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A Stopband Control Technique for Conversion of CPW-Fed Wideband Antenna to UWB

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Abstract—A technique for converting a wide-band coplanar waveguide fed antenna to UWB by positioning slots in the modified ground plane (MGP) adjacent to the feed is proposed in this paper. The slots can be symmetrically or asymmetrically positioned for optimum performance. One slot pair is initially positioned through parametric analysis in the modified ground plane at an equal distance from the feed end for the maximum achievable impedance bandwidth. The second slot pair is similarly positioned, optimising the antenna for ultra wideband operation. Two CPW-fed antenna geometries are experimented using the technique, one unique and the other, a generic circular monopole. Both antennas have MGP and are fabricated on an FR4 substrate. The analysis and simulation have been done in FEM based High Frequency Structure Simulator (HFSS). The performance of the two antennas is measured with a Vector Network Analyzer 'Agilent PNAE8362B'. The impedance bandwidth and radiation pattern validate the performance of the antennas for ultra wideband applications. The experimentally obtained bandwidth precisely covers UWB, and principal patterns are uniform throughout the band.

1. INTRODUCTION

UWB, a high data rate wireless communication technology [1], has inherent advantages of low power consumption, high data security and avoidance of multipath fading. The low cost and small size of the antenna render it for easy integration into various equipment. UWB antennas are used for short range high bandwidth communications like indoor wireless networks, sensor networks, automatic target recognition, RF industrial, SAR system integration and near-field biomedical applications such as microwave imaging for breast cancer detection, to name a few [2–4]. The UWB antenna has to provide wide impedance bandwidth and omnidirectional radiation pattern over the entire band. Thus the modelling of a suitable optimal antenna is always a challenging task in the design of antenna for UWB applications.

Patch antennas with coplanar waveguide feed have inherent advantages of easy design, comparatively less tolerances in fabrication, and smaller copper area. Most wideband antenna designs with CPW feed evolve from a narrowband patch design by the introduction of multiple resonances using complex geometry modifications. Various techniques for impedance matching over a wide bandwidth such as ground plane shaping, feed gap optimization, multiple feeding, feed modification, use of curvature in the radiating patch and ground, to name a few, have been reported [5–8]. In addition to the above mentioned techniques, it can be shown that any existing standard wideband antenna with CPW feed can be modified for UWB operation instead of designing a new antenna.

The design of a UWB antenna from a wideband coplanar waveguide fed patch antenna with asymmetrically positioned square slots in the modified ground plane adjacent to the feed and radiating patch with curvature has been reported [9]. The unique antenna with identical dimensions and symmetrically positioned square slots in the modified ground plane adjacent to the feed optimised for

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performance in UWB was reported [10] but not validated experimentally. In [10], the use of symmetrical square slots in the modified ground plane to adjust the impedance bandwidth of the unique wideband patch geometry using a CPW feed was proposed. In the current paper, the strength of the technique is validated using two different antenna geometries, one the unique antenna and the other a CPW-fed circular monopole (standard geometry) with a modified ground plane. The corresponding simulated and experimental results are discussed in Section 2 and Section 3.

2. ANTENNA DESIGN

The labelled geometry of the unique antenna is shown in Fig. 1, and the detailed dimensions are shown in Table 1. The antenna is simulated on an FR4 substrate material with a thickness of 1.6 mm. The modification of the ground plane using curvatures and the shaping of the radiating patch has been done for extending the impedance bandwidth. The simulated return loss in Fig. 2 shows an impedance bandwidth from 3.1 GHz to 19.3 GHz without the use of slots. The use of square-shaped slots of dimension 1 mm × 1 mm adjacent to the feed gap in the modified ground plane has been done to optimise the bandwidth as shown in the same figure. One pair of symmetrical slots is introduced in the modified ground plane adjacent to the feed at a distance of $h8 = 2.5$ mm from the feed end, for an achievable maximum impedance bandwidth. Introducing a second pair of symmetrical slot at $h9 = 15$ mm optimises the antenna bandwidth to the range 3.1 GHz to 10.75 GHz. The first and second slot positions have been arrived at after parametric analysis.

