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Performance Analysis and Development Of Printed Circuit Microstrip Patch Antenna with Proximity Coupled Feed at 4.3 GHz (C-band) with Linear Polarization for Altimeter Application

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Abstract: This paper aims at design, develop, optimize and realize a printed circuit Microstrip patch antenna at 4.3 GHz (C-band) with Linear polarization for Altimeter Application with proximity coupled feed method. Antenna is a device which acts as a transducer converting electrical signal to electromagnetic wave and vice-versa during transmission and reception respectively. Development, optimization and testing of high performance Microstrip antenna working in C-band are carried out for Altimeter applications. Various types of antennas are available to meet these requirements. Among these, the printed circuit Microstrip antennas have gained great prominence. With modern wireless method of contact the basic antenna requirements are Gain, Bandwidth, polarization, Size must be low, weight must be low, ease of fabrication. All the requirements mentioned above could be done with the help of printed circuit antennas. Patch antenna is resonant style radiator having narrow bandwidth. Because of its narrow bandwidth this antenna tends to be more efficient and also it tends to be smaller in size which allows the use of this element in antenna arrays and helps in good control of radiation performance. In this project, first we design patch antenna with some design equations and model it in HFSS software.. The simulated results obtained from software are compared with tested fabricated results.

Keywords: Antenna, Gain, Microstrip Patch Antenna, Return Loss , VSWR, Return loss.

1. Introduction

Webster's dictionary defines an antenna as a "normally metallic structure" designed to radiate or absorb radio waves as a rod or cord. An antenna is a device that provides radio wave propagation or receives radio waves. The transformation from a directed wave to a transmit line wave called "Free Space" provides a different term [1].. It is an information instrument that converts EM photons into circuit current and can convert energy into photons which are radiated in space. For Radar Altimeter (RA) applications, Microstrip Antenna (MSA) operating in a C-band is performed [2]. In the previous forty years, the information paces of optical correspondence frameworks have encountered a bewildering increment from 100 Mbit/s per fiber during the 1970s to 10 Tbit/s in current business frameworks [3]. As of now, more than 95% of advanced information traffic is continued optical fiber organizations, which structure a significant piece of the public and worldwide correspondence framework [4]. To meet these requirements there are numerous types of antennas available. The MSA printed circuit has gained considerable popularity among these. Gain, bandwidth, polarization, size must be medium, weight must be medium, ease of fabrication are the basic antenna specifications of modern wireless method of communication. Most of them, however, are not workable or impractical. Compact MSA has been developed for RA applications at operating frequencies from 3.98 to 4.47 GHz. But antenna production was not examined [5]. MSA with I slot was designed and simulated at 4.5GHz. The results shown are not very promising and can hardly be feasible [6]. Antenna is designed to work within 4.3 GHz. Designed antenna is unfeasible and have not been analyzed for practical applications [7]. An array MSA with 2x2 configurations has been simulated and measured for RA which makes the design complex because of array

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of antennas [8]. The practical results are not embedded and will not be useful for communication applications [9]. Double L-probe fed for RA applications is developed in [10] at 4.3 GHz and a gain of about 5.95 dB is observed.

Radar Altimeter (RA) is a device that is used to measure a low altitude or elevation from an aircraft or a satellite to land or sea level. With the theory of radar, a vertical distance in an aircraft from the terrain just below it can be determined with an altimeter. Radio altimeter is a member of the radar [5-10]. With the support of printed circuit antennas any of the above requirements could be done. The fundamental theory of radar is that radio waves are transmitted to land or sea level and receive an echo signal for a long time.

Fig 1. depicts the schematic of MSA. It consists of ground plane at the bottom, a dielectric substrate of height h and a patch built on the substrate. Dimensions of ground plane are greater than substrate and patch [11].

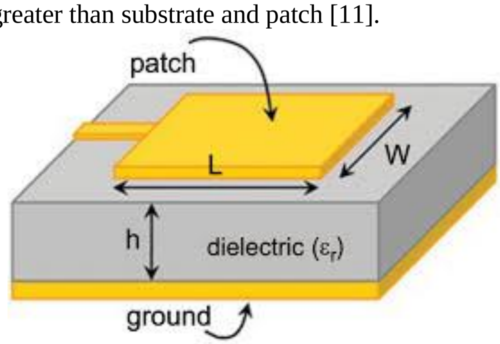

Figure 1. Microstrip Patch design

For the design of antenna, finding the parameters are essential. Important parameters are described below.

A. Radiation Pattern and HPBW

An antenna radiation is defined as "a graphic representation of the antenna's radiation properties as function of the space coordinates. The reflection coefficient is measured in the field region for certain instances and is perceived as a feature of the directional coordinates. It provides information on the antenna beam diameter, antenna side lobes. The most functional antenna designs include a main lobe and many secondary lobes which are called side lobes. The width of half the Power Beam "HPBW" is the same division in which the scale of the geometry of the radiation reduces by half (or-3 dB) from the peak of the main beam [12, 13].

