Design of Wide-Band Microstrip Antenna for S-Band Telemetry Applications

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ABSTRACT This paper exemplifies the design of a low profile wide-band microstrip antenna suitable for S-Band telemetry applications. The proposed design explores the concept of wide-band antenna with improved omnidirectional gain and smaller size essentially aiming at low-earth orbit (LEO) satellite telemetry. The proposed partial annular radiating patch design has an operating impedance bandwidth ranging from 2.7 GHz to 3.8 GHz with a percentage bandwidth of 31%. It exhibits vertical polarization with a gain of around 1.434 dBi. The design and simulations are carried out using 3D EM tools and the measurement results for various performance metrics of the antenna are validated with the simulation results.

INDEX TERMS Microstrip Antenna, Wide-Band, LEO, S-Band, Telemetry.

I. INTRODUCTION

Accelerating growth in the field of wireless communication and network technology has led to increasing demand for antennas having a small size, low return loss, high gain, and increased bandwidth. Hence, resulting in extensive research on miniaturized, compact, and well-organized antennas among microwave and RF engineers [1]. The development of antennas is one of the most important key points in the development of any wireless communication network [2]. With the rapid advancement in technology in a short period, microstrip patch antennas have become a prime choice over other radiating systems [3]. They are the backbone and driving force behind the recent developments in wireless communication systems because of their low profile, lightweight, low cost, conformal design, and ease of fabrication and integration [4]. However, the major drawbacks of microstrip patch antennas includes low gain, narrow bandwidth and relatively bigger size at lower frequencies [5].

The development of modern wireless systems has prompted an increased investigation on microstrip radiators considering miniaturization, band enhancement and cost as the primary concerns [6]. A lot of techniques have been implemented to improve antenna's radiation pattern, bandwidth and efficiency [7]. Several attempts have been made to achieve the same by selecting a substrate of suitable thickness and dielectric constant [8]. In addition to it, modification of antenna geometry by incorporating number of patches, slots and shorting pins has also resulted in better efficiency, bandwidth, and size of the antenna [9]. Microstrip patch antennas are being widely used in varieties of applications such as telemetry and communications, naval communications, aviation, automatic guidance of intelligent weaponry, satellite, biomedical, radar, and GPS systems [10-13].

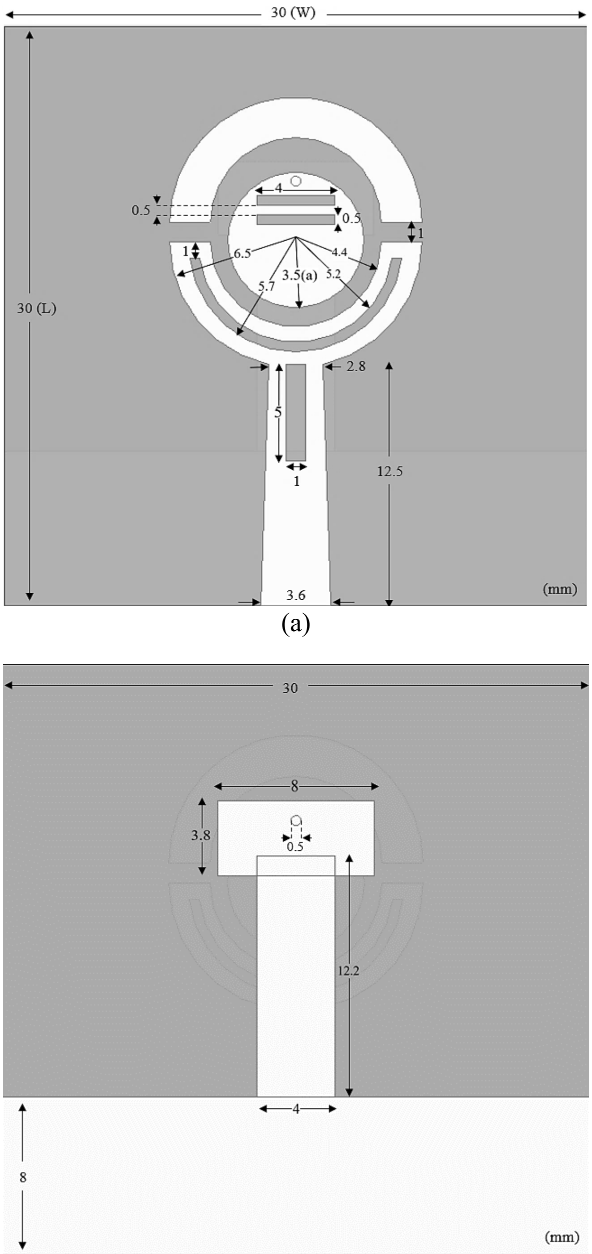
TT&C (Telemetry, Tracking, and Control) antennas systems are an essential component in several kinds of space missions such has communication [14], remote sensing [15], and Earth observations [16]-[17]. There are some critical periods in these missions where continuous telemetry is obligatory [18]. As the size and weight constraints are obvious given the fact that the antenna must be compact enough to be mounted inside a minimizing wireless communication device [19], an S-Band antenna adhering to these constraints is addressed in this paper. Hence, the proposed antenna for telemetry applications is of small size and simultaneously has better performance characteristics such as wide-band and nearly omnidirectional radiation pattern. The vertical polarization is obtained in the proposed single fed antenna and it satisfies the requirements of small satellite in low earth orbits.

