T-Slotted Rectangular Microstrip Patch Antenna for WIMAX and WLAN Applications

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Abstract: **This letter presents the design and performance of T-slotted rectangular microstrip patch antenna (RMPA) with modified ground plane for the applications of WI-MAX and lower band of UWB communication system. The prototype of the proposed patch having dimensions 27 x 23 mm2 has been designed, fabricated and tested. The overall size of the antenna is 33mm × 33 mm × 1.59 mm. In addition to modifications of ground plane, the radiating patch is also modified in various steps by using CST Microwave Studio simulator 2014 and performance of antenna at various stages are obtained in free space. The proposed antenna effectively operates at two resonant frequencies and presents broad impedance bandwidth 2.32GHz or 72.27% with respect to central frequency 3.21 GHz. Antenna also provides nearly flat gain in the desired frequency range with maximum gain 2.48dBi normal to patch structure and 2.99dBi in an inclined direction.**

Index Terms— Microstrip antenna, Strip line feed, Broadband, Gain, Radiation patterns

1. INTRODUCTION

With advancements in communication technologies; the modern wireless communication systems should be compact in size with improved performance. Micro strip antennas may be proved suitable candidates for modern communication systems due to their compact size, light weight, low manufacturing cost on mass production and easy coupling with other circuit elements. Further these antennas may be put inside the handset without protruding out. Hence, these antennas may be proved very practicable structures for modern communications systems. However in their conventional form; these antennas have narrow bandwidth, low gain and generally operate at a single resonant frequency corresponding to their dominant mode of excitation.

Looking associated advantages with planar antennas; extensive efforts have been made in recent times to improve their inherent limitations; so that these structures may be directly applicable in military applications, global positioning systems, and direct broadcast satellite system application etc [1-6]. These efforts including; cutting of suitable slots at appropriate locations on the patch geometry [3], patches under stacked arrangement [4], application of air and low permittivity substrates [5], application of co-planar arrangement with one or more parasitic patches to attain broadband operation [6]. With these modification techniques; limited higher impedance bandwidth achieves but saturates after reaching certain optimum value. It is realized that alternations in ground plane also modify the current distribution significantly on patch [7-8]; which realize to improve the performance of antennas. The defected ground plane controls the propagation of electromagnetic waves through the substrate layer. These defects in ground plane create new dimensions in antenna developments for modern wireless communication systems and provide compact and thin antennas. In this letter, a micro strip line feed rectangular patch antenna is modified in different step to obtain much improved performance. The design and performance of this modified antenna has presented in the next section.

2. ANTENNA DESIGN AND RESULTS

The designing process of the proposed antenna is dividing in the various steps such as modifications in ground plane, modifications in patch etc. To design the proposed patch antenna we consider a rectangular patch of size 27mm x 23mm.This antenna with overall dimension 33mm x 33mm is designed on glass epoxy FR-4 substrate having relative permittivity $\varepsilon r = 4.4$, substrate height h = 1.59 mm and loss tangent = 0.025. A 50 Ω micro strip feed line having length 7.0 mm and width 3.0 mm has applied for feeding. This rectangular micro strip patch antenna (RMSA) is simulated using CST Studio suite 2014 [9]. A comparison between finite ground plane configuration and infinite ground plane configuration with same patch dimension has depicted in Fig.1.

Proposed antenna with finite ground resonates effectively at frequency 5.03GHz but depicts narrow impedance bandwidth (~1.9%). Theoretical analysis reveals that the resonance frequencies of this antenna for dominant TM10 and TM02 modes of excitation are 3.1 GHz and 5.2 GHz respectively. However under finite ground and strip feeding condition, the dominant mode TM10 is non-resonant mode while second dominant mode TM02 is effectively excited which is shown in Figure 1. The maximum gain of this antenna is close to 1.2dBi and radiation patterns have dumbbell shape with maximum radiation normal to patch antenna. This antenna is further modified in two steps to improve its performance.

