A Practical Approach for Design of a Wideband Microstrip Patch Antenna Conformed to Cylindrical Surface

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***Abstract*— Conformity of the antenna to the mounting surface is the most essential requirement of modern communication system, whether it be antenna mounted on vehicles or airborne applications primarily due to the aero dynamical advantages of such antennas. In this paper we present the analysis of a inset microstrip line fed patch on cylindrical substrate with electrically small radius of 0.1 times free space wavelength. We try to analyse the effect that the bending has on the resonant frequency, inset length of the feed line of the patch antenna. We present the design dimensions, S11 & Radiation pattern results for the designed conformal patch antenna.**

***Keywords*- Cylindrical Microstrip Patch Antenna (CMPA), Inset Microstrip Line Feed, Impedance Bandwidth, VSWR, Angular Width.**

I. INTRODUCTION

In high-performance aircraft, spacecraft, satellite, and missile applications, where size, weight, cost, performance, ease of installation, and aerodynamic profile are constraints, the antennas should be low-profile and conformable to the installation surface. Present day applications cannot afford the antenna to be protruding from the structure; rather it should be integrated with the structure. Presently there are many other government and commercial applications, such as mobile, radio and wireless communications, that have similar requirements. To meet these specifications, microstrip antennas can be used **[1]**. These antennas are low profile, conformable to planar and non-planar surfaces, simple and inexpensive to manufacture using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, and when the particular patch shape and mode are selected, they are very versatile in terms of resonant frequency, polarization, pattern, and impedance **[2]**.

Microstrip patch antennas have always attracted the attention of researchers in the antenna field. Besides the merits these antennas seem to suffer from drawbacks like limited bandwidth, low gain etc. Several techniques have been devised to overcome these limitations.

II. THEORY

Electromagnetic field analysis of Patch antennas mounted on curved bodies is very essential to design patch antennas conformal to various curved geometries. There are many analytical techniques to analyse the patch antennas, the full wave analysis being the most accurate. The transmission-line model is the easiest of all, it gives good physical insight, but is less accurate and it is more difficult to model coupling. The cavity model is the most rugged and simple model for analysis. As we are dealing with cylindrical conformal microstrip patch antenna(CMPA) the assumption that the conducting patch and the conducting cylinder (ground surface) act as electric walls, and that the open cavity ends act as magnetic walls can be applied to the analysis for obtaining the fields and associated modal resonant frequencies **[3]**.

Another model has been presented for analysis of antennas printed on dielectric coated metallic cylinders, which assumes electric surface current distribution on the patch as the source of radiation. The printed radiator is replaced by an assumed surface current distribution, and the EM fields are solved taking into account the presence of the dielectric layer and the metallic cylinder and applying appropriate boundary conditions**. [4]** The effect of curvature on change in resonant frequency for the cylindrical-rectangular case in comparison to a planar rectangular microstrip antenna case is made in terms of ratio of radius of curvature to the substrate thickness. It is observed that as the radius of curvature decreases there is a change in resonant frequency as compared to planar case **[5], [6]**.

A full-wave analysis and a moment-method calculation can be employed to derive the radiation pattern of a single or multi patch configuration of probe-fed rectangular microstrip antennas mounted on a cylindrical body, with electrically small radius, with an arbitrary number of substrate and superstrate layers **[7], [8]**.

A very explicit description with comparative study of the work done by so far various researchers for developing the techniques and mathematical models for analysis of cylindrical patch antennas is given in **[9]**.

III. DESIGN, NUMERICAL RESULTS AND DISCUSSIONS

We started our design of the patch antenna with the well-known equations **[3]**. First requirement was the choice of frequency of operation. It is known that the S band frequencies are suitable for conformal patch antennas especially for air borne applications. So we chose to design an antenna for frequency 2.4 GHz. Initially applying the mathematical equations, we found out the dimensions of patch as: W=38.3 mm, L=29.718(Fringing effect taken into consideration). The dielectric constant ε_r has been taken as 4.3 and the height of the substrate, h=1.6 mm. The thickness of metal (Copper) has been assumed as 0.035 mm which is the standard value. Feeding has been implemented as inset microstrip line feed which will not disturb the conformity of the antenna due to the fact that it is on the same plane as the patch. The gap between feed line and patch has been taken as standard 0.5 mm on each side irrespective of the configuration. The inset length calculated for planar case was 11.73 mm for good matching.

Now we transfer the designed patch to the cylindrical geometry which is our desired configuration. FIT based CST Microwave Studio simulation software is used for characterization and numerical modeling of the designed antenna.The design is shown in Fig 1. We have chosen the radius as $0.1\times \lambda_0$ where λ_0 is the free space wavelength. This radius being electrically small will best demonstrate the effect that curvature has on the various parameters of the CMPA. The length of the cylinder is taken as $1.5\times \lambda_0$ which is a good approximation to practical applications.