II. ANTENNA DEVELOPMENT

The choice of appropriate parameters is very essential to achieve better results. One such parameter is selection of suitable substrate, as mechanical strength and other properties of the antenna depends on it [20]. In this paper, the proposed microstrip patch antenna was designed on an FR-4 epoxy substrate of a thickness of 1.52 mm, with the dielectric constant of 4.6, and a loss tangent of 0.01. The top surface of an antenna has a circular, partial annular radiating patch and a trapeziform microstrip feedline, while the bottom surface has an I-shaped ground plane. The main role of an I-shaped ground plane instead of a partial ground plane is to obtain the required bandwidth as well as for the optimized omnidirectional radiation of the antenna in S-Band. More details on the design and development of the proposed antenna are discussed in the subsequent sections.

A. ANTENNA GEOMETRY

The dimensions of the proposed antenna are shown in the Fig. 1.



(b)

FIGURE 1. Proposed Antenna Configuration (a) Top View (b) Bottom View

The top surface of the antenna has a metal via-hole of radius 0.25 mm which connects the circular shape patch with the ground plane as shown in Fig. 1(a). By loading a shorting pin between the circular patch and the ground plane, a significant reduction in size of an antenna is achieved [9]. The circular patch is coupled by two partial annular rings surrounding it. The circular patch on the top of the antenna surface is coupled by the lower partial ring, which in turn couples the upper partial ring making it resonate at the desired frequency range. The microstrip feed line which consists of the partial ring and the trapeziform patch acts as an impedance matching network in the proposed antenna design. A Finite Element Method (FEM) based structural simulator is used to carry out a computer simulation of the proposed antenna.

B. ANTENNA DESIGN

Designing of any well-structured microstrip patch antenna for communication applications requires a proper selection of the resonating frequency (f_c), dielectric permittivity (ε_r) and the thickness of the substrate (h). In this paper, as the radiating patch is in the form of circular patch, it requires only one design parameter i.e., radius of the patch [21]. The approximate value of the radius can be calculated from the following equations (1) and (2) using relative dielectric permittivity and thickness of the substrate.

Radius of the Patch (a):

$$a = \frac{F}{\sqrt{1 + \frac{2h}{\pi \varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]}} \quad (1)$$

where, a = circular radius dimension (cm),
h = thickness of substrate (m),
ε_r = relative permittivity of substrate (F/m), and
F = logarithmic function (F) of radiating element.