B. Voltage Standing Wave Ratio (VSWR)

When reflection occurs in an incorrectly terminated line, voltage and power vary in magnitude along its length. When the transmission line is not terminated correctly, at the termination, the electromagnetic wave traveling from the generator at end of the line reflected in whole or in part. The standing wave ratio may be defined as the ratio of maximum to minimum current or voltage on a line having Voltage Standing Waves and this Ratio is abbreviated (VSWR) [14, 15].

Thus,

$$VSWR = \left| \frac{V_{\max}}{V_{\min}} \right| \tag{1}$$

Relation between VSWR (S) and Reflection coefficient (Γ):

$$VSWR = \left| \frac{V_{\max}}{V_{\min}} \right| = \frac{1+\rho}{1-\rho} \tag{2}$$

C. Return Loss

This is the best and most convenient method for estimating the sources of signal input and output. If the other end is not balanced the power returned is Return Loss [16]. In dB it is given as

$$RL = -20 \log |\Gamma| \text{ dB} \tag{3}$$

$$\Gamma = \frac{V_o^+}{V_o^-} = \frac{Z_L - Z_o}{Z_L - Z_o} \tag{4}$$

Where,

Γ = Reflection coefficient.
Vo^+=Incident voltage.
Vo^- = Reflected voltage.
Z_L and Z_o are the load and characteristic impedance.

D. Gain

Gain of antenna is the capacity of antenna to focus emanated power in proper direction [17].

2. METHODOLOGY

A patch antenna (PA) consists of a conductive layer of one side of the dielectric substratum and the opposite leg, covered by certain planar arrangement ground line [18]. A variety of benefits including lightweight, low volume, low cost, planar configuration, integrated circuit performance, etc. Less profile antennas are needed for high-performance space craft, missile applications are restricted in size, weight, expense, strength, installation ease & aerodynamic profile. A feed line is used for arousing over or indirect interaction with the radiation. There are several different feeding methods, and four most common methods are the line Microstrip feed, Coaxial probing, Aperture coupling, Coupling of proximity [19, 20].

A. Coaxial Feeding

Coaxial feeding is a method of feeding during which the coaxial inner conductor is bound to the antenna's radiation field where as the external conductor is linked to basement as described in Fig. 2 [22, 23].

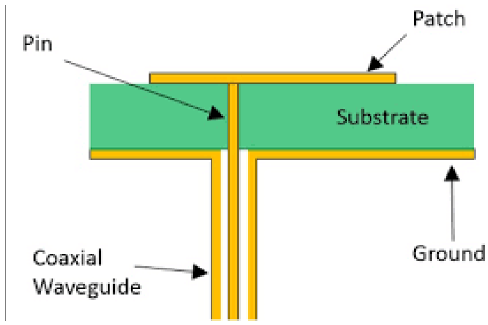

Figure 2. Coaxial Probe

The inner coaxial conductor is attached to a patch of radiation. The outer coaxial runner fits in to the ground plane. Has low spurious radiation. Its bandwidth is narrow. Particularly for thick substrates this is a difficult model (h>0.02>0).

B. Proximity Coupling(PC)

Low PC is used for high bandwidth and radiation, as defined in Fig. 3. However it is difficult to manufacture [21]. It has the highest bandwidth (as much as 13 per cent). It uses a two layer substrate.

1. Microstrip line→Lower layer.
2. Patch Antenna→ upper layer.

In this article, the results of the simulation are carried using HFSS software, and MSA is done using proximity-coupled feed method and both results are compared.

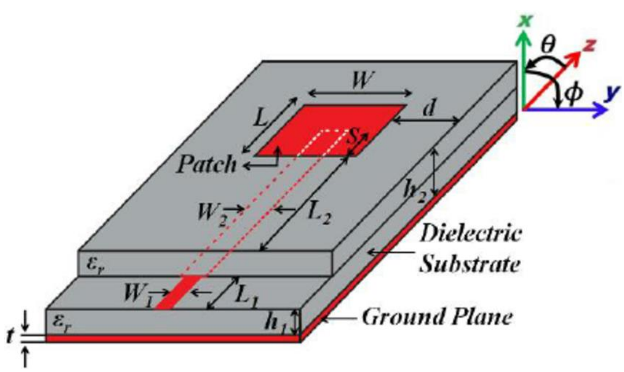

Figure 3. Proximity Coupling

C. Manual design calculations of MSPA

To design any MSPA, prior selection of few parameters is required. The design parameters of the proposed antenna are the operating frequency fr=4.3GHz, and RT / Duroid 5880 is taken as a dielectric substrate with di-electric constant of 2.20±0.02 and a normal factor for Dissipation is 0.0009[22, 23]. MSPA design parameters procedure is as follows

1) Width (W):

With the specifications including information about the ($\in_r$), (f_r), and (h). The procedure is as follows:
Equation 5 gives the width which provides efficient radiation.

