Design & Development of a 32 Elements X-band Phased Array Antenna for Airborne & Space Borne SAR Payloads

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Abstract— **Air Borne & Space Borne SAR Payloads are used now a days in variety of missions for different applications. Onboard SAR payload consists of a digital signal processing & data storage unit, a transceiver and an antenna unit. Onboard antenna is a vital unit of a communication system and design of antenna becomes much more critical and complex once electronic beam steering is an essential requirement. Usually for SAR applications, electronically steerable high gain antennas are required to support different operating modes. In this paper, design of 32 elements X-band Phased Array is discussed along with its simulation and measurement results. Design antenna is based on microstrip technology and orientation of feeding mechanism to a certain group of elements is such that it provides circular polarization both across range/azimuth. Electronically steering is possible by changing the phase at the inputs of the antenna ports and different possible steering scenarios are discussed in this paper. An advanced EM simulation software is being used for design and simulation purpose. Simulated results provide a gain of approximately 20 dB with a VSWR < 2 at desired frequency range in the band. Axial ratio of < 3 is targeted and achieved in the desired frequency range.**

I. INTRODUCTION

Use of SAR technology both for air borne and space borne platform is increasing day by day. Advantage of using SAR technology over optical imaging is that it has a capability of acquiring imaging during day and night time and also in all weather conditions. With these distant advantages, there are some disadvantages associated with it, one is the high power generation and other is the complex signal processing algorithms. With advancement in technologies, considerable amount of mass and power consumption has reduced thus making SAR technology ideal for remote sensing.

SAR payload comprises of an antenna, transceiver and digital signal processing and data storage unit. Antenna design and its performance is one of the critical part of any communication link and in case of SAR, the design becomes much more complex and its performance critical due to electronically beam steering. Electronic beam steering is mandatory in order to support ScanSAR and Spotlight modes. Cross range resolution (also known as along track or azimuth resolution) is directly dependent on the physical size of antenna. Larger the size of antenna in one plane finer is the resolution [1]. Usually high gain antennas (> 20dB) are used for SAR Applications.

Electronic beam steering is possible only while using a phased array antenna and a beam forming network. As the name indicates phased array antenna consists of an array of elements, each or group of elements excited by a phase shifter in order to provide the necessary phase difference between these elements for the necessary steering of the beam in a desired direction. This steering of the beam is due to the resultant sum/cancellation of electric filed vectors of each element which results in the constructive/destructive interference. Phased array antenna can be of planar or conformal form depending upon the shape of mounting structure on which phased array antenna needs to be mounted. In this paper planar phased array antenna is discussed and the design is based on the assumption that the moving platform (satellite or aerial vehicle) has a planar surface. Type of antenna elements to be used in phased array antenna varies from horn, slot waveguides, helix, helical & microstrip patch etc. In this paper, microstrip phased array antenna is preferred due to its low mass, easy fabrication, low cost, conformance to the mounting structure, beam steering in few microseconds

Based on the designer topology different phase shifting methods can be employed some of which are mechanical phase shifters, ferrite phase shifters; semi conductor devices phase shifters and transmission line phase shifters. In this paper, architecture is designed in such a way that semi conductor phase shifters will be used and these phase shifters are controlled by the On Board Computer (OBC) for providing the necessary phase difference between the elements for the steering of the beam. Fig. 1 [2] shows a corporate phase shifting network and resulting a steering of beam

Phased array antenna has been designed using advance EM simulation software and the simulation results shows conformance with the measurement results. Testing of antenna has been performed in an anechoic chamber test facility.

