SHAPED BEAM LOW LOSS MICROSTRIP ARRAY ANTENNA FOR INDIA COVERAGE AT KU-BAND FROM A STABILIZED SATELLITE

Chandrakanta Kumar, Praveen Kumar, Debojyoti Choudhuri, VV Srinivasan, V Mahadevan, Dr.V K Lakshmeesha, Dr. S Pal FIEEE

kumarchk@gmail.com, djyoti@isac.ernet.in

Communication Systems Group, ISRO Satellite Centre, Bangalore-560017

ABSTRACT

Microstrip antenna arrays can be designed to produce shaped footprints, which are advantageous in saving the onboard power of satellites by restricting the radiation of the antenna in the desired regions only. However the major disadvantages of using microstrip antenna arrays are their narrow bandwidth and high loss mainly in the feeding network. In this paper the design of a hybrid array – a waveguide-fed microstrip-radiating element, for onboard transmit and receive applications at Ku-band is presented to realize a low loss system. Further electromagnetically coupled patches are designed to operate over a bandwidth of 10 %. The radiation patterns of the arrays are synthesized applying Woodward Lawson (W-L) technique to fit the Indian main landmass with an End of Coverage (EOC) gain of 31dBi. The waveguide feed array generates a complex aperture distribution across the array to generate the shaped footprint. This array is low profile, lighter in weight, has low insertion loss and can handle RF power of about 1 KW.

INTRODUCTION

Satellite antenna systems require a radiation pattern, which illuminates the desired region at constant power with an acceptable variation (ideally zero) and a minimal spill over. To get desired radiation pattern of the antenna, different types of synthesis algorithm is used depending on their usability and the convenience in the situation under consideration [6]. It's the geometry of the aperture and the distribution of the phase and amplitude of excitation across the aperture mainly govern the final pattern of the antenna. In arrays the element pattern is also a controlling parameter. In the case of arrays the number of elements within a specified aperture has a direct influence on the final pattern. For the finer control of the footprint the number of the elements should be more. But this is again controlled by the physical size of the array, radiating elements and the complexity of the feed network. So we have to have an optimal choice between the performance requirements and the real estate available.

Considering all the facts, an antenna pattern synthesis algorithm for planer array was developed to derive the aperture distribution in order to generate a beam, which uniformly illuminates the Indian main landmass from geostationary orbit [1]. The analytical model on the basis of W-L technique is implemented for the array pattern synthesis. The size of the array has been optimized for the EOC gain requirement of 31dBi; with synthesized peak gain of 32.5dBi and EOC gain of 31.5dBi. Considering the facts mentioned above and the sampling point requirement for the W-L technique the optimal numbers of the elements for the synthesis has been taken to be 16 x 16, and the inter element spacing of $1.5\lambda_0$. The basic radiating element is a 2 x 2 array of elements fed with equal amplitude and phase. So the overall antenna is effectively a 32 x 32 array with spacing of $0.75\lambda_0$.

DESIGN OF THE ANTENNA

The basic aim for the present work is to develop the antenna required for the payload at Ku band (10.9-11.8 GHz for downlink and 13.9-14.3 GHz uplink) to cover the Indian main landmass from a satellite at geostationary orbit. Apart from the coverage there is stringent requirement of the cross-polar component of the antennas (better than –25dB) to enable the frequency reuse using polarization diversity for collocated satellites. For this purpose two antennas for the frequency bands mentioned above are designed. The basic design of these antennas is the same and can be divided into three segments namely the radiating elements, the feed network, and the coupling mechanism of power from the wave-guide to the radiating elements. The complex aperture distribution generated from the synthesis algorithm is having a wide range of variation in terms of magnitude and some of the elements are having 180° phase [1]. Proper thinning of the elements has been done to eliminate the elements having negligible effect on the footprint. In an array of this size the main challenge comes out to keep the loss to bear minimum. To achieve this a hybrid, waveguide-microstrip, power-dividing network has been implemented. The synthesized power coefficients are realized in waveguide up to 16 x 16 level. After that the 2 x 2 equal divisions and the required phase correction due to the unequal division in the wave-guide, has been implemented in microstrip. The radiating elements have been chosen to be a stacked patch to have a return loss bandwidth (-15dB) of 10%. These elements has been integrated with the 2 x 2 feed network using a novel technique to get very good polarization purity [3]. So basically we can assume that the radiating element is a 2 x 2-stacked array. The energy from waveguide is coupled to these radiating elements with the help of a pin.