$$W = \frac{c}{2f_r}\left(\frac{\varepsilon_r + 1}{2}\right)^{\frac{-1}{2}} \quad (5)$$

For C=3*10^8 m/sec, f=4.3GHz, ε_r =2.2

Width calculated using above values is **W= 27.5 mm.**

2) Effective dielectric constant (ε_{eff}):

Find E_{eff} for MSA using equation 6

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{12h}{W}\right)^{\frac{-1}{2}} \quad (6)$$

Where, h = Height of the substrate.
W= 27.5 mm; ε_r = 2.2 ; h = 0.8 mm

Effective dielectric constant, calculated using above values is ε_r **= 2.116**

3) Extension length (ΔL):

Once W is found, determine the extension length ΔL (due to fringing effect) using equation 7.

$$\frac{\Delta l}{h} = 0.412\frac{(\varepsilon_{eff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{eff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (7)$$

Where, ε_{eff} = 2.116, h = 0.8 mm, W = 27.5 mm

Length extension calculated using above values **(ΔL)= 0.422** mm

4) Actual length (L):

The actual length of the patch can now be determined by equation 8

$$L = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} - 2\Delta l \quad (8)$$

Where, f_r = 4.3 GHz, C = 3 *10^8 m/sec, ΔL= 0.422 mm, ε_{eff} = 2.116.

Actual length calculated using above values is L= 23.131 mm

5) Effective length (Leff):

The L_{eff} is found by using equation 9.

$$L_{eff} = L + \Delta L \quad (9)$$

By inserting values of L and Δl we get

L_{eff} =23.975mm

6) Ground Plane (GP) parameters:

Parameters are its length Ls and width Wg, which are two times of patch dimensions.

Ls=46 mm and Wg =56mm.

7) Microstrip line width (W_o):

The width of the microstrip line patch can be determined by equations 10, 11 and are given by,

$$Z_o = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left[\frac{W_0}{h} + 1.393 + 0.667\ln\left\{\frac{W_0}{h} + 1.414\right\}\right]}$$

$$\text{for } \frac{W_0}{h} > 1 \qquad (10)$$

$$Z_o = \frac{60}{\sqrt{\varepsilon_{eff}}}\ln\left[\frac{8h}{W_o} + \frac{W_o}{4h}\right] \qquad \text{for } \frac{W_o}{h} < 1 \qquad (11)$$

By trial and error method for Zc = 50 Ω. We get W_o as 2.06 mm. (~2.1) and $\frac{W_o}{h}$ = 2.625 thinner microstrip substrate results in less spurious radiation from feed lines, but higher loss. A compromise of 0.001λ to 0.002λ can be chosen for iterations. When the value is greater than 1, equation 10 can be used to get the value of Wo and is given by Wo=2.95mm. The wavelength equation is given by

$$\lambda = cf \qquad (12)$$

Where, C= 3*108 m/sec; f = 4.3 GHz = 4.3*109 Hz.

Wavelength λ=69.76m

8) Calculation of Microstrip length yo: (Distance from patch edge to position of feed):

In general, the conductance is given by,

Radiating Conductance, Gr = 1.7 X10 $^{-3}$

$$Z_c = \frac{1}{2(G_T)}[\cos^2\left(\frac{\pi}{2}y_0\right)] \qquad (13)$$

Where, Zc = 50Ω, Gr = 1.7 * 10^{-3}

From equation (13) the microstrip length is calculated and is given by microstrip length, **Yo = 8.77mm.** MSA designed values are calculated and are shown in table 2.

TABLE I. FINAL MSA DESIGNED VALUE

Parameter	***Value***
Length, L	23.13 mm
Width, W	27.5 mm
Microstrip Width, W_o	2.95 mm
Microstrip Length, Y_o	8.77 mm
GP length, L_g	46 mm
GP width, W_g	56 mm
Effective length, L_{eff}	23.975 mm
Effective dielectric constant, ε_{eff}	2.116
Wavelength, λ	69.76
Length extension, ΔL	0.422 mm
Radiating conductance, G_r	1.7 * 10^{-3}

3. Simulation of MSA using Proximity Coupled Feed Method using HFSS

The Proximity feeding technique is chosen for successful impedance matching. In this case, a square micro stripe patch is used using 50-ohm probe feed. Altimeter's proximity feeding is best suited for fast mounting and it provides low cost and manufacturing flexibility.

HFSS is an immersive simulator, with tetrahedron as the base mesh part. This helps us to resolve some arbitrary 3D geometry, particularly those that use such techniques in a fraction of the time it would take for complicated curves and forms. Following steps are to be performed in the design of MSA MSPA modeling

A. MSPA modeling *using HFSS*

MSPA dimensions carried with HFSS involves following steps:

- The HFSS co-ordinates are designed or calculated using patch antenna dimensions.
- From the obtained coordinates at 3D proximity coupled microstrip patch is drawn as illustrated in Fig. 8.
- Mark, ground plane and microstrip feed are assigned as ideal material for electrical conductors, and RT/5880 is assigned to substrates.
- An air box "radiation box" is created around the patch and the boundary of the radiation is allocated to either side of the box.
- Wave port is assigned to the patch antenna for excitation purpose.