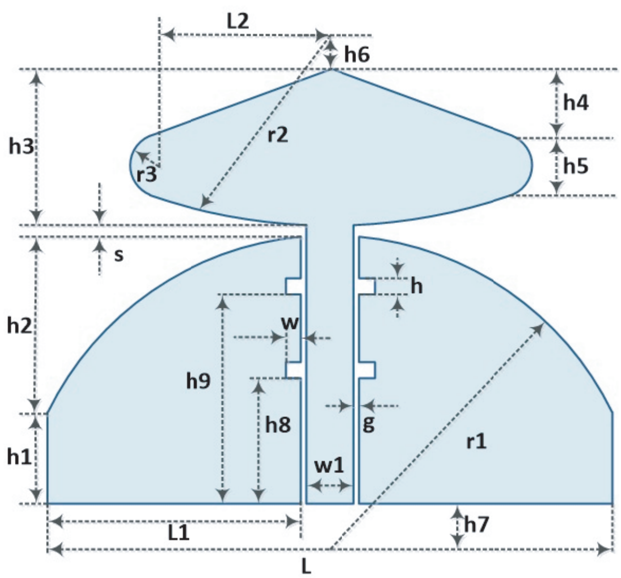

Figure 1. The unique antenna with defective ground structure and symmetrical slots.

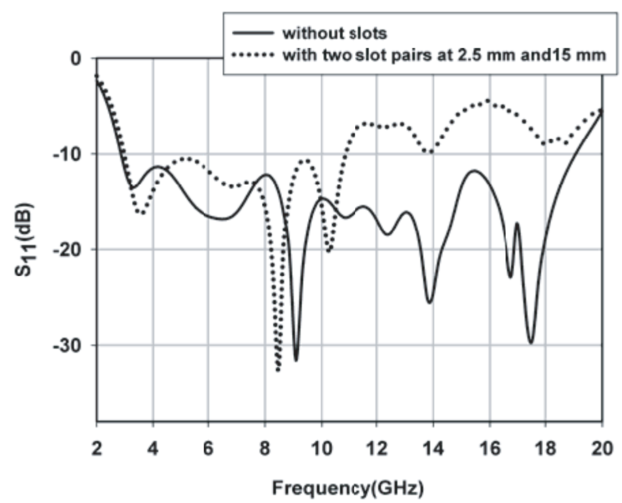

Figure 2. Simulated return loss.

Table 1. Dimensions (mm) of symmetrically slotted antenna.

$h1 = 5.76$	$h8 = 2.5$	$L2 = 11.36$	$h6 = 24.64$
$h2 = 11.08$	$h9 = 15$	$r1 = 19.7$	$h7 = 2.77$
$h3 = 10.12$	$w = 1$	$r2 = 34.8$	$L = 35.5$
$h4 = 4.2$	$h = 1$	$r3 = 2$	$s = 1.03$
$h5 = 4$	$w1 = 3.2$	$g = 0.25$	$L1 = 15.9$

Table 2. Dimensions (mm) of circular monopole.

$b = 17.64$	$y = 4$	$p = 11.6$
$f = 0.35$	$r = 1$	$s1 = 6$
$s = 0.445$	$R = 12$	$s2 = 8$

The technique used in [10] is extended to a generic coplanar waveguide fed circular monopole whose geometry is shown in Fig. 3, and dimensions are specified in Table 2. The ground plane of the antenna has been modified by introducing curvature on the top edge corners near the radiating patch. The optimum radius of curvature, height of the ground plane and dimensions of the circular radiating patch have been optimised through parametric analysis. The antenna is simulated on an FR4 substrate material with a thickness of 1.6 mm. The first pair of symmetrical slots is introduced in the modified ground plane adjacent to the feed gap. The dimension of each slot is 1 mm $\times$ 1 mm which was optimised through parametric analysis. The slots are positioned at distance ($s1$) from the feed end for an achievable maximum impedance bandwidth. The second pair of symmetrical slots at a distance ($s2$) from feed end is introduced in the ground plane adjacent to the feed. The position of the second pair of slots is optimised for ultra-wideband operation. The simulated return loss with two pairs of symmetrically positioned slots is shown in Fig. 4. The simulated impedance bandwidth of the monopole without slots is wideband which exists from 2.6 GHz to 13.8 GHz and with two pairs of slots at $s1 = 6$ mm and $s2 = 8$ mm, and the band is reduced to UWB which extends from 2.69 GHz to 10.7 GHz.

