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Design of broadband circular patch microstrip antenna with diamond shape slot

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The radiation performance of a circular patch microstrip antenna having a concentric diamond shape slot has been presented in this paper. The side lengths and angles of the inserted diamond shape slot have been optimized to achieve a single layer multi frequency microstrip antenna applicable for C band space communication systems. For simulation work, IE3D simulation software has been applied and later this antenna has been designed and tested by applying glass epoxy FR-4 substrate. The proposed antenna provides much improved bandwidth (measured impedance bandwidth 0.87 GHz or 13.58%) than a conventional circular patch antenna. The gain of proposed antenna is almost constant in the frequency range where broadband performance is realized, however, it is improved considerably in comparison to a conventional circular patch antenna. The performance of proposed antenna has been compared with that of a conventional circular patch antenna having identical patch radius. The measured co and cross polar patterns of proposed antenna at one of the three resonance frequencies have been presented.

Keywords: Circular patch microstrip antenna, Microstrip antenna, Broadband antenna

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1 Introduction

In recent times, microstrip antennas have attracted the attention of scientists for their possible applications in satellite, mobile and wireless communication systems due to their compact size, light weight and easy production characteristics. These antennas, in general, resonate efficiently at a single resonance frequency corresponding to their dominant mode and have typically narrow bandwidth (1-2%) and low gain[1,2]. Therefore, in their conventional form, microstrip antennas fail to find much application in modern satellite and wireless communication systems. Satellite mounted antennas operating in C band of frequency spectrum must be conformal and compact in size, capable of operating at two or more frequencies at a time and must present broadband performance. Considering these requirements, conventional printed circuit antennas fail to serve their purpose in satellite communication systems. Extensive work in recent past has been reported through modifications in conventional microstrip antenna geometries. Lee *et al.*[3] reported a round corner rectangular wide slot antenna with novel feeding geometry to have better wideband characteristics than a normal rectangular wide slot antenna. Printed wide-slot antenna fed by a microstrip line with a fork-like tuning stub was proposed to achieve improved impedance and gain bandwidths[4]. Wong & Hsu[5] applied a U-shaped slot in an equilateral triangular microstrip antenna to make it broadband structure while improved bandwidth up to 8.67% was recently reported for a circular patch antenna having U-slot[6]. A semi-circular slot antenna with a protruded small rectangular slot was excited by a 50 ohm microstrip line[7] to achieve broadband performance. Krishna *et al.*[8] reported the improved bandwidth design of a compact dual band slot loaded circular microstrip antenna with a superstrate. Bao & Ammann[9] proposed the design of a compact circularly polarized wideband circular patch antenna embedded in a narrow annular-ring which uses an unequal cross-slotted ground plane. Azenui & Yang[10] proposed a transmission line fed crescent patch antenna with displaced center of circular region from center of outer ellipse for wide band applications. Bhardwaj *et al.*[11] applied a pair of triangular notches in square patch geometry while Sharma *et al.*[12] applied a narrow L–shaped slot in right triangular patch geometry to achieve broadband performance.

In this paper, a novel design of single layered circular microstrip antenna having concentric diamond shaped slot is proposed and its simulated and measured radiation performances in free space conditions have been presented. The proposed antenna is found useful for satellite communication systems as it presents the desired performances, *viz.* improved bandwidth and gain and multiple operating frequencies needed for satellite communication systems. A comparison of performance of proposed design with conventional circular patch antenna having identical patch radius has also been reported for better understanding.

2 Circular microstrip patch antenna

First, a circular patch microstrip antenna with radius, *r,* has been considered. The patch having substrate thickness ($h << \lambda_o$), substrate dielectric constant ε_r and relative permeability $\mu_r = 1$ has been considered lying in XY plane over a large ground plane as shown in Fig. 1. The magnetic field in this structure has essentially x and y components. Since $h << \lambda_o$, the fields do not vary along the z-direction and the component of the current; normal to the edge of the microstrip antenna approaches to zero at the edges. With these assumptions, structure has been considered as a cylindrical resonator with magnetic sidewalls, bounded at its top and bottom by electric walls.