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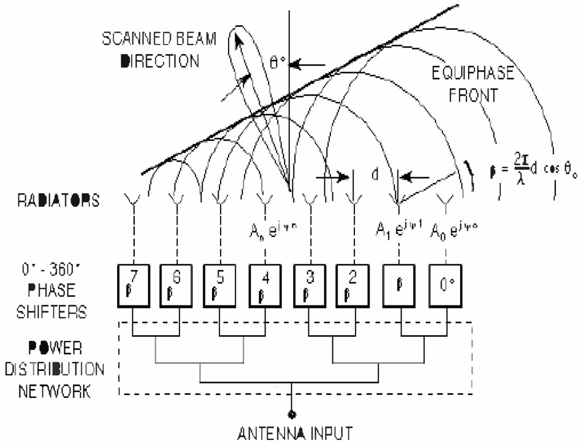

Fig. 1 Corporate Phase Shifting Network [2]

II. DESIGN METHODOLGY

The design of phased array antenna was sub-divided into three stages. In the first stage, a single microstrip element needs to be designed and optimized to resonate at X-band with VSWR and axial ratio requirements met. In the second stage, a group of elements fed by a single port placed along a plane will be designed and optimized to resonate at X-band with VSWR and axial ratio requirements met. In this scenario a complete transmission line network also needs to be developed for efficient radiation of energy in space. In the third stage, a number of groups of group of elements are designed and optimized in both planes to provide the required beamwith (both in elevation and azimuth plane) at X-band with VSWR and axial ratio requirements met.

a) Substrate Selection

Selection of substrate is a critical task for an antenna designer. Low permittivity and thicker substrates are more desirables for antenna design applications since they provide high bandwidth, much more efficient and radiate maximum energy into space but at the expense of larger antenna element size [3]. Usually dielectric constant is in the range from 2.2 to 14. Rogers 5880 with a dielectric permittivity of 2.2 is selected for design purpose having a thickness of 1.5mm.

b) Microstrip Patch Shape Selection

Microstrip patch antenna element shape varies from square, rectangular, circular, elliptical, triangular to thin strip dipole [3]. Rectangular patch and nearly square patch is the most widely used since it is very easy to perform analysis using transmission line and cavity models. In our design configuration, nearly square patch is being considered

c) Microstrip Feeding Mechanism

Microstrip patch element can be fed in different manners such as microstrip line, coaxial probe, aperture coupling and proximity coupling [4]. Table-1 shows different properties of different feeding mechanisms. Based on the properties in Table-1 and also on the heritage, Line Fed in combination with Co-axial fed probe is used for design purpose since it provides better matching and wide bandwidth and low spurious radiations.

Table-1 Microstrip Feeding Mechanisms Properties

Characteristic	Line Feed	Probe Feed	Aperture Coupled Feed	Proximity Coupled Feed
Spurious Feed Radiation	Less	Less	Less	Minimum
Reliability	Better	Good	Good	Good
Ease Of Fabrication	Easy	Soldering Required	Alignment Required	Alignment Required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth	2-5%	2-5%	2-5%	13%

d) Circular Polarization Technique

Circular polarization of an element and an array can be accomplished via different methods [4]. For microstrip element, it can be achieved via slotline, edge truncation, diagonal fed, dual fed etc. Edge truncation is the most suitable choice since it provides much wider axial ratio bandwidth as compared to other available techniques.

III. DESIGN SIMULATION

After finalizing the substrate, microstrip patch shape, feeding mechanism and circular polarization technique, the next step is to design and optimize in the first stage a single microstrip patch element. Fig. 2 below shows the design of nearly square patch element with Length ‘L’ and Width ‘W’.

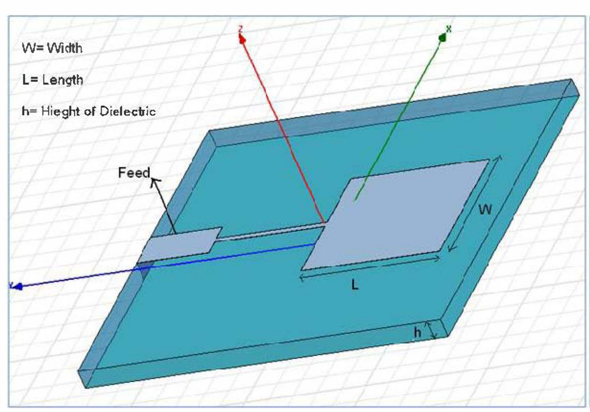

Fig. 2 Microstrip Patch Element Design

The actual length 'L' of the patch is calculated using Eq (1) [3].