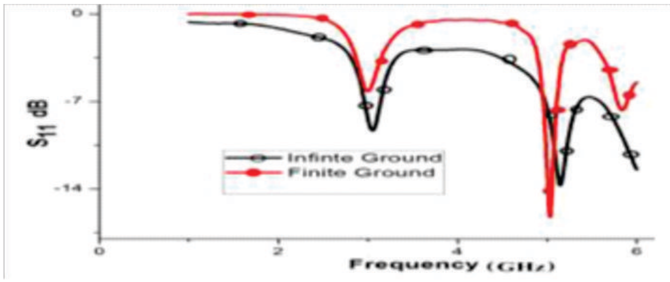


Fig.1 Variation of simulated reflection coefficient of antenna with finite and infinite ground plane.

(a) Modification in ground plane

In modification process, finite ground plane is modified in various steps to achieve defected ground plane while the patch dimensions remain same as mentioned above. In the first step, two slots namely 'slot A' and 'slot B' are applied continuously one by one. The size of each slot is 15.5mm x 13.5 mm and separated with a narrow strip having dimensions 2mm x 13.5mm as shown in Figure 2(b). The dimensions of upper and lower part of ground plane 'C' and 'D' are 33mm x15.5mm and 33mm x 4mm respectively.

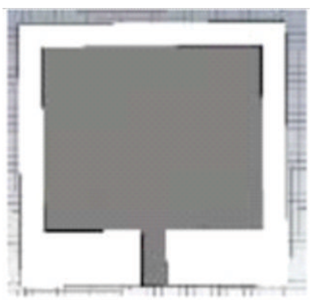


Fig.2 (a): Front View of Modified Antenna

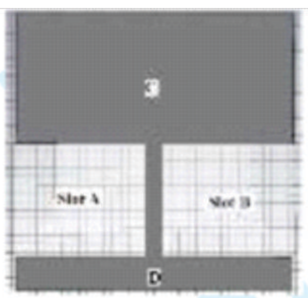


Fig.2 (b): Rear view of Modified antenna

The variation of S11 parameters for modified antenna with both slots 'A' and 'B' is shown in Figure 3. It indicates that antenna is resonating effectively at a single frequency (3.83 GHz) which is significantly lower than the initial case i.e. with finite ground plane.This significant reduction in resonance frequency with introduction of applied slots in ground plane can be correlated with the effective patch size of antenna. The maximum gain achieved in the present case is close 2.70 dBi which is improved marginally.

In the next step, the ground plane of antenna is further modified by introducing four narrow slits one by one in upper part of ground 'C'. Different views of prototype develop in this stage are shown in Figures 3(a) and 3(b). The width of each slit is 2mm while the separation between two successive slits is 0.5mm. The width of outer most rectangular part of the ground plane is 5.5mm. In each stage of modification, antenna is simulated to check its performance.

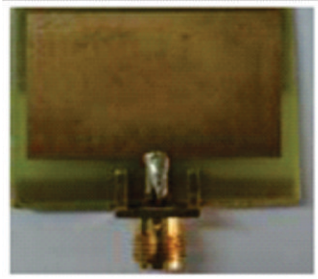


Fig.3 (a) Top view of Prototype

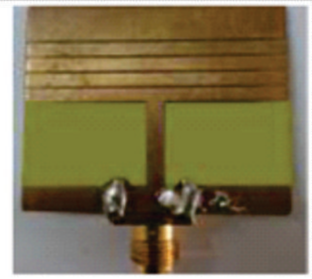


Fig.3 (b) Rear view of Prototype

The comparisons of S11 parameter in different cases; having slots only and having both slots and slits as shown in figure 4. It is seen that with combined effect of slots and slits, the performance of antenna further modifies. This antenna now efficiently resonates at single frequency 4.21 GHz and provides an impedance bandwidth close to 2.27GHz which is close to 69.63% with respect to central frequency 4.21 GHz. However a small dip occurs at frequency 2.27GHz. These frequencies probably correspond to dominant mode as well as some other low order modes.

