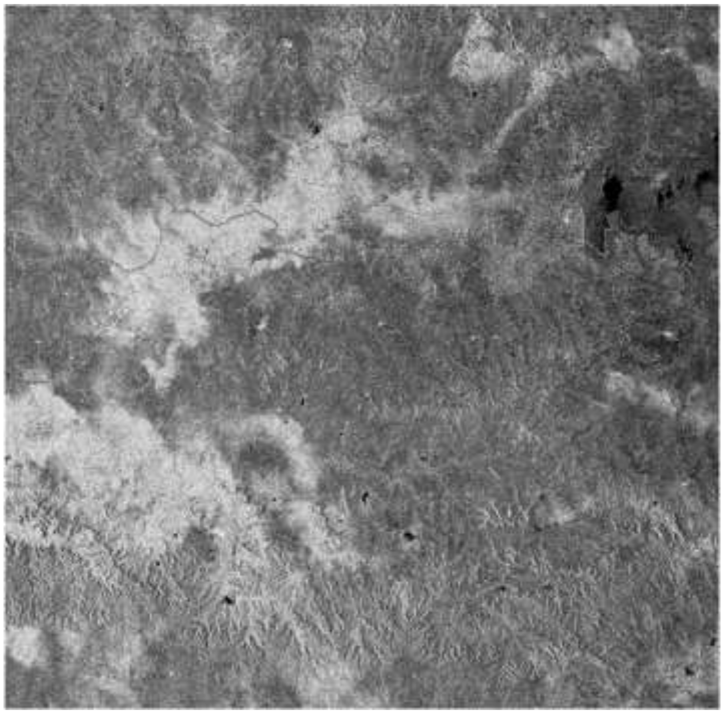

Fig:5.0(a) ERS-1 SAR data in Orissa, Processed by the generic RISAT processor, 2008

The above algorithm was modified to take into account the BAQ(Block Adaptive Quantization) introduced in RISAT data. With the relevant modifications peculiar to RISAT FRS-1 data mode, the software was tested using DMSAR data, which is similar in acquisition mode to RISAT. The processed data is shown in Fig 5.0(b). It is to be noted that the image has degraded performance at the far range. This is because no motion compensation was incorporated in the processing, and secondly because no gain correction was applied for this interim software. The main purpose of this software was to verify the algorithm and the BAQ decoding and format checking, pertinent to RISAT-1.

With the algorithm developed a software processor was implemented for handling RISAT-1 data sets. An example of image processed with the above algorithm is shown below in Fig: 5.0(c)

Fig: 5.0(b) DMSAR 6 bit BAQ data of 1m resolution (near Ahmedabad), processed by the RISAT-1 generic processor, 2008

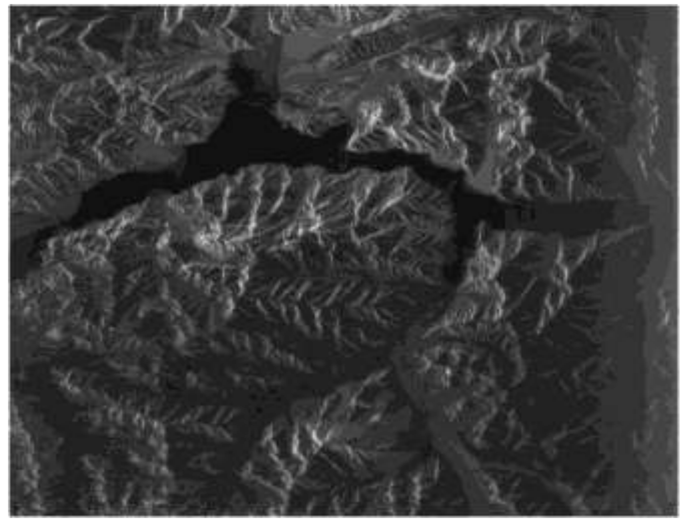

Fig: 5.0(c) Data Processed from RISAT-1, 2012 (Courtsey MRSA)

6.0 Hybrid Polarimetric SAR Data Analysis: The Hybrid circular polarimetric SAR processing being a novelty, a lot of simulation activity went into it during the last four five years, in order to understand its features. In order to do that fully polarimetric data (AIRSAR data of JPL), ESAR data of DLR and ALOS PALSAR data were used to simulate hybrid polarimetric SAR Stokes parameters, and the novel 'm-delta' decomposition was carried out over that ,in order to identify the single bounce and double bounce features. A sample result of decomposition over San Francisco is given in Fig 6.0. below.

Fig 6.0(a) : Image obtained from JPL , AIRSAR data

Fig 6.0(b): Pauli decomposed image for Original linear quad pol data.

Fig 6.0(c): Pauli decomposed image for Simulated Circular polarimetric data

Conclusion: With the success of RISAT-1, the area of SAR processing and application will no doubt be reaching a great height. Actual data sets in different modes and in different views will surely open up a pandora's box. The power of supercomputing has already made processing almost near real time. The turn around time for products, are coming down drastically, which will render the data more and more useful to critical events such as disaster monitoring and mitigation, flood mapping etc. Research in diverse applications will pose a challenge to the scientists in India, which will in the long run benefit human beings.

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(7) Implementation of RISAT Stripmap Processor by Suneela T J V D and Arundhati Misra, SAC/MRSA/MSIG/ MSSD/RISAT /03/2008, Dec 2008.

(8) Sensitivity Study Of Polarization Asymmetry In Circular Polarimetric SAR, By Arundhati Misra and Tapan Misra Presented at the National Symposium on "Advances in Remote Sensing Technology and Applications with Special Emphasis on Microwave Remote Sensing" organized by the Indian Society of Remote Sensing in Dec, 2008.

(9) Novel Polarization Decomposition Methods For Circular Polarimetric SAR - Filed for Patent: Inventor: Tapan Misra, Biswajit Maity and Arundhati Misra

**The above work was done by the author during her tenure in Data Products (Signal and Image Processing Area) and Microwave Remote Sensors Area. The author is currently posted in GRD, AOSG, EPSA.

Applications of RISAT-1 Data

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1. Introduction: RISAT-1 operating in C-band with multiple polarizations and imaging modes is likely to boost various geo-science applications through its' all weather and day-night imaging capability. RISAT-1 has been designed and developed with various novel techniques, the most prominent among them is the hybrid polarimetric mode of operation, where the signal is transmitted in 'circular' polarization and received coherently in horizontal (H) and vertical (V) polarizations. The hybrid polarimetric mode imaging of in RISAT-1, which is the first of its kind in terrestrial remote sensing, not only promises better imaging facility in terms of larger coverage area, better repeativity and higher information content, but also offers development of newer applications through the use of hybrid polarimetric data. Apart from that the SAR data with varying incidence angles, resolutions and swath customized for various land, coastal and oceanic applications will tremendously enhance the scope of microwave remote sensing in India, most importantly, crop monitoring during *kharif* season and flood mapping during monsoon season.

Efforts have been initiated in ISRO to operationalize many of the remote sensing applications projects with the help of RISAT-1 data through "RISAT-Utilization Programme". The major goals of the RISAT-UP include development of tools/techniques for RISAT data processing and analysis, development of operational procedures for various geo-science applications and capacity building in India for utilization of SAR data.

2. Applications of RISAT Data: RISAT-1 through its multiple imaging parameters offers solution to various remote sensing applications such as agriculture, forestry, oceanography, snow & glacier studies, polar ice studies, coastal zone mapping, flood mapping, landslide & subsidence, oil slick and ship detection. Some of the applications are described below.

3. Agriculture: The sensitivity of SAR signal to crop canopy geometry and moisture provide complementary information for crop growth models and condition assessment, hence SAR has the potential to improve crop discrimination and parameter retrieval. In India, monitoring of agriculture and estimation of crop acreage and production forecasting is a major activity that relies heavily on SAR data especially during *kharif* season when cloudy sky conditions prevail. So far, mapping and monitoring of *kharif* crops, mostly paddy have been undertaking using SAR data from foreign satellites over selected areas only. The high cost of SAR data and lack of suitable operational procedures for other *kharif* crops have restricted the use of SAR data for agricultural applications in India. RISAT-1 will not only provide cost effective solution to this but also with the higher repeat cycle and larger swath of RISAT medium resolution data, the acreage estimation and production forecasting of *kharif* paddy will improve. RISAT data will also help in development of methods / models for monitoring and biophysical parameter retrieval of other crops like jute, cotton, soybean, groundnut and sugarcane.

4. Soil Moisture: The knowledge of soil moisture is important for meteorology, hydrology, agronomy and numerous other earth systems sciences. SAR systems show a relatively high sensitivity to soil moisture due to the large contrast in the dielectric constants of dry and wet soils at microwave frequencies especially below 10 GHz. Studies in the past decade have resulted in a multitude of methods, algorithms, and models relating satellite-based images of SAR backscatter to surface soil moisture. However, no operational algorithm exists for soil moisture retrieval using SAR data acquired by existing space borne sensors. In this regard, RISAT data with higher temporal resolution will help in developing empirical and semi-empirical models suitable for Indian conditions.