The logarithmic function (F) of radiating element is determined by (2) using Resonating Frequency (f_c) in MHz [22].

$$F = \frac{8.791 \times 10^9}{f_c\sqrt{\varepsilon_r}} \quad (2)$$

In this paper, the radiating patches on the top and full ground plane on the bottom of the proposed microstrip antenna uses copper of thickness 0.02 mm. The basic structure of the radiating circular patch was calculated analytically using (1) and (2). Further modifications are made in the geometry to optimize antenna for its performance namely gain, bandwidth and cross-polar suppression. In order to feed the antenna, a trapeziform microstrip feedline is attached to the lower partial annular ring. The microstrip feedline is essentially an impedance matching to the SMA connector, traditionally a 3 mm – 3.7 mm width of the microstrip line suitable for antenna feed. The slots on feedline and annular ring are made to provide better impedance matching and to get the required return loss (S_{11}). Two rectangular slots on the circular patch are used to improve the gain and coupling of the antenna and also to maintain the omni-directional pattern. By combining I-shaped ground plane with the radiating patch, quasi-omnidirectional radiation pattern is attained. Even though the structure has no such closed form expression for the structure, the basic idea is to have a circular patch that has been coupled feed. The simulations are conducted using a 3D EM Simulation Software (FEKO and EMPro) for a frequency range of 2 GHz – 5 GHz.

C. ANTENNA DIMENSION

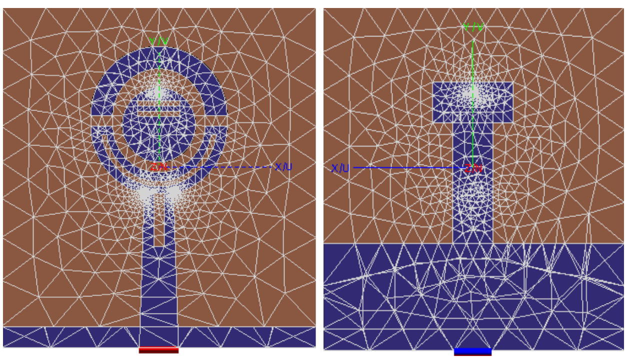
The designed parameters and its dimensions for the proposed antenna are tabulated as shown in Table I.

TABLE I. Antenna Parameters and Dimensions

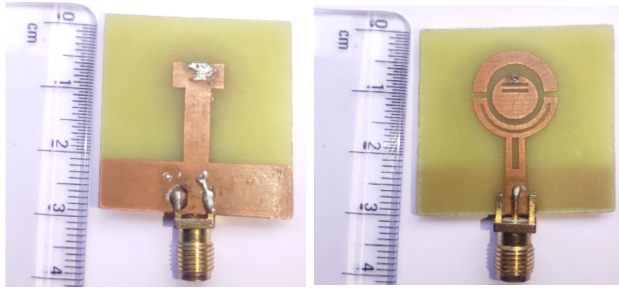
Parameters	Dimensions
Width of the Substrate (W)	30 mm
Length of the Substrate (L)	30 mm
Thickness of the Substrate (h)	1.52 mm
Dielectric Constant of the Substrate (ε_r)	4.6
Loss Tangent (tan δ)	0.01
Radius of the Patch (a)	3.5 mm
Resonant Frequency (f_c)	3.5 GHz

D. ANTENNA REALISATION

The proposed antenna design makes use of an FR-4 substrate of a thickness of 1.52 mm. On the top surface, two oppositely faced partial rings are imprinted around the circular patch and the distance of 1 mm is maintained between the two rings. Furthermore, a partial annular ring formed by concentric circles of radii 5.2 mm and 5.7 mm is removed from the lower partial annual ring patch to provide the desired resonating effect. An SMA connector with an impedance of 50 Ω is used as the feed port to the microstrip line. The realized antenna has been tested using a Vector Network Analyzer (VNA) to verify the obtained measurement results. The prototype of an antenna simulated on a 3D Electromagnetic simulation software and fabricated is shown in Fig. 2.



