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BROADBAND CPW-FED PLANAR SLOT ANTENNAS WITH VARIOUS TUNING STUBS

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Abstract—This paper investigates broadband planar antennas that consist of a wide rectangular slot with various tuning stubs. The antennas are fed by coplanar waveguides. Wide slots containing a single tuning stub, V-shaped stubs, as well as inverted F-shaped stubs are investigated. Despite using a high dielectric constant substrate, the proposed antennas exhibit very broad bandwidth. They also have broadside bidirectional radiation. The radiation pattern stability with frequency for the various configurations is presented. One of the proposed configurations, the inverted F stub in a wide rectangular slot, produced very stable radiation patterns over its entire impedance bandwidth of about 40%. Also, an impedance bandwidth of 44% was obtained for the V-shaped stub in a rectangular slot. Simulations as well as experimental results are presented.

1. INTRODUCTION

Planar antennas fed by coplanar waveguides (CPW) have many advantages including being low profile, low cost, and suitable for integration with active device. Many configurations have appeared in the literature such as CPW-fed slot and microstrip antennas [1–6]. In addition, due to mobile applications, there is a great deal of interest in compact antennas that fit inside devices, such as the planar inverted F-antenna (PIFA) [7–9]. Bandwidth enhancement techniques for planar antennas were also extensively investigated [10–12]. In this paper, we investigate three types of CPW-fed wide rectangular slot with tuning stubs using high dielectric constant substrates to obtain broad impedance bandwidth along with stability of the radiation patterns. A single tuning stub, V-shaped stubs, and inverted F-shaped stub placed in rectangular slots are investigated. The investigation shows that the addition of a tuning stub creates an additional resonance that enhances the bandwidth substantially. Furthermore, for the case of the inverted F-shaped tuning stub a stable radiation patterns is obtained throughout its very broad frequency band of operation.

Section 2 of this paper presents the geometry of the proposed configurations, Section 3 presents the results of theoretical investigations, Section 4 presents experimental results followed by conclusions in Section 5. All computer simulations were performed using a commercial software package based on the method of moments (Ansoft Ensemble which is now part of Ansoft designer).

2. PROPOSED ANTENNA CONFIGURATIONS

Conventional CPW-fed slot antennas have narrow bandwidths. For example, the capacitively-coupled slot antenna shown in Figure 1 has the return loss shown in Figure 2 where only a 10-dB bandwidth of less than 1% is obtained for the narrow slot. The return loss of this antenna, as well as all simulation results in this paper, were obtained using Ansoft Ensemble, a 2.5D full wave electromagnetic simulation software based on the method of moments. The substrate used is RT/Duroid 6010 with dielectric constant of 10.2 and thickness of 1.27 mm. The slot dimensions for the antenna in Figure 1 are: length = 48 mm and width = 2 mm. The CPW has strip width of 2 mm and gap width of 0.7 mm resulting in 50 ohm characteristic impedance. The same substrate and CPW dimensions were used throughout this paper for simulation as well as experimental verification.

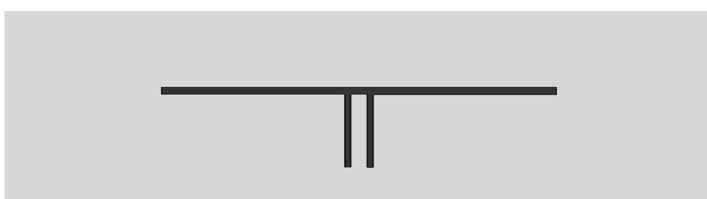


Figure 1. CPW-fed narrow slot antenna (slot length = 48 mm, slot width = 2 mm).

Increasing the slot width alone does not help in improving the impedance bandwidth. On the contrary, it makes the input impedance very high, approaching an open circuit, as shown also in Figure 2 for a slot width of 24 mm, similar to the width used with some of the antennas investigated in this paper, as described in the next section.