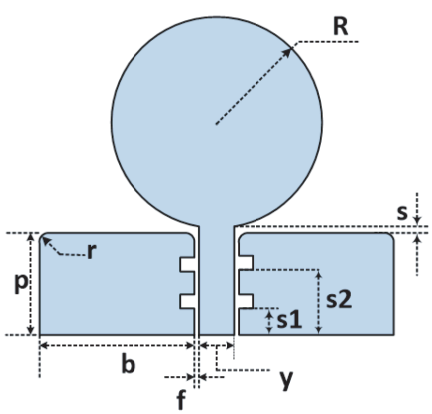

Figure 3. Circular monopole with slots.

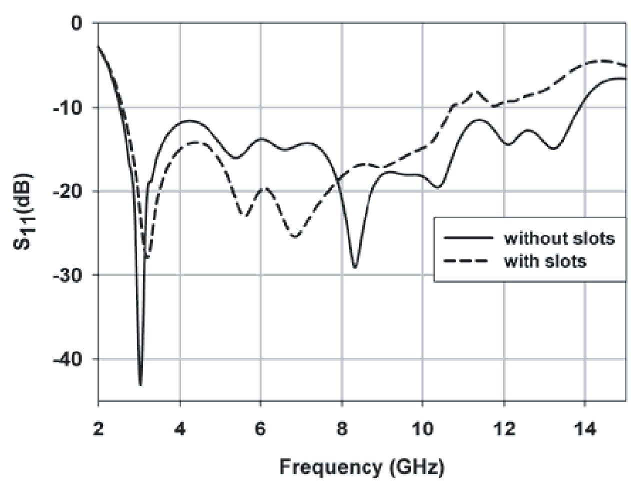

Figure 4. Simulated return loss.

The current density at three resonant frequencies is computed and shown in Fig. 5 for the unique antenna [10]. Similarly, the current densities for the CPW-fed circular monopole geometry of three resonant frequencies are computed and shown in Fig. 6. The number of resonant frequencies for which computations are done is limited to three for brevity. The antenna current distribution in both cases is interpreted with respect to its performance as in [11]. It can be seen that the currents are concentrated along the lower edge of the radiating patch and the upper edge of the modified ground plane. Effect of slot pair nearer to the feed end on the current density dominates at lower frequencies of the band. The current density at slot pair positioned nearer to the radiating patch dominates at higher frequencies of UWB and also effects the truncation of the wideband behaviour of UWB.

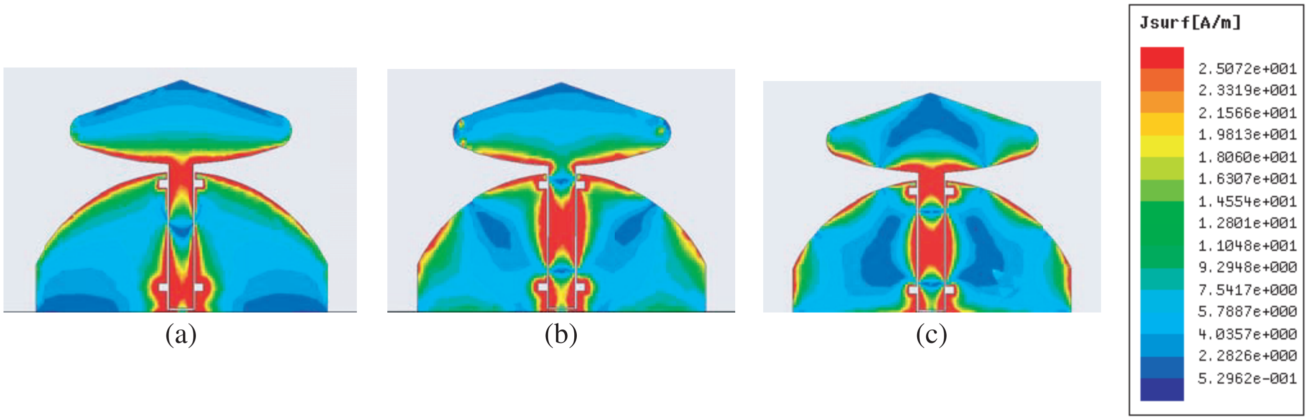

Figure 5. Simulated current density of the unique antenna. (a) 3.6 GHz. (b) 8.5 GHz. (c) 10.3 GHz.