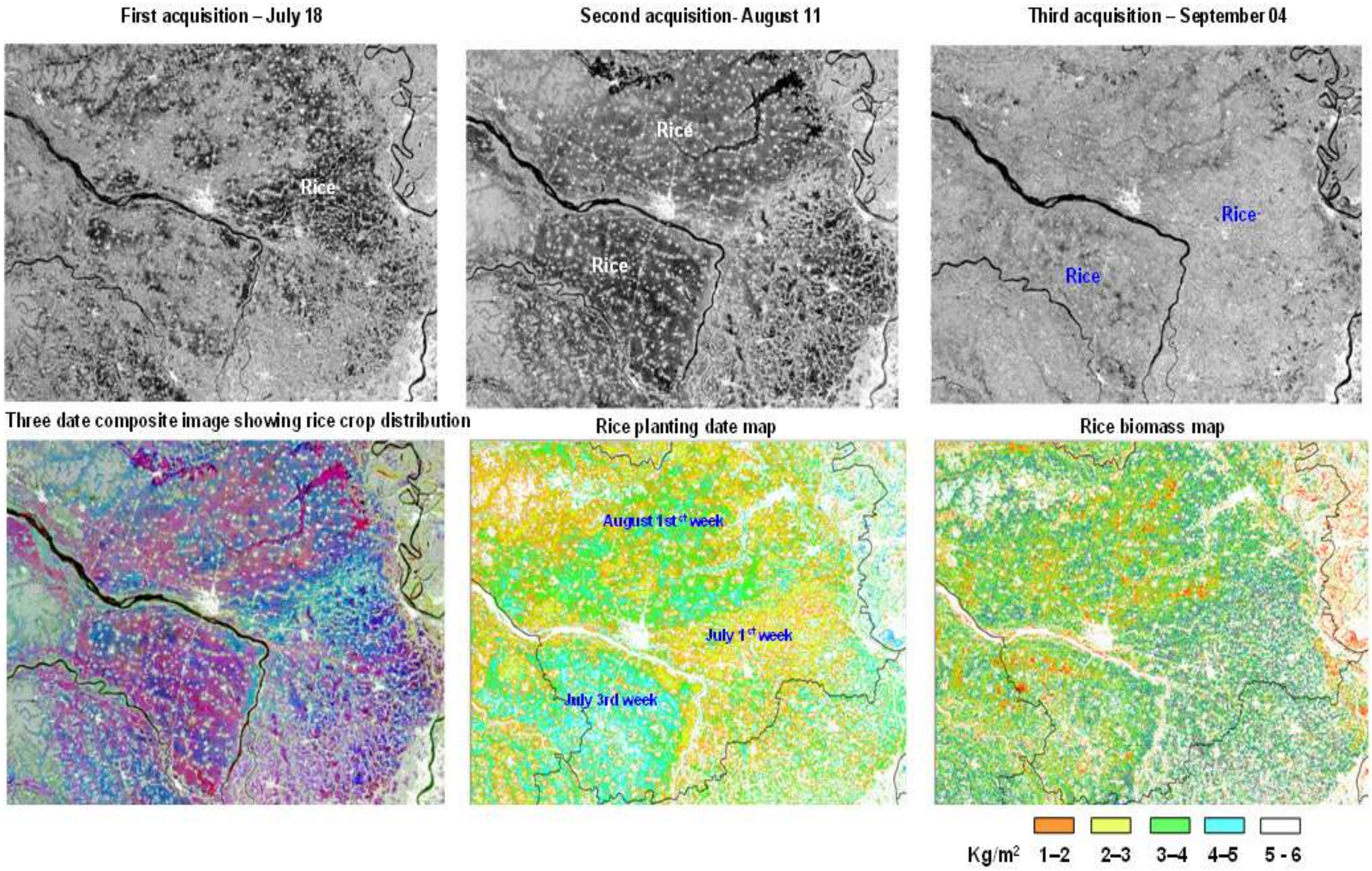
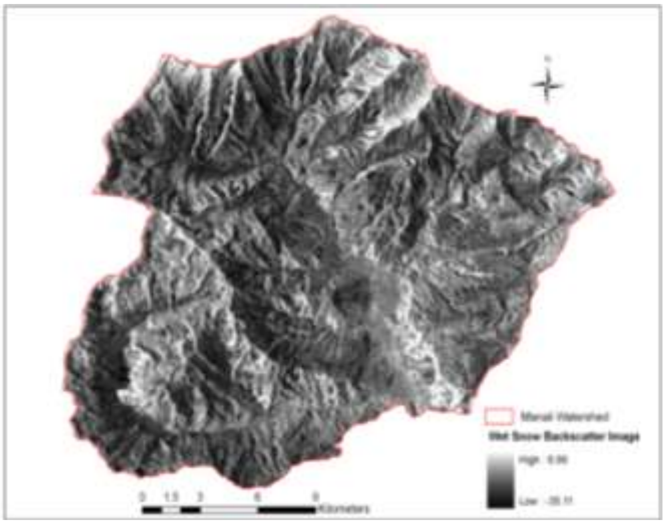


Figure-1: Rice crop identification and mapping using temporal C band HH polarization data: over a site in West Bengal- 2011

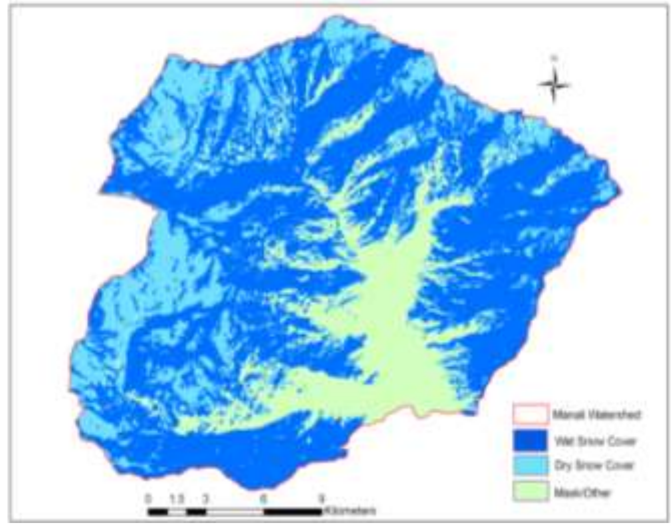
5. Forestry: The radar backscatter at higher wavelengths i.e. P and L bands, have been found to be significantly correlated with tree density, biomass and volume, as they penetrate below the crown. But the radar backscatter at lower frequencies i.e. C and X bands usually have greater textural details than P and L bands, as they do not penetrate below the crown layer of the trees. C-band SAR was found to be a good estimator of forest biomass due to its sensitivity to canopy heterogeneity. RISAT linear and hybrid polarimetric data through multi-polarization, higher range of incidence angles and better repeat cycles, promises development of operational procedures for categorization of Indian forests in terms of type, density and biomass. RISAT data also promises retrieval of various other forest biophysical parameters through synergetic use with lower-frequency SAR data (L, and P-band) and optical data. The interferometric SAR data from RISAT, if acquired will also help in estimation of forest stand height.

6. Snow and Glacier Studies: Snow and glaciers are important for many applications such as melt runoff, hydropower stations and long term climatic change studies. Because they are often cloud-covered, microwave remote sensing is particularly useful for studying these areas due to its all-weather and day/night imaging capability and ability to penetrate dry snow and ice surface. RISAT data is likely to play a key role in the studies of snow and glaciers, especially in the Himalayan regions. RISAT data in both linear and hybrid polarimetric modes will enable development of operational procedures for mapping of glaciers and related landform features, snow cover, depth and density estimation and retrieval of snow water equivalent and snow wetness. Other than that, RISAT data will help in developing techniques for glacier mass balance study and glacier movements.

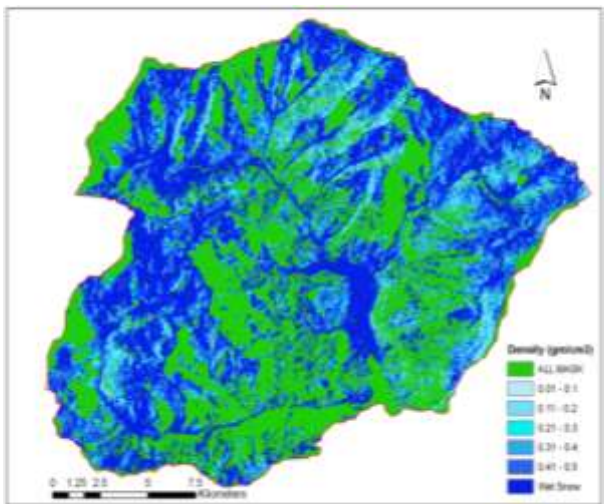
6.1 Polar ice: The polar ice processes play a critical role in the Earth climate system. Identification and detection of sea-ice and icebergs is also important for the navigation purpose. As sea ice develops and ages, the physical structure, visual appearance and electrical properties of the ocean surface change. The changes in dielectric properties follow a general pattern that can be exploited in ice retrieval algorithms using microwave sensors. RISAT data has the potential to contribute significantly in the study and monitoring the dynamics of polar sea ice, ice shelves and ice sheets. The SAR data is likely to be used by the global community for the study of polar and Antarctic ice.



Envisat ASAR Image



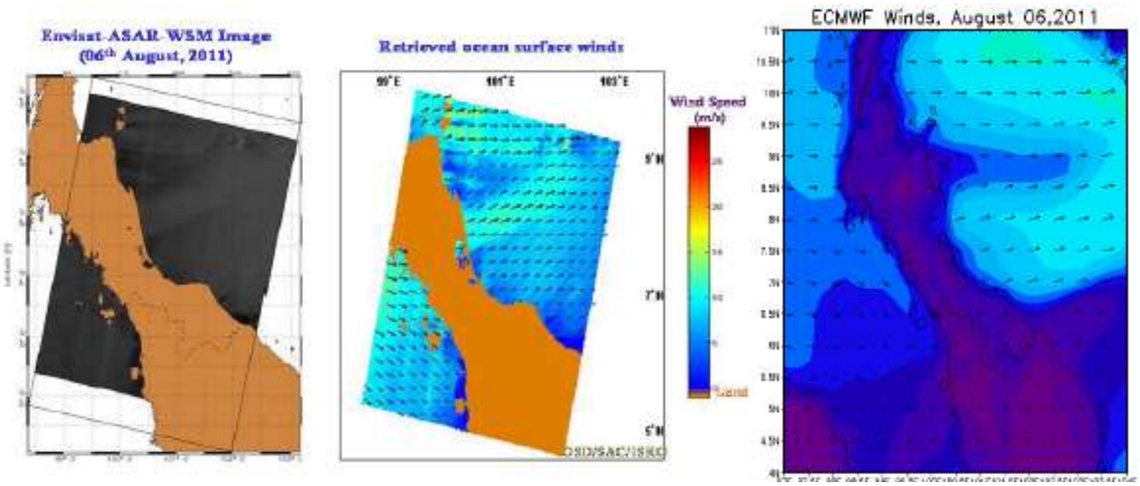
Snow wetness Map



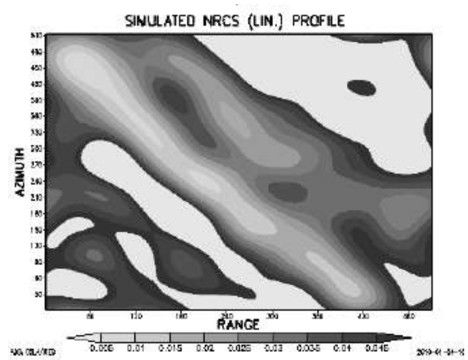
Snow density Map

Figure-2: Snow wetness and snow density maps of Manali sub basin generated from Envisat ASAR data of 11 Mar 2008.

