Uni-directional CPW-fed Slot Antennas Using Loading Metallic Strips and a Widened Tuning Stub on Modified-Shape Reflectors

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Abstract

We have observed that the size and shape of the conducting reflector of CPW-fed slot antennas using loading metallic strips and a widened tuning stub have significant impact on the antenna impedance matching and radiation pattern. By shaping the reflecting conductor, noticeable enhancements in both radiation pattern which provides uni-directional all frequency operating band and characteristic impedance matching are achieved.

1. Introduction

The technique for reducing back radiation of the CPW-fed slot antennas is of interest due to it is possible place some type of conducting reflector behind the slot in order to reduce backside radiation and increase the gain. Among the several popular reducing back radiation techniques, a flat conducting reflector is easy in fabrication and most popular method for the electrically thick substrate CPW-fed slot antenna [1]. However, the presence of the flat conducting reflector may cause problems such as power leakage in the parallel-plate modes which degrade impedance bandwidth and radiation pattern. In addition, the reflector must be placed a quarter-wavelength away from the slot reflector for proper operation. Hence, the resulting structure is not of low-profile nature at lower RF frequencies. Other methods of introducing compensation and modification to the reflector for improving the directional properties of the antennas are proposed, such as using a cavity backed [2], a W-shaped ground plane [3], a cylindrical or conical surface [4] and many reflector shapes. Each configuration belongs to its own advantages and disadvantages.

In this paper, CPW-fed slot antennas using loading metallic strips and a widened tuning stub on modified-shape reflectors are proposed. For this kind of antenna varying the size or shape of the reflectors offer the possibility to influence or control the radiation characteristics in wide range. Two significant parameters –impedance bandwidth and uni-directional radiation pattern–can be adjusted for a specific application in this way. Details of the design considerations of the proposed antennas are presented in following sections.

2. CPW-fed Slot Antenna Above Various Types of Conducting Reflectors

The geometry of a CPW-fed slot antennas using loading metallic strips and a widened tuning stub is depicted in Fig. 1(a). Three different geometries of the proposed conducting reflector behind CPW-fed slot antennas using loading metallic strips and a widened tuning stub are shown in Figs. 1(b), (c), and (d). It comprises a single FR4 layer suspended over a metallic reflector, which allows to use a single substrate and to minimize wiring and soldering. The

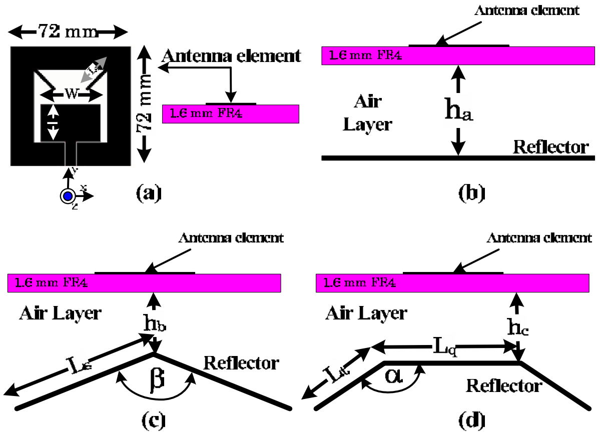


Fig. 1: CPW-fed slot antennas using loading metallic strips and a widened tuning stub (a) antenna element, above (b) flat reflector, (c) corner reflector, and (d) Λ-shape reflector with the horizontal plate.

antenna is designed on a FR4 substrate 1.6 mm thick, with relative dielectric constant 4.4. The antenna has a widen tuning stub width (W), length(L), and loading metallic strips ($L_1 \times 2$ mm), chosen to widen bandwidth. From our previous work [5] which the impedance matching of the antenna can have an impedance bandwidth larger than 67 % (1475-2966 MHz) from the center frequency. This structure without a reflector radiates a bi-directional pattern and maximum gain is about 4.5 dBi.

