URSI AP-RASC 2019, New Delhi, India, 09 - 15 March 2019

U-Shaped Microstrip Patch Antenna with Partial Ground Plane for Mobile Satellite Services (MSS)

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Abstract

This paper presents a compact planar monopole microstrip patch antenna with a U-shaped patch and a diagonally cut partial ground plane. It has been designed and simulated on commercially available low-cost FR-4 material with relative permittivity ε of 4.3 and 0.025 loss tangent. Miniaturization of the original antenna has been achieved by optimizing the chamfered length of the partial ground plane as well as introducing a cut in the patch and optimizing this cut in order to achieve a U-shaped structure. The overall dimension of the proposed antenna is 20 × 20 × 1.5 mm^3. The gain of the first band (from 1.9 to 2.2 GHz) is 3.2 dB, and for second band (from 3.9 to 4.8 GHz) is 1.2 dB and the radiation efficiency of the first band is 22% and for second band is 75% is observed. This paper presented a low-gain, Dual-band compact monopole antenna. The simulation has been done through CST Microwave studio. The proposed antenna detailed structure with simulated return loss, parameter study, impedance curve, the radiation pattern of the proposed antenna are elaborated in this paper. The proposed antenna can be used for Space to earth, Mobile Satellite Services (MSS).

1. Introduction

Since the time when wireless communication started seeing big advancements and started to gain popularity in the day-to-day applications, more and more researchers have made use of the recent technologies to develop high gain, high efficiency, and small sized antennas with omnidirectional radiation patterns. Microstrip patch Antennas gain popularity in the 1970s primarily for space bound applications. Today they are used for government as well as commercial applications. It consists of a substrate (usually FR-4) of a particular length, a thin ground plane (usually copper) on one side and a thin patch attached to a microstrip line (copper) on the other side. Researchers have implemented the antenna theory to design broadband as well as narrow band antennas by changing the shapes and sizes of the ground plane and the microstrip patch.
Miniaturized dual broadband printed slot antenna with parasitic slot and patch showing dual band operates from 2.4 to 6.1 GHz and 9.4 to 13.8 GHz [1]. By Cylindrical patch array high gain beam was achieved for Mobile satellite service in [2]. Dual band characteristics achieved by stacked patch-array design for MSS in [3]. Bandwidth enhancement is achieved by the introduction of curved slot in the patch [4]. A printed wide-slot antenna is with the parasitic patch is used for bandwidth enhancement [5]. Printed microstrip slot antennas are widely used in various communication systems because wide-slot antennas have two orthogonal resonance modes, which are merged to create a wide impedance bandwidth [6]. A simple microstrip patch antenna is designed on FR4 material to achieve 2.4 GHz frequency [7]. An inset fed rectangular microstrip patch antenna is simulated for achieving WLAN frequency [8]. By designing a rectangular microstrip patch antenna, 2.4 GHz frequency is reported [9]. Bandwidth enhancement is obtained by the rotated square wide slot. A printed wide-slot antenna with rotated slot is proposed for bandwidth enhancement in [10]. Ultra-wideband applications have been reported by excitation of higher order resonance on introduction of a U-shaped slit in the partial ground plane and rectangular parasitic patches adjacent to the microstrip line [11]. Recently a compact planar antenna with a stair shaped ground plane with broadband characteristics has been reported [12]. Various designs have been suggested and demonstrated for the UWB application and WLAN range of frequency such as Elliptical patch with circularly symmetric slot [13], Open-ended T-shaped slot with feed line extension [14]. A fork-shaped radiating patch have been reported for Ultra wide band applications [15]. Monopole antenna has achieved broadband characteristics by introducing parasitic elements in a design [16].
This paper proposes a microstrip patch antenna, with a U-shaped patch with the diagonally cut partial ground plane. The optimum size of the proposed monopole antenna is 20*20*1.5 mm^3. The compact monopole patch antenna shows stable radiation pattern. The gain and the radiation efficiency of the first band (from 1.9 to 2.2 GHz) is 3.2 dB and 22%, for second band (from 3.9 to 4.8 GHz) gain and the radiation efficiency are 1.2 dB and is 75% is observed. In the next section the geometry of the antenna is elaborated.