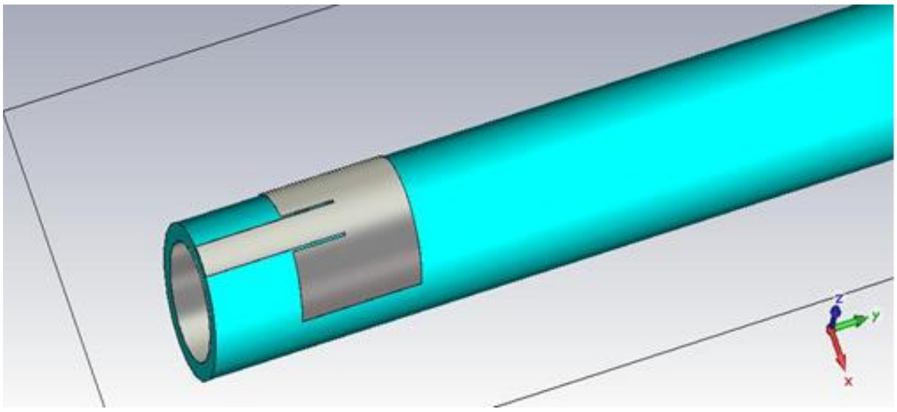

Fig 1: Geometry of the inset fed CMPA on cylindrical substrate.

When the calculated inset length of planar case was applied to the patch bent on cylinder of radius $0.1\times \lambda_0$, it was seen that the matching was not good. This is due to the variation of the edge impedance of the patch due to curvature. So, the inset length for the Cylindrical CMPA was varied until the optimum location found out to be 11.12 mm from the edge. We see that the return loss is very good, but we see that the resonant frequency has decreased to 2.2815 GHz. The S11 result is shown in Fig 2. Hence we see that the curvature has an effect of reducing the resonant frequency of the patch when the patch is bent on cylindrical substrate. The impedance bandwidth has been found out to be approximately 50 MHz. The VSWR is found to be below 2 in this bandwidth and the impedance is purely real and equal to 50 ohms which ensures that there is no reflection of power and the efficiency is very good.

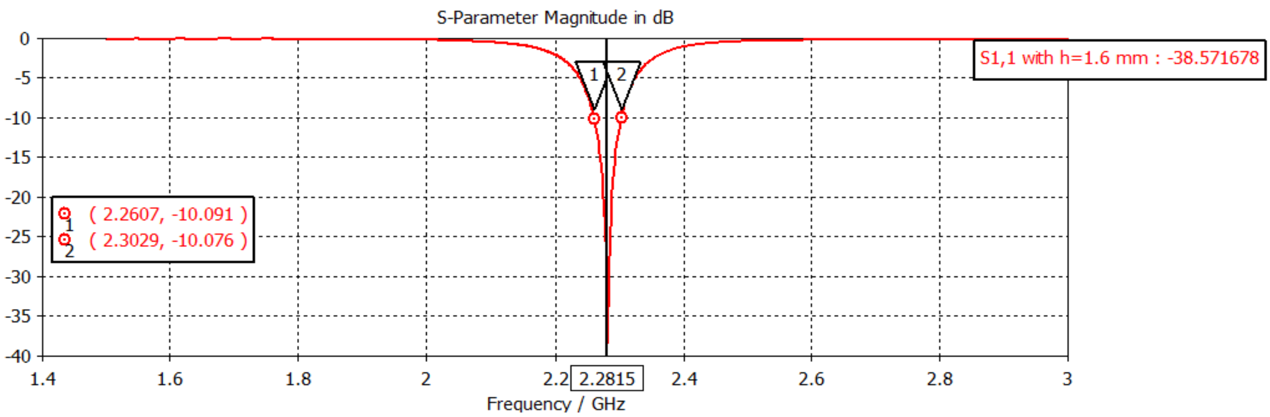

Fig 2: S11 result with h=1.6mm

Many techniques have been suggested in the literature to improve the bandwidth of the Microstrip Patch Antenna. A few of the methods which have been investigated include the use of electrically thick elements **[10]**, stacked multi patch configuration, employing multilayer elements **[11]**, the use of multiple-resonator elements (parasitic elements) **[12]** & the use of L shaped probe to feed the patch**[13]** to name a few.

In this work, we try the method of increasing the substrate height to improve the bandwidth. The height of the substrate is increased to 3.2 mm. This thickness is very small compared to the wavelength so large surface waves will not be generated and hence will not have any adverse effect on the antenna performance.

This can be achieved practically by employing two substrates of 1.6 mm back to back, on one side the patch can be etched and the other side may be used as ground plane.