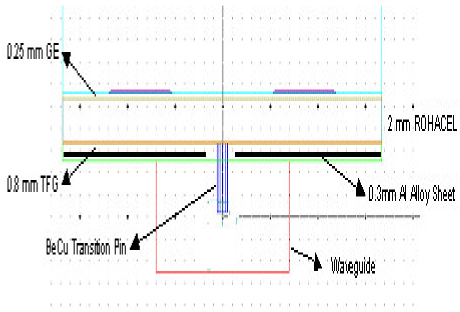

Fig. 1: Different Layers in the Antenna

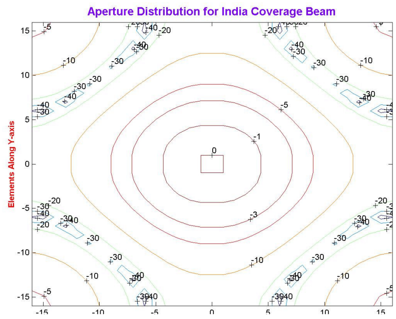

Fig. 2: Computed Excitation Coefficient

The Radiating Elements

The antenna is meant for satellite on board application, so it is implied that the weight of the antenna should be as low as possible. So microstrip patch become one of the obvious choices for the radiating elements. As mentioned earlier the basic element is a module is a 2 x 2 array. Stacked configuration is chosen to achieve broadband performance over a bandwidth (-15dB) of 10%[2] & [5]. The configuration consists of radiating patches in two layers, Fig.1. The lower layer of the patches are printed in a 2 x 2 configuration on a 0.8 mm thick RT Duroid-6002 Teflon Fiber Glass (TFG) substrate of ε_r = 2.94. The energy from the wave-guide is directly coupled to this layer by means of a pin. The required phase corrections are also implemented in this layer, by adjusting the lengths of the microstrip feed lines for the 2 x 2 array. The other layer of the patches are electromagnetically coupled from the lower layer and placed on a 2mm thick Rohacell-51 HF material (ε_r=1.07). These patches actually printed on a10 mil thick Glass Epoxy (GE) substrate of ε_r = 4.55 and the printed side is placed towards the foam. So the top GE layer is acting as a radome. All the layers were bonded at one shot using the adhesive Redux-312UL.

The Feed Network

To generate the required shape of the radiation pattern a complex distribution of excitation coefficients is required [1], Fig.2. The maximum of the excitation amplitude occurs at the center of the aperture and tapers to –16.6 dB at the edges along the principle planes. However along the diagonal planes it is observed that the distribution tapers down to null around the 10th element and then again increases towards to edges. The null signifies that the phase required for the elements beyond the nulls is 180° compared to the other elements. The elements receiving an excitation power level of –20 dB or less are knocked off, because they do not contribute much in the footprint. Corporate feed architecture is well suited for this application as it maintains constant input to radiating element length and hence can operate over wide bandwidth. To keep the loss minimum and to increase the power handling capacity, the network is realized in waveguide. For the 11 GHz segment the cross section of the waveguide used is 18 x 9mm^2 and for 14 GHz it is 14 x 9mm^2. The required phase shift for the corner blocks is implemented by introducing ridge inside the waveguide. Realization of the required amplitude distribution calls for unequal power divisions. The imbalance in the division ranges from 0.6 dB to 9.4 dB. These power divisions are realized by incorporating a septum and in some of the case septum on a pedestal, at the power-dividing junctions. These unequal divisions give rise to the unequal phase at the output of the 'T' junctions. The final phase at the outputs of the divider was noted and appropriate correction was implemented in the subsequent microstrip divider level. As the required aperture distribution is quadrant symmetric about the center of the array, feed network for one quadrant, Fig. 3, has been simulated and optimized for the required amplitude distribution. The final simulation indicates maximum imbalance of 0.1 dB in amplitude, which is found tolerable for the required shaping.