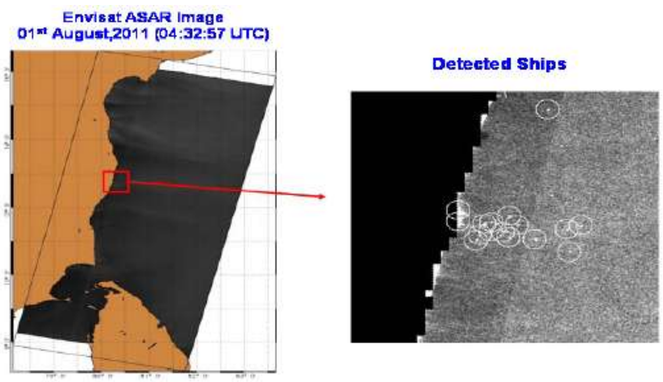
7. Oceanography: Oceans, covering around three fourth of the earth's surface area, act as a global temperature moderator and play an important role in influencing global climate. SAR is capable of providing a variety of ocean process such as internal waves, ocean surface waves, surface winds, oil spill and coastal depth. The ocean wave spectrum information is operationally used to improve wave forecasting and weather forecasting through assimilation in ocean wave model and coupled models. RISAT, due to its better resolution, larger swath and multiple incidence angles and polarizations is likely to provide very valuable data for oceanographic studies. The SAR data in C-band is very sensitive to the ocean roughness with wide dynamic range, enabling study of oceanic internal waves, current fronts and upwelling zones. RISAT SAR with wide coverage of the oceans will enable mapping of surface wind speed, coastal bathymetry, currents and eddies at high resolution. In addition, the high target-to-background contrast at C-band hybrid polarization as reported earlier will help in identification of oil slicks and ships in the open as well as coastal ocean.



Ocean Winds from Envisat-ASAR-WSM Image



Water depth estimated from SAR data



Ship detection from Envisat-ASAR Image

Figure-3: Applications of SAR for oceanography

8. Natural Disasters: Microwave remote sensing such as SAR have a great potential as a source of relevant and near real time information for the early warning, mitigation, and management of natural disasters. Natural disasters like flood, tropical cyclone, volcanic eruptions, forest fire etc. are better studied using SAR data. RISAT data is also likely to contribute significantly towards the management of natural disasters such as floods, landslide / land subsidence and earthquakes due to its larger swath and high repeat cycle of imaging.

8.1 Flood: Flood is a recurring phenomenon in India and results into huge loss of life and property every year. Effective and timely mapping of flood is an important task that can be addressed with microwave remote sensing. Flooded areas appear darker on SAR intensity images and, therefore, comparing two images before and during flooding it is possible to map flooded areas with a high degree of accuracy. By combining SAR with other geospatial data such as DEMs, it is also possible to estimate the depth of water in flooded regions. By comparing multi-temporal images acquired during a flooding event, flood progression mapping can be done, which is crucial for damage assessment and relief operations. RISAT-1 data will play a crucial role for improving the present services of operational flood mapping system by providing improved timeliness and improved flood layer detection due to multi-polarization data. It also promises development of further techniques towards understanding the river dynamics and generating probabilistic flood inundation maps.

9. Geology and Geo-morphological studies: Over the past few decades, radar remote sensing has proven to be an effective tool for the extraction of geological information. Outlines of topographic features and textures of rock surfaces commonly appear more prominent in radar images. SAR, due to its sensitivity to the target dielectric properties and geometrical structure has been emerged as a powerful tool to discriminate rock types and sediments with contrasting moisture content or mineralogical composition. RISAT through its multiple modes of imaging capability will greatly help in developing operational procedures for geo-morphological and structural mapping and buried-channel detection. Apart from that, the SAR is also likely to provide solution for lithological mapping and other geological investigations such as minerals and hydrological features.

10. Land use / Land cover Mapping: Land use / land cover mapping is an important activity under natural resources management program. The activity requires remote sensing data at different spatial scales and resolutions. RISAT with its multiple imaging modes, resolutions, incidence angles provides a vital solution for mapping of various land use /land cover features. Some of them are discussed below:

10.1 Wetland mapping: Mapping of wetlands has been one of the important elements of Natural Resource Census Program and its being done routinely. Space Applications Centre, Ahmedabad at the behest of the MoEF, Govt. of India has carried out first scientific inventory of wetlands for India using IRS data of 1992-93. SAR data provides a new prospective in delineating features based on their electrical and geometrical properties. RISAT data have been planned to be used for reclassification of certain wetland features and modification of earlier maps with higher scales using a combination of optical and RISAT SAR data.

10.2 Desertification study: Desertification is defined as the continuous process of land degradation in Arid, Semi-Arid and Dry-Sub humid regions, inflicted mainly by human interference. RISAT data through its multi-parameter imaging capability is likely to play a crucial role in mapping of indicators for desertification in Indian region.

10.3 Coastal zone mapping: SAR data due to its higher sensitivity to moisture content and target geometrical properties has been found to be ideal for coastal zone mapping including demarcation of high tide line and low tide line for Coastal Regulation Zone (CRZ); mapping of mangroves and emergent coral reef edges and fronts along the Indian coast; mapping of coastal erosion features and shore-line change.

Call for Articles

Readers are requested to contribute short articles for publication in the forthcoming issue of *Signatures*, related to the specific theme "Megha-Tropiques Mission- Radiometers for the Tropics".

The deadline for inclusion in the next issue is **Sep 30, 2012.**

\- Editorial Team

RISAT-SAR Calibration

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Importance of SAR Calibration: For any quantitative analysis, it is necessary to radiometrically calibrate SAR data. With radiometrically-calibrated data, it is possible to compare values obtained by one SAR sensor to that obtained by other SAR sensors, and also to ground based observations. Thus one is able to extend results of studies carried out using one sensor to other. This cumulative knowledge base leads to possibilities of developing robust parameter retrieval models for a variety of applications. Besides radiometric calibration of a SAR sensor with polarimetric capability calls for even phases between different polarisations channels to be calibrated. For a given SAR image, the digital number (DN) is proportional to the received voltage. Therefore the image intensity I, is proportional to the received power P_r. The process to retrieve SAR backscattering coefficient from the observed SAR image intensity is known as the radiometric calibration. Radiometric calibration of synthetic aperture radar (SAR) data is an essential component for all the SAR applications that requires quantitative analysis. Over a period of time, radiometric calibration has become absolutely necessary, due to availability of SAR data from various space borne sensors like ERS-1, Radarsat-1/2, Envisat-1, PalSAR and RISAT-1. Radiometrically calibrated SAR data allows us to carry out temporal or multi-sensor analysis for various resources applications as it provides a reference to evaluate the change in SAR backscatter due to temporal changes or due to change in SAR sensor parameters.

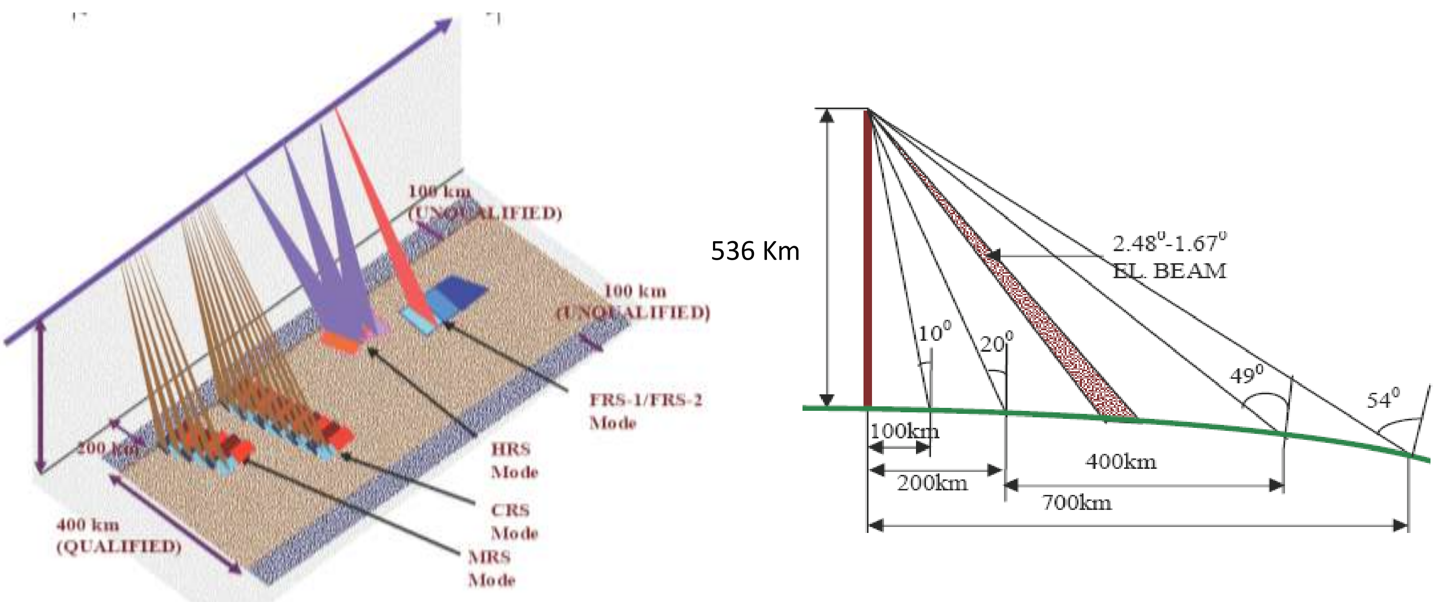

Fig.1: Schematic Diagram showing different beam modes of RISAT SAR

Calibration of RISAT-1 SAR sensor: RISAT-1, Radar Imaging SATellite (Fig.1), is India's first space borne SAR sensor operating at C-band at various beam modes having a number of combinations of linear polarization modes as well as circular polarisation modes, incidence angle, swath and resolution. Fig.1 shows schematic diagram of RISAT-1 SAR beam modes. Specifications of RISAT-1 SAR beam modes are given in Table-1.