Following the formulations proposed by Carver[13], it is found that an inset feed circular patch antenna having patch radius of 16.2 mm; resonates at two frequencies 5.906 and 7.49 GHz in the C-band when it is designed on glass epoxy FR-4 substrate ($\varepsilon_r = 4.4$, $\tan\delta = 0.025$, substrate thickness, h = 0.159 cm) with infinite ground plane. These two frequencies correspond to TM_{31} and TM_{12} modes of excitation.

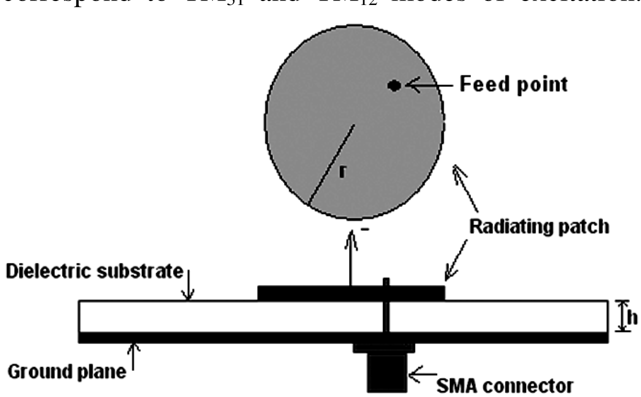

Fig. 1—Geometry of conventional circular patch antenna

The simulated reflection coefficient (S_{11}) variation of same antenna with frequency obtained by using IE3D software[14] has been shown in Fig. 2. This variation indicates that resonance frequencies of antenna in C-band are 5.819 and 7.419 GHz, respectively which are very close to computed resonance frequencies. The impedance bandwidths corresponding to both resonance frequencies are very low (2.42 and 2.53%, respectively). The gain and efficiencies of antenna are also very poor. These outcomes suggest that circular patch antenna in its present form is not suitable for application in satellite communication systems. Therefore, this patch geometry has been modified by introducing concentric diamond shaped slot at the center of the patch geometry and its performance has been presented.

3 Circular patch antenna with diamond shaped slot

The single layered circular patch geometry discussed above has been modified by inserting a concentric diamond shape slot in the circular patch geometry as shown in Fig. 3(a). The top view of designed antenna has been shown in Fig. 3(b). The circular patch with infinite ground plane designed on glass epoxy FR-4 substrate still has radius of 16.2 mm. On applying a diamond shaped slot of dimensions '*a*' and '*b*' on patch geometry as shown in Fig. 3(a), in addition to already existing TM_{31} and TM_{12} modes in conventional circular patch antenna, few additional modes get excited. This fact may be visualized through the presence of additional dips in Fig. 4.