(a)



(b)

FIGURE 2. Antenna Prototype (a) Simulated Antenna (b) Fabricated Antenna

III. RESULT AND DISCUSSION

A 3D EM Tool (FEKO and EMPro) is used to design, simulate and optimize all parameters of the proposed antenna. It has been found that a small change in the distance between the circular patch and the annular ring as well as the ground plane will result in greater variation in the antenna parameters viz., the impedance bandwidth, gain and the pattern. With the increase in distance between the circular patch and the lower partial ring, the upper resonance frequency moves towards the higher frequency range while the lower remains almost unaffected. On contemplating, it is also noticed that when the width of the rectangular patch (12.2 mm × 4 mm) in the ground plane is continuously decreased, the -10 dB bandwidth deteriorates. The single most important feature is the pattern distortion due to modification in the ground plane has been observed. Hence, change in dimensions of the rectangular patches in the ground plane has a significant effect on the antenna bandwidth. The comparison of simulated and measured result of return loss magnitude (dB) as a function of frequency (GHz) for the designed antenna system is shown in the Fig. 3.

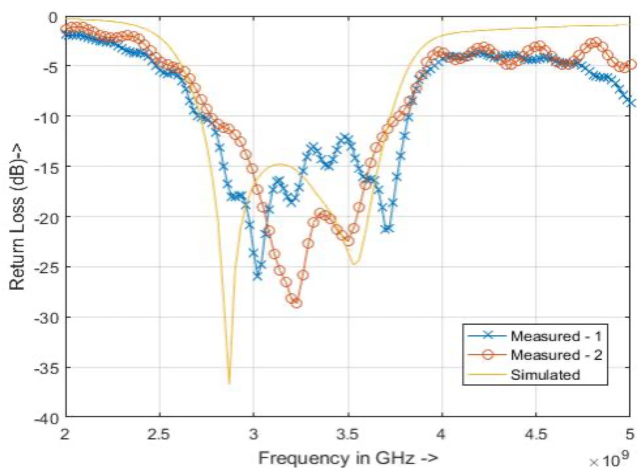
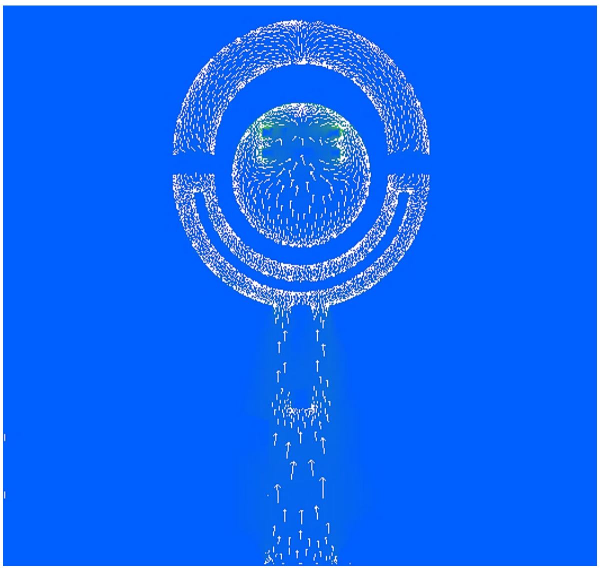


FIGURE 3. Comparison of Simulated and Measured Return Loss

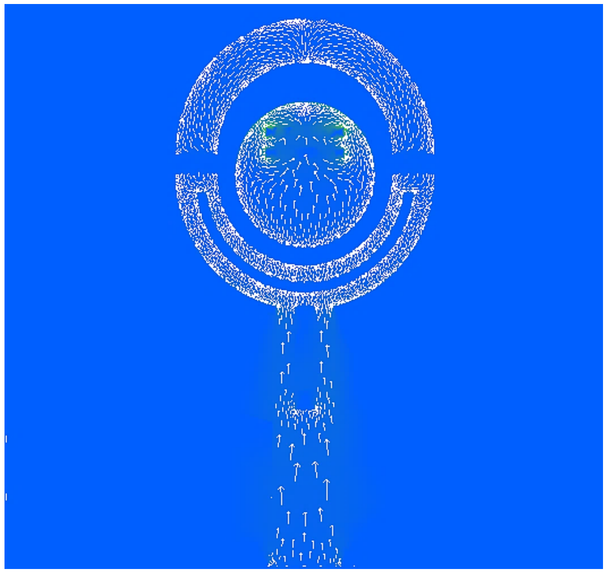
The simulation results of the modelled antenna depict the return loss in excess of -10 dB in Fig. 3. The measured results show the optimized antenna resonates in the desired frequency band of 2.7 GHz to 3.8 GHz with a fractional bandwidth of