The first antenna, Fig. 1(b), is the antenna located above a flat reflector, with a reflector size 100×100 mm^2. The distance between the reflector and the CPW-fed slot antenna is h_a. The second antenna as shown in Fig. 1(c), a corner reflector is designed with two flat planes forming a triangle in the apex of the angle β or a Λ-shaped reflector. The length of the slope reflector is L_s. The distance from the apex through the antenna element to the forward edge of the reflector planes will be the depth h_b. In the third structure as shown in Fig. 1(d), it is placed by a Λ-shaped reflector, which comprises a rectangular horizontal reflector (dimensions $L_q\times72$ mm^2), two rectangular slope reflectors (dimensions $L_t\times72$ mm^2). The angle between the horizontal reflector and the two sides slope reflector is α. The distance between the rectangular horizontal reflector and the CPW-fed slot antenna is h_c.

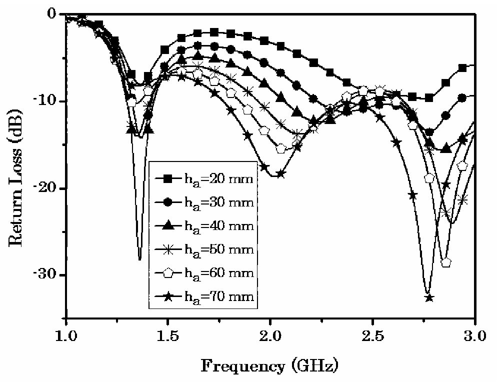


Fig. 2: Simulated return loss of the antenna above a flat reflector on different reflector distance h_a.

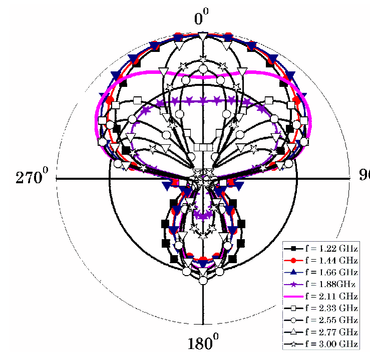


Fig. 3: Simulated normalized radiation pattern in E-plane with h_a=70 mm.

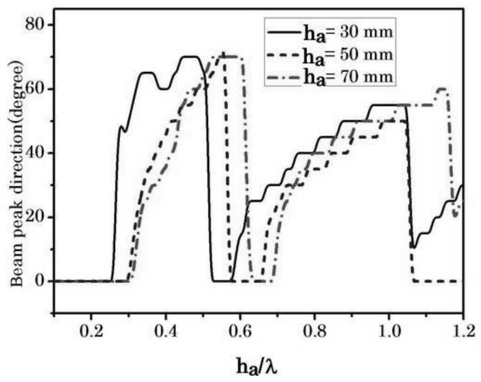


Fig. 4: Beam peak direction (E-plane) with different reflector distances h_a .

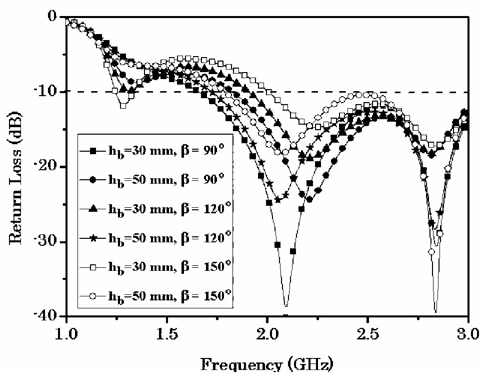


Fig. 5: Simulated return losses for various height between antenna element and corner reflector(h_b) and the angle of corner reflector (β).

3. Effect of the Reflector Shape

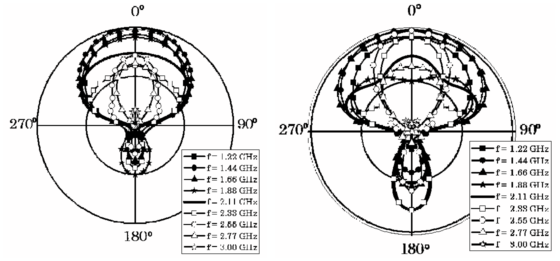
The proposed antenna is composed of the CPW-fed slot antenna using loading metallic strips and a widened tuning stub as a fundamental component and the modified-shape reflectors which have an effect on the impedance characteristics and radiation pattern. Therefore in this section, parameter study in performed is terms of the parameters associated with the CPW-fed slot antenna and modified reflectors. The commercial simulation software IE3D is available for this study, which makes the optimal dimensions of the proposed antennas easy to determine.