2. Antenna Design

The evolution of the proposed antenna is shown in Fig. 1, with simple monopole antenna (stage 01) and proposed antenna (stage 02), and the configuration of the U-shaped

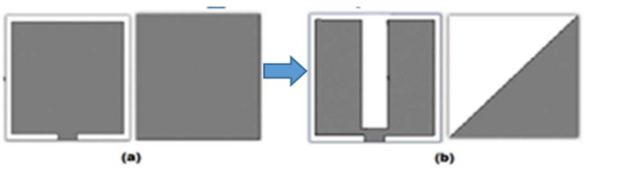


Figure 1. Evolution of proposed antenna (a) simple antenna stage 01 (b) proposed antenna stage 02.

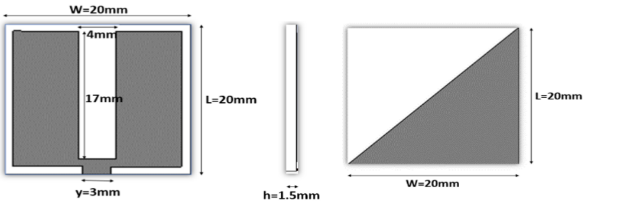


Figure 2. Geometry configuration of proposed antenna (a) front view (b) side view (c) back view (all values are in mm).

Patch with Partial ground plane microstrip antenna is shown in Fig.2. The dimensions of the overall antenna are 20*20*1.5 mm^3 with a ground and patch thickness of 0.018mm. The antenna is simulated with FR-4 substrate with the relative dielectric constant of 4.3 and loss tangent of 0.025. The thickness, 'h' of the substrate is 1.5mm. The patch and ground are of copper material. The patch is a U-shaped structure with the dimensions as shown in the figure. The ground is partial with the shape of a right-angled triangle where the hypotenuse is equal to the diagonal of the overall antenna. The antenna is fed by a 3mm and 50Ω microstrip line. All the Simulation are done using CST microwave studio, a finite integration technique (FIT) based commercial electromagnetic simulator.

The ground plane is chamfered up to the length where the most optimal result is obtained. This was done to improve the impedance matching and achieve a resonance at a lower frequency than that of the original monopole antenna

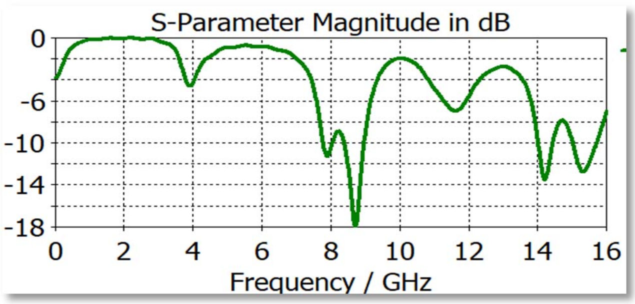


Figure 3. Simulated return loss of simple monopole antenna (stage 01).

The rectangular cut was initially introduced to the patch which was further increased in length and a U-shaped patch was achieved. This not only enhanced the bandwidth of the antenna at 4 GHz but also introduced a new impedance matching at 2 GHz. Hence the proposed antenna had a bandwidth from 4GHz to 4.7GHz and at 2GHz to 2.1GHz which is much more efficient than the original monopole antenna which only showed resonance between 7.7GHz to 8.9GHz (that too, not continuous). In the next section the parameters of the antenna geometry is elaborated.

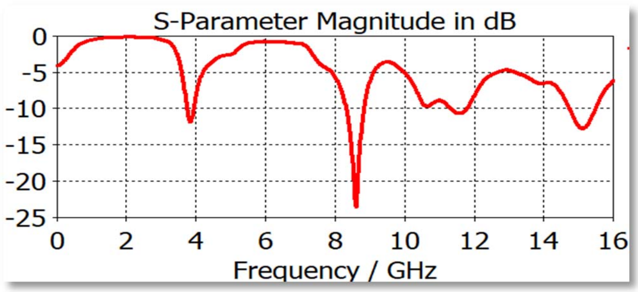


Figure 4. Simulated return loss when ground plane of simple antenna is chamfered.