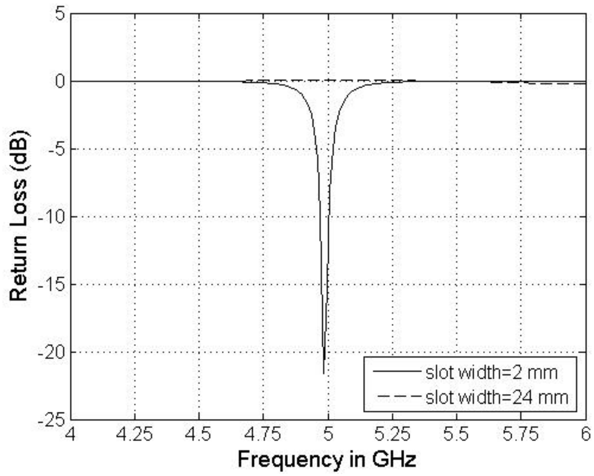
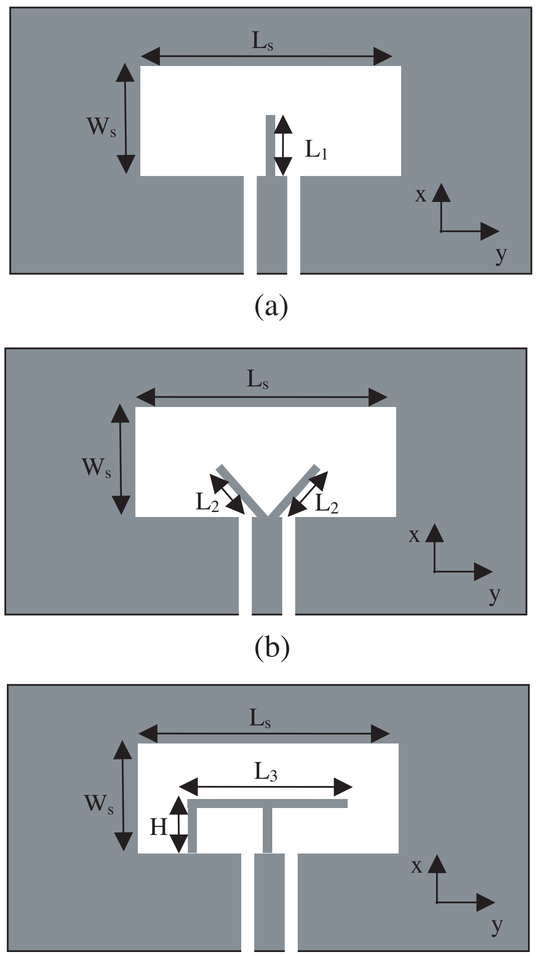


Figure 2. Return loss for the CPW-fed narrow and wide slots.

The main idea in this paper is to place various shaped stubs inside a wide rectangular stub to create a very broad impedance bandwidth. Specifically, three configurations were investigated: a single stub, V-shaped stubs, and an inverted F-shaped stub placed in a wide slot, as shown in Figure 3. It is worth noting that the inverted F-shaped stub in a wide slot investigated in this paper behaves very differently than the CPW-fed PIFA without the slot, in both impedance and radiation pattern properties. The proposed configuration in this paper produces a much wider bandwidth as well as broadside radiation (perpendicular to the substrate). The CPW-fed PIFA without the slot has end fire radiation pattern (parallel to the substrate) and much narrower bandwidth. Excellent results are obtained with our proposed configurations when the various dimensions are properly chosen, as described in the next sections. First, simulation results are presented followed by experimental verification.

3. THEORETICAL INVESTIGATIONS

The three proposed configurations were investigated numerically using Ansoft Ensemble. Results of these theoretical investigations are presented in this section.



