EFFICIENT TRANSPONDER UTILIZATION TECHNIQUE IN VARIABLE TRAFFIC SCENARIO USING ANALOG MESH PROCESSOR

Pravina Bhatt, Surinder Singh, Shilpi Soni, Vikas Gupta,
Ambrish Ghadiya, Pankti Pandey
Space Applications Centre, ISRO, Ahmedabad, Gujarat, India

ABSTRACT
Analog Mesh Processor is an on-board traffic control system designed at VHF frequency band. It allows a mean to increase the capacity of four-beam satellite through the use of 16 types of sub-channels having fixed different finer bandwidth. The finer bandwidth is achieved using SAW filters. The uplink and downlink frequencies of all the beams are at Ku band. Designed Mesh-processor allows independent sub-channel routing and controls the gain of each sub-channel which can be adjusted independently having input power range from -44dBm to -60dBm and output power range from -28dBm to -22dBm. This gives advantage of accommodating different classes of terminals for each sub channel as well as helps in equalization of uplink signal levels of all the four beams, before being combined for down link. The analog mesh-processor offers this high-tech highly efficient mesh link in multi-beam Indian GEO-communication satellite. It offers the way for rapidly switching sub-channel among the beams, which includes one is-to one, multi-cast and full broadcast mode. Since it is designed at baseband frequency it can be used as drop-in-box which is independent of uplink/downlink frequencies. FPGA based digital interface control logic implementation done for tele-command controller from ground. The designed Mesh-processor successfully under gone the entire qualification level test required for GEO space applications.

KEYWORDS: *Analog Mesh-Processor, switch Matrix, SAW filters*

I. INTRODUCTION

An Analog Mesh Processor was developed for a multibeam Indian GEO-communication satellite indigenously to provide the special services, like delay sensitive services, for direct user to user switchable Mesh connectivity at narrow sub channel level. Mesh Processor (MP) is an ANALOG ON-BOARD TRAFFIC CONTROL SUBSYSTEM that provides flexibility to utilize the capacity of Multi beam satellites in most efficient manner. It makes use of fixed finer bandwidth sub-channelization using surface acoustic wave(SAW) based filters[4] and offers independent routing of sub channels using 4X4 switch matrix bank at sub-channel level. It is accommodated in Ku-band payload of multibeam Geo-communication satellite in conjunction with bent-pipe payload as add-on flexibility for on-board inter-beam and intra-beam connectivity and gain adjustment at each sub-channel level for variable traffic scenarios. A portion of Bandwidth from Ku-band transponder is taken and down converted to VHF band for narrow band filtering using brick-wall SAW filters for sub-channelization and after required signal conditioning and connectivity, up-converted and merged with Ku-band bent-pipe payload to utilize common antenna interface.
The analog mesh-processor is designed at VHF band and it is independent of uplink and downlink frequencies of the multibeam Geo-communication satellite. This technology is particularly useful for multi-beam satellites, which employ frequency re-use among the beams, to accommodate increasing demands for traditional communication services. It allows fixed (0.5MHz, 1.0MHz, 1.5MHz & 2.0MHz) narrow “switchable bandwidth on demand”. Hence optimizing traffic capacity and the

advantages of a bent pipe system can be retained. SAW[4] based conventional processors utilizing up and down converters with processing of traffic signals at IF level are proposed in [1][2].