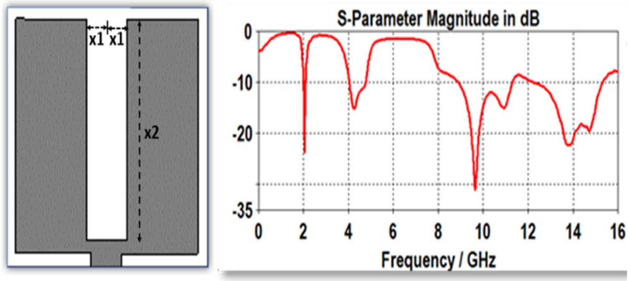


Figure 5. (a) Slot of width 2*x1 and length x2 introduced. (b) Return loss when x1=2mm and x2=17mm (most optimal result)

3. Parameter Study

In this section, the study of various parameters of the proposed antenna is carried out to understand their effect and to find out the best possible design parameters. Fig. 3. Shows the return losses of a simple monopole antenna for the most optimal square patch length (i.e. 18mm). This length was chosen to begin with for its original return losses being less than -10 dB between 7.7GHz to 8.9GHz (not a continuous band).

Now the objective was to shift this resonant peak to a lower frequency (also called miniaturizing). In the next step ground plane corner (opposite to the port) was chamfered and a parametric sweep was run on the length of the chamfered part keeping the angle at 45^0 in order to optimize the result, keeping all other parameters fixed. The return losses are shown in Fig.4. for most optimal chamfered length.

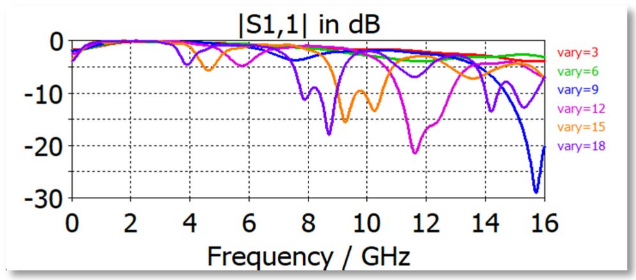


Figure 6. Simulated return losses for various values of "vary" which here denotes the length of the square patch.

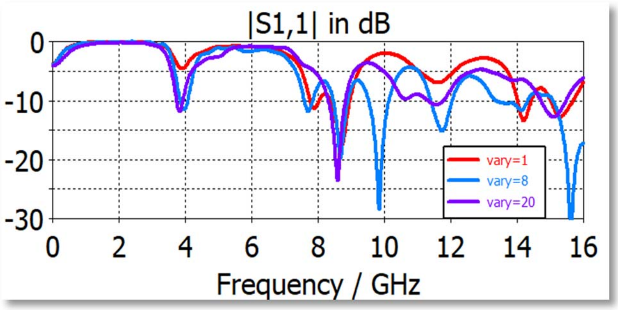


Figure 7. Simulated return losses for various values of "vary" which here denotes the chamfering length.

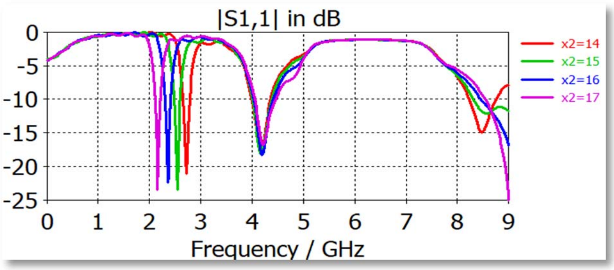


Figure 8 (a). Simulated parametric sweep of dimension x2 while keeping x1=1mm.

It can be seen that when the chamfered length is equal to 20mm (the ground is chamfered along the diagonal of the substrate), the return losses for the band 3.7GHz-3.9GHz were seen to be below -10dB. It implies that the chamfering the ground plane gave two improvements: first, it shifted the resonating peak of the original monopole antenna to a lower frequency (3.7GHz-3.9GHz). Second, it made the resonating peak of the simple monopole antenna more continuous. This is because partial ground plane plays a crucial role in the impedance matching. Hence for the next analysis, a partial ground plane with a 20mm chamfered length was chosen.