A. A Flat Reflector

It is generally believed that the simplest method to redirect the back radiation forward is to place a conducting reflector at a fixed distance away from the antenna. Fig. 2 shows the simulated return loss of the CPW-fed slot above the reflector on different reflector distance h_a. It can be seen that the matching of the antenna is affected by the distance from the reflector. The matching of the CPW-fed slot antennas becomes worse when the distance of the reflector (H) is less than 50 mm. To gain some insight into the performance of a flat reflector, Fig. 3 shows the normalized pattern for frequencies of 1.22 to 3 GHz when fixed h_a = 70 mm. It is evident that for the low frequencies the pattern consists of a single major lobe whereas multiple lobes appear for the higher frequencies (f $>$ 2.11 GHz). For f = 2.33 GHz the pattern exhibits two lobes separated by a null along the $\phi_0 = 0^0$ axis. The maximum beam peak direction in E-plane with different reflector distances (h_a) as a function of the reflector distance-to-wavelength (h_a/λ) has been computed and shown in Fig. 4. It is found that the uni-directional beam is achieved only at some specific spacings which have two intervals. The first interval of beam peak direction at zero degree is at h_a around 0.1 to 0.3 and the another interval is around 0.5 to 0.7 depends on reflector distance.

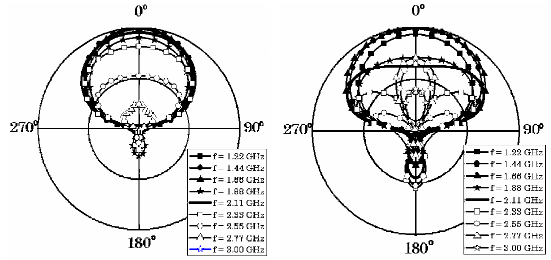
B. A Corner Reflector

Thereafter, the same CPW-fed slot antenna above a corner reflector is analyzed. The length of the two sides slope reflector (L_s) is 72 mm for all cases. The height between antenna and the corner reflector (h_b) is chosen to be 30 mm and 50 mm. For the corner reflector, the radiation patterns for including angles β = 90^o, 120^o, and 150^o have been evaluated. Fig. 5-9 show the effects of the height between antenna and the corner reflector and the angle of the corner reflector of the above six cases on the impedance bandwidth, radiation patterns, and gains of the antenna above the corner reflector. Fig. 5 shows the simulated return losses for various height between antenna element and corner reflector(h_b) and the angle of corner reflector (β). In Fig. 5, the cases of h_b = 30 mm and 50 mm and β = 90^o, 120^o, and 150^o are shown. Its angle has significant effects on improving the impedance matching of the desired band (1 to 3 GHz) to compare with the antenna without reflector. It is seen that the impedance matching is greatly improved with decreasing β when h_b is constant. By increasing the height between antenna element and corner reflector when β is fixed, the impedance matching of the lower band is affected. Moreover, it can be seen that the impedance bandwidth may be excess 3 GHz in higher band.



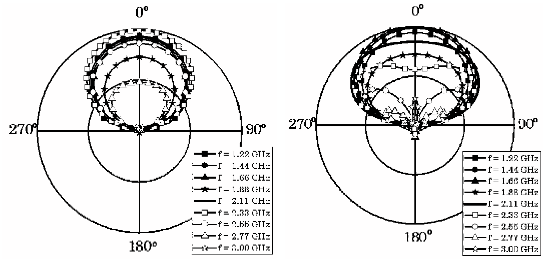
(a) (b)

Fig. 6: Simulated normalized radiation pattern in E-plane when β = 90^o with (a) h_b = 30 mm, and (b) h_b = 50 mm.



(a) (b)

Fig. 7: Simulated normalized radiation pattern in E-plane when β = 120^o with (a) h_b = 30 mm, and (b) h_b = 50 mm.



(a) (b)

Fig. 8: Simulated normalized radiation pattern in E-plane when β = 150^o with (a) h_b = 30 mm, and (b) h_b = 50 mm.

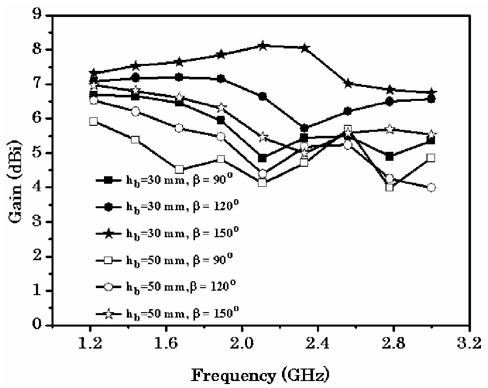


Fig. 9: Computed gain of the antenna above the corner reflector with different reflector distances h_b and the angle of the corner reflector (α) .