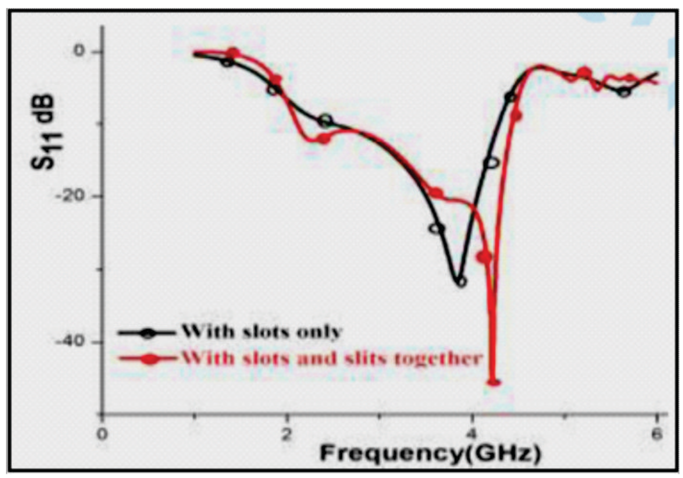


Fig.4 Simulated reflection coefficient for both antenna geometries with modified ground

The maximum gain achieved with this antenna is close to 2.72dBi which is almost same as realized in previous case.

(b) Modifications in radiating patch

After achieving optimum performance through ground plane, further patch modification steps are used to improve the performance of the antenna. These modifications are carried out in two steps. In first step, the two side edges are truncated one by one with truncation length d2 = 19.0 mm and truncation width d4 = 2.0mm. The dimensions of d1 and d3 are 3.0mm and 1.0mm respectively. In final step a 'T' shaped slit with dimensions h1 = 2mm, h2 = 8mm, h3 =16.0mm and h4 = 1.0mm is cut on the patch. These 'T' shape slot and truncations are shown in Fig. 5.

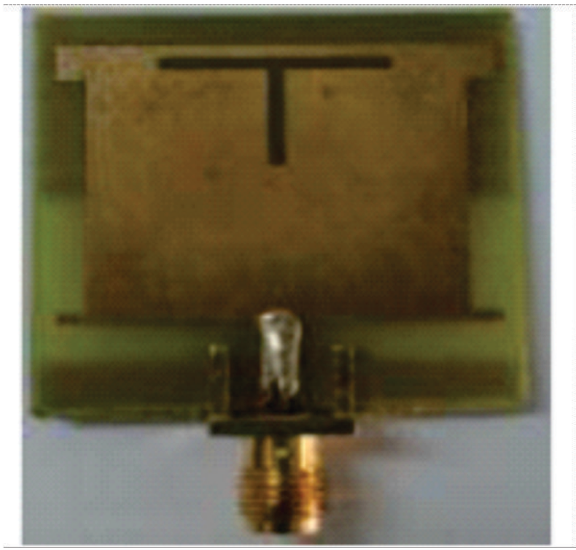


Fig.5 Front view of modified patch antenna

The current distributions have seen on the patch as well as on the back side of the patch which is also shown in figures 6(a) and 6(b) respectively. The patch current with proposed modifications in patch geometry is modified significantly.