The last step was to introduce a rectangular cut on the square patch. Fig. 5. (a) Shows the dimensions "x1" and "x2" which were varied as shown and a rectangular cut was chosen in accordance with the best result. Fig 5. (b). shows the most optimal result for variable lengths x1 and x2. It was seen that at x1 equal to 2mm and x2 equal to 17mm, the impedance matching band (3.7GHz to 3.9GHz) was shifted to 4GHz-4.7GHz. Moreover, a new peak return loss was introduced by this patch cutting. This peak was observed at a frequency band of 2GHz to 2.1GHz.

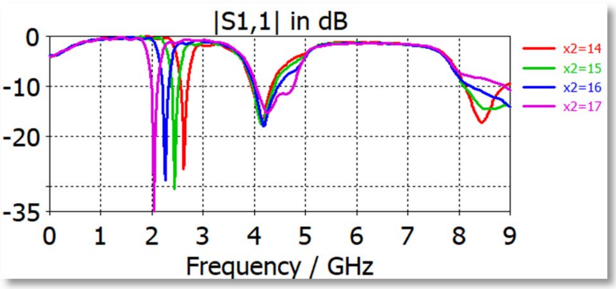


Figure 8 (b). Simulated parametric sweep of dimension x2 while keeping x1=2mm.

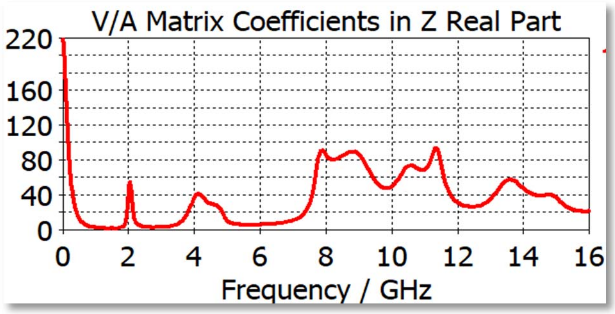


Figure 9 (a). Simulated real part of Z-matrix for the proposed antenna.

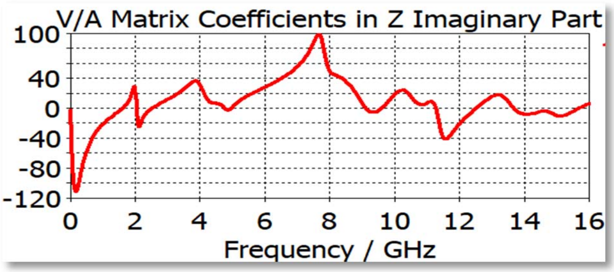


Figure 9 (b). Simulated imaginary part of Z-matrix for the proposed antenna.

Due to excitation of higher order resonating modes, the frequency band of 4-4.7GHz was seen as an impedance match and as x1 was increased, the impedance mismatching started to take place. As for 2-2.1GHz band, it can be observed that due to increase in the number of edges in the patch, the signals are radiated more efficiently for the given frequencies.

4. Results and Discussion

To find the most optimal length of square patch for the simple monopole antenna, a parametric sweep is done taking the length as a variable and varying it from 3mm to 18mm with an interval of 3mm. The results are shown in Fig. 6. It can be seen from the figure that at "vary" = 18mm, the return loss (magnitude less than -10dB) can be seen at the lower frequency range as compared to all the other values of "vary". Keeping the aim of miniaturization (excitation of resonance at lower frequency) in mind, a partial ground plane is formed by chamfering one of its corners. The length of chamfering is used as a variable for the next sweep.

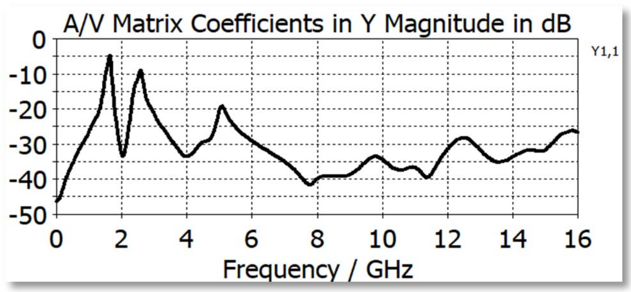


Figure 10. Simulated Y-matrix for the proposed antenna.