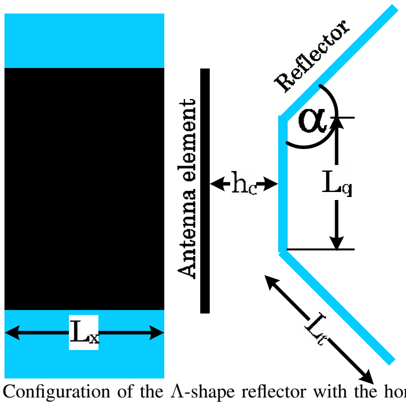


Fig. 10: Configuration of the Λ-shape reflector with the horizontal reflector.

Fig. 6-8 show the simulated radiation patterns in the E-plane of the antenna on different β with h_b = 30 mm and 50 mm. As expected, the front-to-back ratio is increased with the addition the angle of reflector. For high h_b, 50 mm, the front-to-back ratio is lower than 30 mm and there is a considerable amount of the backward radiation. Consequently the gain is small (see Fig. 9). As the reflector height decreased, the main beam becomes narrower and the backward radiation decreases rapidly. The beamwidth achieves a minimum value with h_b = 30 mm and β = 150^o, which results in a maximum gain as shown in Fig. 9. The gain of an antenna is one of of its main condition parameters. The effect of the the corner size on the gain is shown in Fig. 9. It can be seen that the gain is high initially and decreases to a minimum value around 2.0 to 2.3 GHz except when h_b=30 mm and β = 90^o. When h_b = 50 mm, the two lowest gains occur with β being 120^o and 150^o. Beyond these reflector sizes, however, the beamwidth increases and it achieves a maximum gain values around f $\approx$ 2.56 GHz, which naturally results in attaining a lower gain. Focus on the uni-directional, it is found that the uni-directional beam is achieved only h_b = 30 mm which the E-plane beam peak is 0^o.

C. A Λ-shape Reflector with the Horizontal Reflector

For the given CPW-fed slot antenna, we modified the shape of the reflector. Instead of a corner reflector, we took the reflector to have the form of a Λ-shape (Fig. 1(d)). The Λ-shape reflector, which is a useful modification of the corner reflector. To reduce the overall dimensions of a large corner reflector the vertex can be cut off and replaced with a horizontal reflector. We varied the dimensions of the Λ-shape: the height (h_c) and the angle between the horizontal reflector and the two sides slope reflector α. By tuning this angle and the height (h_c), impedance matching and radiation pattern of the proposed antenna can be improved. In this section, the dimensions of horizontal reflector were 44$\times$72 mm^2 ($L_x \times L_q$) and the rectangular slop reflectors were 40$\times$72 mm^2 ($L_q \times L_x$). Fig. 11 shows the simulated return losses for different angle between the horizontal reflector and two sides slope reflector α (120^o, 150^o, and 170^o) when h_c is 30 mm and 50 mm. It can be seen that the impedance matching is degraded when α is further increased. The results, when h_c is chosen 50 mm, the resonant frequencies decrease. The radiation properties are computed for h_c = 30 mm and 50 mm with different αs as well and are shown in Fig. 12-14. It is interesting to observe that behaviors with the h_c for α = 120^o are different. From, Fig. 12- 14, it is seen that, for different h_c, a uni-directional beam can be achieved only with h_c = 30 mm. The antennas with h_c = 50 mm have 2 front-lobed patterns at about 60^o and 300^o, which are separated by

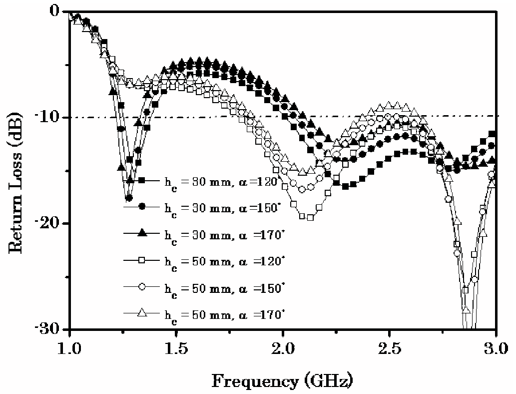


Fig. 11: Simulated return losses for various height between antenna element and horizontal reflector (h_c) and the angle between horizontal reflector and two slope reflectors (α).