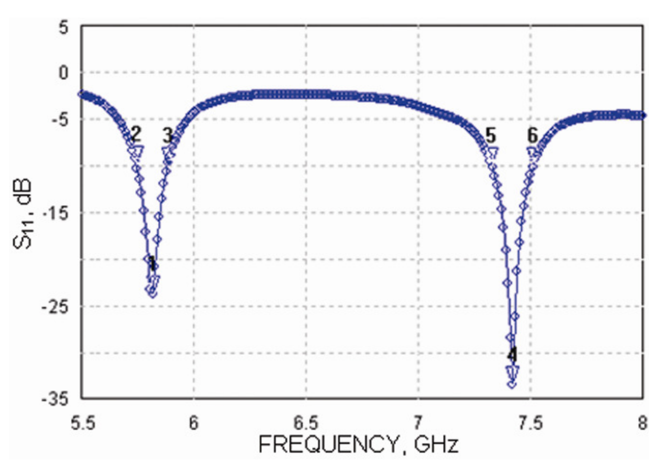

Fig. 2—Simulated variation of return loss as a function of frequency

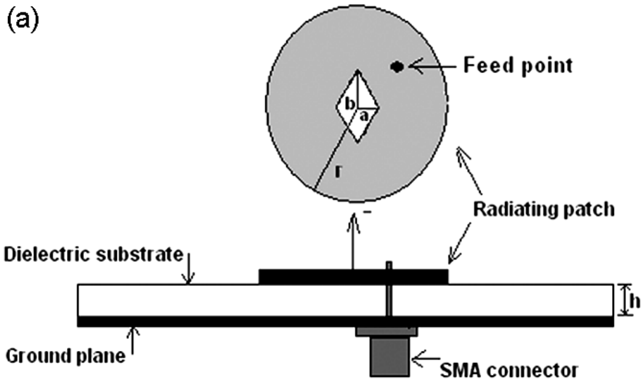

Fig. 3a—View of circular patch geometry with concentric diamond slot

Fig. 3b—View of designed circular patch geometry with concentric diamond slot

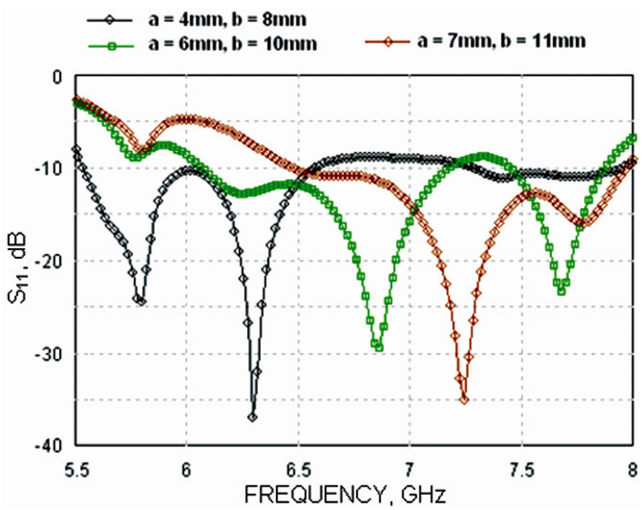

Fig. 4—Variation of return loss with change in slot dimensions

It may be realized that on increasing the size of inserted slot, the effective radius of circular patch decreases, which in turn increases the resonance frequency of antenna under consideration. Extensive optimization in side lengths and slot angles has been carried out and three representative variations of S_{11} parameters as a function of frequency have been shown in Fig. 4. From these variations, it has been realized that on selecting a = 4 mm and b = 8 mm, input bandwidth of antenna approaches to 17.28% while on selecting a = 7 mm and b = 11 mm, input bandwidth approaches to 20.78%. With insertion of diamond shaped slot in the patch geometry, the path of patch current increases, which in turn improves the impedance bandwidth of antenna. In addition to this fact, an additional mode TM_{mn} mode close to TM_{12} mode also gets excited and the two resonance frequencies corresponding to TM_{12} and TM_{31} modes move towards higher frequency side. On increasing the parameters a and b, a stage arrives where the return loss curves corresponding to additional TM_{mn} mode and TM_{12} modes start overlapping each other to give improved bandwidth. This bandwidth value keeps on increasing with increase in slot size. Finally, a limit of parameters a and b arrives and thereafter, bandwidth of antenna starts decreasing. However, in two cases mentioned above, *viz.* a = 4 mm, b = 8 mm and a = 7 mm, b = 11 mm, the radiation patterns in the entire frequency bandwidth are not identical in shape as shown in Fig. 5 for two representative frequencies. An improvement in impedance bandwidth of antenna is not useful till identical radiation patterns in entire bandwidth range are not achieved.

It is realized that out of four geometries reported in Table 1, overall best performance may be achieved with a circular patch antenna having diamond slot having dimensions a = 6 mm and b = 10 mm and therefore, entire work is reported on this antenna. Structure is fed through an inset feed arrangement using a SMA connector associated with 50 ohm feed line. The simulation results suggest that in the range of 5.85 - 7.5 GHz, antenna resonates at two frequencies 6.23 and 6.859 GHz as shown in Fig. 6(a). These frequencies are significantly close to measured resonance frequencies 6.166 and 6.66 GHz. An additional resonance frequency 7.42 GHz of antenna is also realized as shown in Fig. 6(b), which in simulation results is realized beyond 7.5 GHz. With insertion of diamond shaped slot in the patch geometry, the measured S_{11} curves corresponding to frequencies 6.166 and 6.66 GHz overlap each other to provide improved bandwidth. The measured

