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MODIFIED UNIDIRECTIONAL CIRCULAR PATCH ANTENNA WITH PARABOLIC SHAPE GROUND PLANE HAVING T-SLOTS FOR MICROWAVE LINKS

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Abstract

A modified design technique of unidirectional circular patch antenna with parabolic shape ground plane for the application of microwave links is being presented here. Firstly, T-slots are inserted diagonally at the corners of parabolic ground plane in order to increase the directivity. Thereafter, for the further improvement in the directivity as well as gain the ellipse slot in circular patch has also been introduced. The microstrip feed line is given for the proposed unidirectional antenna. The simulation analysis of the antenna is done on software CST Microwave Studio using FR-4 substrate with dielectric constant 4.3. The simulated results and parametric analysis show a good return loss with respect to -10 dB. The radiation pattern characteristic, gain characteristic, VSWR pattern and surface current distribution performance of the antenna have also been compared at different resonate frequencies.

Keywords:

Parabolic Ground, Ellipse Slot, Unidirectional Antenna, Microwave Links, Microstrip Line

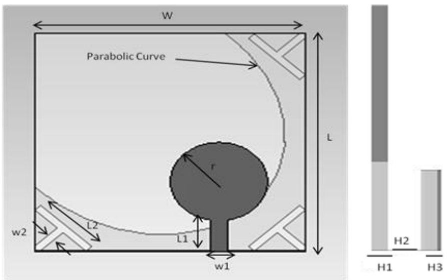
1. INTRODUCTION

Recently, there is an increase in the requirement of unidirectional ultra-wideband (UWB) antennas in the area of communication systems. The Federal Communication Commission (FCC) has allocated 7.5 GHz of bandwidth which covers the frequency range of 3.1 to 10.6 GHz for ultra-wideband applications [1]. One important aspect of choosing a unidirectional UWB antenna design is to ensure that the design will not cause the pulse to spread over the large bandwidth and low-power pulses when it is transmitted and another is that the antenna will be highly efficient in radiating electromagnetic energy [2-3]. The aim of the unidirectional antenna is to increase the directivity as well as it optimizes the half power beamwidth (HPBW) for the long distance communication [4-5]. A number of designs have recently been introduced which demonstrate the wide impedance bandwidth and unidirectional radiation patterns that include the Horn or Vivaldi antennas [6]-[7]. The printed wideband monopole antennas having an L-shaped or parabolic shaped ground plane have been demonstrated for microwave breast cancer imaging [8-10]. The ground plane optimization of the co-planar waveguide feed has been reported with different shapes of the antenna patch like circular, ellipse, egg-shaped for ultra-wideband applications [11-12]. In all the above research works, the effect of the optimization characteristics of the ground plane unidirectional antennas has been reported.

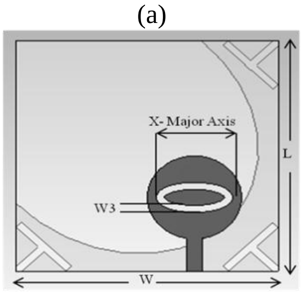
In the present work, a modified design approach of the unidirectional patch antenna is presented. The proposed unidirectional circular patch antenna is designed with modified parabolic ground plane by inserting the T-slots diagonally at the corners of the parabolic ground plane. The proposed antenna operates in the frequency range of 4 GHz to 10 GHz. Further, the ellipse shape slot is inserted in circular patch to increase the directivity as well as gain as compared to conventional parabolic ground plane antenna. The antenna consists of a parabolic ground with T-slots, a circular patch having ellipse slot and 50 ohm microstrip feeding line. The applications of the antenna are in the area of microwave links, airborne radar and satellite communications. Optimum dimension of the antenna is obtained by simulation CST software.

2. ANTENNA DESIGN

The proposed design of the parabolic ground plane having T-slots diagonally and circular patch with ellipse slot is shown in Fig.1.



(a)



(b)

Fig.1(a). Top and side view modified parabolic ground plane, (b). Geometry of the proposed modified circular patch antenna, with all dimensions

The antenna has a ellipse slotted circular patch having radius r designed on FR-4 substrate with dimensions L, W and H, which are the length, width and height of the substrate, respectively. The ellipse slot introduced carefully with major and minor axis. The major and minor axis of ellipse slot is placed at the center of circular patch in X, Y directions, respectively. In the back side of the substrate there is a parabolic shaped ground plane which is designed carefully by inserting the T-slots at the optimum corners of the parabolic ground plane to improve the directivity. The edges of the parabola are placed in X, Y directions at 25mm, 30mm, respectively. The focal point of the parabola is placed on the circular patch having X_{center} and Y_{center}.