(c)

Figure 3. CPW-fed wide slot with various tuning stubs (slot dimensions: $L_s = 48\,\text{mm}$, $W_s = 24\,\text{mm}$), (a) single straight stub in a wide slot, (b) V-shaped stub in a wide slot, (c) inverted F-shaped stub in a wide slot.

3.1. CPW-fed Rectangular Slot with a Straight Tuning Stub

Four versions of the CPW-fed slot with a straight stub is shown in Figure 3(a) were investigated to study the effect of stub length on impedance bandwidth; each version has a different stub length L_1. The slot dimensions for all four configurations are: length=48 mm and

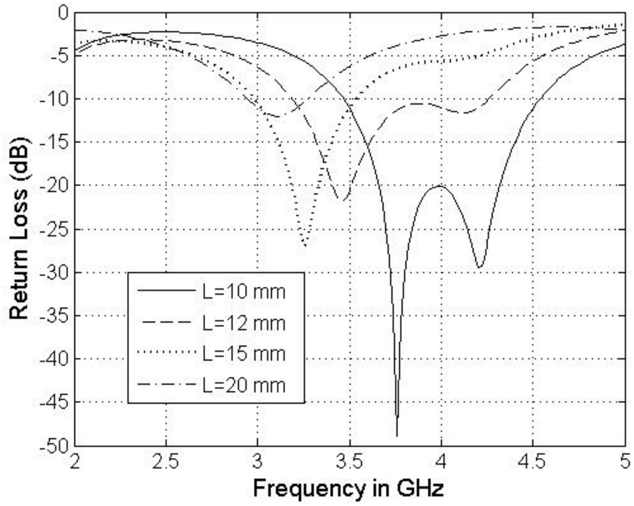


Figure 4. Return loss for CPW-fed wide slot with straight stubs.

width = 24 mm; the same width as the slot width used for the wide-slot simulation of Figure 2. The lengths of the single tuning stub $L1$ are: 10 mm, 12 mm, 15 mm, and 20 mm. The return losses for the four versions are shown in Figure 4. For the slot width of 24 mm, the 10 mm and 12 mm monopoles provide the best bandwidth; 26% and 30% respectively. The return loss exhibits two resonances; one due to the stub and the other due to the aperture. If a different center frequency is desired the monopole length as well as the aperture dimensions can be optimized to provide the desired frequency band.

The E-plane and H-plane radiation patterns for the antennas with the 12 mm monopole are shown in Figure 5 for three frequencies within the 10-dB frequency band 3.15–4.28 GHz. The frequencies chosen are: 3.2 GHz, 3.45 GHz, and 4.2 GHz. The figures show that the radiation patterns obtained are somewhat stable throughout the frequency band of operation. The radiated fields are linearly polarized, parallel to the monopole which is also parallel to the fields in the aperture. Cross polarization levels in the H-plane are low at boresight ($\theta = 0°$); however, the levels move higher away from boresight. Cross polarization in the E-plane is negligible. Since the software used for the simulations is based on a 2.5D moment method approach, infinite ground plane is assumed resulting in a null in the radiation pattern for the tangential electric field component.