31%. The simulated return loss is in excess of -16 dB in the entire intended frequency band. The results indicates that the antenna can work in the wide bandwidth range having the resulting bandwidth of 1036 MHz. Measured-1 and Measured-2 values from the Fig. 3 explains the measured result of the return loss using two different Vector Network Analyzers (VNA). Both the simulation and measured S_{11} results emphasize that the antenna is well matched at the desired operational frequency, satisfying the requirement on the S_{11} that is well below the value of −10 dB. In particular, the Fig. 3 clearly shows the S_{11} results obtained by simulating the proposed design on 3D EM tools and by the measurements of the fabricated antenna, performed using two different VNAs. They both are in good agreement to each other and both share a similar bandwidth range.

The return loss results can be further explained with the help of surface current density distributions of the proposed antenna at 3.25 GHz and 3.5 GHz respectively as shown in Fig. 4. It is clearly observed that the strength of current vectors on the circular patch at the lower frequency (3.25 GHz) is more when compared to the higher frequency (3.5 GHz) as the current vector directions towards the circular patch from the feedline. The impedance of the microstrip line with the feed has been optimized by looking into the current distribution patterns from the EM Tool.



(a)



(b)

FIGURE 4. Simulated Surface Current Distributions at 3.25 GHz, (b) 3.5 GHz

Another important parameter for any antenna is its radiation pattern. The individual simulated gain plots in azimuth plane (phi = 0) are obtained for the frequency points 2.75 GHz, 3.5 GHz and 3.75 GHz as shown in Fig. 5, Fig. 6 and Fig.7 respectively. From the gain plots, it is clearly visible that the antenna has nearly omni-directional radiation pattern in the entire S-Band with a gain in excess of 1.2 dB and a cross-polar suppression of -20 dB.