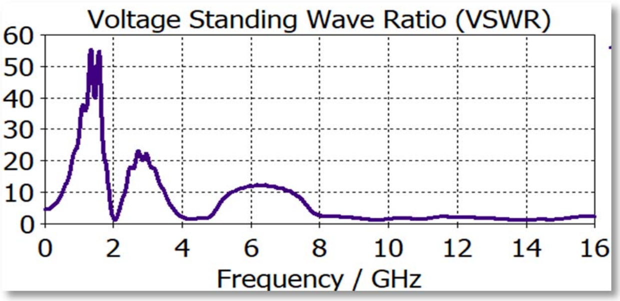


Figure 11. Simulated value of VSWR for the proposed antenna.

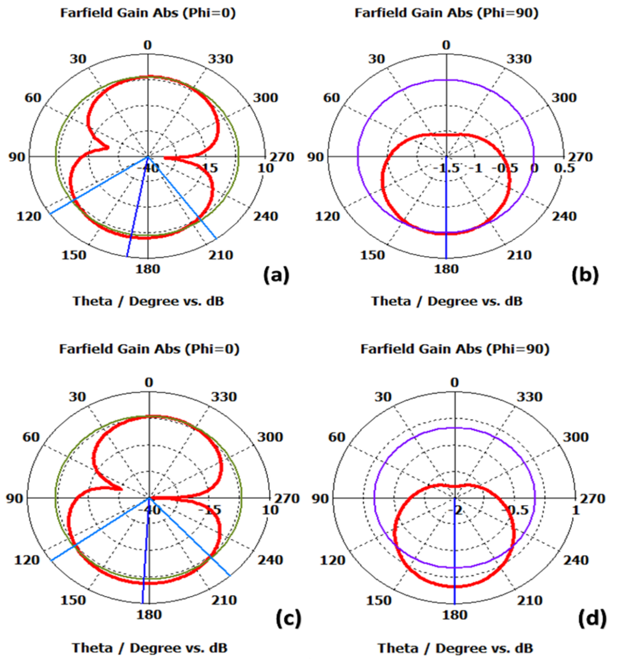
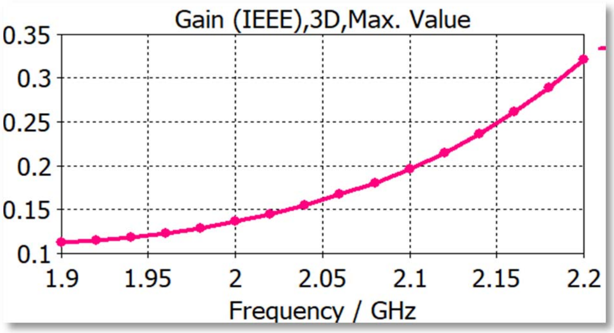


Figure 12. Simulated radiation patterns of the proposed antenna at frequency 2.1GHz (a) Phi=0 (b) Phi=90 and 4GHz (c) Phi=0 (d) Phi=90).

The results are as shown in Fig. 7. It is clearly seen that the best results come from a chamfering length of 20mm. This condition arises due to better impedance matching at this chamfering length. The parametric sweep has been shown for the variable length x2 for two most optimum values of x1, i.e. x1=1mm and x2=2mm. To be noted that x1 and x2 are the dimensions of the slot cut on the square patch and are shown in Fig. 5. (a)



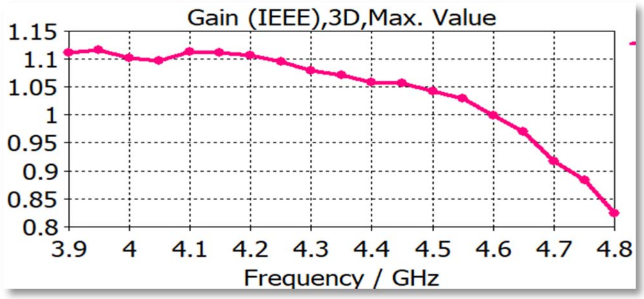


Figure 13. Simulated gain for the proposed antenna. (1.9GHz-2.2GHz and 3.9GHz-4.8GHz).

