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Printed wideband CPW-fed slot antenna with high polarization purity

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Abstract: This paper introduces a novel compact wideband CPW-fed slot antenna comprising of an E-shaped patch that is excited with a trident shaped feed-line structure. The antenna design exhibits a very wide operating bandwidth of over 168% with $S_{11} < -10$ dB in the frequency range 1.6 to 18.9 GHz. The antenna's radiation characteristics are stable across this wide bandwidth. The proposed antenna exhibits high polarization purity with cross-polarization level that is well below −40 dB. A comprehensive parametric study was carried out to get insight on the effects of various antenna parameters that enable optimization of the antenna's performance. This antenna easily fulfills the requirements for ultra-wideband (UWB) wireless communication systems as specified by FCC over the designated band 3.1 GHz–10.6 GHz.

Keywords: slot antenna, UWB, CPW-fed

Classification: Microwave and millimeter wave devices, circuits, and systems

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1 Introduction

UWB communication systems will offer enormous available bandwidth permitting high-speed data transmission of 500 M/bps to 1 G/bps to be achieved. As is the case for conventional wireless communication systems, antennas will play a very crucial role in UWB systems. However, the design of UWB antennas present a significantly more challenge than is the case for narrow band antennas. A suitable UWB antenna should be capable of operating over the entire ultra-wide bandwidth allocated by the FCC. Concurrently, the antenna needs to satisfy omni-directional radiation coverage over the specified frequency range.

Planar monopole and printed wide-slot antennas are the good candidates for use in UWB wireless technology because of their relatively wide impedance bandwidth and approximately omni-directional azimuthal radiation patterns. However, the planar monopole, which is a metallic configuration, is not the most preferred option for UWB application because it is generally mounted on a large ground-plane, which is perpendicular to the plane of monopole. This feature is undesirable as it makes the antenna a 3-D structure. Furthermore, the large size of the ground-plane limits the antenna's radiation pattern to only one half hemisphere. On the other hand, printed wide-slot antenna is a truly planar structure which has radiation patterns comparable to that of a dipole antenna.

Printed wide-slot antennas have numerous attractive features, in terms of: small size, light weight, low cost, ease of fabrication and integration with planar and non planar surfaces. These features make this type of antenna widely used in variety of communication systems [1, 2]. It is also well known that wide-slot antenna acts more similar to a printed monopole antenna especially when the size of the slot is large. The disadvantage of this type of antenna is that its bandwidth is narrow. In an attempt to simplify the antenna's structure it is fed using a CPW instead of a microstrip-line, however this has a detrimental impact on its impedance bandwidth which is further reduced [3]. When the antenna is fed by a microstrip line, misalignment can result because etching is required on both sides of the dielectric substrate. The alignment error can be eliminated if a coplanar waveguide feed (CPW)

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is used to excite the slot, since etching of the slot and the feeding line is one sided. Moreover, the efficiency of the antenna which is fed by CPW is much better than that of which is fed by microstrip-line due to less usage of metallic layer. Some bandwidth enhancement techniques using the CPW-fed slot antennas have resulted in some impedance bandwidth improvement, but it is limited to about 60% [4].

In order to enhance the bandwidth of a patch antenna several approaches have been proposed previously, such as using: a thick substrate with low dielectric constant and multiple resonators [5], parasitic patches stacked on the top of the main patch or close to main patch in the same plane [6], U-shaped slot [7], L-probe feeding [8], lossy materials [9], a capacitively probe fed structure [10], and a 3-D transition microstrip feed-line [11].

In this paper a unique technique is introduced to overcome the impedance bandwidth limitation associated with wide-slot antenna. The proposed wide-band slot antenna is excited by an E-shaped patch which is fed with CPW in the form of a trident shape. The proposed antenna configuration is small in size and has a substantially wider bandwidth compared to an equivalent wide-slot antenna in [2]. An impedance bandwidth achieved for the antenna proposed in this paper is over 168% from 1.6 to 18.9 GHz with $S_{11} < -10$ dB. In addition, this configuration provides high polarization purity. The proposed printed CPW-fed wide-slot antenna was analyzed with a commercially available full-wave finite element electromagnetic (EM) simulator, Ansoft's HFSS.