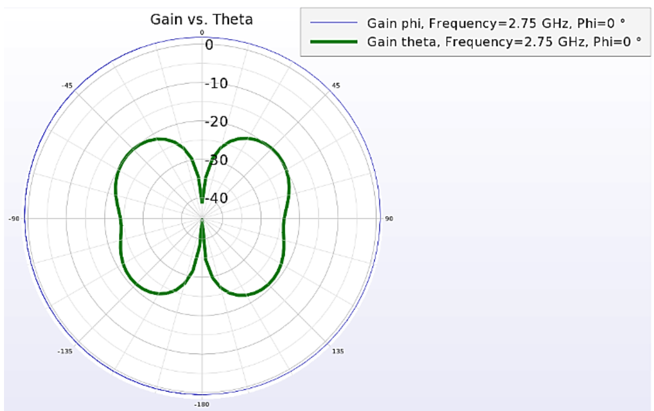


FIGURE 5. Simulated Gain Plots for 2.75 GHz

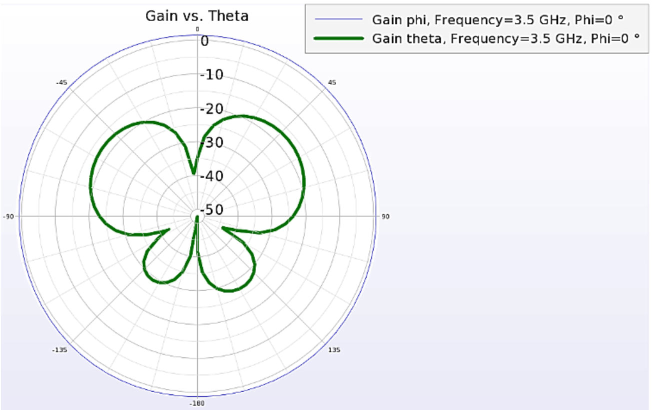


FIGURE 6. Simulated Gain Plots for 3.5 GHz

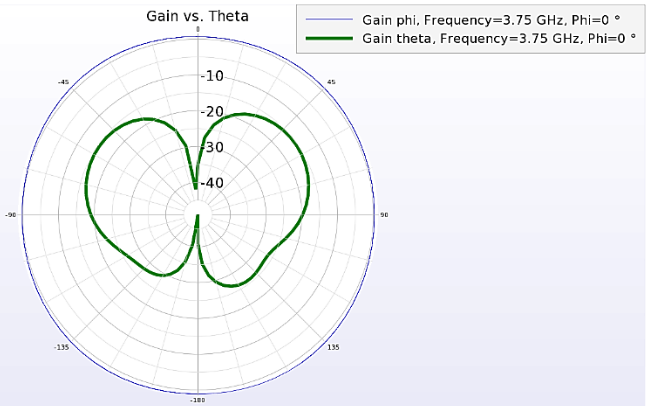


FIGURE 7. Simulated Gain Plot for 3.75 GHz

Far-Field radiation patterns for the proposed antenna is measured in the anechoic chamber at frequency 3.25 GHz and 3.5 GHz as shown in Fig. 8. The cross-polar and co-polar pattern of both simulated and measured radiation pattern from Fig. 8 indicates that the proposed antenna has nearly an omni-directional radiation characteristic and has a nearly similar radiation patterns at both 3.25 GHz and 3.5 GHz. The comparison of simulated and the measured normalized radiation pattern of the proposed antenna in Azimuth Plane (phi = 0) at frequency of 3.25 GHz and 3.5 GHz were obtained and it is evident that no significant differences are observed in the results.

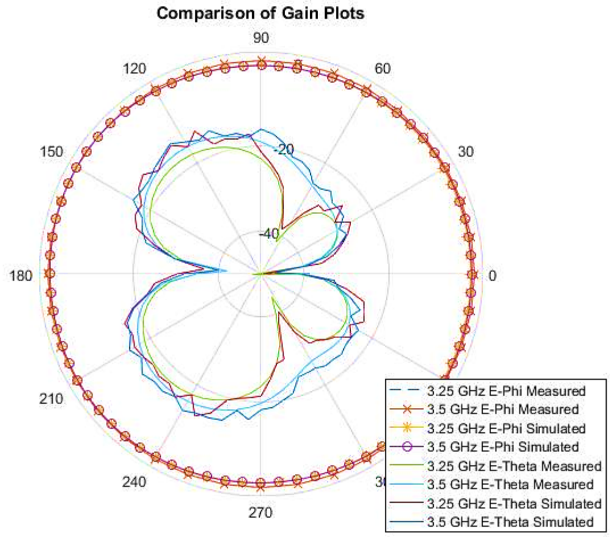


FIGURE 8. Comparison of Simulated and Measured Far-Field Co-Polar and Cross-Polar Radiation Pattern

The Radiation Efficiency vs Frequency (2 GHz – 5 GHz) is shown in Fig. 9. It is noted that we get highest radiation efficiency (greater than 90%) for the antenna in the frequency range of 2.7 GHz to 3.8 GHz. Also, the Gain (dBi) vs Frequency (2 GHz – 5 GHz) plot is shown is Fig. 10. It is inferred that the gain of the antenna is almost stable over the given bandwidth range.