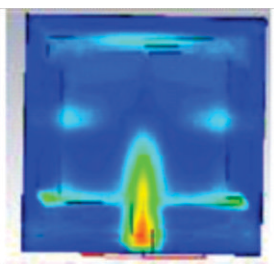


Fig.6(a) Simulated current distribution at 3.4 GHz

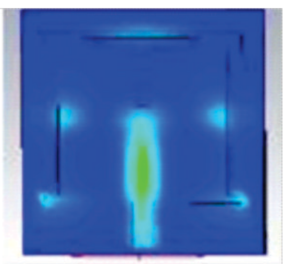


Fig.6(1) Simulated current distribution at 4.6 GHz

A comparison of S11 variations for antennas with only ground plane modified and with both patch and ground modified is shown in Figure 7. The proposed modified rectangular patch antenna with defected ground now resonates at two frequencies namely 3.36GHz and 4.54GHz obtained through simulation analysis and 3.13GHz and 4.09GHz obtained through measurements in free space as shown in Figure 8. The simulated impedance bandwidth with proposed antenna is close to 2.60GHz or 83.18% with respect to central frequency 3.21 GHz while measured impedance bandwidth is close to 2.32GHz or 72.27% with respect to central frequency 3.21 GHz. The first frequency may be used for lower band in Wi-Max communication systems or in fixed mobile except in aeronautical mobiles while the second frequency is suitable for lower band of UWB communication systems. The measured variation of input impedance of antenna as a function of frequency is shown in Figure.9. The modified rectangular patch shows good impedance matching at two resonance frequencies with impedance (47.57+j2.31) ohm and (50.76 – j1.68) ohm respectively. The measured input impedance variation shows the presence of several small loops and notches in input variation which suggests the possibility of circular polarization at these frequencies. However these loops and notches were not realized in simulated impedance variation. The presence of circular polarization of developed prototype could not be experimentally verified due to limited test facilities at our centre.

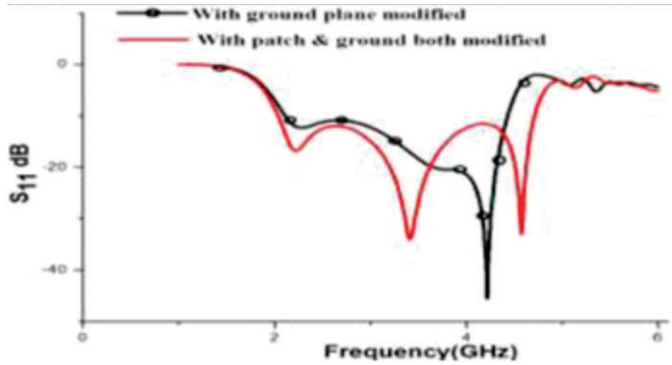


Fig.7 Simulated variation of reflection coefficient of proposed antenna

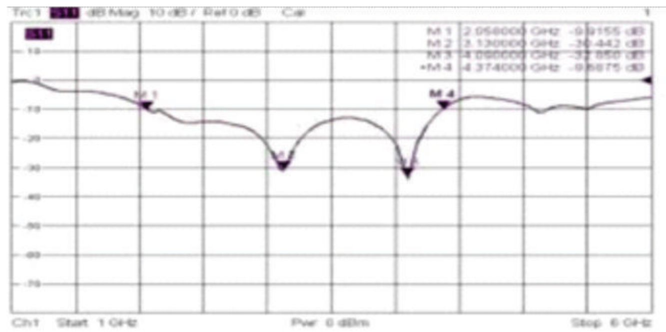


Fig.8 Measured reflection coefficient of developed prototype

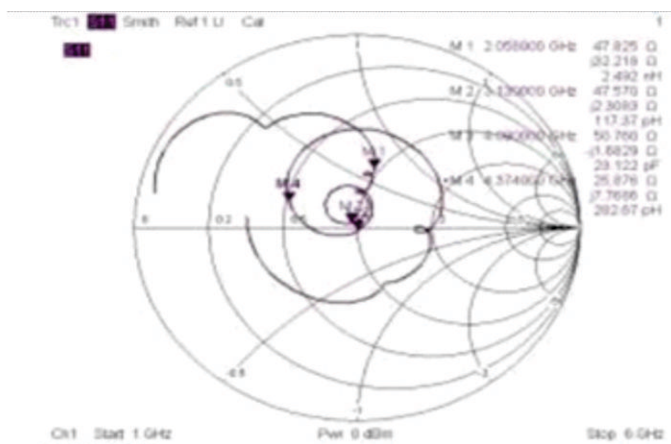
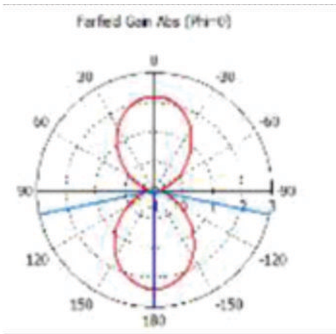


Fig.9 Measured input impedance of developed prototype

The simulated gain of antenna (ϕ = 0 plane) in the operating frequency range is almost flat. The maximum gain of antenna is close to 2.48 dBi at frequency 3.75GHz which is marginally lower than that realized in previous case but it is still higher than the base antenna considered in the beginning of work. The simulated two dimensional and three dimensional gain variations of antenna as a function of angle θ at frequency 3.7GHz (where maximum gain is achieved) are shown in figures 10(a) and 10(b) respectively. The 3D variation suggests

that in an inclined direction (θ = -160o and ϕ = 80o), maximum gain up to 2.99dB may be achieved with proposed antenna. The impedance bandwidth of proposed antenna has improved considerably without much loss in its gain.