B. *Optimization using HFSS*

In HFSS Software, there are six optimization techniques

- Quasi Newton (Gradient) is being used to find the maximums and minimums of local features. These are based upon Newton 's principle, where a function point is 0.
- Pattern Search is a mathematical technique of optimisation that does not inherently require a gradient and is suitable for functions that are not continuous or differentiable.
- Genetic Algorithm (Random search) are used to produce high quality search optimization solutions using bio - inspired providers such as iteration, crossover and selection.

- Sequential Quadratic Programming "SQP" is iterative method of minimal, non-linear optimization. SQP approaches are used with a double continuous discrepancy between objective function and constraints in the context of mathematical problems.
- Sequential Mixed Integer discrete computing describes scalability problem with continuous and integer factors in the optimization area.
- Matlab is a computing environment designed for recursive design and operational processes is paired with a programming language that explicitly communicates mathematics in matrix and arrays.

If the buildup co-ordinates are defined in HFSS software, a 3D perspective on repairing and re-enacting to get different attributes. If the characteristic doesn't fit once with the anticipated, the patch and feed measurements differ in small steps and re-simulate until characteristics are necessary or obtained. Thus parameters such as feed duration under the patch, feed width, and patch length are optimized` directly without creating a handmade patch and then checking it with practical measuring techniques.

Therefore, the patch length is adjusted during optimization to suit the antenna requirements. During optimization to meet the antenna specifications, the patch length (mm) is optimized. Fig. 4 depicts 3D view of proximity coupled MSA and its view in HFSS is depicted in Fig 5.

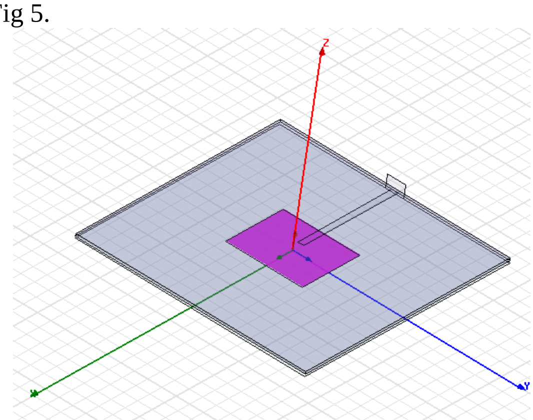

Figure 4. 3D view of Proximity Coupled

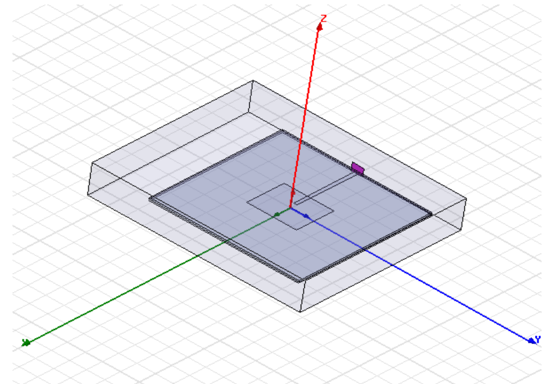

Figure 5. View of HFSS Model

C. Simulation

After the designing of the microstrip patch antenna the simulation is performed. Following steps are to be performed for the results in HFSS.

- After the design of MSA the simulation is performed.
- To view the errors and warnings, firstly validation is performed.
- Next, the set up is assigned to the antenna, which includes operating frequency 4.3 GHz, sweep in the range of 3.5 to 4.5 GHz. With step size of 0.1 GHz.
- Analyze all is selected to perform the simulation.
- Finally, the required antenna parameter graphs are observed in HFSS.

D. RL Graph (dB)

Fig 6 depicts the plot of RL(dB) and f(GHz)

E. VSWR Graph

From the plot as given in Fig. 7 the VSWR is minimum at resonant frequency 4.3 GHz. As, VSWR is approximately closer to 1, no signal is reflected back towards the feed i.e entire signal will be transmitted to the patch.