The System has capability of left as well as right looking. It operates in following basic modes.

- **Fine Resolution Strip map Mode-1 (FRS-1):** It provides nominal single look 3 m resolution image over 30 km swath in either single or dual polarization
- **Fine Resolution Strip map Mode-2 (FRS-2):** It provides nominal single look 12 m resolution image over 30 km swath in quad polarization.
- **Medium Resolution ScanSAR Mode (MRS):** It provides nominal single look 25 m resolution image over swath of 120 km

- **Coarse Resolution ScanSAR Mode (CRS):** It provides nominal two look 50 m resolution image over swath of 240 km
- **High Resolution Spotlight Mode (HRS):** It generates single look better than 1 m nominal resolution image for a spot of 10 km (Azimuth) and 10 km (ground range swath) for either single or dual polarization.

Table-1: Specifications of RISAT SAR Beam modes

Altitude		536 km				
Frequency		5.35 GHz				
Antenna		Microstrip Active antenna, 6m x 2m				
No. of TR Modules		288				
Imaging Modes		HRS/ *C-HRS*	FRS-1/ *C-FRS-1*	FRS-2/ *C-FRS-2*	MRS/ *C-MRS*	CRS/*C-CRS*
Swath Coverage		Selectable within 100 – 700 KM off-nadir distance on either side (200 – 600 KM region is qualified, the rest is unqualified)				
Inc.angle coverage	Qualified	20^0-49^0 (200-600 Km)				
	Total	10^0-54^0 (100 –700 Km)				
Swath/Spot km	*Defined*	10x10	30	30	120	240
	Experimental	100x10	---	---	---	---
Applicable Polarization combinations		Single/ Dual (co + cross)/ (CH &CV)*	Single / Dual (co + cross) / (CH & CV)*	Quad / (CH&CV)*	Single / Dual (co + cross) / (CH & CV)*	Single / Dual (co + cross) / (CH & CV)*
Resolution (Az x slant range)		1m x 0.7m	3m x 2m	9m x 4m	21-23m x 8m	41-55m x 8m
Minimum sigma naught (dB) *(Qualified Region)*		-16.3	-17	-18	-18	-18
Total no. of beams		*64* on each side of the flight track: total *128*				
Azimuth and Range ambiguity		< -20 dB				

* Hybrid polarimetric mode: CH = Circular transmit linear H receive; CV = Circular transmit linear V receive

As can be observed from the system configuration, RISAT-1 is not only capable of acquiring data in multi polarisation mode, including quad linear polarisation, but it is also first of its kind to operate in hybrid circular polarimetric mode for earth observation. Thus, apart from calibrating the amplitude, polarimetric calibration of the RISAT-1 is also of importance. While calibration of the amplitude will lead to meaningful utilisation of the RISAT-1 system for a large number of applications, calibrated circular hybrid polarimetric would offer user community to explore potentials of polarimetric SAR data over large geographical areas. It should be noted that while typically the polarimetric SAR sensors, like Radarsat-2 and PalSAR on board ALOS, offers linear polarimetric data over an image scene of 30km x 30km at 24 days temporal revisit, RISAT-1 can offer circular polarimetric data with high temporal revisit of 13 days with swath width of 240 km. Such a high temporal revisit and large swath width polarimetric SAR data, would create interest in user community to exploit the state of the art technique of SAR polarimetry for almost all large area applications like agriculture, soil moisture, forestry, snow and glacier, geology, oceanography etc. However, calibrating the circular transmit, linear receive SAR data is a challenging task and would require development of innovative approaches. The calibration would be carried out by analysing standard targets response as well as reference distributed targets analysis. Firstly, standard targets like active radar calibrator (ARC) and corner reflectors can be deployed to derive radiometric parameters of the data and computing the necessary calibration records. Apart from the study of standard target response, reference distributed target needs to be continuously monitored and any deviation in the radiometry needs to be analysed to trace out the reason. In case of any deviation in radiometry for the reference distributed target, a rigorous campaign of standard target deployment would be required to be carried out to adjust the calibration parameters.

Calibration using point target

Calibration of Intensity: When the SAR raw data is converted to SAR image, what the SAR image contains is the information of the amplitude received at each of the pixels position. However, analysis of Synthetic Aperture Radar (SAR) data for various remote sensing applications requires a through understanding of the interaction of SAR signal with target and the mechanisms that takes place during interaction of SAR signal with target. For this purpose, it is required to find a relationship between the characteristics of the radar, the target and the received signal. This fundamental relationship is also well known as 'Radar Equation'. If P_r is the power received at the receiving antenna and the P_t is the power transmitted by the transmitting antenna, then the power received at the receiver is given by following expression:

$$(P_r) = (P_t G_t)\ (1/4\pi R_t^2)\ A_{rs}\ (1-f_a)\ G_{ts}\ (1/4\pi R_r^2)\ A_r \quad (1)$$

Where, G_t = Gain of the antenna (transmitted), R_t = Transmitted range, R_r = Received range, A_{rs} = effective area of the scatterer, F_a = Fraction of the transmitted signal absorbed by the scatterer, A_r = Effective area of the antenna (receiver).

For a given SAR processor, a calibration constant for the processor needs to be derived using which SAR backscatter for area extended targets can be derived. In order to arrive at calibration coefficient, standard targets needs to be deployed. A standard target is a target with a known Radar cross section. Standard targets could be passive, like Dihedral corner reflector, Trihedral corner reflector, sphere, Lunesberg lens or active like that of ARC (Active Radar Calibrator) consisting a transmitter and a receiver. It should be noted that Dihedral corner reflector can be used to calibrate cross polarised intensities while trihedral can be used to calibrate like polarised intensities. Once standard target response is available, the radar equation is used to determine the calibration coefficient as described below.

For radiometric calibration, the standard target of known radar cross section σ_c, is deployed in the uniform background. After correcting for the background, the power received for the standard target after correcting the background clutter (Pc) & along with the radar equation (1) is used to arrive at C_c, the calibration constant given by:

$$Cc = \frac{P_c}{\sigma_c} \frac{A}{\sin\alpha} \quad (2)$$

Once the calibration constant is derived using power received from standard point target, it can be used to convert the power received for any area extended target (P_u) to the backscattering coefficient using the following equation.

$$\sigma^0 = \frac{P_u\ x\ \sin\alpha}{C_c} \quad (3)$$

Integrated power from two dimensional impulse responses needs to be analysed for radiometry after removing clutter noise for the standard target. From point target impulse response, apart from deriving calibration constants, range and azimuth Impulse response width (IRW), range and azimuth peak side lobe ratio (PSLR), integrated side lobe ratio (ISLR), peak intensity (PI), background to peak ratio (BPR) and absolute location errors also needs to be studied. From the interpolated response of the point target, firstly, calibration constant will be derived using the above procedure and then the data quality parameters will be obtained.

Calibration of Hybrid Polarimetric mode: RISAT-1 SAR can also operate in circular hybrid polarimetric mode. In circular hybrid polarimetric mode, circular polarisation is transmitted and received in linear Horizontal (H) and vertical (V) polarisation. This in turn, gives rise to coherent dual polarised channels (CH and CV). In order to calibrate the hybrid circular polarimetric mode offered by RISAT-1 SAR, point target as well as distributed target analysis needs to be carried out leading to calibration of the scattering matrix resulting from the hybrid circular polarimetry. The measured polarimetric matrix M can be written as

$$M = cRST + N \tag{4}$$

Where, c is constant, R and T are distortion matrices. They are the polarization transfer matrices describing the characteristics in radar receiving and transmitting systems. N is a noise matrix in the radar polarimetric channels. For circular transmit linear receive, the scattering matrix is

$$[s] = \begin{bmatrix} Scv \\ Sch \end{bmatrix} \tag{5}$$

Polarimetric active radar calibrator with dual-pol horns capable of receiving in H and V both polarisations simultaneously and transmitting in vertical and horizontal mode needs to be employed for hybrid polarimetric mode SAR calibration. Response of passive reflectors can also be studied for calibration of hybrid polarimetric mode. While polarimetric calibration using polarimetric active radar calibrator will be carried out using the controlled phase as well as amplitude, the scattering matrix for the passive standards targets will be analysed to study any phase or intensity imbalances in the polarimetric channels to arrive at calibration matrix, which in turn will be used to calibrate the polarimetric scattering matrix.

Calibration using distributed target response: Amazon rain forest is a typical volume scatterer. Amazon rain forest has been studied extensively for satellite SAR missions and it has been observed that the response is constant with little seasonal variation. After the removal of seasonal variation, the SAR backscatter is observed to be within 0.5 dB. Thus it can be used to study any deviation in SAR backscatter in VV/VH/HH/HV polarisation. When the uniform area of Amazon Rain forest is illuminated by circular polarised waves, being a volume scatterer, the statistical average of power in horizontal as well as vertical polarisation is expected to be equal with phase offset using which, inter channel relative gain and phase calibration can be carried out.

