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An Ultra-Wideband Quasi-Planar Antenna with Enhanced Gain

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Abstract—A new ultra-wideband antenna with enhanced and nearly constant gain is presented. This quasi-planar antenna is composed of a CPW-fed printed monopole and a short horn, both made out of a single substrate. The measurements demonstrate an almost flat peak gain of 5.5 dBi ± 0.7 dB from 2.5 GHz to 15 GHz with the average gain difference in XZ plane is roughly 2 dB up to 8 GHz, which further rise to 6 dB at 10 GHz. The antenna also has a nearly linear phase response in this band. Well tested performance both in frequency and time domains, along with broad azimuth pattern, results in minimal ringing of a radiated pulse. The new antenna is suitable for establishing good line of sight link for UWB transmission and other broadband applications.

1. INTRODUCTION

UWB antennas are required for UWB communication, impulse radio, emerging consumer electronic products, microwave imaging, non-destructive detection and ground-penetrating radar (GPR) [1–4]. Compared to narrowband systems, the UWB systems offer potentially higher image resolution and better target characterization. The design of a high performance UWB antenna is crucial in these applications. The transverse electromagnetic (TEM) horn antennas, developed for the ground penetrating radar (GPR) and other such applications [5, 6], have an ultra-wide bandwidth and nearly constant high gain over the operating bandwidth. However, these antennas are λ to 10λ long and in addition a UWB balun is required to feed the balanced TEM horn from a coaxial cable. These antennas are too bulky and inconvenient for compact UWB impulse radar and wireless communication systems. On the other hand, novel feeding methods have been reported for metallic horn antennas. These include a long conical horn fed by a Yagi antenna and a compact, surface-mounted, $\lambda/4$-horn fed by a microstrip patch [7–10]. However, the Yagi-fed long horn is not a UWB radiator, because of a limited bandwidth of the Yagi feed and the microstrip patch is also not a UWB feeding element, because of its relatively narrow impedance bandwidth. In another research area, several planar and printed monopole UWB antennas have been investigated [11–17] for the FCC-based UWB systems, operating from 3.1 GHz to 10.6 GHz. Most of these antennas have very wide impedance bandwidths and nearly omni-directional radiation patterns in the azimuth plane. However, these antennas have low gain at lower frequency end in the UWB band and the gain increases with frequency. An ideal UWB antenna should have a flat gain and a linear phase response for the faithful radiation of short UWB pulses. A critical analysis of the effect of variations in antenna gain and group delay on the integrity of pulse transmission in 3.1 to 10.6 GHz shows that the fidelity factor drops from 0.9867 and the pulse stretch ratio increases from 1.202, with larger variations of the gain and group delay in the band [17].

We investigated earlier a short quasi-TEM horn fed by a printed monopole and slot to get a flat gain [17–19] respectively. The printed monopole has a microstrip feedline. However the orthogonal orientation of the electric field component in the feed, with respect to the electric field component at