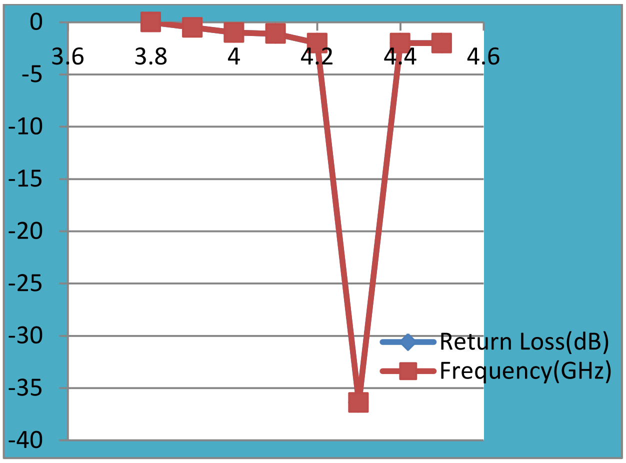

Figure 6. Return Loss (RL) (dB) plot

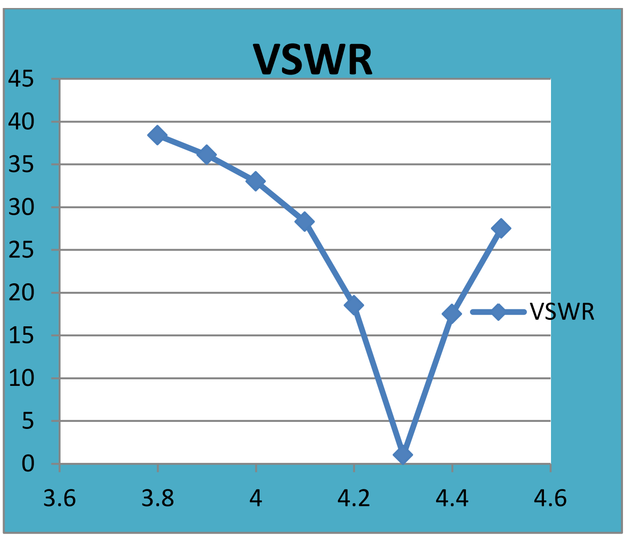

Figure 7. VSWR Graph

F. 2D Radiation Pattern Graph (Gain vs Theta, far field region)

The below graph shown in Fig. 8 is a 2D rectangular radiation plot observed in the far field region.

Figure 8. 2D Radiation Pattern Graph

G. Polar Radiation Pattern Graph

The below graph Fig. 9 is a polar radiation pattern plot.

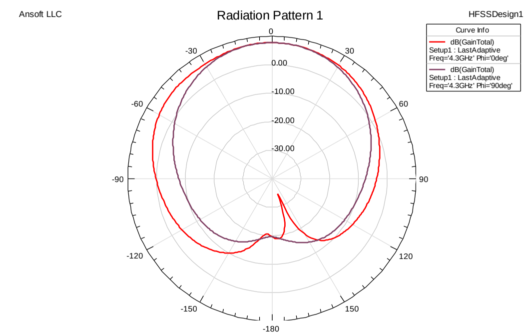

Figure 9. Polar Radiation Pattern Graph

H. 3D Polar Radiation Pattern Graph

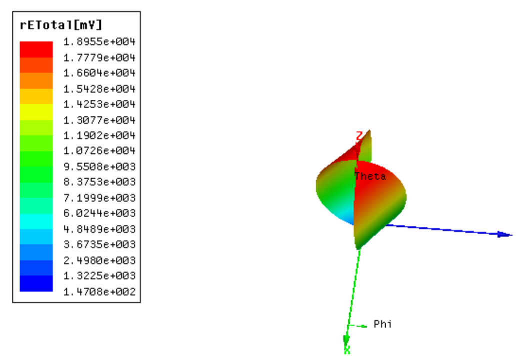

Figure 10. 3D Polar Radiation Pattern Plot

Fig. 10 is 3D polar radiation plot depicting the radiation intensity with respect to spherical coordinates is observed.

I. 2D Radiation Pattern Graph: (Gain vs Frequency)

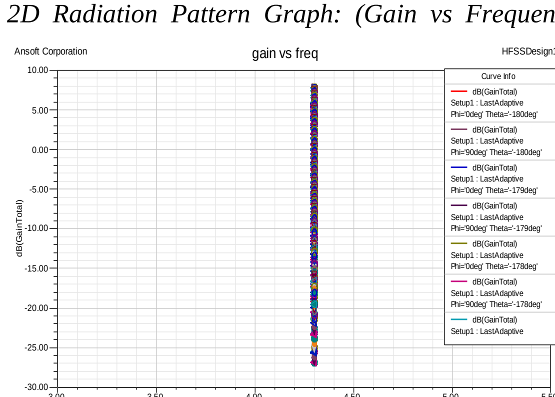

Figure 11. 2D radiation Pattern Plot (Gain vs Frequency)

The 2D Radiation pattern plot is shown in Fig 11. It will resonate at 4.3GHz.

4. Fabrication and Testing of Antenna

The design parameters specify all of the patch antenna measurements. Coordinates are obtained according to dimensions of antennas. The coordinates are the optimised to achieve the requirements of the given antenna using HFSS as described earlier. The results obtained by 95 per cent using HFSS correspond to the realistic results, so the coordinates can be fed directly to AutoCAD to generate the antenna layout. Fig.12 demonstrates the configuration of the patch Interface and MS feed section. Fig.13 displays the flowchart for measures involved in the manufacture of patch antennas.