M–chi Decomposition of Hybrid Dual-Polarimetric RADAR Data

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Abstract: Hybrid dual-polarimetric radar (CL) is a new class of orbital imaging system, transmitting circular polarization and receiving orthogonal linear polarizations and their relative phase. RISAT-1 includes a CL mode, thus making it the first earth-observing hybrid-polarimetric radar. Conventional quadrature-polarimetric analysis tools are not appropriate for the resulting data products. The classical Poincaré parameters (m, chi, psi) which fully describe a partially polarized electromagnetic field may be used for CL data classification (decomposition). Examples drawn from lunar CL radars illustrate the method, and demonstrate the disadvantageous sensitivity of the m-delta method to imperfect polarization circularity of the transmitted field.

Introduction: Compact polarization modes currently are being implemented for Earth-orbiting synthetic aperture radars (SAR) by four national programs (India, Japan, Argentina, and Canada), the first of which (RISAT-1) was launched by India 26 April 2012. The radar data user community is relatively unfamiliar with analysis methods for data from this class of radars. This paper describes an applicable analysis methodology that has proven to be effective when applied to data from two radars in orbit about the Moon. Mini-RF aboard NASA's Lunar Reconnaissance Orbiter (2009-) [1], together with its precursor, Mini-SAR on India's lunar Chandrayaan-1 satellite [2] (2008-9), were the first space-based compact polarimetric SARs. These radars are hybrid dual-polarimetric, receiving orthogonal linear polarizations, while transmitting circular polarization (CL) [3]. The precedent for this architecture may be found in radars used for meteorological measurements [4], and radar astronomy [5]. The Mini-RF and Mini-SAR radars offer the same suite of polarimetric information from lunar orbit as Earth-based radar astronomical observations of the Moon, since both types measure the 2x2 covariance matrix of the backscattered field. These data may be represented in convenient form through the classical 4-element Stokes vector.

In the established practice of radar astronomy, the four Stokes parameters (S_1, S_2, S_3, S_4), lead to child products that are used individually, of which CPR [6] and the degree of linear polarization [7] are well known examples. The Stokes parameters also support matrix decomposition techniques that to date are relatively unknown in radar astronomy, although they are well established analysis tools in Earth-observing SAR data. Techniques such as the "entropy-alpha" method [8], developed for quad-pol 3x3 data matrices, are not directly applicable to the simpler CL-pol architecture whose data are only 2x2 matrices. However, the grounding principle of decomposition—using two or more parameters jointly to distinguish between classes of radar backscatter—applies directly to compact-polarimetric data in general, and to CL-pol data in particular.

Methodology: The degree of polarization, m, long has been recognized as the single most important characteristic parameter of a partially-polarized EM field, and is defined by

$$m = (S_2^2 + S_3^2 + S_4^2)^{½} / S_1 \qquad (1)$$

The close relationship between entropy and degree of depolarization (1-m) has been verified experimentally [9]. The degree of depolarization (1-m) is indicative of randomly-polarized backscatter, typically arising from radar-quasi-transparent volumetric materials, such as lunar regolith or forest canopy. The degree of polarization m is a natural choice for the first hybrid dual-polarimetric decomposition variable.

The Poincaré ellipticity parameter χ is an obvious and the most robust choice for the second decomposition variable. It is one of the three classical principal components (m, χ, ψ) that are necessary and sufficient to describe the polarized portion of a partially-polarized quasi-monochromatic EM field of average strength S_1. Further, the sign of χ is an unambiguous indicator of even versus odd bounce backscatter, a property that is maintained when the radiated EM field is not perfectly circularly polarized, which is a likely property of realistic radar.

The m−chi decomposition methodology has proven to be an excellent analysis tool for hybrid-polarimetric data from lunar observations. In this formulation the key inputs are m, and the degree of circularity

$$\sin 2\chi = -S_4/mS_1 \qquad (2)$$

The m−chi decomposition may be expressed through a color-coded image, where

$$B = [mS_1(1-\sin 2\chi)/2]^{1/2}$$

$$R = [mS_1(1+\sin 2\chi)/2]^{1/2} \qquad (3)$$

$$G = [S_1(1-m)]^{1/2}$$

In this formulation, Blue indicates single-bounce (including Bragg) backscattering, red corresponds to double-bounce, and green represents the randomly polarized constituent.

In the special case of forestry, it has been shown that the entropy-alpha decomposition derived from the 3x3 matrix typical of an Earth-observing quadrature-polarimetric SAR, following application of the "random volume over ground" model, reduces to an expression for data from a hybrid dual-polarimetric radar that is equivalent to the m−chi decomposition of Eqn 3 [10].
Our approach suggests that this is generalizable to other applications.

An alternative to χ could be the relative phase δ between the received linearly polarized components [3]. Like χ, δ has the advantage that it is sensitive to the even versus odd bounce characteristics of the backscatter. However, δ also is dependent on ψ, the orientation of the polarization ellipse of the backscattered EM field. Thus, if there is a significant linearly polarized component in the transmitted field (as is the case for the imperfect circularly polarized field of the Mini-RF radar [11]), then a change in the angular orientation of any dihedral structure in the scene could cause the sign of δ to reverse polarity.

Double-bounce example: One situation in which often there is obvious double-bounce geometry at the lunar surface is the backscatter from an impact crater's floor and far wall, which together form a large natural dihedral. The surrounding imagery arises from features that are typical of the surface, and these reflections are mapped at their appropriate distance (range) from the radar. In contrast, backscatter that corresponds to forward scatter from the floor of the crater to the far wall, and then back to the radar, travels an extra distance. These double-bounce reflections will appear at greater range in the radar image, hence appearing as if they come from an area that lies beyond the far crater rim.

Such double-bounce signatures will be strongest when the crater walls are terraced or relatively steep, where in this context terracing or steepness depends on the age, materials, and perhaps layering exposed by the generating impact. Figure 1 shows two interpretations of such an observation. The double-bounce return is indicated unambiguously through the *m-chi* decomposition (Fig 1b) by the red "halo" at the far range side of the crater. The range extent of the double-bounce halo is proportional to the depth of the crater floor below the rim. Much of the area outside of the crater in Fig 1b is dominated by blue, which indicates Bragg scattering.

It is instructive to look at these same data through the *m−delta* decomposition, as in Fig 1a. In this case, the halo is split into two colors, red and blue. This indicates that the sign of δ has been reversed from one side to the other, which is caused by the orientation ψ of the axis of the floor-wall dihedral feature relative to the linear component of the radar's incoming illumination. Such a reversal will induce interpretation ambiguities for situations in which the backscattering geometry is not so obvious. This undesirable effect is illustrated by the mottled colorations outside of the crater in Fig 1a, in contrast to the dominant Bragg scattering signal (blue) exposed in Fig 1b by the *m-chi* method. From another point of view, however, the effect also suggests that three-component decomposition (*m*, χ, ψ) could offer further insight into the detailed structure of the backscattering features than is available from an *m-chi* decomposition, thus taking advantage of the known ellipticity of the transmitted field.

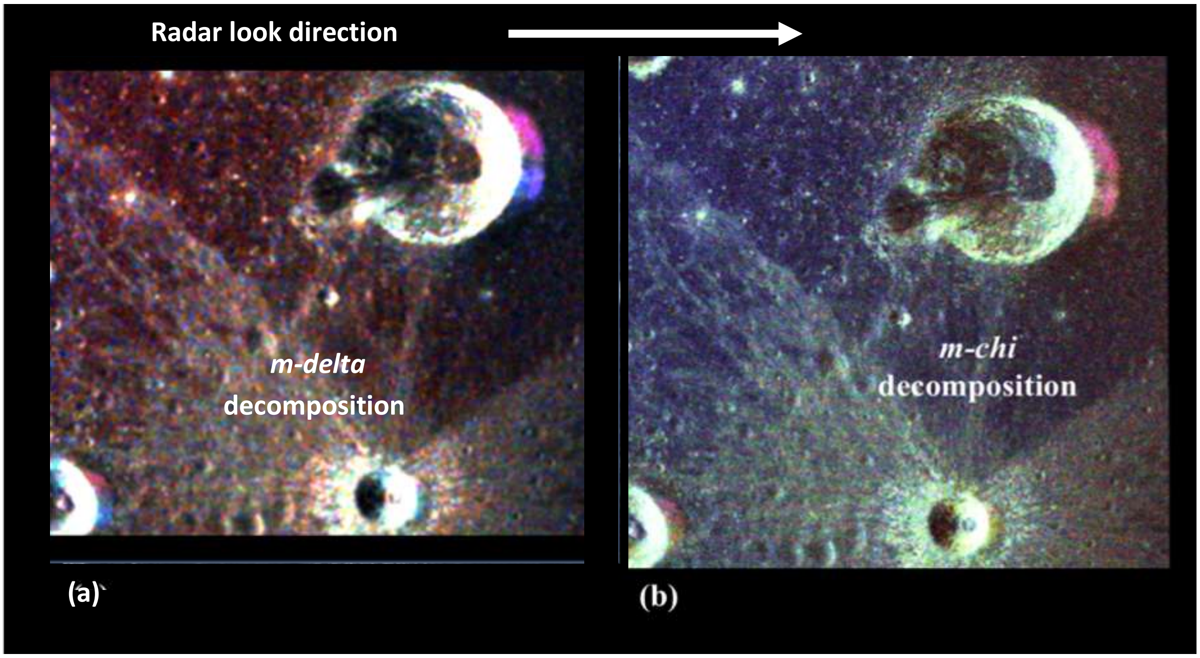

Figure 1. An m-delta decomposition (a) and an *m-chi* decomposition (b) of floor-wall double bounce from the crater Kies C. (26°S, 26°W), observed by Mini-RF at S-band zoom [11].