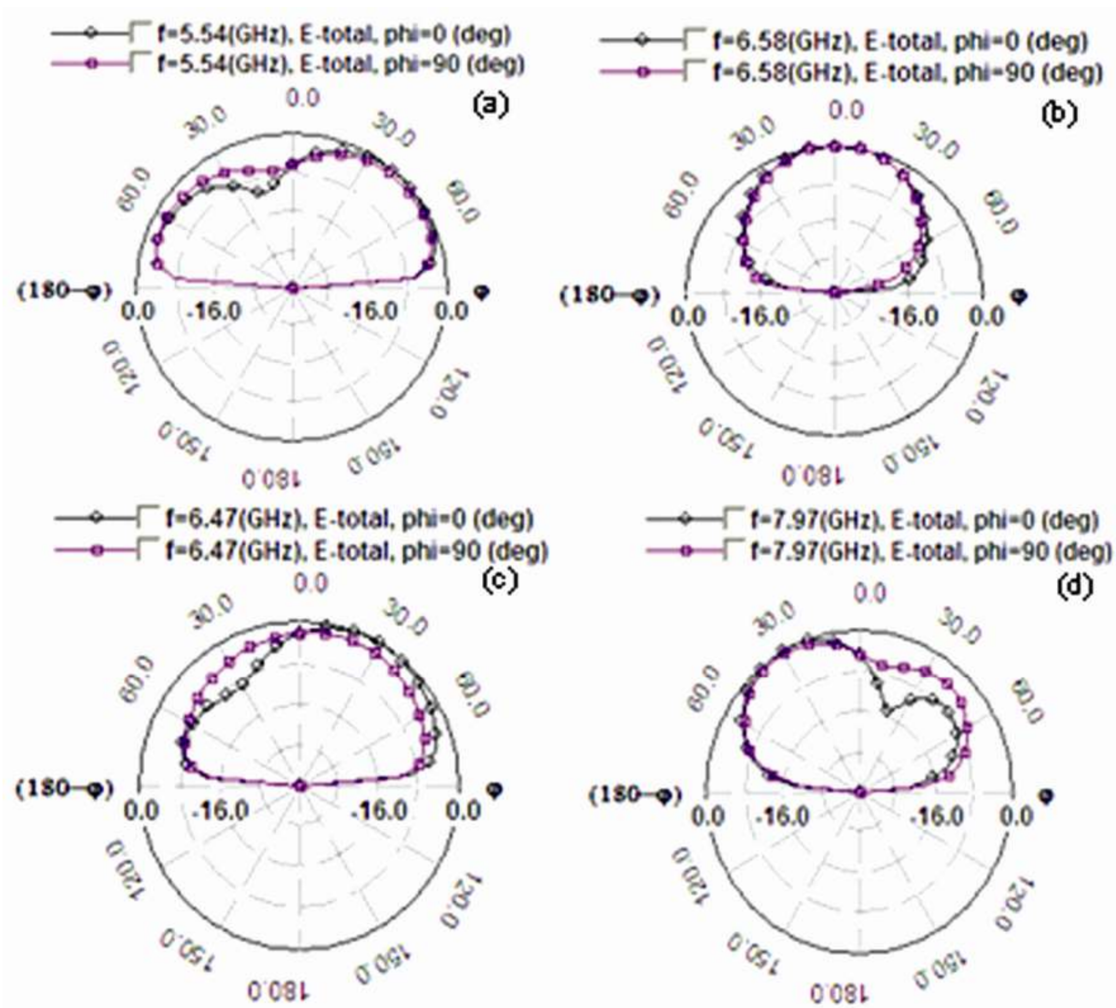

Fig. 5—Two dimensional elevation pattern when slot dimensions are: (a) a = 4 mm, b = 8 mm; (b) a = 4 mm, b = 8 mm; (c) a = 7 mm, b = 11 mm; and (d) a = 7 mm, b = 11 mm

Table 1—Resonance frequencies of circular patch antenna with diamond slot

Slot dimensions	*f1* GHz	*f2* GHz	*f3* GHz	*f4* GHz
Without slot	--	5.819	--	7.419
a = 4 mm, b = 8 mm	5.56	5.80	6.28	7.06
a = 5 mm, b = 9 mm	5.64	5.86	6.45	7.38
a = 6 mm, b = 10 mm	5.76	6.23	6.86	7.67
a = 7 mm, b = 11 mm	5.80	6.62	7.24	7.78