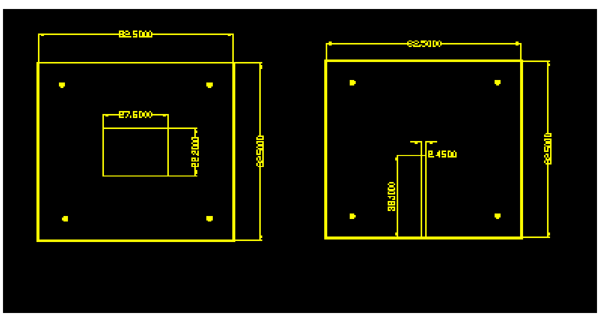

Figure 12. Patch Layout and Microstrip Feed line Layout

A. Selection of Substrate materials

Substratum content determination plays a big job in organizing the Patch radio wires. It is taken from the dielectric substratum RT / Duroid 5880. It has a range of 2.20±0.02 and a standard dissipation factor of 0.0009. RT / Duroid 5880 is responsible for the high efficiency and light antenna weight.

B. Metallization

At the base between the range of ten and thirty five mm, thickness must be of the metallic layers, provides great patching influence, great attachment to the base, must've been heat safe during the fastening interaction. The proposed design uses PEC's "perfect electrical conductor" for metallization.

C. Fabrication

Fabrication is the method of realisation of the planned antenna. The dimensions of a antenna being designed are given in the form of coordinates. Using the Aristo programme a master drawing is created with the coordinates given. The substrate material metalized by the use of photolithographic process on both sides as mentioned below is manufactured of the antenna.

D. UV lithiography process

The assembling of the microstrip circuits/reception apparatuses depends on the photolithographic strategy in which a photosensitive/photograph resistive layer is uncovered through a veil to bright radiation. Steps to be followed for the realization of MSA on the composite material are: 1. cleaning, 2. Deposition of Photo resistive layer 3. Resist Exposure, 4. Resist Development 5. Inspection 6. Etching 7. Stripping and 8. Bonding. Assembly of antenna

The MSA is mounted in the patch element with a wide connector. To mount the connector L- Shape metal strip. (sometimes silver paint is used to make perfect contact). The proximity produced coupled microstrip antenna, as shown in the Fig. 14.

5. Fabrication Results

VSWR graphs are plotted for the proposed manufactured antenna model, the radiation pattern, return loss. Vector Network Analyzer "VNA" has been used to test the MSA with VSWR. The pattern and gain of antenna radiation is measured in the Rectangular Annechoic Chamber. The pattern of radiation shown in figures and the smooth pattern of radiation in the blue colour is E and the pattern of the Airplane in the red colour is in H-plan.

Figure 13. Flowchart for steps involved in Patch antenna fabrication

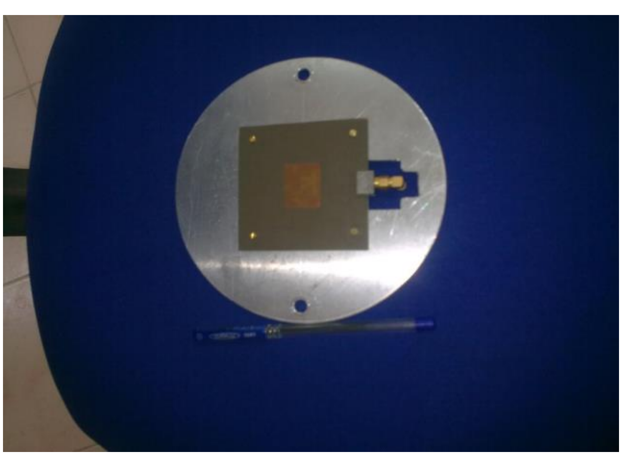

Figure 14. Fabricated Proximity Coupled MPA.

1) Radiation Pattern at 4.1 GHz.:

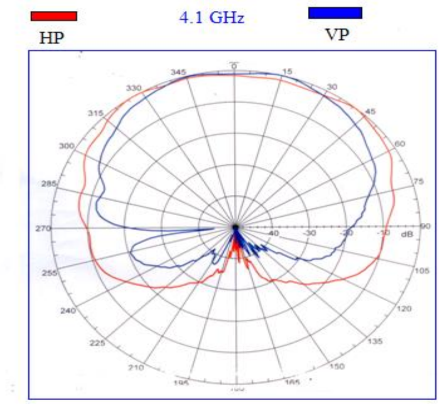

Figure 15. Radiation Pattern at 4.1 GHz.

2) Radiation Pattern at 4.2 GHz.:

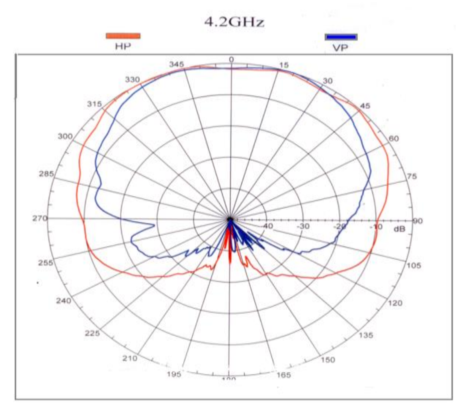

Figure 16. Radiation Pattern at 4.2 GHz

3) Radiation Pattern at 4.3 GHz:

For various C-band RA applications where low spurious radiation, compatibility with modular designs and compactness are of paramount importance, it can be used at 4.3 GHz for 100 MHz bandwidth.