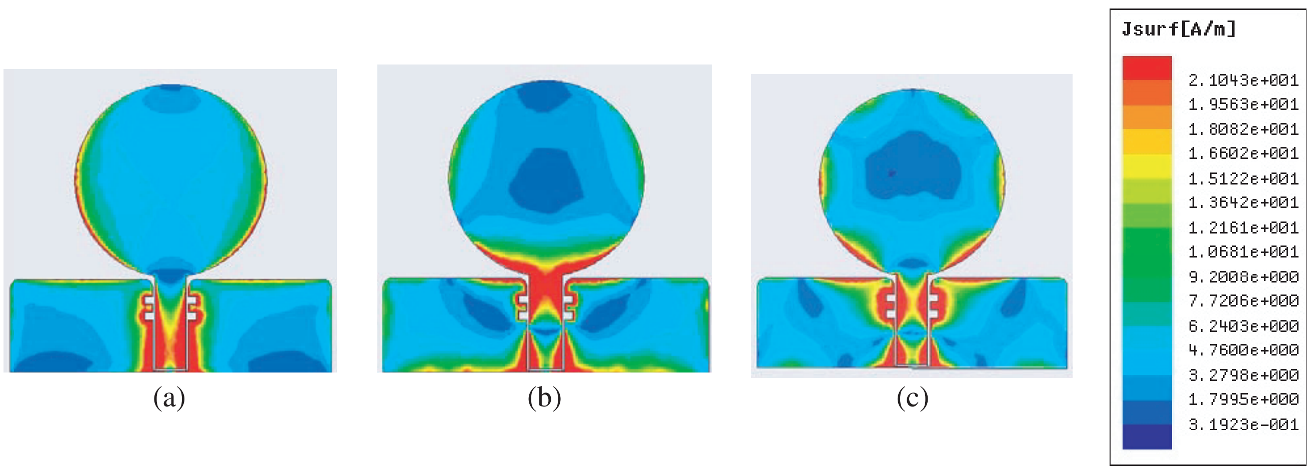

Figure 6. Simulated current density of circular monopole. (a) 3.4 GHz. (b) 6.8 GHz. (c) 10.2 GHz.

3. EXPERIMENT RESULTS

The unique antenna was fabricated on an FR4 glass epoxy substrate single-sided copper clad PCB of thickness 1.6 mm as shown in Fig. 7. The return loss and radiation pattern were measured on Vector Network Analyzer 'Agilent PNAE8362B'. The return loss obtained experimentally for two pairs of slot positions at $h8 = 2.5$ mm and $h9 = 15$ mm is shown in Fig. 8. The resonances are seen at 3.6 GHz, 6.9 GHz, 8.5 GHz and 10.3 GHz from simulation and at 3.81 GHz, 5.88 GHz, 8.381 GHz and 10.70 GHz from the experiment. The shift in the resonances can be attributed to tolerances in the fabrication of the antenna. The radiation pattern of the antenna is measured and plotted as shown in Figs. 9(a) to 9(f). The principal patterns are uniform in the range 3 GHz to 11 GHz, with cross-polarisation fields dominating towards the upper frequencies within the band.