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L \quad (1)$$

Where, 'f_r' is the resonating frequency, 'ε_{reff}' is the effective dielectric constant and is calculated using Eq (2) and 'ΔL' is the effective increase in length due to fringing effects and is calculated using Eq (3).

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \quad (2)$$

Where, 'h' is the thickness of substrate.

$$\Delta L = 0.412h\frac{\left(\epsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\epsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \quad (3)$$

For an efficient radiator, a practical width 'W' that leads to good radiation efficiencies is [4],

$$W = \frac{\vartheta_0}{2f_r}\sqrt{\frac{2}{\epsilon_r + 1}} \quad (4)$$

In the first design stage, using Eq (1) – (4), a single microstrip patch antenna element was optimized at X-band and truncations were performed at the two edges of the element for circular polarization. Line fed technique is employed for matching with the antenna element. Single element provides a gain of approximately 5 dB. To achieve a gain of > 20 dB, number of elements in an array needs to be used are 32. Fig. 3 shows the top view of the single patch element designed and optimized.

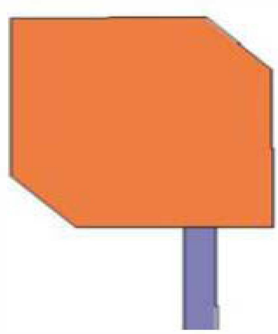

Fig. 3 Top view of Microstrip Patch Element with truncations

In the second design stage, a group of 04 elements is formed to be fed by a single coax fed. Total numbers of 32 radiating elements are sub divided into 8 groups with each group fed by a separate coaxial feed and a phase shifter. A complete transmission line model is being developed including a quarter wave transformer used to interconnect and match different elements in the same group. Fig. 4 shows the optimized design of 04 elements in a group with a single coax feed.

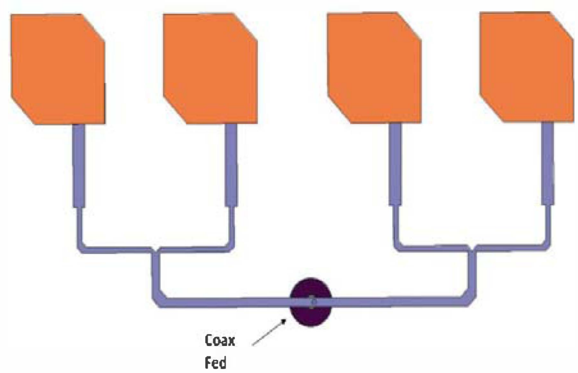

Fig. 4 Array of 04 elements in a group fed a single coax feed.

In the third design stage, all the 32 elements are placed in such a way that beamwidth in elevation plane (across track) is high and in the azimuth plane (along track) is narrow. After detailed and thorough analysis, an array of 2 x 16 elements is designed and optimized. Fig. 5 shows the isometric view of 32 elements array, in which elements are arranged in a 2x16 configuration.

IV. SIMULATION & MEASUREMENT RESULTS

a) Input Reflection Coeffecient

Input Reflection Coefficient was targeted less then 10 dB for all the 08 excitation ports. Due to symmetrical nature of elements and structure, input reflection coefficient is more or less the same for all the exciting ports. Fig. 6 shows the simulation results of the 04 ports. Remaining 04 ports have the same input reflection coefficient due to symmetry in nature.