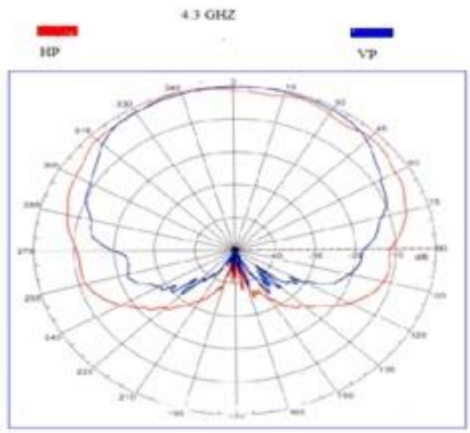

Figure 17. Radiation Pattern at 4.3 GHz

4) Radiation Pattern at 4.4GHz:

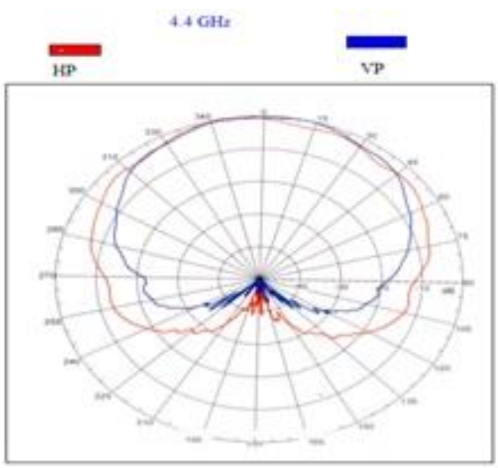

Figure 18. Radiation Pattern at 4.4 GHz.

5) Radiation Pattern at 4.5GHz. :

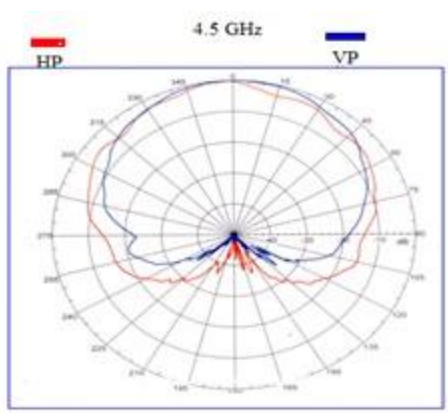

Figure 19. Radiation Pattern at 4.5 GHz

6) Radiation Pattern at 4.6 GHz:

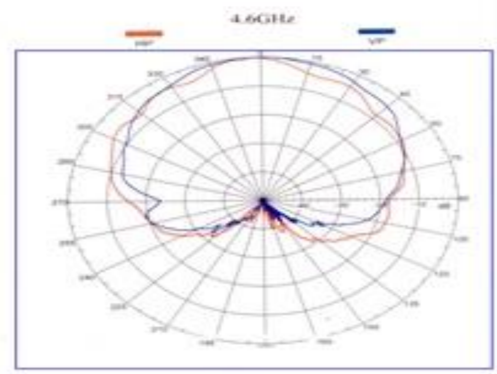

Figure 19. Radiation Pattern at 4.5 GHz.

A. Radiation Pattern Plot

The radiation pattern of MSA at 4.1, 4.2, 4.3, 4.4, 4.5 and 4.6 GHz are depicted in Fig. 14, Fig. 15, Fig. 16, Fig. 17, Fig. 18, and Fig. 19 respectively. MSA's radiation pattern is broad and reaches narrow frequency bandwidth at 4.3GHz with lower directionality.

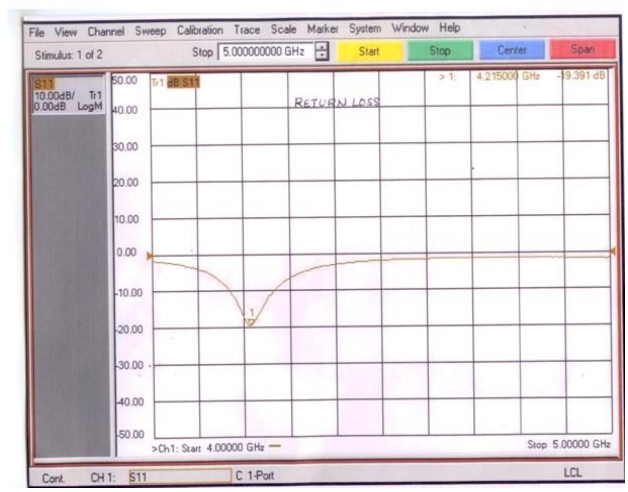

Figure 21. Return loss plot

B. Return Loss

The return loss is obtained from the frequency of graph dB Vs that is given in the figure below. The loss of Return at 4.215 GHz is -19.391 dB as shown in Fig. 21. Twenty-one. The return is much less strong matching impedance is obtained between feed and patch.