The circular monopole antenna with two pairs of symmetrical slots was fabricated on an FR4 glass epoxy substrate single-sided copper clad PCB of thickness 1.6 mm as shown in Fig. 10. The return loss for the circular monopole is measured on the VNA and is shown in Fig. 11 along with simulated values. The resonances obtained experimentally with slots at $s1 = 6$ mm and $s2 = 8$ mm are at 3.4 GHz, 4.7 GHz, 6.03 GHz, 8.7 GHz and 10.2 GHz with impedance bandwidth extending from 3.07 GHz to 10.86 GHz. The introduction of symmetric slots in the modified ground plane has truncated the impedance bandwidth without slots (2.7 to 13.2 GHz) to ultra wideband. The radiation patterns of the antenna are measured for the frequency range from 3 GHz to 11 GHz and plotted as shown in

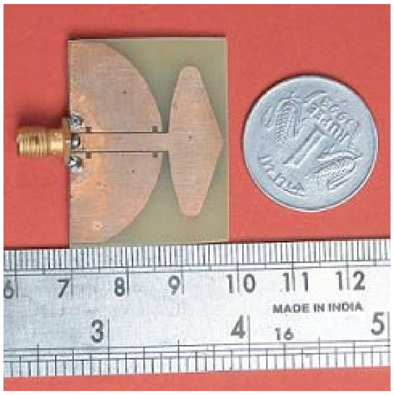

Figure 7. Fabricated antenna.

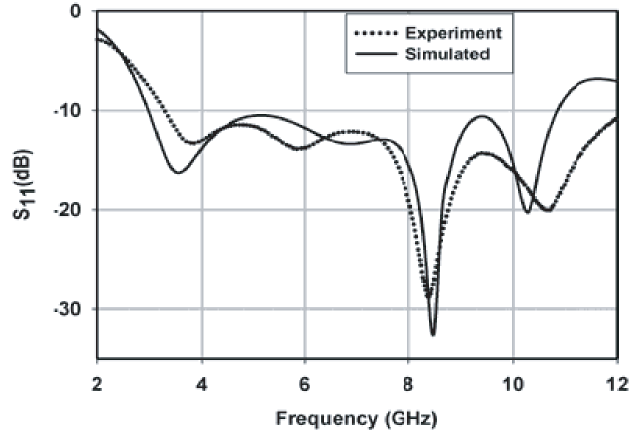

Figure 8. Return loss of fabricated antenna.