The best possible miniaturizing result came from x1=2mm and x2=17mm which is clear from the return loss plot, at a frequency band of 2-2.1GHz as well as 4-4.7GHz, which is the proposed antenna and is a drastic improvement as compared to the simple monopole antenna (Fig. 6). The parametric sweep for the corresponding analysis has been shown in the Fig. 8. After choosing x1=2mm and x2=17mm, a full simulation was run for a frequency range of 0-16GHz. The result has been shown in Fig 5(b). Imaginary and Real parts of Z-matrix have been plotted in Fig. 9. and Y-matrix has been plotted in Fig. 10. It is evident from the real part of Impedance curve that the antenna is purely resistive in nature at 2-2.1GHz and purely inductive in nature at 4-4.7GHz frequency range. A similar interpretation can be made by observing the Y-matrix plot. The Voltage Standing Wave Ratio (VSWR) has also been calculated in Fig. 11. From the figure one can observe that at the 2 proposed frequency bands, the VSWR values are coming out to be less than 2 (which corresponds to return loss less than 11% and are internationally accepted) Since the two proposed bands are 2-2.1GHz and 4-4.7GHz, the simulated radiation patterns (for theta=90 and for phi=90) of the proposed antenna have been shown at frequency 2.1GHz and 4GHz in Fig 12.

By observing the radiation patterns, it is evident that the radiation patterns are stable in both the frequency bands and stable radiation pattern validated the monopole characteristics of the proposed antenna. The gain (IEEE) has been simulated on CST for two significant bands of frequencies. The gain of the first band (from 1.9 to 2.2 GHz) is 3.2 dB, and for second band (from 3.9 to 4.8 GHz) is 1.2 dB. The results are shown in Fig. 13. To check how well the antenna performs at the proposed frequency bands, antenna efficiency was simulated.

It can be seen that at a frequency as low as 2.1GHz, the antenna incurs too many losses and therefore the simulated efficiency at the lower band is less than 13%. At the higher frequency band, it is observed that the proposed antenna works at around 75% efficiency. Although this efficiency is seen to be reducing as one goes to higher frequencies due to impedance mismatch. The simulated result has been shown in Fig. 14.

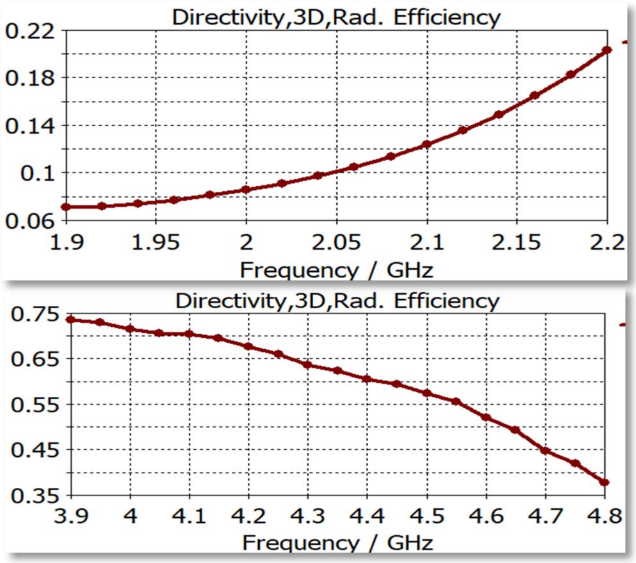


Figure 14. Simulated efficiency plot for the proposed antenna at two frequency bands.

5. Conclusion

A simple narrow band antenna with partial ground plane and U-shaped patch, operating at low frequencies is proposed. While attempting to miniaturize the natural resonating frequency of the antenna, a design is proposed that can be operated at 2 low frequency bands (2-2.1GHz and 4-4.1GHz). The simulated impedance of real part and imaginary part shows the optimum result, which are sufficient as the requirement. The antenna works with a maximum radiation efficiency of 13% for frequency range 2-2.1GHz and a maximum radiation efficiency of 75% for frequency range 4-4.7GHz. Stable radiation patterns are obtained at both the frequency bands. As it can be clearly seen from the various optimum results, the antenna is well suited for working in 2 to 2.1 GHz range. This antenna has been proposed for Space to earth, MSS Communication.

5. References

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