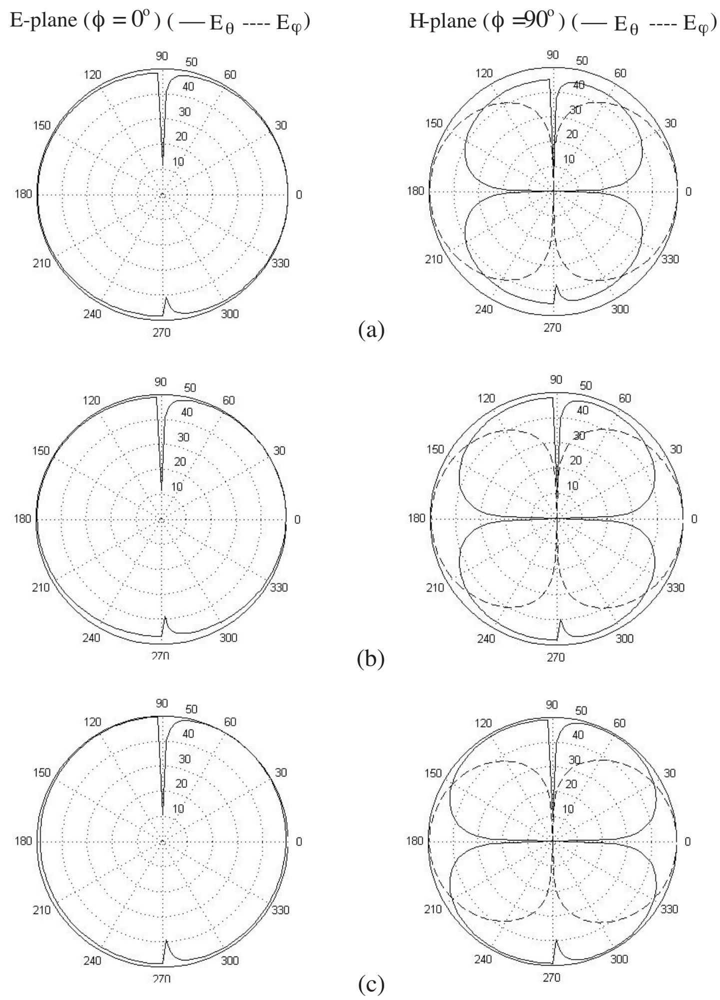


Figure 5. E-plane and H-plane radiation patterns for the antenna with 12 mm straight stub, (a) Frequency=3.2 GHz, (b) Frequency=3.45 GHz, (c) Frequency=4.2 GHz.

3.2. CPW-fed Rectangular Slot with V-Shaped Tuning Stubs

The CPW-fed wide slot with V-shaped tuning stubs is shown in Figure 3(b) was also investigated. Two versions were designed to optimize impedance bandwidth; stubs lengths (L_2 in Figure 3(b)) in the two versions are the same (12.5 mm), but the V-angles are different.

The angles were varied to optimize the bandwidth. The angles of 31.2° and 58.5°produced the return losses shown in Figure 6. The slot dimensions are similar to the previous case (length = 48 mm, width = 24 mm).

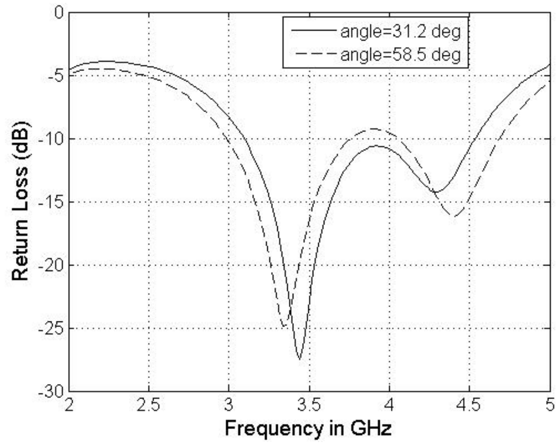


Figure 6. Return Loss for the CPW-Fed wide slot with V-shaped stubs.

Again, as in the straight stub case, two resonances are observed; one due to the length of the V-shaped stubs and the other is due to the slot length. The bandwidth obtained is 3.08–4.48 GHz (37%) and 2.94–4.62 (44%) for the 31.2° and 58.5° V-shaped stubs, respectively. Clearly, the wide angle version has a much wider bandwidth (44%) than the straight tuning stub ($< 30\%$). The E-plane and H-plane radiation patterns for the wide angle V-shaped stub are shown in Figure 7 for three frequencies within the 10-dB frequency band 3.15–4.28 GHz. The frequencies chosen are: 3 GHz, 3.5 GHz, and 4.5 GHz. The figure shows that the radiation patterns obtained are somewhat stable throughout the frequency band of operation. Similar to the previous case, the radiated fields are linearly polarized and the cross polarization levels are low at boresight; however, the levels move higher away from boresight.