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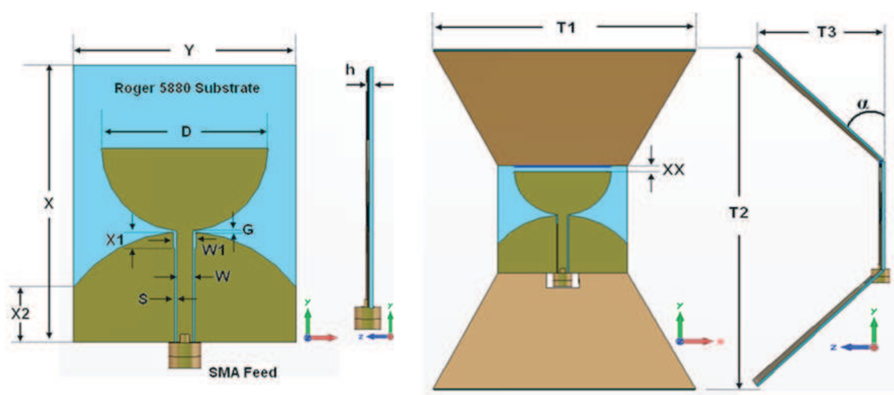
the aperture of TEM horn, caused distortions in the radiation patterns at higher frequencies, making this antenna less attractive for the broad-beam operations [18]. In addition a bulky metallic horn is mounted separately on the top of a monopole [19] and slot [20, 21]. This paper improves the design on both these accounts, with a quasi-planar, surface-mounted (SM) short TEM horn. A smaller CPW-fed semicircular disc monopole [15] is used to excite the quasi-planar short horn. It is half in size, as compared to the microstrip based printed circular monopole used in [16]. The present feed arrangement provides collinear electric fields both in the feed and in the horn's aperture regions, improving both the gain and quality of radiation patterns up to 15 GHz. We would like to mentioned at these stage of studies, designer can use any other monopole feeds with these kind of horns to further enhanced the bandwidth of overall design. The CPW-based monopole and the short horn are printed on a same substrate. The proposed integrated antenna is compact in size and easy to fabricate. The antenna has ultra-wideband impedance matching and intend to be abroad beam directional coverage with a small gain variation across the band. The proposed antenna also has nearly linear phase response in the UWB band, resulting in non-dispersive pulse transmission without ringing [22]. The proposed antenna highlight the feed mechanism with a printed structure and it is having low power handling. However for GPR applications one can use alternative monopole feed to support the power requirements. Validation of predicted results and time domain study is presented first time in this paper. The main aim of this paper is to explore a new integrated antenna with a CPW-fed semicircular disc monopole mounted with a short horn to create a new ultra-wideband antenna that operates from 2.5 GHz to 15 GHz with enhanced gain.

2. ANTENNA DESIGN

Figure 1 shows the new CPW-based antenna. Fig. 1(a) shows the CPW-fed semicircular disc monopole antenna that excites the short TEM horn shown in Fig. 1(b). The proposed antenna is called as a quasi-planar structure because the two plates of the short TEM horn and the CPW-fed semicircular disc monopole are fabricated on the same substrate, Roger 5880-0031 with $\varepsilon_r = 2.33$ and thickness 0.787. As shown in Fig. 1(b), the printed plates are bent at 45° to form a short TEM horn. Fig. 2 shows a fabricated prototype. The dimensions, in mm, are as follows: $X = 45$, $Y = 40$, $D = 30$, $W = 3$, $S = 0.33$, $W1 = 4$, $X1 = 3$, $X2 = 10$, $T1 = 80$, $T2 = 114$, $T3 = 40$, $xx = 2$. The slant angle $\alpha = 45°$.

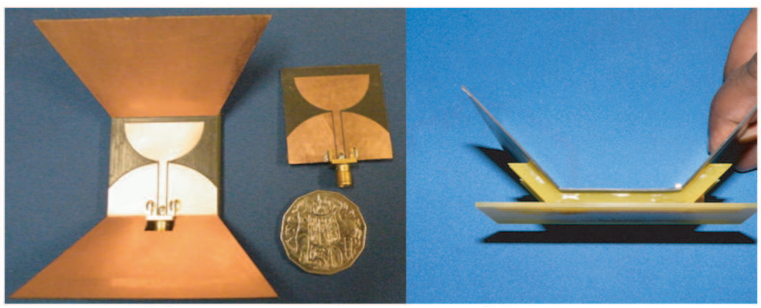


(a) (b)

Figure 1. (a) CPW-fed semicircular disc monopole antenna. (b) CPW-fed semicircular disc monopole antenna with the printed surface- mounted short two-plate horn.