The parabolic curve is rotated 45 degrees diagonally for stable unidirectional pattern. The feed line width and length are selected in the x, y directions, respectively to obtain the 50 ohm impedance matching. The dimensions of the proposed design have been given in Table.1.

Table.1. Design parameters of the proposed antenna

Parameters	Dimensions (mm)
Length of Antenna L	50
Width of Antenna W	50
Height of Antenna H	1.6
Radius of Patch r	09
Length of Microstrip line L_1	7.2
Width of Microstrip line W_1	03
Height of Patch H_1	0.5
Height of Dielectric (FR-4) H_2	0.6
Height of Ground H_3	0.5
Parabola Curve Edge [X,Y]	25, 30
Parabola Focal Point [X_{center}, Y_{center}]	0, 9
T-Slot Length L_2	1.5
T-Slot Width W_2	0.5
Ellipse Slot Axis [X_{major}, Y_{minor}]	6, 2

3. RESULTS AND DISCUSSION

The simulation analysis and characteristic of the proposed antenna geometries is done by software CST Microwave Studio.

3.1 RETURN LOSS/VSWR

The simulated return loss variation is shown in Fig.2, which represents the effect of the bandwidth due to varying the different position of the parabola curve edge and ellipse slot axis in x-y plane. The variation of return loss (S11) and bandwidth of the designed antenna are the function of the frequency due to ellipse slotted patch and inserted T-slots in the parabolic ground plane.

The modified ellipse slotted circular patch resonates at frequencies of 4.5 GHz, 6.0 GHz, 7.5 GHz and 9.3 GHz and the return loss of each of these frequencies fall below -10 dB which are -39 dB, -60 dB, -52 dB and -38 dB, respectively. The calculated -10 dB bandwidth is given in Table.2. These resonate frequencies are useful for satellite communication and radar applications.

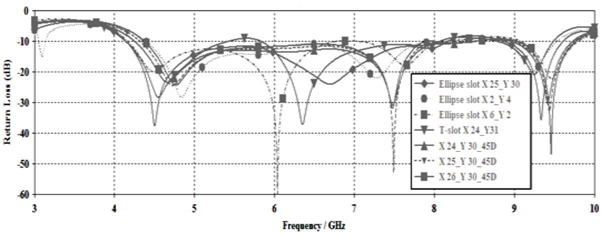


Fig.2. Comparison of return loss performance with frequency of modified parabolic ground and ellipse slotted patch antenna

The VSWR defines the matching properties of the antenna, which indicates the mismatch amount between the transmission line and the antenna. If the antenna is not perfectly matched with the transmission line then the incident signal is reflected back which causes the existence of voltage standing waves in the feed line. Due to this, very few radiations are emitted by the antenna because only small portion of incident signal is accepted. Ideally, the value of VSWR should be equal to 1 means 100% power is accepted with zero reflection.

The simulated VSWR plot of the modified parabolic ground plane and ellipse slotted patch is shown in Fig.3. The VSWR represented by the proposed antenna is between 1 and 2.2 at resonant frequency as shown in Fig.3. It can be observed that, the value of VSWR is lower than 2:1 for ellipse slotted patch antenna, therefore, it can provides the better matching between the antenna and transmission line.

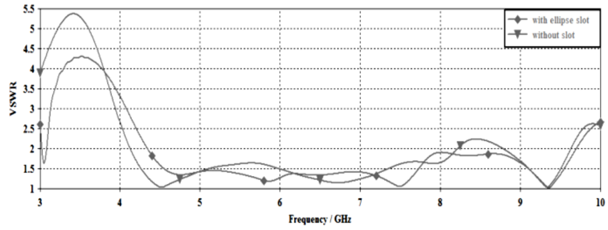


Fig.3. Comparison of VSWR with frequency of modified parabolic ground plane and ellipse slotted circular patch antenna

3.2 ANTENNA GAIN

The simulated gain variation plot of the modified parabolic ground plane antenna and ellipse slotted patch antenna are shown in Fig.4. It can be observed that the gain for modified parabolic ground plane antenna at 8.5 GHz frequency is obtained 8.9 dB whereas, the maximum gain for ellipse slotted patch is obtained 10.9 dB at 7.5 GHz which means that the gain of the proposed antenna has increase up to 2 dB when size of the patch is reduced by inserting the slot.