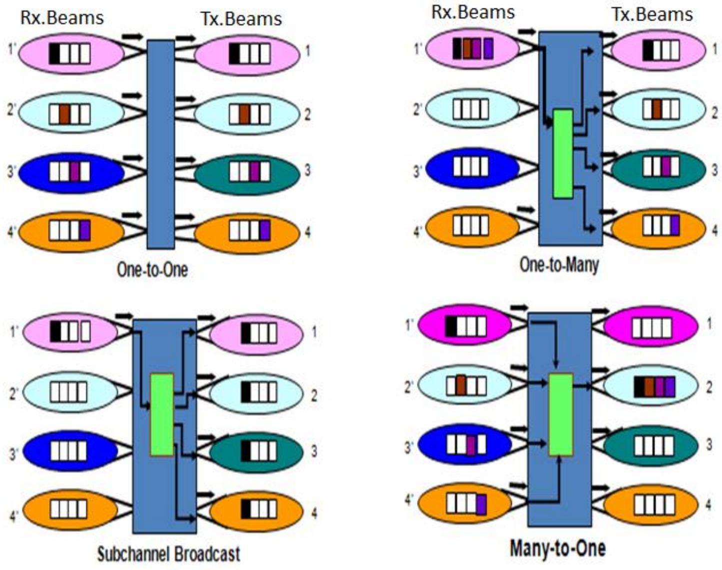


Figure 1. Analog Mesh Processor connectivity

BEAM*LINK® processors [3] [4] use advanced SAW filtering techniques for signal processing at higher operating frequencies (L-Band) & wider bandwidth. Proposed Analog mesh processor, realized at VHF Band, offers flexible method for mesh connectivity in advanced multi-beam satellites for new generation communication link. Being a drop-in-box in conjunction with up converter and down converter in Ku band Payload, it provides operation at VHF band which is independent of uplink/downlink frequency. Miniaturization is achieved at VHF Band by using advance packaging and interconnection techniques. Section II provides the key features of system, Section III describes the analog mesh-processor system architecture, Section IV provides hardware implementation details, Section V discusses system performance.

II. SYSTEM FEATURES

Analog On-board Processor, in multibeam payload having hub less connectivity is introduced for the first time in Indian multibeam GEO-communication satellite. It efficiently manages the routing of traffic by dividing potion of transponders from four main beams into 16 sub-channels with selectable Bandwidth from 0.5 MHz to 2 MHz. It provides independent gain control to accommodate input range of -44dBmto -60dBm and output range of -28dBm to-22dBm to accommodate different classes of terminals for each sub channel as well as to equalize the uplink signal levels of all beams, before being combined for down link. It is also necessary to minimise cross-talk interference between adjacent sub-channels after they are combined, since the inherent non-linearities of the output linearized travelling wave tube amplifier (LTWTA) would cause higher power sub-channels to interfere with lower power sub-channels. It also provides Beam to beam switching at a sub-channel level which includes multicast as well as broadcast connectivity of any sub-channel as per Figure 1. The concept is scalable and can be extended for any number of sub-channels. Mesh-processor is a drop in unit whose operation is independent of Uplink & Downlink frequency by using suitable up/down convertors. System retains purely bent pipe architecture and no modification is required in ground terminals.

III. SYSTEM ARCHITECTURE

Mesh Processor is a mini payload in itself. As shown in Figure 2 functionally it caters input power division, narrow band sub channelization, individual sub channel routing, level control and recombination to provide a single composite spectrum containing the desired signals from all four input beams. Signals in each of the received beams is first amplified and then divided into four sub-channels through the combination of one 4-way power divider and four SAW filters. SAW filters [4] provide very flat in-band channel performance & excellent adjacent channel isolation. These SAW filters have pass bands of sub-channel bandwidths as per Table-I.

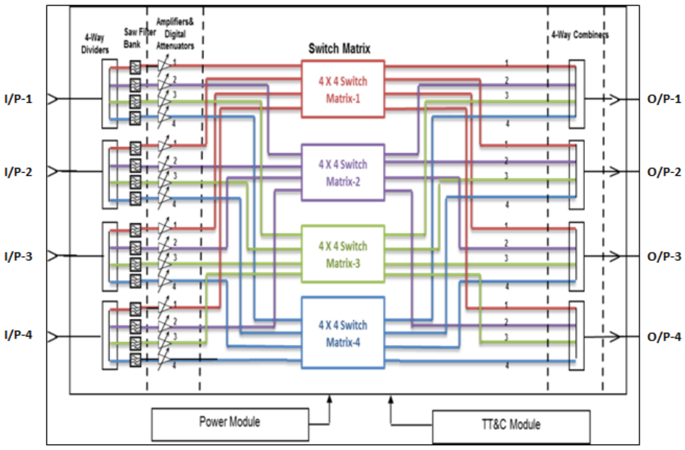


Figure 2. Architecture of Analog Mesh Processor

Table-I Sub-channel frequency plan of each beam

Sub channel #	Centre Frequency (MHz)	Bandwidth (MHz)
1	176.52	0.5
2	178.25	1.5
3	180.78	2
4	183.06	1