impedance bandwidth is close to 0.87 GHz or 13.58% while simulated impedance bandwidth is 1.05 GHz or 15.99% corresponding to central frequency. The measured bandwidth value is approximately six times higher than that of conventional circular patch antenna with same radius. The measured variation of VSWR and input impedance of antenna as a function of frequency are shown in Figs 7 and 8, respectively. The measured VSWR at all the three resonance frequencies are well within acceptable value 2:1. The measured input impedance of antenna at first and third resonance frequencies are close to 50 ohm impedance of the feed line but little poor matching (37.66 + j10.02) ohm at the second frequency 6.66 GHz is achieved. A comparison between simulated gains of modified circular patch antenna with that of a conventional circular patch antenna with same patch radius is shown in Fig. 9. The variation in gain of antenna in the frequency range 6.05 - 7.17 GHz where the broadband behaviour of antenna observed is very small and the maximum gain of antenna is significantly improved (5.25 dBi) than that of a circular patch antenna. The measured gain values of proposed antenna at two measured frequencies 6.66 and 7.42 GHz are 5.84 and 5.71 dB, respectively.

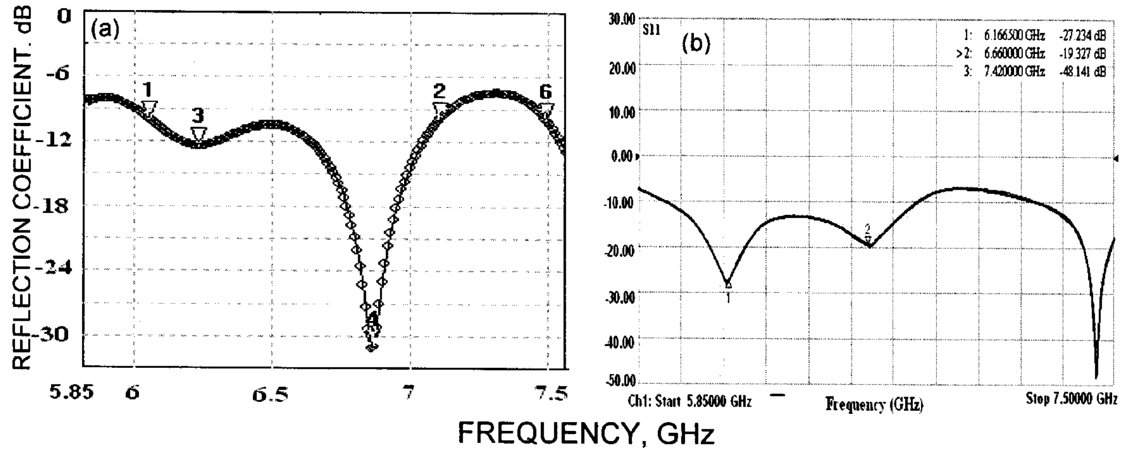

Fig. 6—(a) Simulated; and (a) Measured return loss of modified circular patch antenna