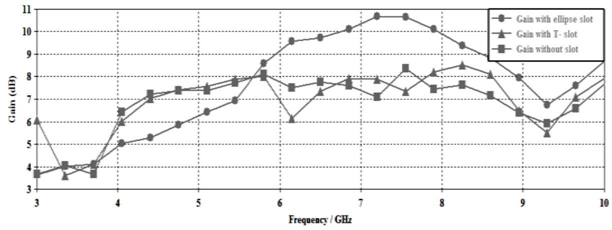
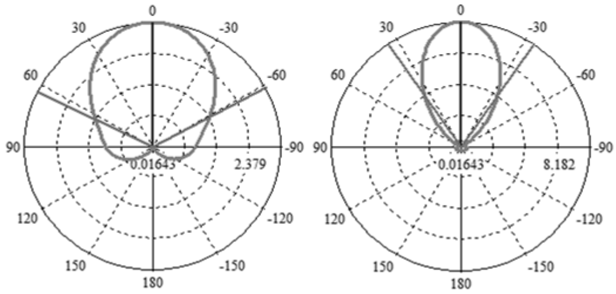


Fig.4. Comparison of gain variation with frequency of modified parabolic ground plane and ellipse slotted circular patch antenna

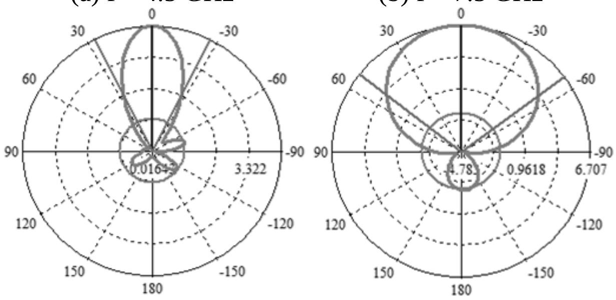
3.3 RADIATION PATTERNS

The simulated radiation patterns of the proposed antennas are compared at different frequencies as shown in Fig.5. The 3-dB angular width or directivity of the parabolic ground plane with T-slots antenna is observed as 125°, 68° and 52° (° = degree) in the x-y plane at 4.5 GHz, 7.5 GHz and 9.3 GHz frequencies, respectively.

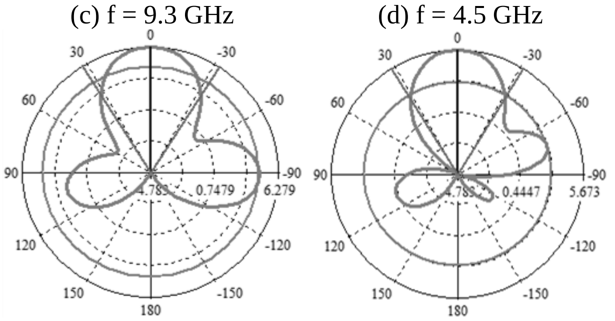
The angular width of the ellipse slotted circular patch is obtained 105°, 64° and 60° at the same frequencies in the x-y plane. It can be concluded that the main lobes of the ellipse slotted patch are more directives towards 0° as compared to parabolic ground plane with T-slots antenna.



(a) f = 4.5 GHz (b) f = 7.5 GHz



(c) f = 9.3 GHz (d) f = 4.5 GHz



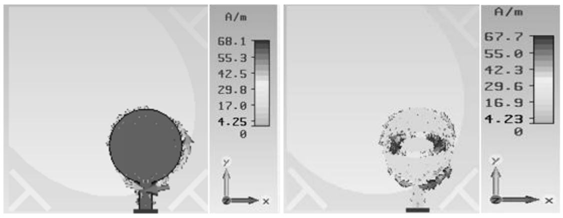
(e) f = 7.5 GHz (f) f = 9.3 GHz

Fig.5. Simulated radiation patterns of parabolic ground plane with T-slots (a), (b), (c) and ellipse slotted patch antenna (d), (e), (f) at different frequencies in x-y plane

3.4 CURRENT DISTRIBUTIONS

The current distributions of the simulated surfaces of the designed patch antennas with microstrip feed line are shown in Fig.6, at resonate frequency of 7.5 GHz. It is observed that, the high value of the current surface distribution is around the edges of the ellipse slotted circular patch as compared to parabolic ground plane with T-slots.

The current is mainly concentrates at the edges of the slots which increases the path length of the current. Due to increasing the path length of the surface current around the slots the resonant frequency decreases. The corresponding values of the surface currents are shown in Fig.6 as labels.



(a) (b)

Fig.6. Surface current distributions of parabolic ground plane with T- slots antenna (a) and with ellipse slotted patch antenna (b) at frequency of 7.5 GHz in x-y plane

4. PARAMETRIC ANALYSIS

4.1 EFFECT OF PARABOLIC EDGE LOCATION

The parabolic curve edge location plays an important role in the design performance of the proposed antenna. The variation of return loss with resonate frequency for different parabolic edge location is given in Table 2. It is observed that when curve edge location is varied along x axis, the better bandwidth can be obtained.