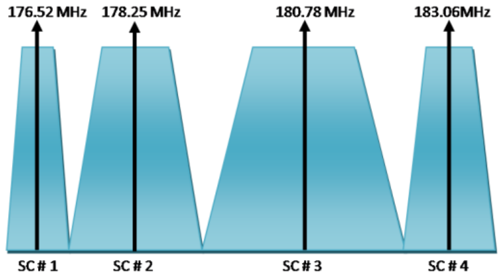


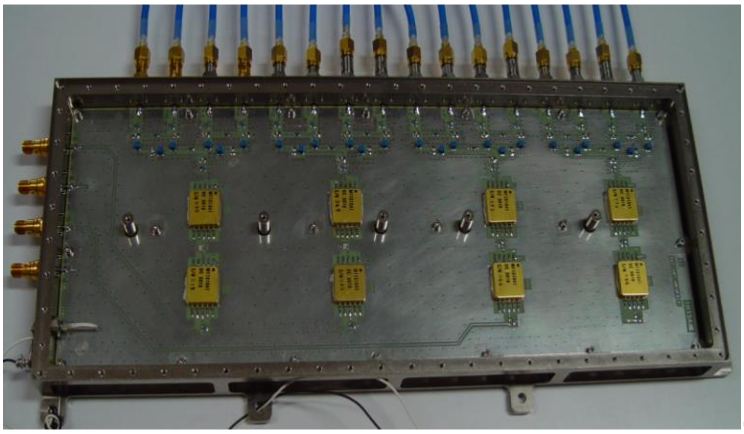
Figure 3. Sub-channel level frequency plan

And Figure 3 shows pictorial view of sub-channel level frequency plan of each beam. Once the sub-channels have been separated, these are again amplified to compensate for SAW filter losses. 5-bit Variable Digital Attenuator provides gain adjustment for the individual sub-channels. The sub-channels having same pass-bands from different input beams are then routed into a common 4X4 switch matrix. The switch matrix provides connectivity to route a sub-channel of a given input beam to anyone or all the output beams. Different outputs from all the four SWMs are selectively combined through 4-way power combiners to form the desired output beams. Combined outputs from all the 4-way combiners are amplified once again for the required output signal level. Required connectivity between various beams at the sub-channel level can be established by Switching Matrix through tele-command. The power level of individual sub-channel can be varied by commanding the Digital Attenuator in each sub-channel. FPGA based digital interface control logic implementation is done for tele-command controller.

IV. SYSTEM ARCHITECTURE

Assembly Consist of three main functional modules stacked horizontally which provides a good interface for dissipating the heat from the packages. Input Package at bottom includes Gain Blocks, 4way-Power Dividers, SAW Filters and commandable 5-bit Digital Attenuators. Middle package consist of 4 X 4 Switch Matrix units along with Digital Interface controller card. Output Package at top includes 4way-Power Combiners & Gain Blocks. Electronic Power Conditioner-EPC (Power Module) is mounted vertically near main assembly. RF Interface between the horizontally mounted packages is provided via semi-rigid coaxial cables & SMA interconnects.

(A)



(B)

Figure 4. (A) Input Package PCB, (B) Output Package PCB

DC interconnects between packages are provided by multipin-D connectors & shielded polyamide wire harnessing. Multiple Layer PCB (MLPCB) implementations have been done to provide RF, digital and DC signals routing. Plated vias were used as transmission structures between various PCB layers without performance degradation. All these techniques resulted in miniaturisation of individual packages and compact overall assembly.