Figure 2(b) also shows an additional supporting FR-4 substrate, without copper cladding on both sides. This rigid FR-4 dielectric substrate provides the mechanical support to the antenna structure on a flexible substrate. It is worth noting that the complete antenna, with the short horn, is realized on a single flexible substrate without any separate metallic plates. Thus it is highly suitable for a low-cost compact system. The two-plate short horn antenna can be considered as a section of a non-uniform

TEM transmission line. One plate of short horn is intentionally put on a ground this help in providing additional ground plane to the printed semi circular disc monopole and the connection of short TEM horn is more or less tile symmetrical planes. The polarization of the electric field, determined by the orientation of the semi circular disc monopole, is parallel to y-axis and the Y-Z plane. This is the E-plane of the TEM horn. The antenna aperture, determined by the slant angle of the short horn, primarily controls the radiation and enhances the antenna gain in the lower part of the UWB, i.e., 2 GHz to 6 GHz. This choice of the slant angle provides a flattened gain across the whole FCC approved UWB. The gap xx between the short horn and the monopole top, shown in Fig. 1(b), controls impedance matching over the operating bandwidth. A parametric study was carried out to investigate the effect of the gap xx on the impedance matching and the effect of the slant angle on antenna gain over the UWB. Such information is helpful for an antenna designer. In parametric analysis it has been found that a 2 mm gap provides good impedance matching across the band, so this value was selected for the present design. Fig. 3 shows that for a slant angle of 45°, the antenna gain variation is minimal over the frequency range from 3 GHz to 10 GHz.



(a) (b)

Figure 2. Prototype of the new antenna and its parts.

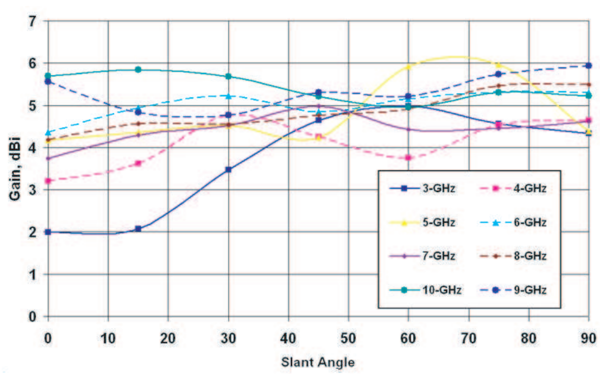


Figure 3. Simulated gain vs. slant angle (α), in degrees, for different frequencies.