3.3. CPW-fed Rectangular Slot with Inverted F-Shaped Tuning Stub

Our proposed CPW-fed wide slot with inverted F-shaped stub has very different impedance and radiation properties than the conventional CPW-fed PIFA without the slot. The radiation pattern of the

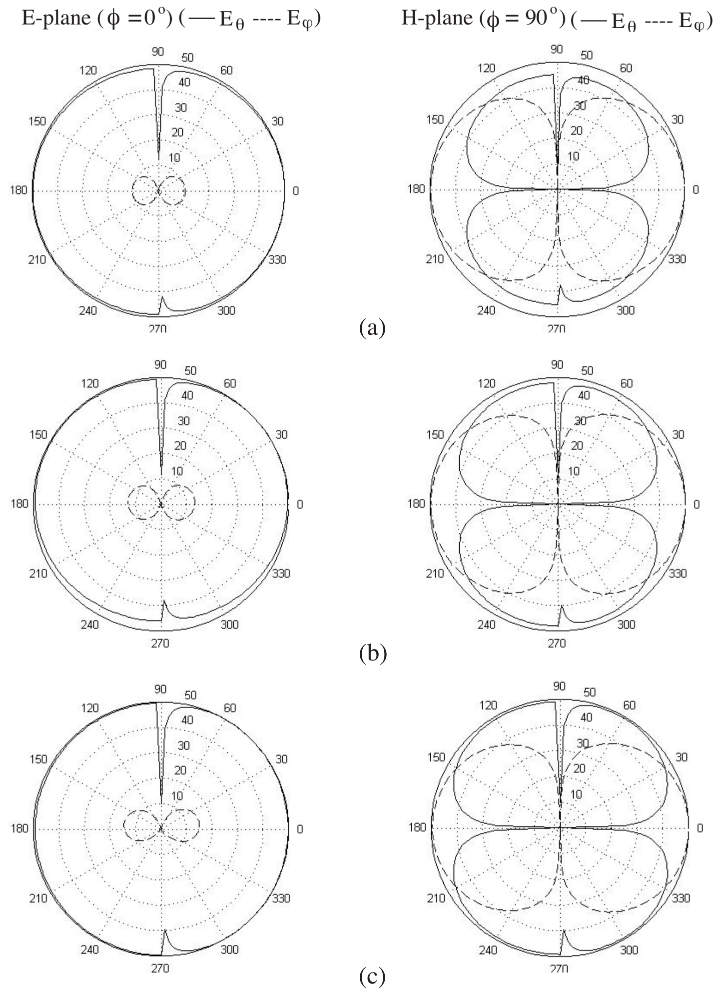


Figure 7. *E*-plane and *H*-plane radiation patterns for the antenna with wide angle (58.5°) V-shaped stubs, (a) Frequency=3 GHz, (b) Frequency=3.5 GHz, (c) Frequency=4.5 GHz.

conventional CPW-fed PIFA without the slot has a main beam that is parallel to substrate with its maximum occurring on the axis along the CPW feed line (end-fire radiation). Furthermore, the antenna is linearly polarized with the polarization parallel to the long strip part of the inverted F (the strip labeled L_p in Figure 3(c)). In our investigation, we placed the PIFA in a wide slot in an effort to obtain a broader bandwidth, similar to the bandwidth enhancement obtained in the straight and V-shaped stubs. In addition to the increase in bandwidth, the radiation pattern for our antenna is broadside rather than end-fire and its polarization is orthogonal to that of the conventional CPW-fed PIFA. The polarization in the proposed antenna is similar to that of a slot alone. We optimized the dimensions of the antenna to produce the widest bandwidth for a center frequency around 1.5 GHz. The dimensions obtained are: the length $L_p = 42.71$ mm, the height $H_p = 8.54$ mm, the slot length $L_s = 72$ mm, and the slot width $W_s = 34$ mm; the long strip (L_p) was fed from the center by the CPW. The return loss obtained is shown in Figure 8, the bandwidth is 1.145–1.725 (40%). This bandwidth is much higher than those of conventional CPW-fed PIFA without the aperture. Furthermore, even though the bandwidth we obtained for the inverted F-shaped configuration is slightly lower than the V-shaped configuration presented in case (b), the radiation patterns are much better; they exhibit much lower cross polarization and they are more stable with frequency throughout the frequency band. The radiation patterns for the four frequencies: 1.2 GHz, 1.35 GHz, 1.5 GHz, and 1.65 GHz are shown in Figure 9 (E-plane) and Figure 10 (H-plane).