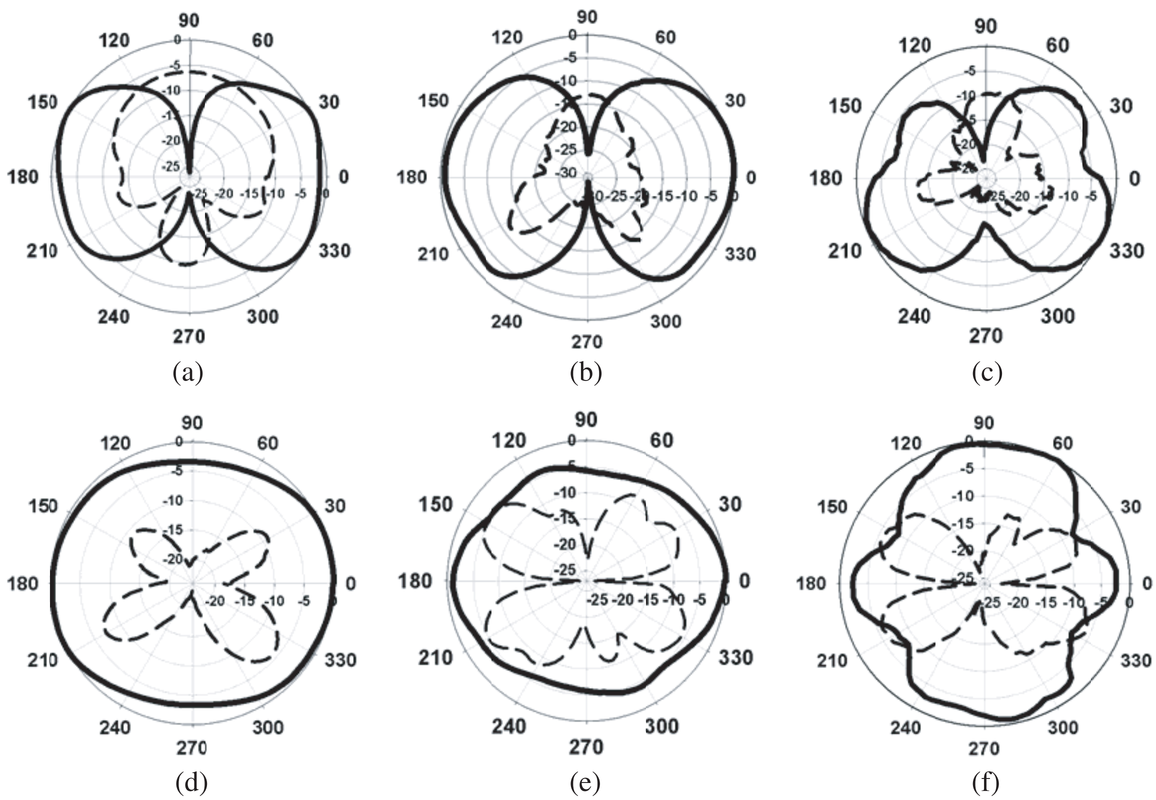

Figure 9. Radiation pattern of unique antenna [3], co-polarised (solid line), cross polarised (dashed line). (a) E-plane (4 GHz). (b) E-plane (7 GHz). (c) E-plane (10 GHz). (d) H-plane (4 GHz). (e) H-plane (7 GHz). (f) H-plane (10 GHz).

Figs. 12(a) to 12(f) for 4 GHz, 7 GHz and 10 GHz. The cross-polarized fields seem to dominate for the upper frequency region in the band, but co-polarized fields are uniform throughout the band. The H-field patterns are omnidirectional at lower frequencies, but show slight deterioration towards the higher frequencies in the band.

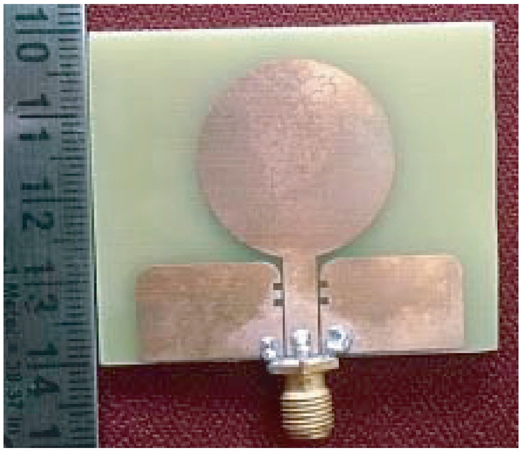

Figure 10. Circular monopole antenna.

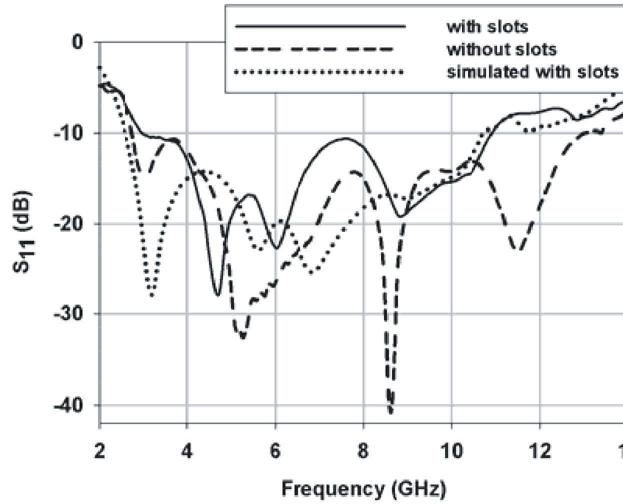

Figure 11. Return loss of fabricated antenna.