The antenna assembly can be recessed in the body of the aircraft/ missile if we are to avoid the antenna from protruding out, which may cause unnecessary air drag or hinder the aerodynamic profile of the body. We see from the S11 results of simulation as shown in Fig 3 below that the bandwidth is improved almost two folds to 86.6 MHz

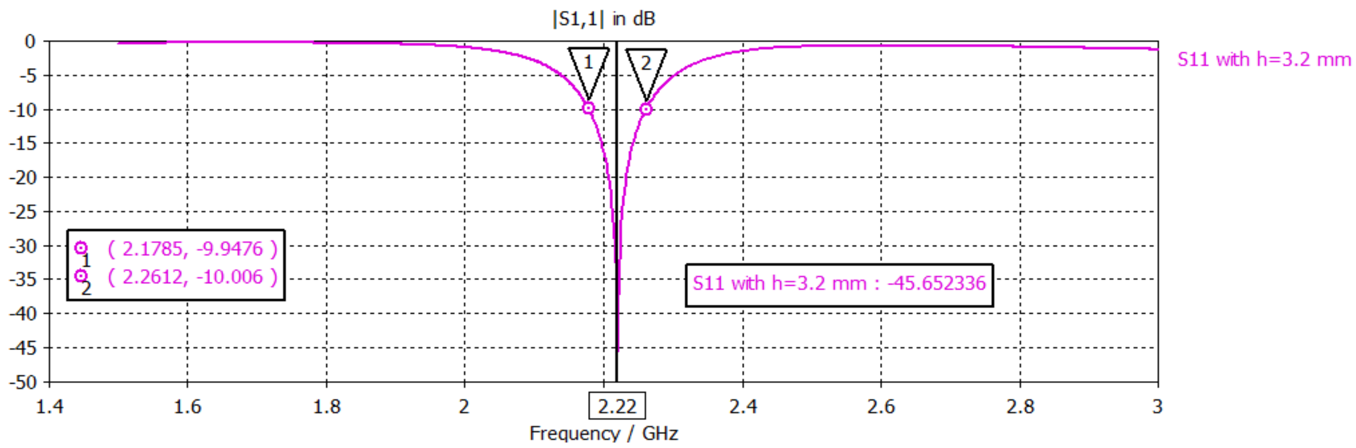

Fig3: S11 result with h=3.2mm

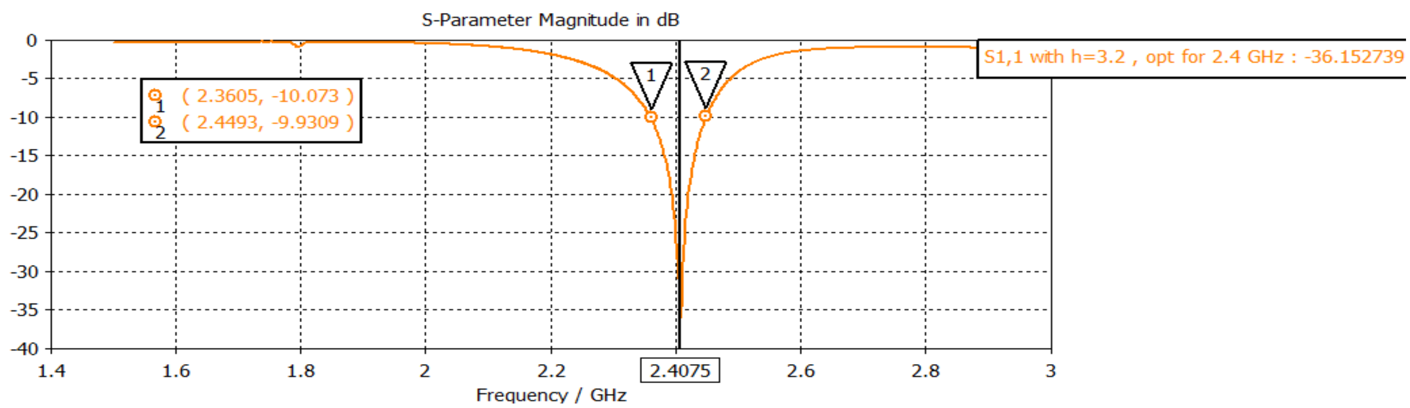

Fig4: S11 result with h=3.2mm, dimensions for frequency=2.4 GHz.

But the above patch resonates at an even lower frequency of 2.22 GHz. Our aim is to design a patch for 2.4 GHz so we need to tune the dimensions of the patch so that it resonates at 2.4 GHz. As the frequency of operation is inversely proportional to the dimensions of the patch, we can reduce the size of the patch to achieve our desired frequency operation.

The dimensions are shown in Table 1. The optimum inset length was found to be 11.25 mm for good impedance match. The S11 result for this configuration is shown in Fig 4.

Now we try to tune the patch with substrate height 1.6 mm to our frequency of interest i.e. 2.4 GHz. In this case also we see that the size of the patch is reduced as compared to planar case.