A. Input Package

Input package consists of two back to back PCBs. Each PCB has two inputs and eight outputs as shown in Figure 4(A). Each path consists of amplifiers, 4-way power divider, SAW filter, Chip attenuators and Digital Attenuator. Complete Input package has 4 RF SMA Inputs, 16 RF SMA Outputs, two DC line filters, two 50-pin D type connectors to give Command to 16 digital attenuators for gain control. Supply voltage required for input package is +5V.

B. 4 way Power Dividers & Combiners

Wilkinson type 4-way power divider & combiner at VHF designed and developed in-house using lumped chip inductors, capacitors & resistors on FR-4, MLPCB.

C. SAW Filters

Four types of SAW filters[4] have been designed at VHF Band to meet the requirements of analog mesh processor. The SAW filters have been designed using the Remez Exchange Algorithm in order to have small overall device size. These are narrowband filters and hence ST-X Quartz has been used as the substrate material. The Temperature Coefficient of Delay (TCD) of ST-X Quartz is approximately zero, thereby ensuring negligible drift with temperature. In-house manufacturing & photolithography processes are utilised. Each SAW filter is individually packaged in a hermetically sealed gold plated kovar package and integrated into Input Package PCB with corresponding matching networks printed on it.

D. Switch Matrix & Digital Interface Control Logic(SWM-DICL) Package

SWM-DICL package at VHF-Band has four nos. of 4X4 Switch matrices, link card for cross-over between beam & Sub-channels and Digital Interface Control Logic card for serial to parallel tele-command conversion. Two nos. of 4X2 switch matrix IC are cascaded to get 4X4 switch matrix connectivity. Radiation Hardened FPGA from ACTEL is used in DICL. Interface-wise it has 16 inputs and 16 output RF SMA ports, a DC line filter for +5V supply, two 50-pin D type connectors for Digital Attenuator command and a 9-pin D-type connector for Tele Command from spacecraft. The design is configured to provide required connectivities with telecommand in single package having good isolation.

E. Output Package

Output Package as shown in Figure 4(B), consists of four nos. of 4-way power combiners for combining the desired four sub-channels routed through middle package to form the output beam which is amplified for the required signal conditioning. Interface wise output package has 16 RF SMA input and four RF output. Supply voltage required for output package is also+5V.

F. Electronic Power Conditioner (EPC)

Two EPCs as shown in Figure 5, one for main and other for redundancy are used to provide required supply voltage and current to individual cards of Mesh processor. It takes input range26V to 42V from raw bus of the satellite and provides regulated +5V supply voltage through a 9-pin D type connector to all packages.