Conclusions: The Mini-SAR and Mini-RF instruments are the first compact polarimetric space-based imaging radars. Their architecture is hybrid-polarimetric, transmitting (quasi-) circular polarization, and receiving orthogonal linear polarizations and their relative phase. The four Stokes parameters that are necessary and sufficient to fully characterize the observed backscattered EM field are calculated from the received linearly polarized data. The Stokes parameter values are independent of the polarization basis in which the backscattered field is observed. These Stokes parameters can be used to formulate an *m-chi* decomposition of the scene, which is a new technique. This method facilitates unambiguous interpretation of surface features according to single (odd) or double (even) bounce signatures in the polarized portion of the reflections, and characterization of the randomly polarized constituents. The *m-chi* decomposition has proven to be robust in the event that the transmitted field is not perfectly circularly polarized. Analysis of lunar data suggests that an *m-chi-psi* three-component decomposition strategy should provide additional backscatter classification finesse. These methods are directly applicable to data anticipated from Earth-observing hybrid-polarimetric radars such as RISAT-1.

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'Spy satellite' RISAT- 1: Top 10 must know facts

Pallava Bagla | Updated: April 26, 2012 08:20 IST

New Delhi: After a highly successful launch of the Agni V, India today successfully launched its own 'spy satellite' RISAT-1. It was powered by the Polar Satellite Launch Vehicle (PSLV) from Sriharikota at 5.47 am this morning. Here are the top 10 facts on RISAT-1:

1. Weighing at 1858 Kg, RISAT-1 is the heaviest satellite ever launched by India.

2. It was powered by a 321 tonne rocket, the most powerful Polar Satellite Launch Vehicle (PSLV).

3. This is the third time that ISRO used a PSLV-XL (Extra Large) rocket. It was first used in October 2008 to put Chandrayaan-1 in orbit and again in July 2011 during the communication satellite GSAT-12 launch.

4. The indigenously made satellite has day and night viewing capacity and will not be blinded by cloud cover.

5. RISAT-1 will help in crop monitoring and flood forecasting. It will give India the ability for continuous surveillance.

6. The satellite carries a C-band Synthetic Aperture Radar (SAR) payload, operating in a multi-polarisation and multi-resolution mode to provide images with coarse, fine and high spatial resolutions. It has a best resolution of up to 1 m

7. It has taken ISRO 10 years to make this sophisticated satellite. So far PSLV has consecutive 19 successful launches.

8. The total cost of mission is about Rs. 500 crores. While the cost of the rocket is about Rs. 120 crores, the satellite costs around Rs. 380 crores. However, none of them are insured.

9. The project Director N Valarmathi, is the first woman to head a remote sensing satellite project, and the second to be the satellite project director at ISRO.

10. Apart from RISAT-1, India already has another spy satellite RISAT-2 acquired from Israel which was launched in 2009.

Ocean Observations using Synthetic Aperture Radar Data

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The ocean plays a major role in the climate variations. Due to its vast size and the harsh environment, the problems arise in obtaining detailed, timely information of sufficient observational density across most of its regions. Efficient management of marine resources and coastal zone are largely dependent upon the ability to observe and analyze processes which operate in the dynamic marine environment. For this purpose measurements are required for the physical, chemical, geometrical and optical features of coastal and open oceans. In last couple of decades, satellite remote sensing has gained tremendous importance due to its ability to observe different components of our Earth's weather and climate systems. The major barrier to the use of satellite imagery for ocean operations is the rapidly changing marine environment. With its all-time and all weather operational capabilities, Microwave Remote Sensing technology has become a powerful and indispensable tool for observing the earth and its atmosphere from the space.

By having combinations of ocean observation systems and numerical models, one can obtain improved ocean state information, which is not available by either of them alone. The major thrust area in ocean research is therefore towards observation, process monitoring and prediction of ocean variability by having optimum combination of observations and numerical models. In the field of Ocean State Forecast, ocean surface winds and waves play a dominant role. The significant impact of ocean surface waves on atmospheric and oceanic circulation has been observed through wave induced stresses. Towards the observation of these parameters, various remote sensing instruments have been launched and are also being planned in near future. To generate higher resolution information of our coastal and deep ocean regions, in addition to various land phenomena, a high resolution Synthetic Aperture Radar (SAR) onboard Radar Imaging SATellite (RISAT-1) has been recently launched by the Indian Space Research Organization (ISRO).

SAR provides a two dimensional image of the sea surface. Surface waves can be clearly seen in SAR images. Since the surface waves are formed primarily in response to surface winds, winds can be derived from SAR data. Detection of upper layer circulation features including fronts, eddies, upwelling, internal waves, tidal circulation, bottom topography and ship speeds have been demonstrated using SAR data. Various studies have been performed using spaceborne JERS-1, ERS-1/2, ENVISAT and Radarsat SAR data. Radarsat operates in ScanSAR mode also, an innovative variation of a conventional SAR with a five-fold increase in swath over previously flown SAR instruments. ScanSAR is able to deliver global near real time coastal wind fields with nearly 2 orders of magnitude greater spatial resolution than conventional scatterometers. However, end to end calibration of multibeam SAR is still largely undemonstrated. Despite this, it offers a unique tool for probing the wind field over the oceans.

Other phenomena revealed by SAR include the detection of current patterns, eddies, and gyres, by their influence on surface waves. Ships, their wakes and their associated wave trains are also readily detected. The wake of ships, after the immediate turbulence following the ship has passed, is usually smoother than the surrounding sea. Hence the wake appears darker on a SAR image. Pollution of the sea surface by mineral or petroleum oil is a major environmental problem. These oil slicks often make it difficult to decide whether the dark patches are due to the mineral oil spills or from biogenic slicks. SAR data has been used globally for obtaining statistical information on oil pollution. SAR images are also very useful in locating the preferred areas where tankers are washed and effluents are discharged.

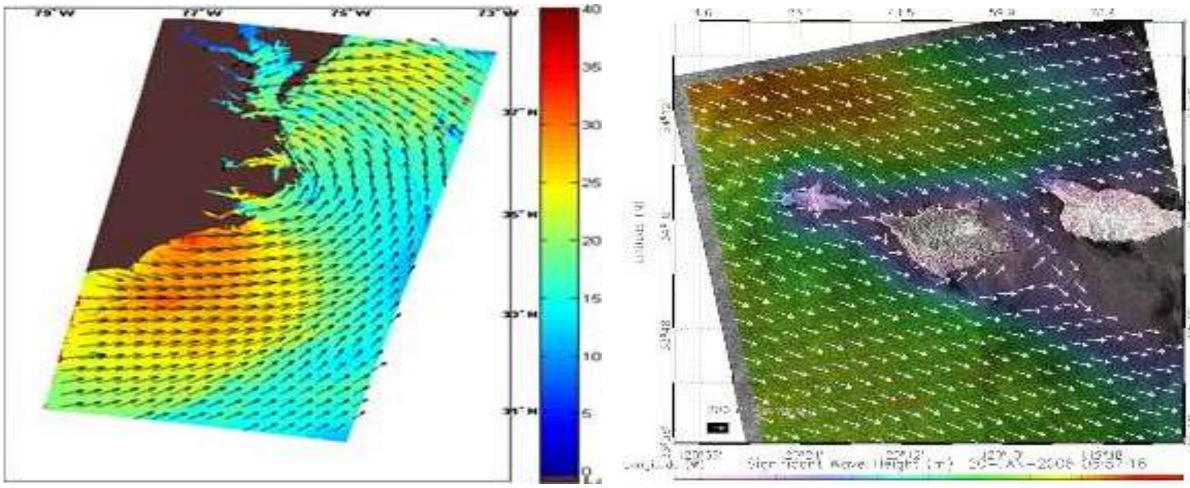

Figure 1 :(a) High resolution coastal winds (b) Wave height (adopted from Boost technology)

As a precursor to RISAT-1 Utilisation programme, under the Joint Experiment Project-Microwaves, retrieval algorithms for various oceanic parameters had been developed and applied on both airborne ESAR and ENVISAT data. The retrieved ocean wave spectrum, on comparison with buoy data and the coastal wave model results showed that SAR is able to estimate swell waves very well, however small scale wind waves features are not well pronounced. The study also brought out the comparison of estimated wave parameters by SAR with different frequency and polarization channels. The results also demonstrated the promise of speckle noise removal algorithm using Single Look Complex data. The wind field retrieval using SAR data had also been discussed with ENVISAT ASAR wide swath mode data. The comparison with scatterometer winds showed very good match between the two measurements with the advantage of very high resolution in the case of SAR derived winds.

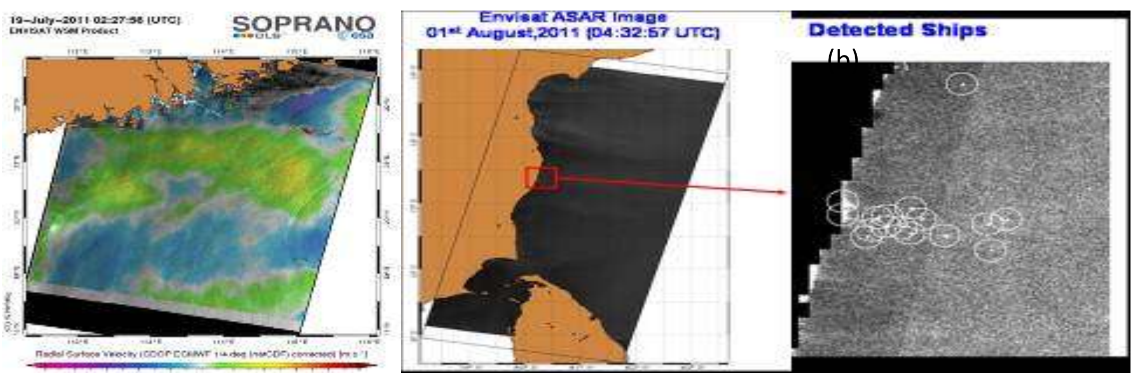

Figure 2: (a) Ocean surface currents (b) Ship detection from SAR data

Under the RISAT-1 Utilisation programme, algorithms are being developed to retrieve wave spectra using Cross Spectra based algorithm. Using cross and co-spectra of different looks, wave spectra will be estimated. The algorithm will be validated using observations from NDBC wave buoys. High resolution ocean surface winds have been retrieved using many ENIVSAT datasets and comparisons have been made with numerical models, QuikSCAT & ASCAT data. For coastal depth estimation, the algorithm is developed using EnviSAT ASAR Alternate Polarisation (APG) images. Simulation experiments have been performed. The depths have also been estimated using the ENVISAT data and backscatter-wave-current-depth approach. Algorithm for ship detection has been developed using EnviSAT ASAR data using adaptive threshold technique and verified with knowing targets locations. These techniques will be fine tuned with larger datasets of RISAT-1 and after proper validation, will be available to use for the retrievals and other applications.