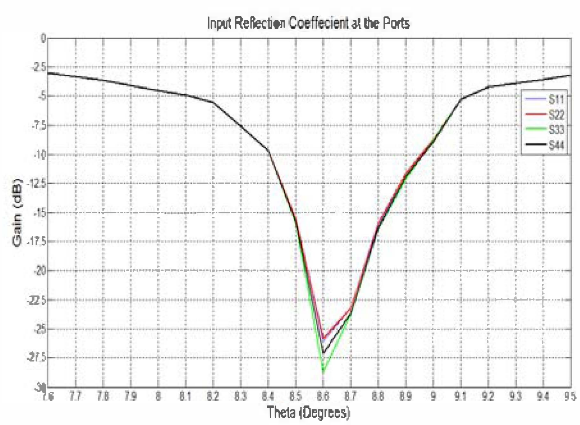

Fig. 6 Input Reflection Coefficient of all 04 ports

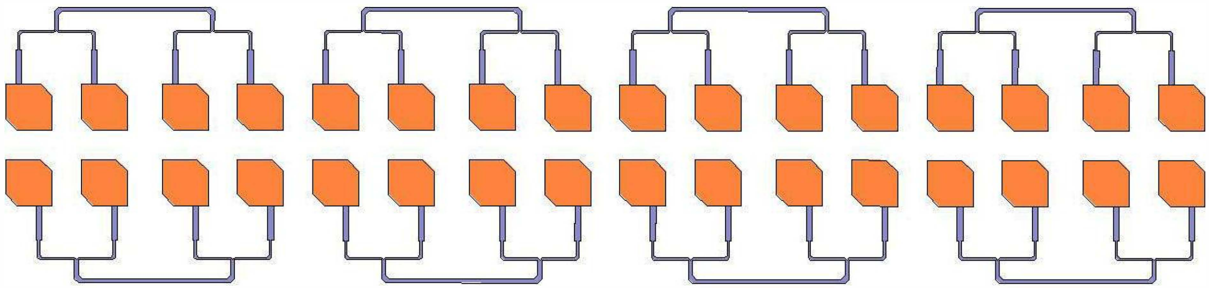

Fig. 5 Isometric View of 32 elements phased array antenna with an elements configuration of 2 x 16

Fig. 7 shows the S_{11} measurement result of one of the port of phased array antenna. Meaurement was carried out on a calibrated Vector Network Analyzer (VNA) and the results shows quite a comparison with the simulated results.

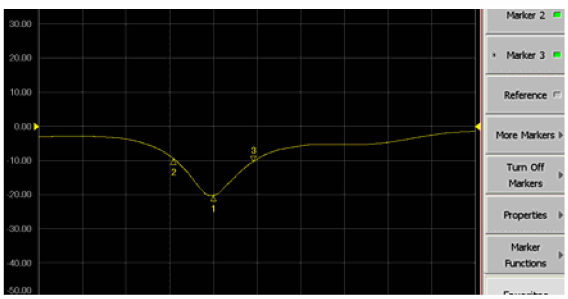

Fig. 7 Measurement of S_{11} of port 1 on VNA.

b) Radiation Pattern

Radiation pattern measurement was carried out in an Anechoic Chamber. Radiation pattern was measured in E & H plane. Fig. 8 shows the simulated & measured radiation pattern plot for φ=90 degree for all values of theta (θ). It shows the elevation plane beamwidth and provides a wide Half Power Beam Width (HPBW) of approximately 60 degrees with a gain of approximately 20 dB.

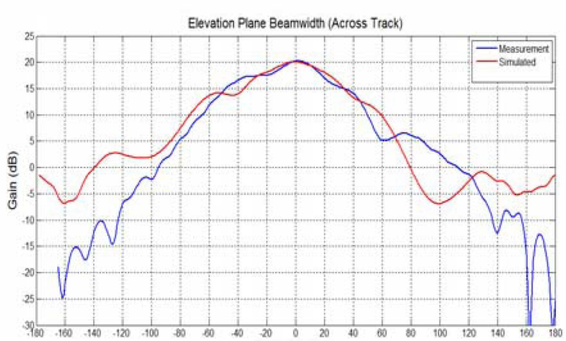

Fig. 8 Simulated & Measured radiation pattern plot for φ=90 degree

Similarly Fig. 9 shows the simulated and measured radiation pattern plot for φ= 0 degree for all values of theta. It shows the azimuth plane beamwidth and provides a narrow HPBW of approximately 6 degrees.