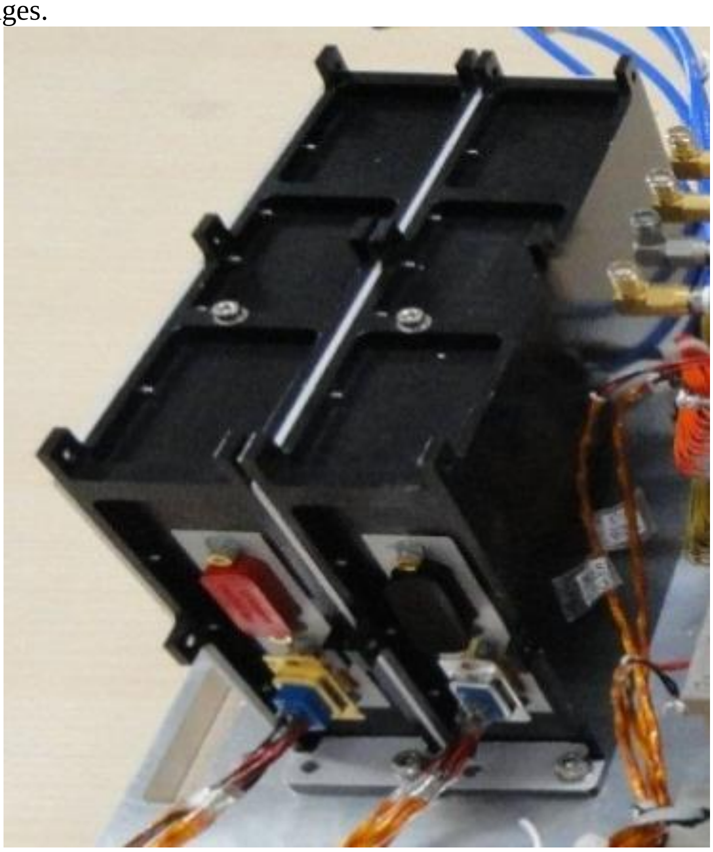


Figure5. EPC for Analog Mesh-Processor (Main & Redundant)

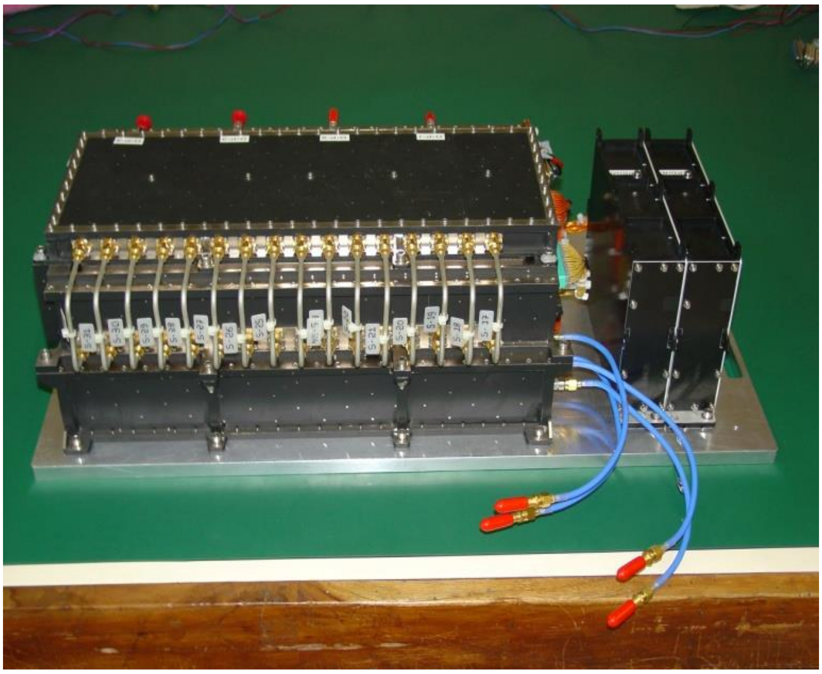


Figure 6. Flight Model Assembly

G. Environmental Design Considerations

The flight model assembly of Analog Mesh-Processor is shown in Figure 6. Considering the space environment, suitable thermal and structural analysis was done on the mesh processor assembly. Thermal Analysis is the analysis of thermal energy distribution on the card and thereby determining the hot spot on the board as shown in Figure 8.

Thermal vias were provided in the PCB below hot components to reduce heat. This helped in arriving at a suitable thermal relief strategy to keep the card components in its safe limit (junction temperatures of active device < 110ºC) during the worst case base plate temperature of +65ºC. Structural analysis was done to validate the structural design of the Input and Output package for the specified Vibration environment. Figure 8 shows FE Model of complete assembly for structural analysis. Modifications based on structural analysis was implemented like additional mounting lug was provided in middle of the PCB, additional Teflon spacers were provided at middle area for both sides of top & bottom PCB of I/P package using studs on mid partying wall of the package, etc. This gave structural margins for on-board application.