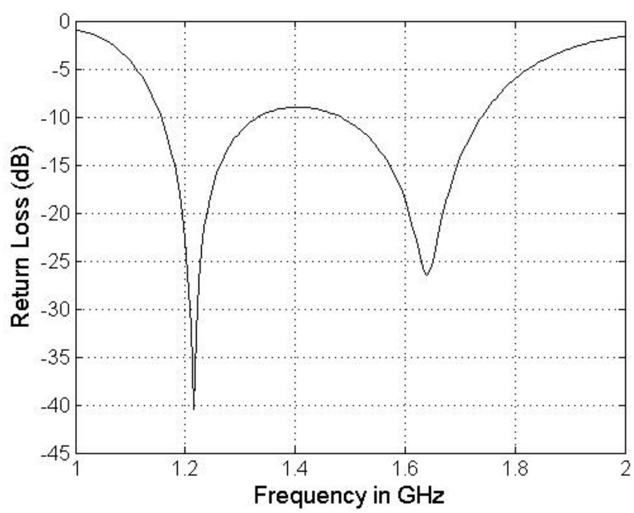


Figure 8. Return loss for CPW-Fed wide slot with inverted F-shaped stub.

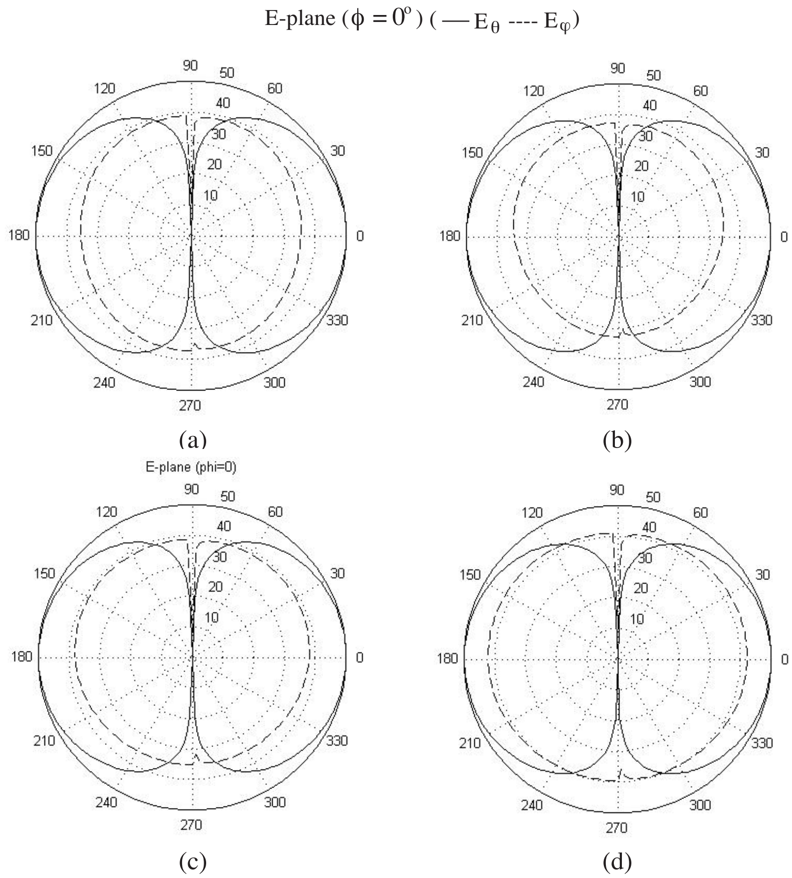


Figure 9. *E*-plane ($\phi = 0°$) radiation patterns for wide slot with inverted F-shaped stub, (a) Frequency=1.2 GHz, (b) Frequency=1.5 GHz, (c) Frequency=1.35 GHz, (d) Frequency=1.65 GHz.

4. EXPERIMENTAL VERIFICATION

Two antennas were designed, fabricated using a milling machine, and tested using an Agilent microwave network analyzer. The first antenna is a CPW-fed wide slot with V-shaped stubs with an angle of 58.5° and length of each arm of 12.5 mm. The substrate used is RT/Duroid 