2 Antenna structure and results

Fig. 1 (a) and (b) show the proposed CPW-fed wide-slot antenna. This antenna was fabricated on a dielectric substrate with thickness of 1 mm and relative permittivity $\varepsilon_r = 2.33$. The proposed antenna employs E-shaped patch with a trident shaped CPW feed-line structure to excite the slot on the ground-plane. As will be shown later this configuration provides a very wide impedance bandwidth and good radiation patterns. The substrate size is 70 mm × 80 mm. The dimensions of the proposed antenna are: $L_s = 26\,mm$, $W_s = 42\,mm$, $L_p = 11\,mm$, $\mathrm{W_p} = 14\,mm$, $\mathrm{W_1} = 4.2\,mm$, $\mathrm{g} = 1\,mm$, $\mathrm{L} = 12\,mm$, $W_f = 2.6\,mm$, $S = 0.15\,mm$, $\theta = 17°$, $h = 2.7\,mm$, $W_L = 0.8\,mm$, $t = 1\,mm$, $V = 9.3\,mm$, and $W_q = 1.65\,mm$.

The proposed antenna's measured co-polar and cross-polar far-field E-plane (x-z plane) and H-plane (y-z plane) radiation patterns at 3 GHz, 8 GHz and 13 GHz are shown in Fig. 2. This figure shows that the antenna has good radiation patterns and relatively low cross-polarization in the band 2–13 GHz. The co-polar/cross-polar ratio of better than 40 dB is observed at boresight in all of the measured radiation patterns. In comparison to the single feed-line structure and the antennas investigated in [2, 4] and [5], the cross polarization of the proposed antenna is improved more than 25 dB, 24 dB, 30 dB, and 25 dB, respectively. As is evident from Fig. 2 the proposed antenna provides symmetrical radiation patterns. At the higher

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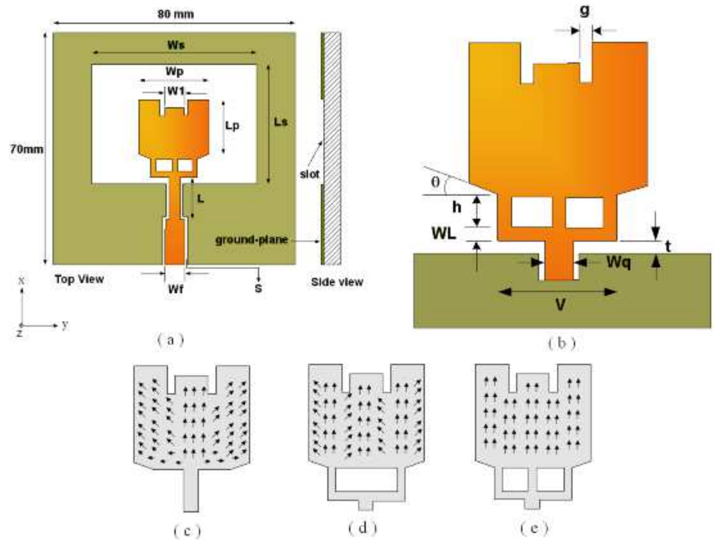

Fig. 1. (a) Structure of the proposed CPW-fed wide-slot antenna (top and side views). (b) Feeding structure of the proposed CPW-fed wide-slot antenna. Current distribution vectors over the antenna patch using different feed-lines: (c) single feed; (d) double feed; (e) trident shaped feed.