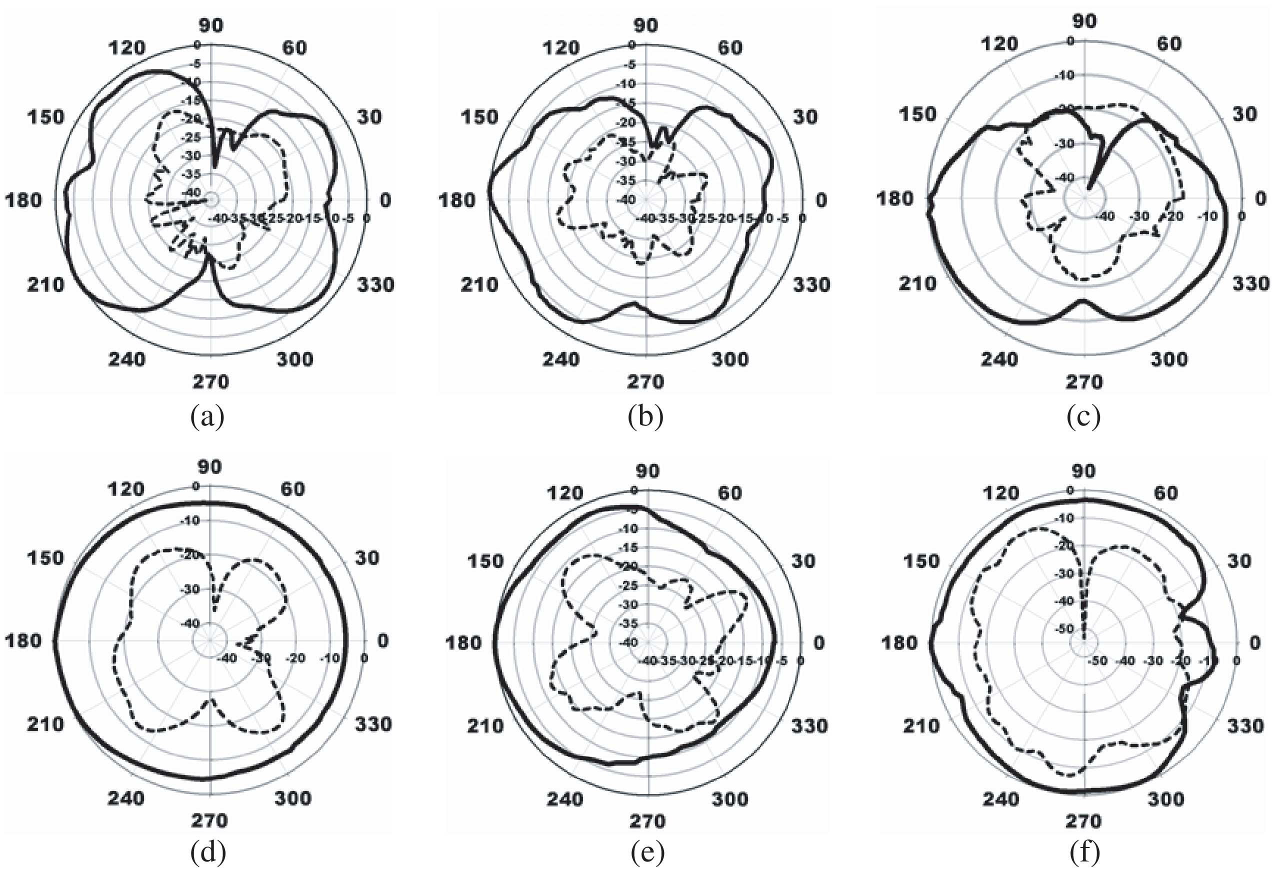

Figure 12. Radiation pattern of the circular monopole with slots in MGP, co-polarisation (solid line), cross-polarisation (dashed line). (a) *E*-plane (4 GHz). (b) *E*-plane (7 GHz). (c) *E*-plane (10 GHz). (d) *H*-plane (4 GHz). (e) *H*-plane (7 GHz). (f) *H*-plane (10 GHz).

4. CONCLUSION

A technique for conversion of a CPW-fed standard wideband antenna (circular monopole) for UWB operation is proposed. This is achieved by introduction of two pairs of symmetrical slots optimally positioned in the modified ground plane adjacent to the feed gap. The simulation and experiment results obtained from two different CPW-fed geometries, the unique antenna and the standard circular monopole are in close agreement. The return loss of the circular monopole with slots validates the performance of the antenna in UWB. The radiation pattern preserves omni-directionality over UWB. The technique can be used for tuning of any standard CPW-fed wideband antenna reported in the literature to UWB.

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