6010 with dielectric constant of 10.2 and thickness of 1.27 mm. The slot dimensions are: length=48 mm and width=24 mm. The CPW feed line has a 50 ohm characteristic impedance (strip width of 2 mm and gap of 0.7 mm). The measured and simulated return loss for the

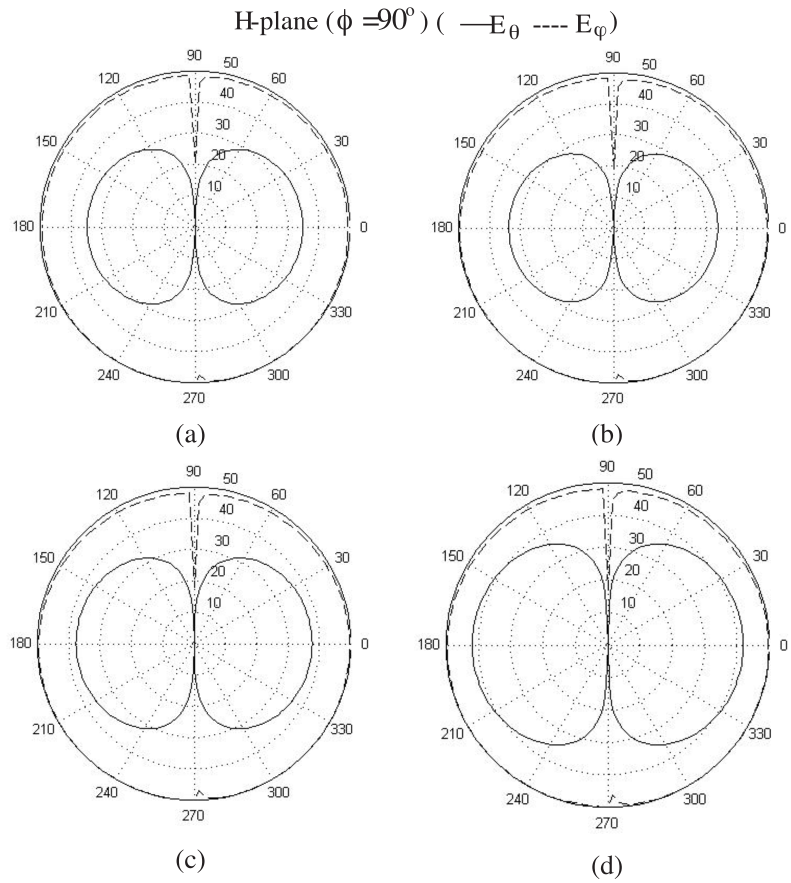


Figure 10. *H*-plane ($\phi = 90°$) radiation patterns for wide slot with inverted F-shaped stub, (a) Frequency=1.2 GHz, (b) Frequency=1.5 GHz, (c) Frequency=1.35 GHz, (d) Frequency=1.65 GHz.

antenna is shown in Figure 11 which shows good agreement between theoretical and experimental results. The 10-dB bandwidth is 44% (3 GHz–4.7 GHz).