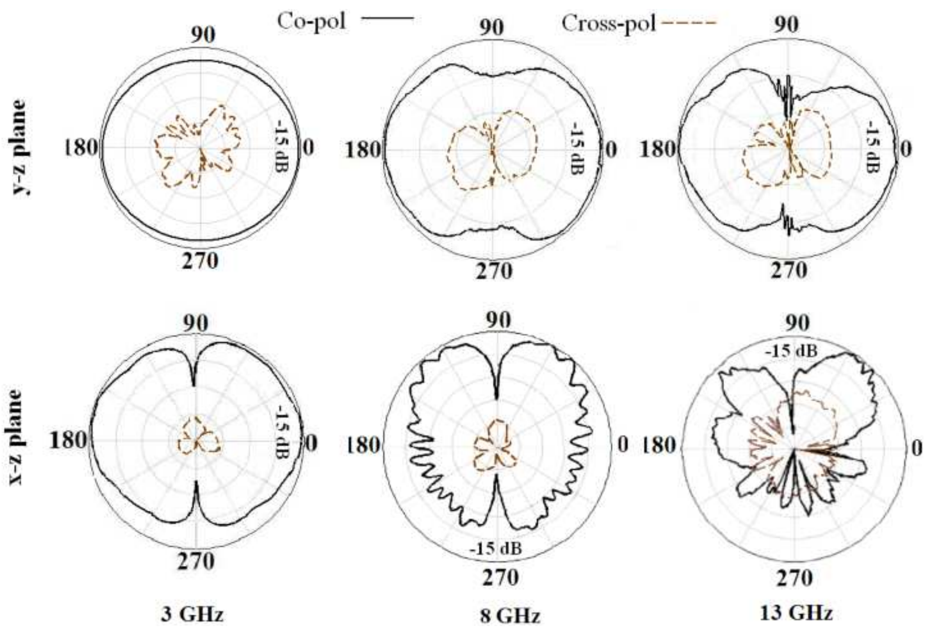

Fig. 2. Measured normalized co-polar and cross-polar far-field E-plane (x-z plane) and H-plane (y-z plane) radiation patterns of the proposed antenna at 3 frequencies over the bandwidth.

frequency the radiation pattern is marginally distorted because of the unequal phase distribution of electrical fields on the slot and increased magnitudes of higher order modes. Moreover, the co-polarization measured gain increases approximately linearly from −1.3 dBi at 2 GHz to a maximum of 7.3 dBi at 8 GHz and then declines in a similar fashion for higher frequencies.

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The radiation bandwidth (2–13 GHz) of the proposed antenna easily accommodates the requirements for ultra-wideband (UWB) wireless communications systems with bandwidth between 3.1 GHz–10.6 GHz.

The simulated and measured reflection-coefficient of the optimized proposed antenna is shown in Fig. 3 (a). The results show the antenna provides a very wide impedance bandwidth of over 168% from a frequency of 1.6 GHz to 18.9 GHz for which $S_{11} < -10$ dB. Compared to the antennas proposed in [2] and [3] the impedance bandwidth is significantly wider by more than 12.3 GHz and 3 GHz, respectively. Detailed numerical and experimental investigation confirms that the impedance bandwidth is limited by the impedance match between the feed-line shape, in particular number of feed branches, and the wide-slot.

In order to understand the effect of the feed branches on the impedance bandwidth of proposed antenna three types of antennas are studied. Antenna-1 has a single feed-line structure, antenna-2 has a dual feed-line; and antenna-3 has a trident shaped feed-line, as it depicted in Fig. 1 (c) to (e). This figure shows the distribution of the current vectors over the E-shaped patch using the different feed-line structures. The trident shaped feed-line provides current vectors aligned upwards in one direction, which indicates that high polarization is achieved with this structure, especially in x-z plane.

The reflection-coefficient of the aforementioned three antennas 1, 2, and 3, is shown in Fig. 3 (b). This simulated result shows the antenna's bandwidth can be enhanced by multiplying the feed-line access to the patch. Bandwidth enhancement is due to the vertical electrical current alignment in the proposed patch, which results in a uniform distribution of the magnetic current within the slot. This therefore confirms that by having a multiple feed-line to the patch eliminates the horizontal electrical current in the patch that results in the improvement of the antenna's cross-polarization characteristic.

A larger slot size will generally improve the operating bandwidth of the antenna. However, this will be at the expense of the bandwidth of the radiation pattern. Therefore the first choice here was not to widen the size of the slot to obtain a larger operating bandwidth. Another technique was needed to enhance the antenna's radiation bandwidth and impedance bandwidth. To achieve this electromagnetic coupling needs to be enhanced between the feed and the slot. This necessitates optimizing the physical parameters of the antenna's feed and the slot. The effect of various physical parameters of E-shaped patch and the slot on the performance of the antenna is investigated in next section.