Section-4 – General Paper

An Approach for Spatial Modelling of Peri-Urban Growth

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Abstract: Peri-urban is defined as an intermediate area between urban and rural areas, whose boundary limits shift from time to time. Today, due to ever increasing population pressure on land and water in the core areas, the urbanization is spreading into the peri-urban areas or urban fringes. Thus, they are attaining the importance as fast growing pockets to accommodate the spillover of urban sprawl developed due to the process of urban dynamics. Therefore, in order to understand the changing urban growth patterns and development processes, there is a need to build predictive scenarios of peri-urban growth through modeling for future urban development and planning. The present study under TDP is being taken up by using, 'Open-Source' tools and technologies viz., GDAL, MapWindowGIS and Quantum GIS and development using C#.Net. The factors / drivers based Spatial Model would be developed with enhanced Cellular Automata Method (CAM). The Database for the model is being generated using IRS satellite data and IGIS software. The testing and evaluation would be carried out for Madanapalle and Khammam towns which are medium and fast growing towns in the state of Andhra Pradesh. The collaborative data required for the study is being provided by DTCP, Government of Andhra Pradesh. This is the one of the attempts to formulate and develop a Spatial Model for generating scenarios of spatial and temporal development of urban growth in Peri-Urban Areas.

Keywords: ***Peri Urban Growth, Spatial Modelling, Remote Sensing, Transition Rules.***

Definition of Peri-Urban Area: Peri-urban is defined as an intermediate or a transitional area from rural to urban from where people commute to the town / city for employment, education, trade and services (Kulshrestha, 2007). It is also called as Urban Fringe (Dikshit, 2011). The dynamic change of peri urban area depends on various factors / drivers which are classified as, '*push and pull*' factors of parent city. The push factors include high population density, land values, pollution and the pull factors are employment, infrastructure and trade.

The spatial patterns of extent of urban sprawl, growth patterns and type of landuses and population are important for understanding the urbanization and its influence on the peri-urban areas. It is here by developing the predictive spatial and temporal scenarios of urban growth and development would help the Urban Planners for better visualization planning and decision making. Modelling has a major role in the formulation and implementation of development strategies (Sudhira etal, 2003). In this context, the Cellular Automata (CA) based approach is the simplest model used for generating scenarios of urban growth and expansion. Further, the Cellular Automata approach has a flexibility to represent the spatial relationship and the processes for scenario development of urban areas over others. The Cellular Automata consists of regular Grids of Cells each one having the finite number of States. The, 'Transition Rules' are applied to cells synchronously, altering the state of cells according to their individual condition and that of the condition of adjacent cells in the neighborhood (Itzhak Benenson and Paul Torrens, 2004). This basic step is repeated over again and again and the output spatial pattern scenarios are developed. The spatial model under development would be drivers / factors based model on the top of enhanced Cellular Automata (CA) Method.

Tools and Technologies: The study envisages the use of strength of Open Source Software for developing various functionalities like processing / database creation, analysis, visualization and modelling. The DIP / GIS Platform is IGIS. The functionality and software tools are listed in Table 1.

Table 1

Functionality	Software
Data Creation and Processing	Quantum GIS
Application Programming & Scripting	C#.Net / Python
Geospatial Data Library	GDAL
GIS Visualization	Map Window GIS
DIP / GIS Platform	IGIS

Methodology: The spatial patterns of urban sprawl and growth on a temporal scale are analyzed using the remotely sensed satellite data by image processing techniques. Analysing the sprawl over a period of time would help in understanding the location and type of urban growth and for visualizing the likely scenarios of future sprawl (Sudhira et. al. 2005). The patterns of sprawl could be contiguous like concentric (circular) radial (ribbon development) and non-contiguous or multi-nuclei.

The various driving factors responsible for growth and expansion of the town are shortlisted based on the discussions with DTCP. The factors include physical, population, infrastructure, land value, industry, land ownership, besides zoning regulations and landuse controls. The explanations to these various driving factors are listed according to the GO 569 of DTCP Act, Government of Andhra Pradesh. The requirement of land (vacant areas) to accommodate the future urban growth and the various landuses is based on the availability of land, demand survey and population projection. The study also envisages collection of primary data on 'Public Preferences' by questionnaire survey in the field during the GT survey. The understanding of the present growth pattern of town and the various driving factors would enable to provide an input for developing the spatial model for arriving at future perspective scenarios.

Thus, the created spatial data layers are used as an input as required by the CA Method. The cell space in a cellular automaton is assumed to be both regular in structure. Each cell in the Cellular Automata has a neighborhood of adjacent cells, states of the cell that surround it. The state of the cell is determined by the driving factors based on which the Transition Rules of a cell are arrived. The Transition Rules are applied for altering the state of cells according to their individual condition and to that of adjacent cells in the neighborhood (Itzhak Benenson and Paul Torrens, 2004). The alteration is carried till the total projected area is allocated to the suitability requirements according to the weightages assigned. For the present study, a few of the Transition Rules framed based on the explanation given to various factors in the GO 569 are given below.

- *If the test pixel has pop_density>400 / km^2 and NonAgriPop>75% THEN urban*
- *If the test pixel is reserved forest, heritage sites THEN no change*
- *If the test pixel is non-urban THEN it becomes urban if:*
    - *Its neighboring Urban pixel count is ≥ No_u, OR*
    - *Its neighboring Road pixel count is ≥ No_s, OR*
    - *Its neighboring Forest pixel count is ≥ No_f, OR*
    - *Its neighboring Water pixel count is ≥ No_w.*

    Where No_r, No_s, No_P and No_l are the minimum number of urban, road, forest and water pixels.

- *If the test pixel is not in set_back_dist THEN urban*
- *example: Set_back_dist=CanalEdge+9m or Edge of Nala+2m*

These rules determine state of the given cell in a matrix at any given time. To generate scenarios the rules are applied repeatedly on a cell to generate its new state which gives the probability of urban sprawl and neighborhood state of the cell. The Model Methodology and example of Transition Rules is given in Figure 1.

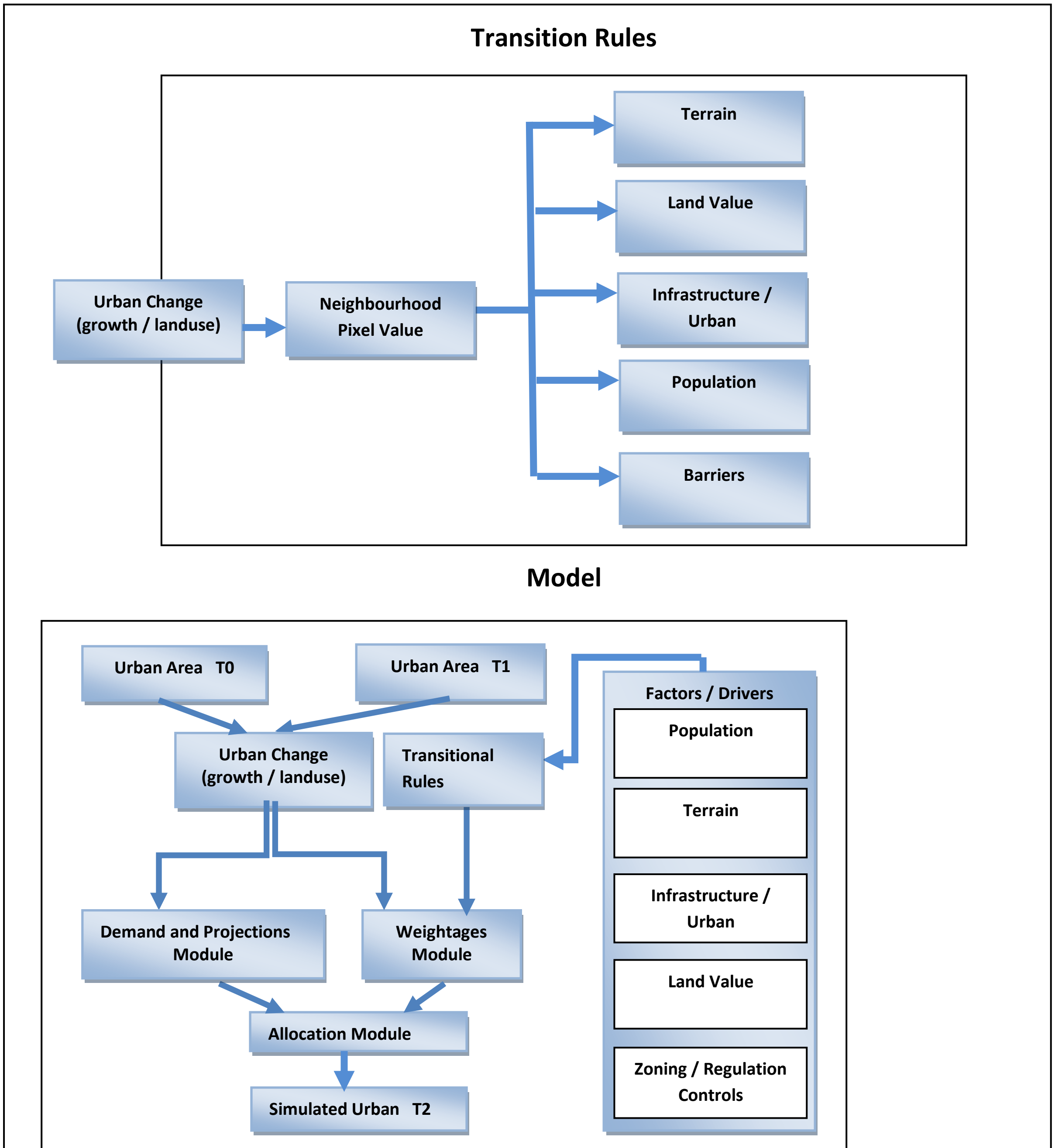

Figure 1: Methodology Framework

Conclusion: The Transitional Rules have been framed based on the driving factors listed in the GO 569 of DTCP. The Open Source Tools and Technologies for developing the spatial model based on the Transitional Rules using the CA Method which is being developed. The basic spatial data input for the Model is captured using the IRS satellite data and the database creation is based on IGIS platform. The non-spatial data of the drivers is based on NUIS data, DTCP data, NUDBI data, Census data, Socio-Economic data besides the field data collected using questionnaires. The Model would be validated for Madanapalle and Khammam towns in Andhra Pradesh.