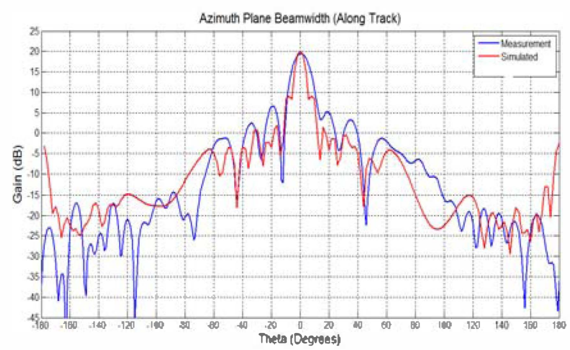

Fig. 9 Simulated & Measured radiation pattern plot for φ= 0 degree

c) Axial Ratio

Measurement of axial ratio in order to determine the circular polarization of antenna was done in an anechoic chamber. Two measurements were performed, one co-polar and other cross polar. After plotting both the data on a single sheet, it was observed that both data points coincides each other (difference with in 3 dB margin level) in the main part of the pattern.

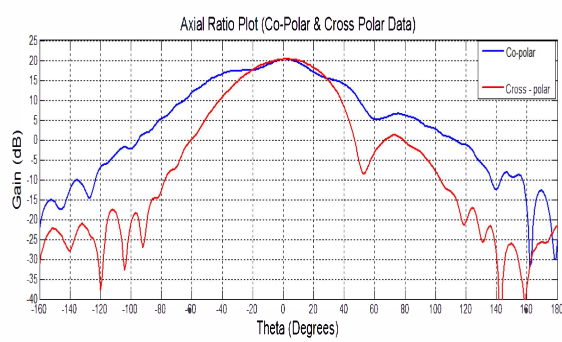

Fig. 10 Axial ratio plot for determination of circular polarization of antenna

Fig. 10 shows the axial ratio plot in which both co-polar and cross polar measurement plots are shown. As can be seen both the plots overlap each other in the center region of the plot and therefore confirms that the antenna designed and developed is circularly polarized.

d) 3D Radiation Pattern Plot

Fig. 11shows the simulated 3D Radiation Pattern plot. As can be seen it has wide beamwidth in the yz-plane (elevation plane) and narrow beamwidth in the xz-plane (azimuth plane).

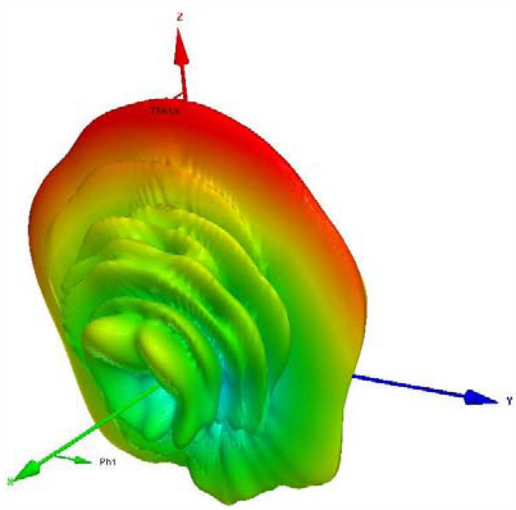

Fig. 11 3D Simulated Radiation Pattern plot

V. CONCLUSION

32 elements X-band phased array antenna is successfully designed, developed and tested and can be used for different applications for Air Borne and Space Borne SAR Payloads. It provides a gain of 20 dB with HPBW of 60 degrees in elevation plane and 5 degrees in azimuth plane. VSWR < 2 is achieved over the complete frequency band with circular polarization of antenna in the desired part of the beam.

VI. REFERENCES

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