(A) *Effect of V*

As was discussed above, the antenna's bandwidth can be enhanced by multiplying the feed-line access to the patch. The position of each of the feed branches directly influences the impedance bandwidth. Fig. 3 (c) shows the effect on the impedance bandwidth of the proposed antenna by the outer feed-line separation to the trident defined by parameter V. By changing the outer feed-line position to the patch, different modes are excited that cause various current distributions on the E-shaped patch. An optimum feed-line

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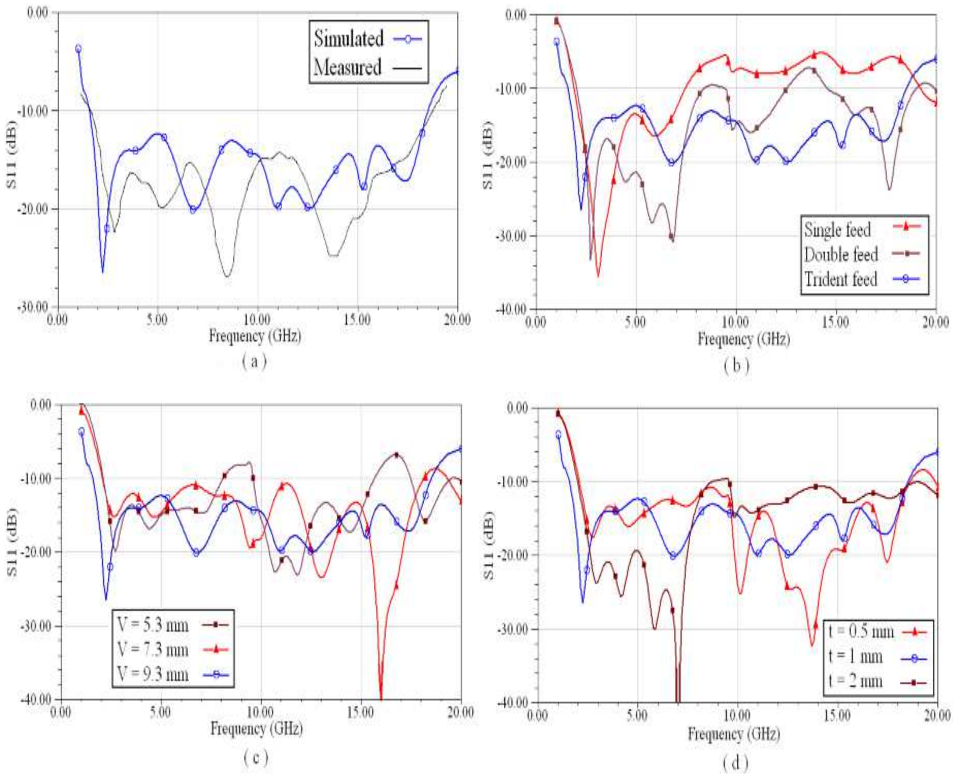

Fig. 3. (a) simulated and measured reflection coefficient of the proposed antenna, (b) for various feed-line structures, (c) for various V values, and (d) for various feed gap t values.

position can be obtained where the purity of the current distributed on the patch is optimized. In this case, the maximum impedance bandwidth with highest polarization purity is realized when V = 9.3 mm.

(B) ***Effect of feed gap t***

The feed gap parameter t determines the impedance match between the feed-line and the wide-slot antenna. In [2] the feed gap effect on the impedance match is investigated. It is found that by enhancing the coupling between the slot and feed, good impedance matching can be obtained. An optimum operating bandwidth is achievable when the coupling is increased to a certain value. However, if the coupling is further increased more than this value, the impedance matching will deteriorate. This shows that over coupling can degrade the impedance matching as does under coupling. Fig. 3 (d) shows the simulated reflection-coefficient of the proposed antenna with feed gaps of 0.5 mm, 1 mm and 2 mm. It can be observed that the frequency corresponding to the lower frequency edge of the bandwidth is clearly independent of the feed gap, but the frequency corresponding to the upper frequency edge is heavily dependent on it. A feed gap value of $t = 1$ mm was selected as it provides the best wideband response.

3 Conclusion

This paper presented the simulation and experimental results of a printed

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CPW-fed wide-slot antenna. This antenna uses a novel feeding structure in the form of a trident shape to excite a truncated E-shaped patch. This configuration is shown to substantially enhance the antenna's bandwidth and provides high polarization purity. The proposed antenna shows a very wide bandwidth of over 168%. In addition to being small in size, the antenna exhibits stable far-field radiation patterns over its operating range, a relatively high gain, and low cross-polarization. Based on these characteristics, the proposed CPW-fed wide-slot antenna can be used for wideband satellite and wireless communication applications.

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