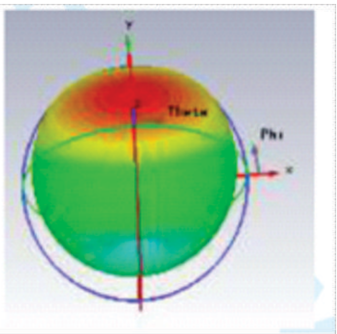


Fig.10 (a) Fig.10 (b)

2D & 3D simulated gain variation at freq. 3.7 GHz

The E (ϕ = 0) and H (ϕ = 90o) plane two dimensional radiation patterns of antenna at two resonance frequencies are shown in figures 11(a) – 11(d) respectively. The E-plane pattern at first resonance frequency is almost omni-directional plane with maximum radiations at angle θ = 180o. The H-plane pattern at this frequency provides 3dB beam width nearly 80o with maximum radiations at angle θ = 20o The E-plane pattern at second resonance frequency provides 3dB beam width close to 115o with maximum radiations at angle θ = 180o while H plane pattern at this frequency provides 3dB beam width nearly 70o with maximum radiations at angle θ = 50o. All these patterns indicate that antenna is radiating almost equal power in front and back direction hence in a way these radiation patterns resemble somewhat with that of a dipole antenna.

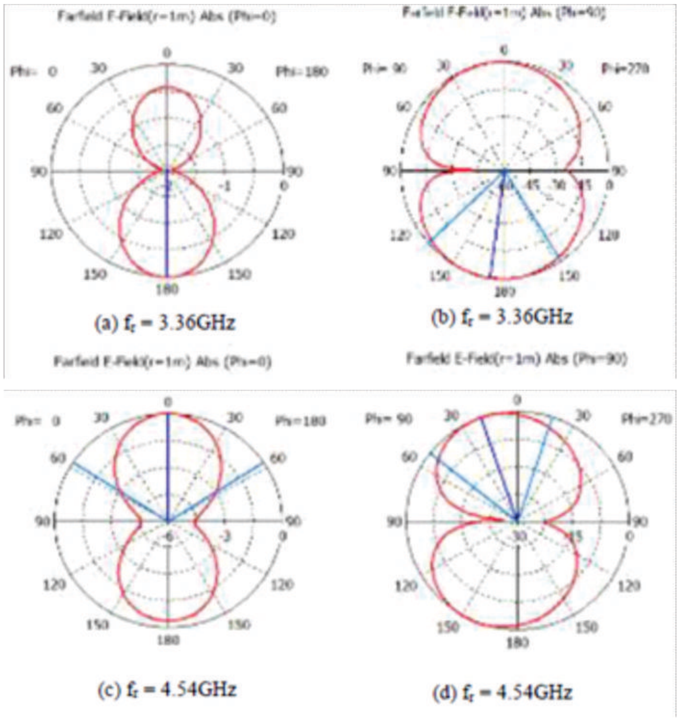


Figure 11: E- and H- plane patterns at frequencies 3.36GHz and 4.54 GHz

III. CONCLUSION

This paper reports the combined effect of defected ground plane and modifications in patch geometry on radiation properties of a rectangular patch antenna having finite ground plane. Proposed antenna provides broader impedance bandwidth (2.32GHz or 72.27% with respect to central frequency 3.21 GHz), VSWR (2:1) and nearly flat gain in desired frequency range in comparison to a compact rectangular patch antenna with finite ground plane. The maximum gain of antenna normal to patch geometry is close to 2.481dBi while gain has maximum value close to 2.99dBi in an inclined direction. Proposed antenna operates well at two resonance frequencies of operations. The first frequency may be used for lower band in Wi-Max communication systems or in fixed mobile except in aeronautical mobiles while the second frequency is suitable for lower band of UWB communication systems.

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