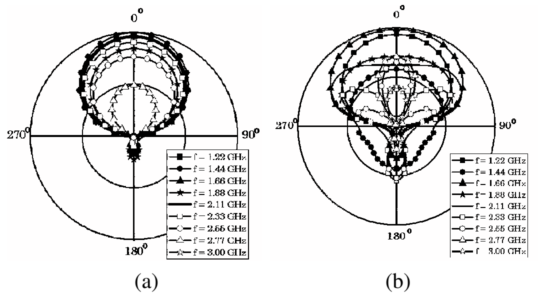


Fig. 12: Simulated normalized radiation pattern in E-plane when α = 120^o with (a) h_c = 30 mm, and (b) h_c = 50 mm.

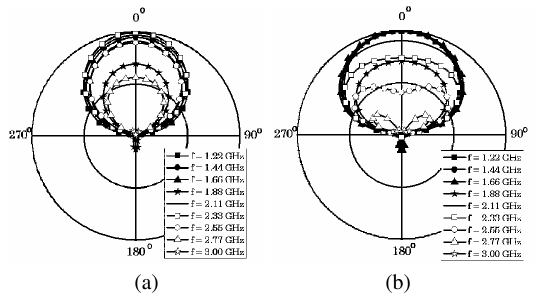


Fig. 13: Simulated normalized radiation pattern in E-plane when α = 150^o with (a) h_c = 30 mm, and (b) h_c = 50 mm.

the null along the ϕ = 0^o axis at some frequencies such as 2.33 GHz in Fig. 12(b) and 2.55, 2.77 GHz in Fig. 13(c). Comparisons of the simulated gain obtained by using 6 different reflector sizes are presented in Fig. 15. In these examples, again, it can be seen that the gain is high initially and decrease to a minimum value at 1.88 GHz.

4. Conclusion

In this paper, the input impedance and radiation characteristics of the CPW-fed slot antennas using loading metallic strips and a widened tuning stub above reflectors have been studied. The size and shape of reflector conductor can enhance the impedance bandwidth and gain of the CPW-fed slot antenna. It is found that bandwidth using

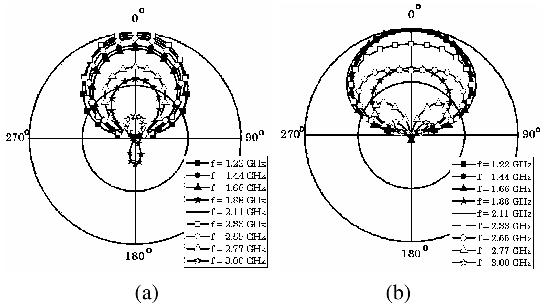


Fig. 14: Simulated normalized radiation pattern in E-plane when α = 170^o with (a) h_c = 30 mm, and (b) h_c = 50 mm.

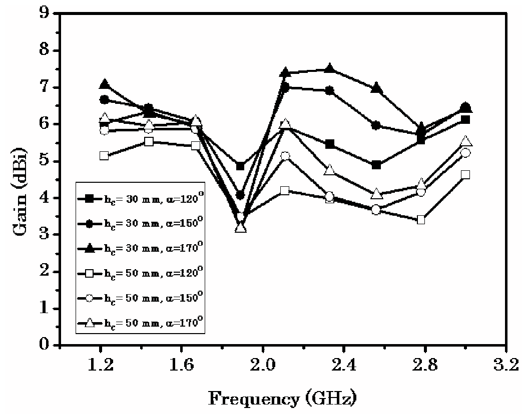


Fig. 15: Computed gain of the antenna above the Λ-shape reflector with different height between antenna element and horizontal reflector (h_c) and the angle between horizontal reflector and two slope reflectors (α).

the modified reflectors can improve both impedance and radiation pattern of CPW-fed slot antenna. The characteristics of the CPW-fed slot above on the corner and Λ-shaped with horizontal reflector are useful in developing uni-directional wide-band CPW-fed slot antenna arrays for wireless communication applications.

Acknowledgments

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