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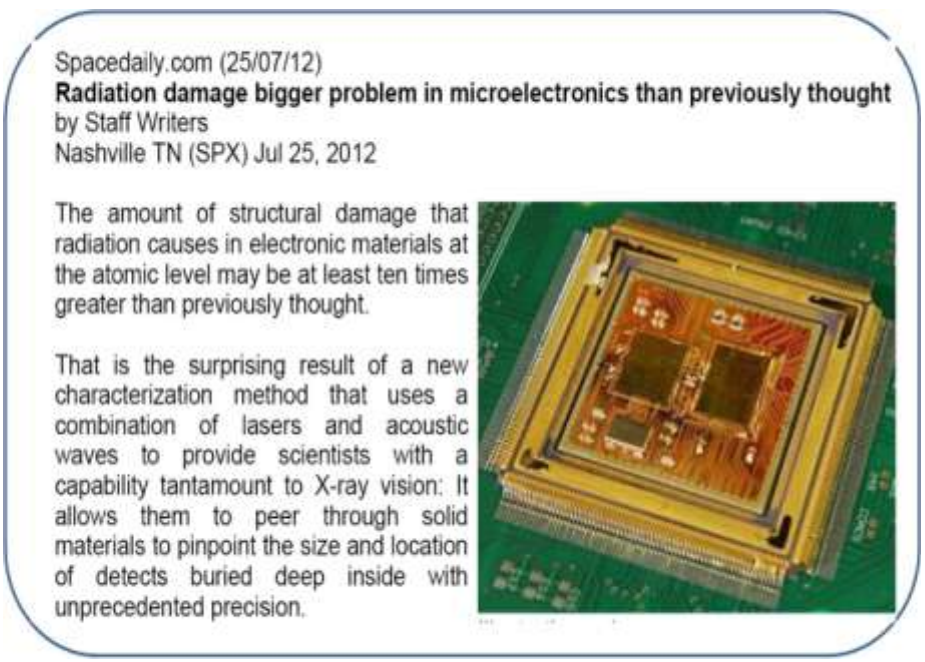

Spacedaily.com (25/07/12)

Radiation damage bigger problem in microelectronics than previously thought

by Staff Writers

Nashville TN (SPX) Jul 25, 2012

The amount of structural damage that radiation causes in electronic materials at the atomic level may be at least ten times greater than previously thought.

That is the surprising result of a new characterization method that uses a combination of lasers and acoustic waves to provide scientists with a capability tantamount to X-ray vision: It allows them to peer through solid materials to pinpoint the size and location of detects buried deep inside with unprecedented precision.

World Environment Day - 2012
Brief Report on Event celebrated on June 02, 2012

S R Joshi, SAC

We all know that June 5th is celebrated as **World Environment Day** every year. The Indian Society of Remote Sensing, Ahmedabad Chapter (ISRS-AC) along with Gujarat State Forest Department and Divya Bhaskar celebrated the event on June 02, 2012. Taking the theme for current year – **Green Economy**, the celebration was organized at Demo cum District Information Centre on S.G. Highway, Ahmedabad. The new executive committee of ISRS-AC engaged itself in the celebration with great enthusiasm and deep sense.

Participation of around 100 nos. of school going children was a keystroke for the event. Almost 50% of them were from under-privileged section of the society staying in far-flung areas. Kavita foundation, an NGO run by Manharben Vaghela, and an NGO sponsored by Divya Bhaskar CSR team co-operated whole heartedly for their participation. Also, the children of ISRS members were among the participating students.

Shri D. Subrahmanyam, Chairman, ISRS-AC, focused on the theme for current year – Green Economy, in his addressing expressions on the event. He also highlighted on various activities taken up by ISRS with the Forest Department in view of the World Environment Day. Shri Kulin, Assistant DCF and Shri Thakkar, a senior official from the Forests Department, delivered very interesting talks and enlightened the participants. They explained in depth about various species of birds and forms of wild life found in Gujarat. Conservation of Environment & related activities was the topic on which Shri Amit Dubey of Divya Bhaskar talked. He explained about various activities carried out by Divya Bhaskar CSR for conservation of environment. Shri D.R.M. Samudraiah, Vice-President, ISRS-National Body encouraged the participants and highlighted the importance of World Environment Day celebrations.

A Drawing-cum-Painting Competition for participating school children of different age groups was followed. All the participants took part with fair & deep involvement. Relevant environment-centric topics, as mentioned below, were effort fully attended by all the participants.

My clean and green city - Ahmedabad

and

Environment protection - my contribution

Their imagination on environment protection in a creatively learning way about the Nature was feeding in as a unique payback to the event organizers!!

Demonstration on Making of Birds Nest and talk on 'Save Sparrows and Save Water' were presented by Shri Jagat Kinkhabwala, an environment expert from RINR (Rich in Natural Resources). Animations and movies on birds and wild life were shown to the participating children. The session was found very much informative and interactive by the participants.

A Nature walk of the campus was also conducted by forest department officials

Finally, the event ended up with honoring the winners and appreciating the participants.

Prizes were distributed by ISRS functionaries and distinguished guests to the winners of the competitions. Shri Deepak Moitro and Ms. Trivedi were the judges for the Painting Competition. For encouraging the participation of children, along with participation certificate to each participant, 1st, 2nd, 3rd and consolation prizes were given in three categorized age groups. Earthen Water Pots sponsored by Divya Bhaskar CSR team were distributed, for feeding the birds, to all the participants.

Readers' Views

Dr. Surendra Pokharna, Ex-Scientist, SAC/ISRO: Thanks a lot for your letter about the article. Actually I am very happy to acknowledge the hard work and professionalism in which you are running the society. I have done some work for ISG and I know how difficult it is to run such societies. The mere fact that such huge newsletters can come out every quarter shows the dedication of you people in getting these things done. Heartiest congratulations and I wish all the best for future also.

Dr. Vijay K. Agarwal, Chief-Scientist (retired), Remote Sensing Applications, ISRO, and DOS-GOI: A very informative and good compilation. Congrats to the team. My congratulations to the ASI award winners.

Superannuation

Dr. R R. Navalgund, Director SAC

Dr. R M. Dwivedi EPSA/MPSG/MBD

Forthcoming Chapter Activities	
Aug 4, 2012	NRS Day Celebration
Sept 15 , 2012	Half day Workshop on RISAT-1.
Oct 8 & 9, 2012	Participation in Kalpana-10 Years Celebration, ISRS & IMSA
Forthcoming Conferences	
05-09 Nov,2012	Pacific (Pan) Ocean Remote Sensing Conference (PORSEC)-2012, Kochi, Kerala, India
21-26 Jul, 2013	International Geoscience & remote Sensing Symposium (IGARSS)-2013, Melbourne

Acknowledgements:

*The editorial team is grateful to **Shri Satish Sharma** and **Shri Ulkesh Desai** for helping in getting the documents printed.*

Signing off

Dear Reader,

*We, the editorial team have endeavored to compile a series of articles on the theme, **"India's Active Eye In The Sky- RISAT-1".** This is the maiden venture of our team, and the task was quite a challenging one. We had to make efforts to approach the experts all across our ISRO centres, the retired league of super-scientists, and also some of the pioneers in the field of SAR in the world. It is a great pleasure to announce that we were successful in our effort, and all the scientists responded in a very positive manner. They took time off from their busy schedules to write the articles and make this issue a grand success.*

Our heartiest congratulations to the contributing authors for the success of RISAT-1 . We are thankful to them for sparing their time and contributing to this special issue of Signatures.

*We are specially grateful to **Dr Keith Raney** for not only giving a candid interview, but also contributing an innovative article on Polarimetric SAR.*

*We are immensely thankful to **Shri OPN Calla, Shri N S Pillai** and **Dr S B Sharma** who responded to our requests to contribute for this issue.*

*We have to thank **Shri Tapan Misra,** for constantly supporting us in getting the articles. We are grateful to **Shri D Subrahmanyam, ISRS-AC Chairman, Shri D RM Samudraiah, Vice President ISRS,** and **Dr Parul Patel, Secretary, ISRS-AC,** for their valuable suggestions.*

*We are specially thankful to **Shri A S Kiran Kumar ,Director, SAC** for extending his support in bringing out this issue.*

*The contribution of **Shri S S Rana**, former DD, MRSA, in the making of RISAT -1 , needs a special mention and applaud.*

*We sincerely thank **Shri N M Desai** for his active contribution to this magazine.*

Finally we thank all those who cared to give their feedback for the earlier issues.

We request our revered readers to send their feedback related to this issue to the editor at arundhati@sac.isro.gov.in.

*Please send your articles for the next issue at the above email address. The theme for the next issue is: **"Megha-Tropiques Mission - Radiometers For the Tropics".***

On behalf Of the Editorial Team,

Arundhati Misra (Ray)

Editor, ISRS_AC

ISRS

Signatures

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The cover page was designed by **Mr. Soumya Misra**.


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