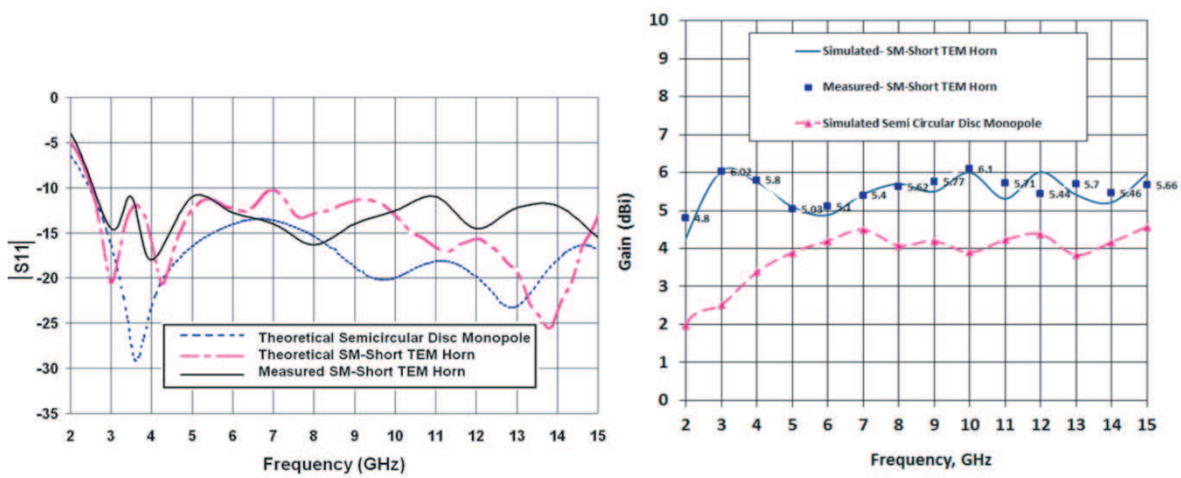
3. RESULTS AND DISCUSSION

The horn height ($T3$) was set to 40 mm for the design example. It is approximately equal to $\lambda/2.5$ at 3 GHz. The simulated return loss of the integrated antenna, shown in Fig. 4(a), reaches 10 dB at 2.52 GHz and it better than 10 dB at least up to 15 GHz, covering the entire FCC-approved ultra-wide band. The presence of TEM horn does not degrade much the return loss the monopole. This figure also shows the measured return loss of the antenna. Fig. 4(b) compares measured antenna peak gains, with and without the short horn. The antenna gain, without the horn, exhibits almost linear increase with frequency, up to 6 GHz, and then it is nearly constant up to 15 GHz. The incorporation of the short horn improves the gain at the lower frequencies up to 6 GHz. As a result of this enhancement, the new antenna has nearly constant peak gain 5.5 dBi ± 0.7 dB from 3 GHz to 15 GHz while 2 dB variation noticed in predicted gain in ZX plane.

Figure 5 shows radiation patterns of the proposed antenna at five representative frequencies: 3, 6, 10, 12 and 15 GHz. Fig. 5(b) shows broad beams in the azimuth plane. As frequency increases, the beam becomes more directional in the direction of the horn. The characteristic null of a monopole in the elevation plane, shown in Fig. 5(a), gradually diminishes with increase in frequency.

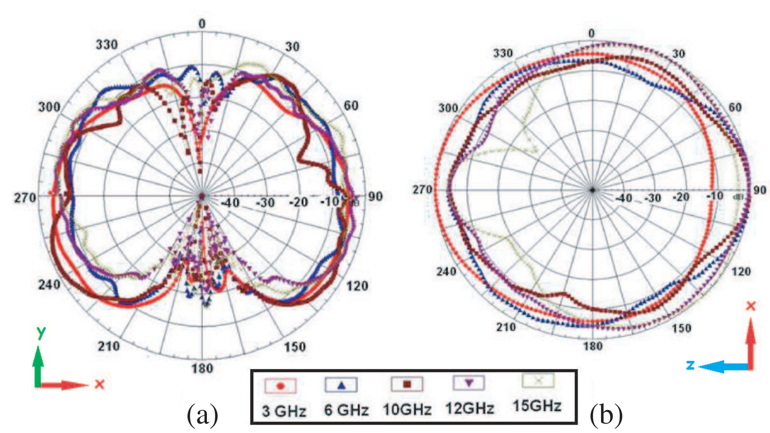
Theoretical results shows the cross polarization levels are more than 30 dB down in the main beam directions and increases with frequencies over the beam coverage. A UWB omnidirectional monopole is used to excite an aperture of short horn and intentions is to make the pattern more direction to line of sight applications. In a printed monopole the ground play a critical part in radiation of field and one arm of the horn is shorted with the ground plane which further modifies the patterns of antenna in azimuthal plane.

The fidelity of the antenna in pulse applications has been analyzed using CST Microwave Studio 2010. Various far-field probes have been placed around a reference semicircular disc monopole and the new antenna in both azimuth and elevation planes at a distance of 250 mm. A first order Gaussian pulse is applied to the input of antennas and the correlation between the far field at each probe location and the input pulse has been calculated. The correlation of pulses is plotted in Fig. 6. It shows the



(a) (b)

Figure 4. $|S_{11}|$ of the CPW-fed disc monopole antenna with and without the short horn. (b) Comparison of the measured peak gain of the CPW-fed disc monopole antenna, with and without the short horn.