The second antenna is a CPW-fed wide slot with inverted F-shaped stub with the following dimensions (as labeled in Figure 3(c)): the length $L_p = 36$ mm, the height $H_p = 5.5$ mm, the slot length is $L_s = 57$ mm, and the slot width=26 mm. The measured return loss and the simulated return loss are in good agreement, as shown in Figure 12. The measured 10-dB bandwidth is about 38% (1.38 GHz–2.02 GHz).

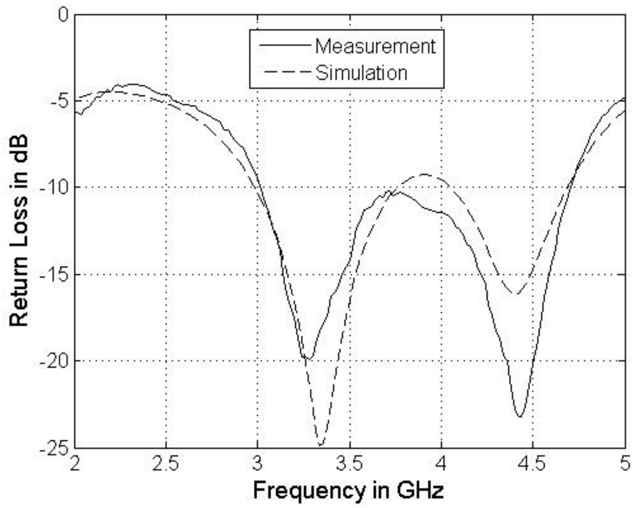


Figure 11. Measured and simulated return loss for the CPW-fed wide slot with V-shaped stubs.

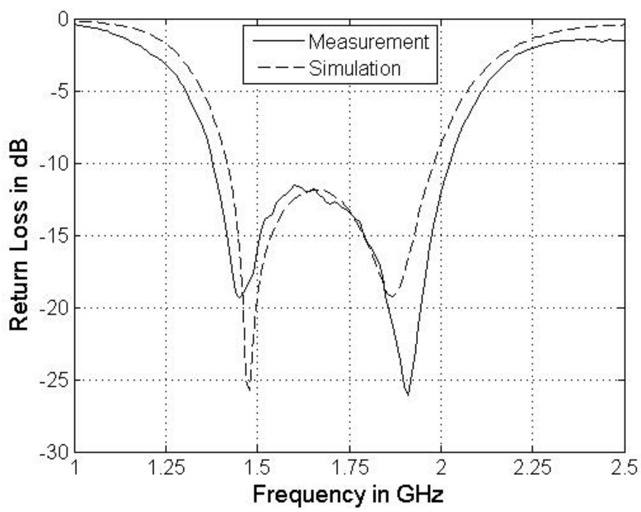


Figure 12. Measured and simulated return loss for CPW-Fed wide slot with inverted F-shaped stub.

5. CONCLUSION

This paper presented various CPW-fed antennas using tuning stubs placed in wide rectangular slots in the ground plane. Straight stubs, V-shaped stubs, as well as inverted F-shaped stubs in wide rectangular slots were investigated. The stub dimensions along with the slot dimensions were optimized to maximize the impedance bandwidth. Impedance bandwidths of about 30%, 44%, and 40% were obtained for the antennas with straight stub, V-shaped stubs, and inverted F-shaped stub, respectively. Stability of the radiation patterns throughout the frequency band of operation was also investigated. It was shown that the antenna with the inverted F-shaped stub in a rectangular aperture has a very stable radiation pattern. In addition, its radiation pattern properties differ from those for the conventional CPW-fed PIFA monopole without the slot. The radiation pattern for is broadside instead of endfire and the linear polarization is rotated by 90° (parallel to the fields radiated by the slot instead of the monopole portion).

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