C. VSWR plot

From the plot in VSWR, as seen in Fig. 22 Minimum resonant frequency below the VSWR is 4.3 GHz. Since VSWR is roughly closer to 1, no signal is reflected back to the feed, i.e. the entire signal is transmitted to the patch.

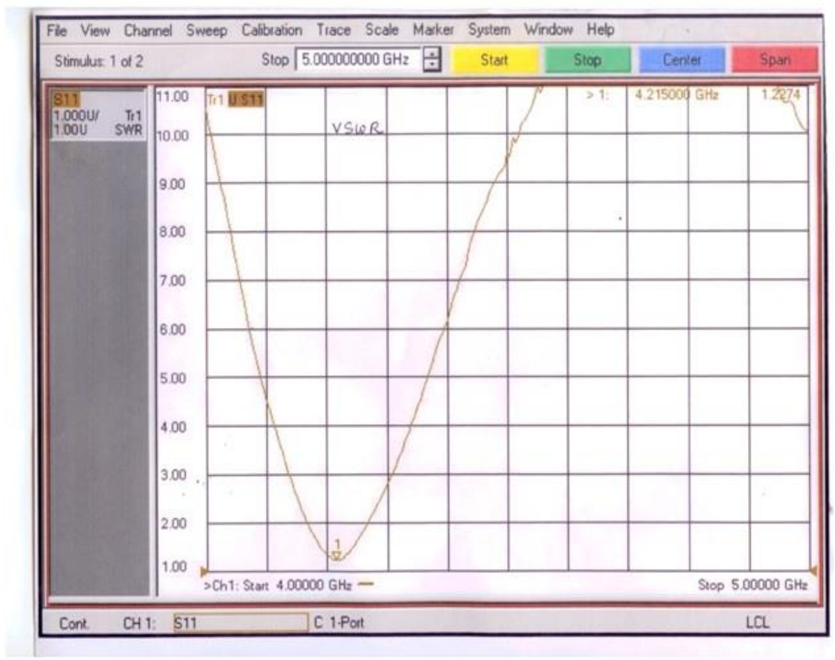

Figure 22. VSWR plot

A. Gain Calculation: Measurements are being carried out in the closed Anechoic chamber

The gain calculation formula is given below,

$$G = \left[\frac{P_{\max}\left(AUT\right)}{P_{\max}\left(REF\right)} \right] XGain(REF) \qquad (14)$$

Below table shows the calculation of gain using equation 14.

TABLE II. GAIN CALCULATED VALUES

S.No	Frequency (GHz)	AUT gain (dB)
1	4.1	4.89
2	4.2	4.94
3	4.3	5
4	4.4	5.56
5	4.5	5.6
6	4.6	6.02

B. Comparison between measured and fabricated

Table 3 shows the comparison between simulated and the measured values with parameters return loss, VSWR and gain. Results shows for different frequencies from 4.1GHz to 4.6Hz the values of VSWR, return loss and gain.

TABLE III. COMPARISON BETWEEN SIMULATED AND MEASURED VALUES

Simulated				Measured			
Frequency (GHz)	**Return loss (dB)**	**VSWR**	**Gain(dB)**	**Frequency (GHz)**	**Return loss (dB)**	**VSWR**	**Gain(dB)**
4.1	-1	19.4	1.3	4.1	- 4.2	4.5	4.89
4.2	-2	11.2	8.2	4.2	-19.2	1.29	4.94
4.3	-32	1.1	9.01	4.3	-10.3	2.9	5
4.4	-2	11.2	7.1	4.4	-4.3	6.2	5.56
4.5	-2	19.3	3.6	4.5	-4.2	9.2	5.6
4.6	-2	25.1	2.2	4.6	-4.1	11.3	6.02

6. Conclusion

MSA design is successfully simulated and produced for Altimeter applications at 4.3GHz, with linear polarization. The basic antenna specifications are gain, bandwidth, polarization, size must be medium, weight must be medium, manufacturing ease with modern wireless method of communication. With the support of printed circuit antennas any of the above specifications could be done. MSA is both software-developed and manufactured using itching technology. For various C-band communication applications where low spurious radiation, compatibility with modular designs and compactness are of major importance, microstrip patch antennas built at 4.3 GHz for bandwidth of 100 MHz can be utilized. It can be observed that the above-mentioned Proximity Coupled feed technique antennas have 90 MHz bandwidth (almost proved to be 90 MHz), provide 5 dB gain and 4,215 GHz resonant frequency, return loss of -19.3 dB. Further antenna optimization can solve the production and assembly errors.

In the future, the research will be expanded to include the multiband antenna enabling high-frequency networks and systems such as the development of next-generation devices for 4 G, WLAN, Wi-Max, Low Frequency Communications Systems and Wireless Network Networks.

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