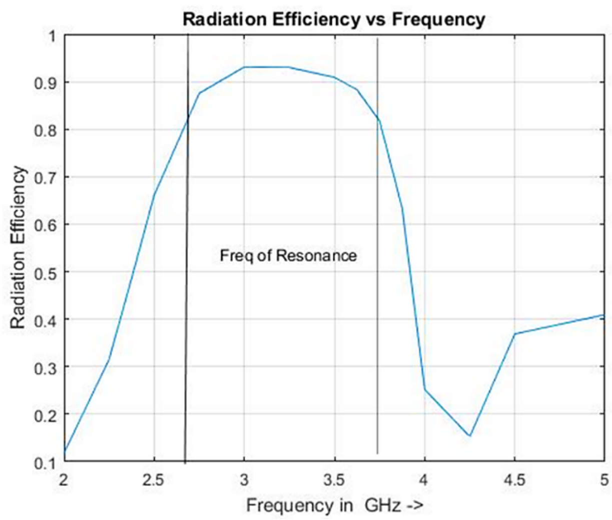


FIGURE 9. Variation in Radiation Efficiency vs Frequency

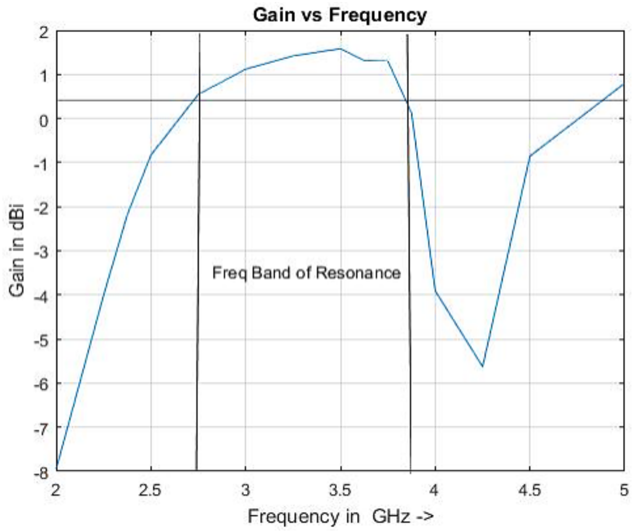


FIGURE 10. Variation in Gain vs Frequency

To conclude, it is important to highlight that there is a good visual similarity for the simulated and measured results of S_{11} return loss and the far-field co-polar and cross-polar radiation pattern. Hence, it can be confirmed that the proposed antenna achieves good return loss and the radiation properties along with impedance matching at the operational frequency, and the desired far field directivity. The results from other S-Band antennas used for telemetry applications are compared and are tabulated as shown in Table II.

TABLE II. Comparisons of results from other S-Band Antennas

References	Return Loss (dB)	Frequency Range (GHz)	Bandwidth (MHz)	Gain (dBi)
This paper	− 31.77	2.70 – 3.80	1036	1.43
[23]	− 23	2.33 – 2.50	170	1.34
[24]	< −15	2.02 – 2.29	> 265	6.50
[25]	< −25	2.13 – 2.44	310	5.70
[26]	< −15	1.98 – 2.35	370	> 6.00
[27]	− 28	2.00 – 2.12	120	6.00
[28]	< −17	3.90 – 11.1	7200	4.8
[29]	−24.68	1.67 – 3.50	1835	6.0
[30]	−19.10 −27.50	1.82 – 2.66 3.46 – 3.72	840 260	− 4.37 1.04

IV. CONCLUSION

In this paper, a wide-band microstrip patch antenna has been successfully designed and simulated using 3D EM tools aiming at S-Band telemetry applications. The antenna has been fabricated on FR-4 epoxy substrate for validation of the modelled design. Various performance parameters such as return loss, radiation pattern, gain and directivity were obtained and optimized by modifying the antenna dimensions to get the best possible result. The proposed antenna works at resonant frequency of 3.5 GHz which is suitable for S-Band applications and results in wide bandwidth of 1036 MHz ranging from 2.7 GHz to 3.8 GHz with a percentage bandwidth of 31%. The gain of proposed antenna is 1.434 dBi and the cross-polar suppression is 20 dB. This compact, small and low size antenna design can be further modified to get high gain and can be used in other suitable applications.

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