Transition form Wave Guide to Microstrip

The input for microstrip 2 x 2 radiating array is coupled to the wave-guide by means of a pin through a hole at the broad wall of the wave-guide. This pin is a 'T' shaped Beryllium-Copper pin, the straight cylindrical segment of which is protruding inside the wave-guide and the top flat hat type of the segment is soldered to the input line of the 2 x 2 array. The pin length, diameter and location in the wave-guide are optimized for maximum coupling of energy over the required band. The total configuration was simulated in HFSS and the performance was optimized.

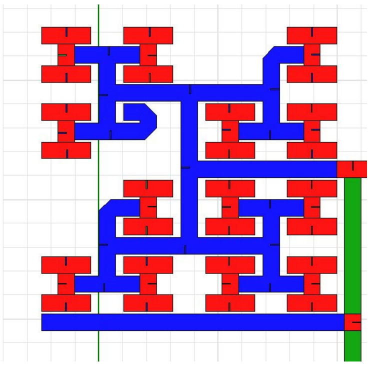

Fig. 3: Wave-guide Feed Quadrant at 14 GHz

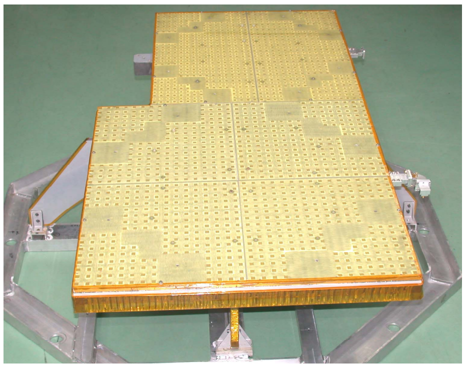

Fig. 4: The Antenna with Mounting Fixture

HARDWARE REALIZATION

At the time of the realization of the hardware the main aspect that is taken care is the weight without compromising on the electrical performance. This antenna is meant for application in a satellite so each and every component of it is qualified for the space environment. The waveguide feed network of required cross section (without the top broad wall) along with the septums and pedestals for the power division is realized by precision (CNC) machining of a 3/8" thick aluminum alloy (Al -2024) block. The extra material at the unused segment of the Al-plate is scooped out to reduce the weight. A 0.3mm thick Al-alloy sheet is bonded, with conductive epoxy, to the machined network to form the complete wave-guide feed network. This sheet is having proper opening to insert the pin for coupling of energy. The transition pins are soldered to the input of the 2 x 2 microstrip patch arrays on the first layer of TFG. All the layers namely TFG, Rohacell and GE are bonded together using Redux-312UL adhesive in a single shot. For the curing of the adhesive the whole antenna was baked at a temperature of 120°C and at an atmospheric pressure of 3 bar in an autoclave chamber for 24 hours.

MEASURED RESULTS

The full antenna with the mounting fixture for the measurement at Compact Antenna Test Facility (CATF) is shown in Fig.4. The wider segment is the 11 GHz transmitting antenna and the narrower segment is the 14 GHz receiving one. Both antennas are tested for their electrical characteristics in the CATF, Bangalore. The measured return loss bandwidth (–15dB) of the 11 GHz antenna is 650 MHz and 700 MHz for the 14 GHz antenna. The measured footprint, Fig. 6, for both antennas matches well with the simulated footprint, Fig. 5. The cross-polar isolation for the antenna is better than -35dB, which is very well suited for frequency reuse for collocated satellites. The measured gain of the antenna is found to be 31.7dBi and meets the mission requirement.