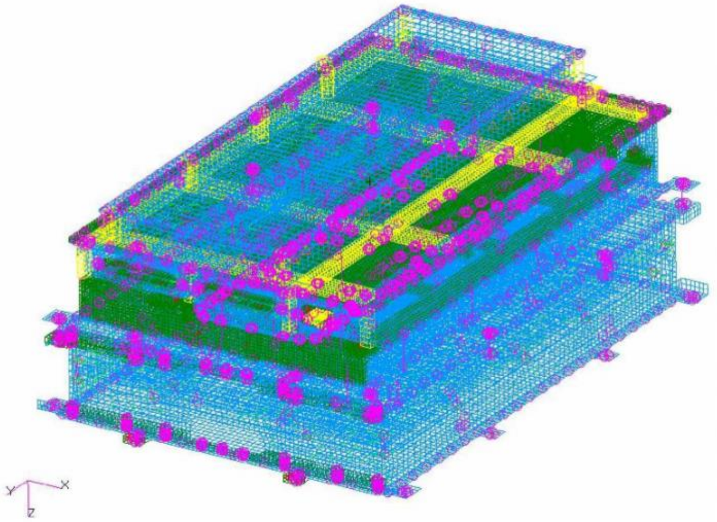


Figure7. FE Model of Assembly with axis definition

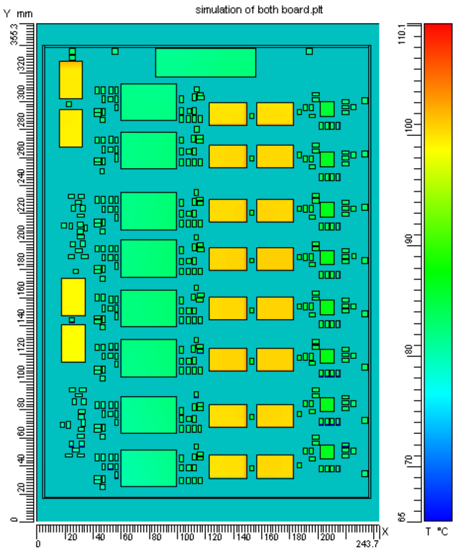


Figure8. Graphical Representation of board temperature from top side

V. MESH PROCESSOR PERFORMANCE

Mesh Processor provides 256 connectivity states for each switch matrix and 32 attenuation states for each sub-channel's digital attenuator. Measured performance result of mesh-processor for default condition is as shown in Figure 9. Default condition is the power ON state with one-to-one connectivity state of all SWM with all the four sub-channels of input beam-1 recombine at output beam-1 and so on. Table-II provides the specifications for the critical performance parameters of the processor over the operating temperature.

Table-II: Typical measured performance

Parameters	**Specifications (dB)**
Gain Adjustment range	22
Gain Step Size	2
Gain Variation	± 1
Gain Flatness	1
Rejection From 10MHz to 175.67 MHz From 184.26 MHz to 800 MHz	>30
Two Tone 3rd order Intermod With two carriers, 100.0 kHz apart at max input power level i.e., -47 dBm	≤ - 44
Beam to Beam Isolation	30
Sub-channel Isolation	30
Operating Temperature Range-Flight Model -Qualification Model	-5 to +55ºC -10 to +60ºC
Storage temperature range	-40 to +65ºC

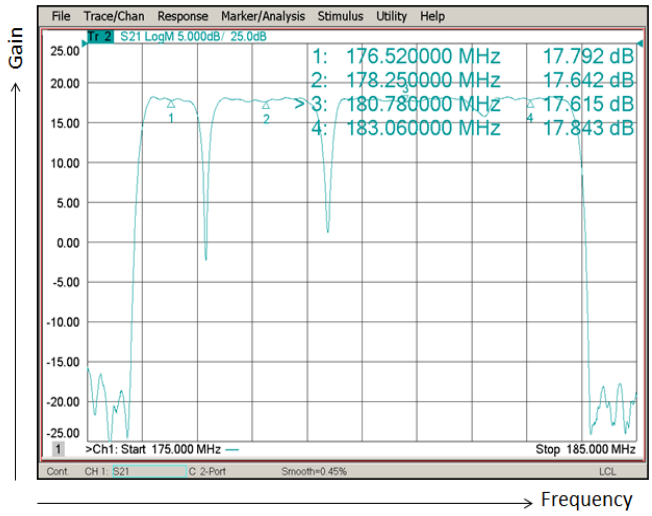


Figure9. Measured Beam Performance (Default condition)

VI. CONCLUSIONS

Fully indigenous Analog Mesh Processor was designed, developed and qualified for space use in one of the multibeam GEO-communication satellite of Indian Space Programme. All the required performance parameters and intended functionality were achieved. The processor was subjected to stringent electrical, mechanical and environmental tests and is successfully inducted into Indian satellite system.