The S11 result for this configuration is shown in Fig 5. It is seen that the decrease in patch area is more in case of substrate height 3.2 as compared to 1.6 mm.

Table1: Consolidated Design Data for all configurations considered in the work.

Parameter	CMPA with substrate height 1.6 mm	CMPA with substrate height 3.2 mm	Miniaturised CMPA with substrate height 3.2 mm for resonant frequency 2.4 GHz	Miniaturised CMPA with substrate height 1.6 mm for resonant frequency 2.4 GHz
Freq. of operation [GHz]	2.2815	2.22	2.4	2.4
Dimension of Patch (l*w) [mm]	(29.718×38.3)	(30.56×38.3)	(28.1×33.2)	(28.5×35)
Inset length [mm]	11.12	12.1	11.25	11.12
Gap between inset feed and patch [mm]	0.5	0.5	0.5	0.5
Dimension of substrate/ground [mm]	187.5 (1.5 × λ_0)	187.5 (1.5 × λ_0)	187.5 (1.5 × λ_0)	187.5 (1.5 × λ_0)
Radius of curvature	0.1× λ_0	0.1× λ_0	0.1× λ_0	0.1× λ_0
Width of the feed line [mm]	3.137	6.274	6.274	3.137

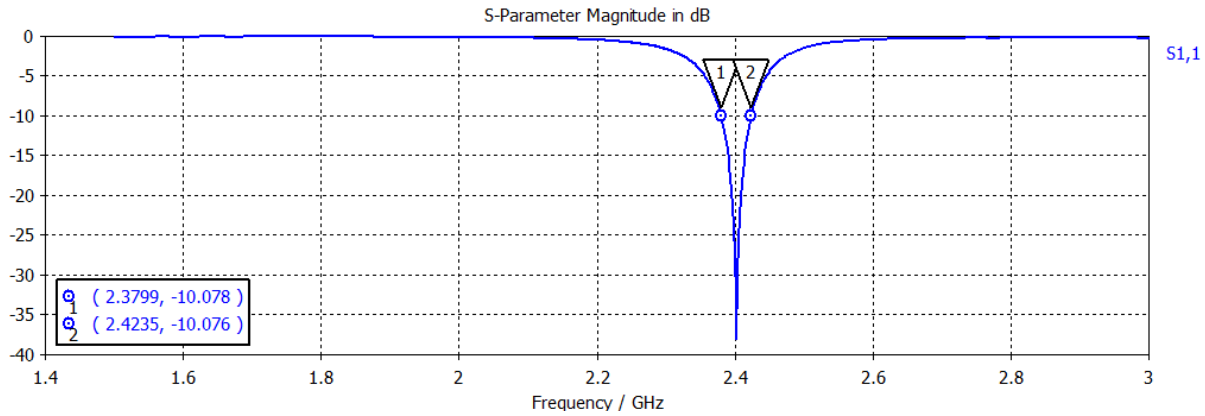

Fig5: S11 result with h=1.6mm, dimensions for frequency=2.4 GHz.

The directivity plots are shown in Fig 6.We see that the directivity/gain of the all designed antennas is low i.e. around 5 dBi. It is due to the large 3dB angular width for all the designs; almost 180^0. Hence the antennas are able to cover almost the whole horizon, which is very helpful feature for airborne communication. The directivity /gain can be improved by employing array feature, which is not covered in this work, and may well be the scope of future work in this direction.

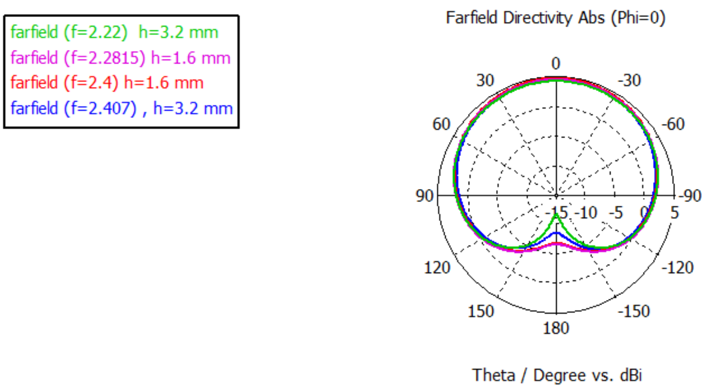

Fig6: Directivity plots for all configurations [4 columns of Table 1]

IV. Conclusions

An approach to design a cylindrical CMPA has been investigated in this work. The matching of feed line to the conformed patch has been done so that the return loss is minimized. The improvement in bandwidth has been demonstrated by increasing the height of substrate. The size of the conformal patch has been shown to be reduced as compared to planar configuration. All the designed antennas exhibit excellent radiation efficiency.

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