CONCLUSION

A high performance, low loss, wideband feed network has been designed and implemented to excite a microstrip antenna array with the required complex aperture distribution with tight tolerance. The network consists of waveguide and microstrip lines that divide the power and control the phase to each of the element in

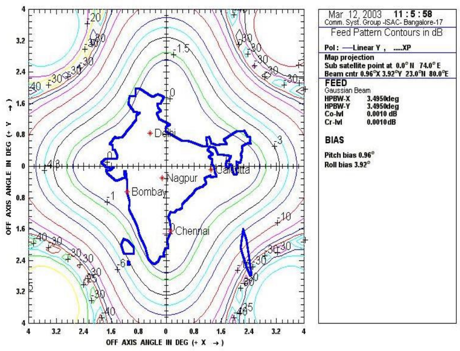

Fig. 5: Simulated Antenna Footprint

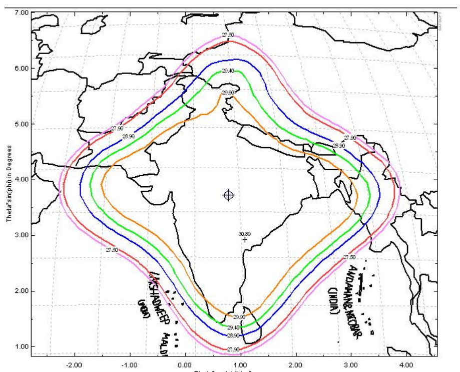

Fig. 6: Measured Footprint at 11GHz

specific manner. Extensive simulations were carried out at various levels to ensure the required performance. Appropriate fabrication and assembling process have been adapted to realize the array. Measurements carried out on the final array exhibits footprint, which matches very close to the simulation. This confirms the superior performance of the complex hybrid feed network described in this paper and other components of the array.

ACKNOWLEDGEMENT

The authors would like to thank our mechanical division, headed by S Aswathnarayan , specially Mr S Natarajan, for their effort in realizing the different components of the system. Our special thanks goes to the Printed Circuit Board (PCB) facility headed by Suresh for their special effort in realizing the PCBs with in the restriction of extremely low tolerance. The team headed by Mr. Prasad did all the bonding of the different layers of PCBs and the waveguide, our sincere thanks to them also. Our sincere thanks goes to Mr. T Mallikarjunaiah for extending his expertise in different capacities throughout the process of realization of the hardware. We thank all of our colleague who may not be directly involved in the project, but their words of encouragements have always become an inspiration to overcome the difficulties faced.

REFERENCES

[1] Chayan Roy, V.V. Srinivasan, Dr.V.K.Lakshmeesha, Dr.S.Pal, "Synthesis of Footprint Patterns From Satellite Planar Arrays With Optimal Boundary", International Symposium on Microwave 1st to 3rd Sept 2004, Bangalore.
[2] S.D.Targonski, R.B.Waterhouse, D.M. Pozer, "Design of Wide Band Aperture Stacked Patch Microstrip Antennas" IEEE Tran. On A&P, Vol-46, No-9, pp 1245-1250,Sept 1998.
[3] P. Kumar, D.Choudhuri, V Mahadevan, V.V. Srinivasan, Dr.V.K. Lakshmeesha, Dr S.Pal, "Novel Feed Technique For Microstrip Antenna Array", Proc. National Conference on microwave antennas and propagation Nov.2-4 (2001), University of Rajasthan.
[4] D.Choudhuri, P. Kumar, V Mahadevan, V.V. Srinivasan, Dr.V.K. Lakshmeesha, Dr S.Pal, "16X16 Microstrip Array Antenna for METSAT", APSYM 2002, Cusat.
[5] S. Egashira, and E. Nishiyama, "Stacked Microstrip Antenna with Wide Band and High Gain." IEEE Trans. On A&P Vol.- 44, No-11, pp 1533-1534, Nov 1996.
[6] Constantine A. Balanis ,"Antenna Theory analysis and Design" John Willey & and Sons (Asia) Pte Ltd, `97
[7] I.J. Bhal, P. Bhartia, "Microstrip Antennas" Artech House, `82.