VII. FUTURE WORK

The proposed mesh processor caters four beams with each beam having 4 sub-channels. This concept is scalable to higher numbers of beam and sub channels. But as we go for accommodation of large beam in analogue subsystem it increase hardware complexity. Thus gives compulsion to move for digital Mesh processor. Future work is to implement the digital mesh-processor having large numbers of beam (say 16 beams) and higher sub channels in each beam.

REFERENCES

[1]. N Miller ,Y. Lee, R.C. peach, R.Kova, B.Van-Osch, A.Veenstra, P.Kenyon, A.Swarup, "The Design and Implementation of the Inmersat III L-Band IF Processor",15thInternational Communication Satellite Systems Conference & Exhibition(AIAA), February 23- March 3,1994,San Diago,CA
[2]. M.Lee,S.Wright,A.Swarup,B.Brodie, Advances in Beam*Link® Technology for Military and Commercial Satellite Systems Conference &Exhibition (AIAA), April 10-14, 2000 Oakland, Ca.
[3]. M.Lee, S.Wright, JimDorey, Jim King, Ronald H.Miyakawa, Advanced Beam*Link® Processor for Commercial Communication Satellite Payload Application,AIAA-2002-1853
[4]. A. Kumar, S. Sinha, U. Mandvia, NR Jivani, S. Singh & O. Kaushik, "Surface Acoustic Wave Filters for Space Use", International Conference on Microwave-08,p. no. 261-264.

AUTHORS

Pravina Bhatt completed graduation in Electronics and Tele-communication engineering from the IETE, New-Delhi. She is currently working in Space Applications Centre, ISRO as a Scientist. She is working for Design and development of Ku band DR based IMUX, DR filters at S, C and Ku band, Helical resonator based PSFs and IMUX filters.

Shilpi Soni received the B.E. degrees in electronics and communication engineering from the IGEC, Sagar, 2000. She is currently working in Space Applications Centre, ISRO as a Scientist. She is working for development of DR based filters at S, C and Ku band, Helical resonator based PSFs and IMUX filters. High Temperature Superconductor based IMUX Filters, LTCC based power dividers and filters and RF MEMS based filter and switch.

Surinder Singh has worked on the design and delivery of the space borne hardware for more than 25 years. He is very actively associated with the communication satellite program right from the indigenous realization of the INSAT series and at present is also engaged in the development of payload for Indian regional navigation system "IRNSS". He has worked on many cutting edge technologies like MMIC, RF MEMS, Dielectric Resonator filters, High Temperature Superconducting Filters to realize High Performance, Reliable , Compact & Light Weight subsystems for SATCOM payloads

Vikas Gupta is currently working in Space Applications Centre, ISRO as a Scientist. He is working for development of DR based filters at S, C and Ku band based IMUX filters. High Temperature Superconductor based IMUX Filters, LTCC based power dividers and filters and RF MEMS based filter and switch.

Ambrish Ghadiya, received the B.E. degrees in electronics and communication engineering from DDIT, Nadiad, 2010. He is currently working in Space Applications Centre, ISRO as a Scientist. He is working for Design and development of various IMUXs, Ultra narrow band DR filters and Couplers at all the bands.

Pankti Pandey, received the B.E. degrees in electronics and communication engineering from LD collage of engineering, Ahmedabad, 2011. She is currently working in Space Applications Centre, ISRO as a Scientist. She is working for Design and development of various IMUXs, DR filters, Helical Resonators based filters and Couplers at all the bands.