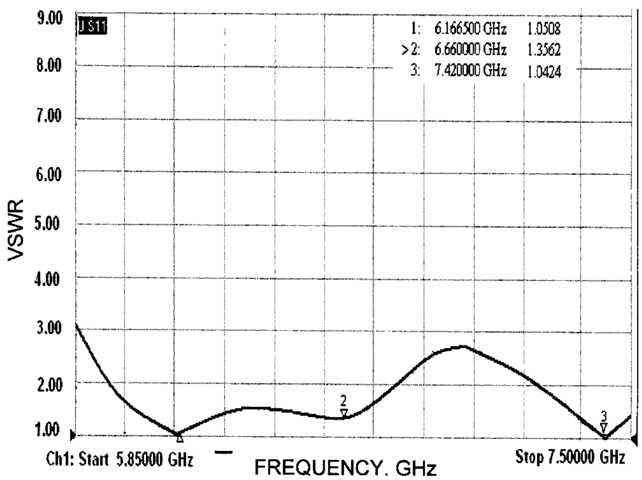

Fig. 7—Measured VSWR of modified circular patch antenna

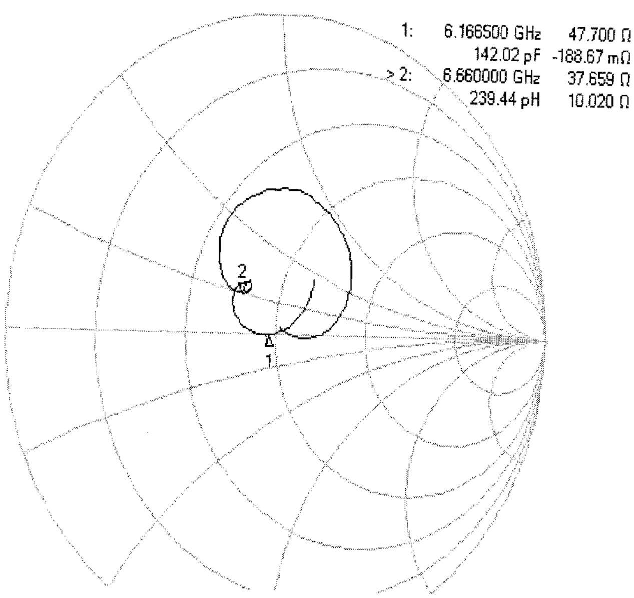

Fig. 8—Measured input impedance of modified circular patch antenna as a function of frequency

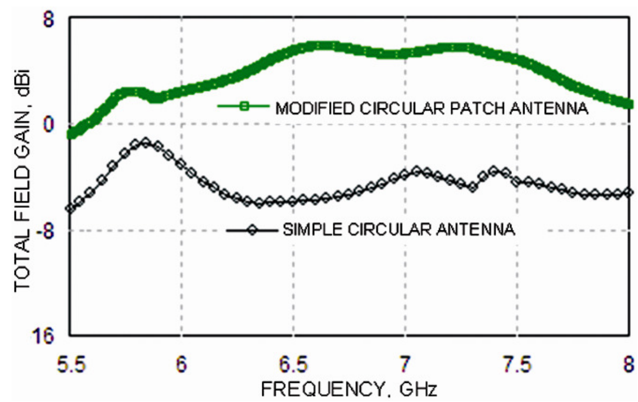

Fig. 9—Comparison of simulated gain of modified circular patch antenna with conventional circular patch antenna

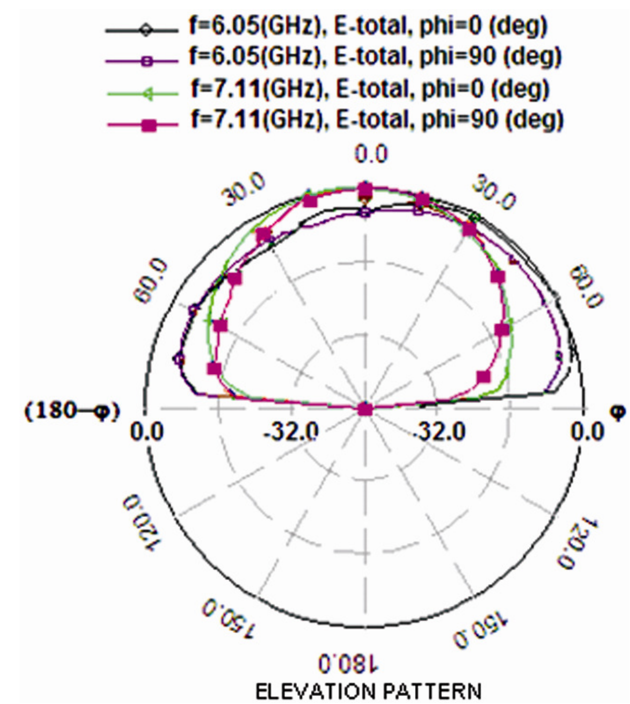

Fig. 10—Simulated E and H plane elevation patterns of antenna at different frequencies