Table.2. Calculated and simulated parameters of the parabolic ground with T-slots antenna and ellipse slotted patch antenna

Proposed Antenna	Parabola curve edge location		Simulated -10 dB bandwidth (GHz)	Return Loss (dB)	Resonate Frequency (GHz)
	X	Y			
Parabolic ground with T-slots	24	31	4.2 - 9.5	-29 -39 -21	4.5 6.3 9.3
	25	30	4.0 – 9.6	-25 -52 -32	4.7 7.5 9.5
Parabolic ground with ellipse slotted patch	25	30	3.5 – 9.4	-39 -24 -52 -38	4.5 6.5 7.5 9.3
	23	29	3.5 – 10	-21 -60 -22	4.5 6.0 9.5

4.2 EFFECTS OF SLOT IN GROUND AND PATCH

The performance analysis of the proposed antenna is given in Table 3. The bandwidth of the proposed antenna increases when the slot is inserted in the ground plane and antenna resonates at multiple frequencies with increasing length and width of slot. The gain of the ellipse slotted antenna increases up to 2 dB due to reduction of patch size as shown in Fig.4.

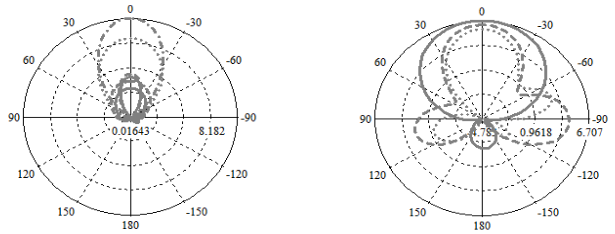
Table.3. Comparative analysis of the proposed antenna

Antenna Parameters	Golezani et al. [8]	Parabolic ground with T-slots	Parabolic ground with ellipse slot patch
Resonate Frequency (GHz)	6	4.5	3.2
	7	6.3	4.5
	9	7.5	6.5
	-	9.3	7.5
3-dB Angular width (°)	110	125	105
	70	68	64
	62	52	60

Gain (dB)	8	8.9	10.9
Bandwidth (GHz)	4 - 9	4.1 - 9.3	4 - 10
Application	Microwave Imaging	Airborne Radar	Satellite, Microwave links

The radiation patterns of the proposed antenna at different frequencies are shown in Fig. 7. The 3-dB angular width or half power beam width (HPBW) of the ellipse slotted circular patch antenna rotates between 60° to 105° degrees in the x-y plane among 4.5-9.5 GHz frequency.

On the other hand, the angular width of the parabolic ground plane with T-slot antenna rotates between 52° to 125° degrees in the x-y plane at same frequency, which means that the main lobes of the ellipse slotted antenna give the more directional pattern as compared to the T-slot antenna and Golezani et al. [8], as shown in Fig 8.



(a) f = 4.5, 4.9, 6.5, 7.5, 9.3, 9.5 GHz (b) f = 4.5, 4.9, 6.5, 7.5, 9.3, 9.5 GHz

Fig.7. Radiation patterns of ellipse slotted antenna (a) and parabolic ground with T-slots (b) at different frequencies in x-y plane

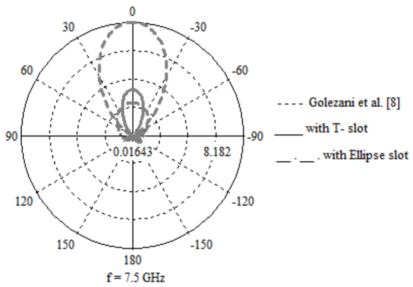


Fig.8. Simulated radiation pattern of the antenna compared with antenna [8] at the frequency of 7.5 GHz in x-y plane

5. CONCLUSION

A modified design technique of unidirectional circular patch having parabolic shape ground plane antenna has been reported for the application of microwave links and satellite communication systems. Wide operating bandwidth of 4-10 GHz and good return loss has been obtained by inserting the T-slots in the parabolic ground plane. Further, the 10.9 dB gain as well as stable unidirectional radiation pattern has been obtained by modifying the patch of the antenna and results are compared with the other conventional antennas. Also, parametric analysis has been given in terms of 3dB beamwidth, return loss, radiation performance, VSWR, gain characteristics and surface current distribution at different frequencies. The proposed antenna is under test for the verification of the obtained results.

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