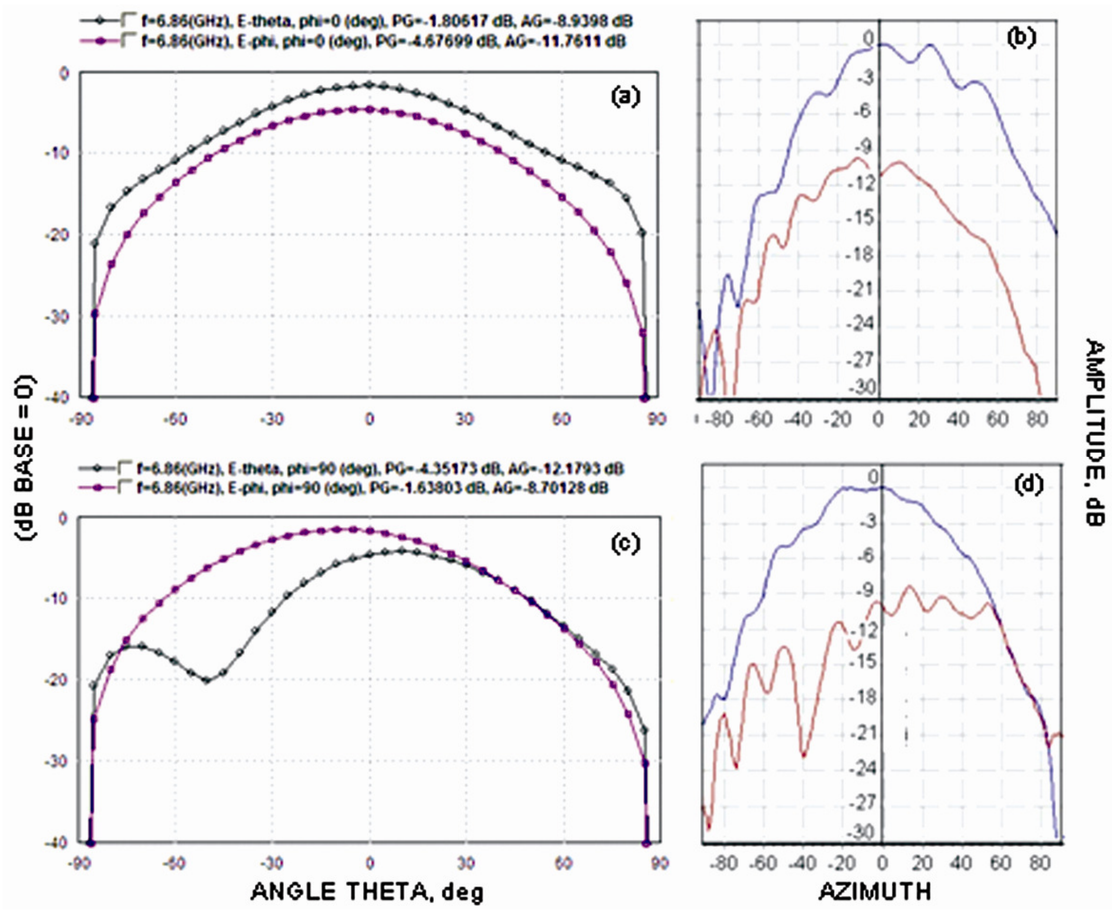

Fig. 11—Co and cross polar patterns of antenna: (a) Simulated E-plane at 6.86 GHz frequency; (b) Measured E-plane at 6.66 GHz frequency; (c) Simulated H-plane at 6.86 GHz frequency; and (d) Measured H-plane at 6.66 GHz frequency

The simulated two dimensional E and H plane elevation patterns of modified circular microstrip patch antenna at two frequencies covering 6.05 - 7.11 GHz frequency range where broadband performance is realized are shown in Fig. 10. Within the selected frequency range, the radiation patterns of antenna are more or less identical in shape and the direction of maximum radiation is nearly normal to the patch geometry. The simulated and measured co and cross polar patterns of this antenna in E and H planes at frequency 6.66 GHz are shown in Figs 11(a-d). These patterns suggest that the simulated and measured patterns are almost identical in shape. In E-plane, the co-polar patterns are nearly 10 dB higher than cross polar patterns; while in H-plane, the co-polar patterns are nearly 8 dB higher than cross polar patterns.

4 Discussion and Conclusions

The radiation performance of a single layer concentric circular patch antenna having a diamond shape slot is reported in this paper through simulation analysis and measured results. The simulation analysis is carried out by applying IE3D simulation software. The proposed antenna is designed on low-cost and easily available FR4 substrate. The designed antenna offers improved impedance bandwidth required for C-band for space communication systems. In the impedance bandwidth range, the gain of antenna is improved significantly than that of a conventional circular patch antenna. The elevation radiation patterns within the frequency range of interest are almost identical in shape. The reported results indicate that the proposed antenna geometry fulfills all the requirements for an antenna required for satellite communication systems, hence, may be proved useful structure for satellite communication systems.

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