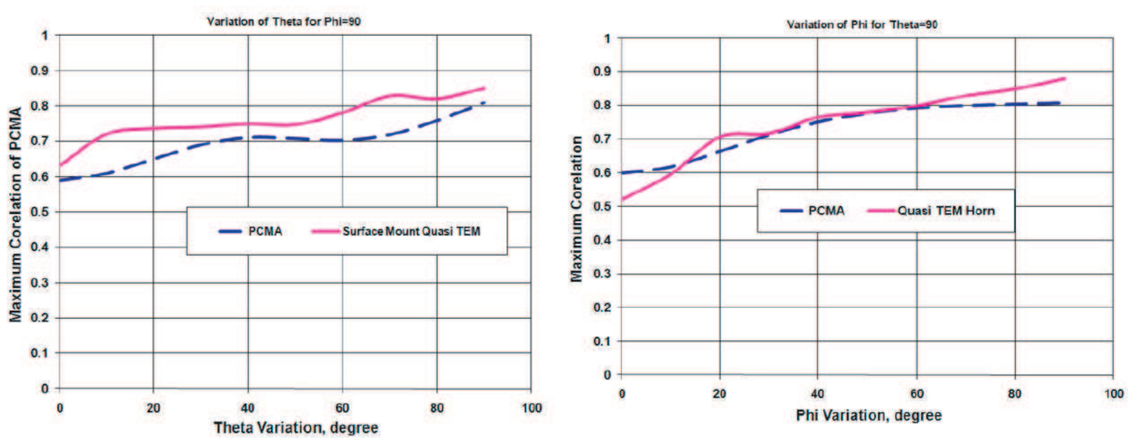


(a) (b)

Figure 5. Measured radiation patterns. (a) X-Y plane. (b) X-Z plane.

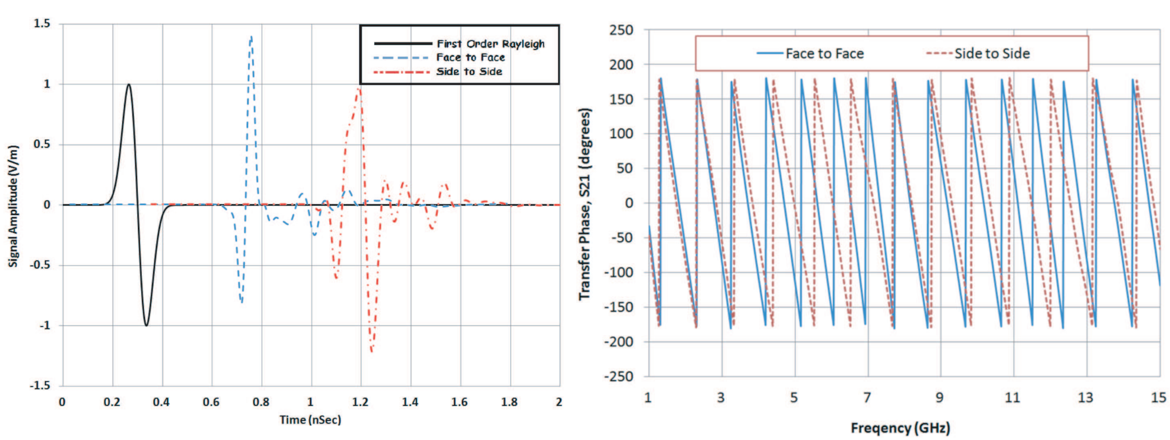
fidelity of pulses in various theta and phi directions. In most directions, the new antenna has better pulse fidelity than the reference antenna. Fig. 7(a) shows the pulse transmission between two identical antennas placed side-by-side and face-to-face. Fig. 7(b) shows the phase of transmission transfer function between two identical antennas placed side-by-side and face-to-face. Fig. 7(b) indicates almost linear transmission phase over 1 GHz to 15 GHz that is responsible for good fidelity of the transmitted pulses. The transmission demonstrate the linearity of the phase over the frequency range.

The TEM horn is a non resonant radiating structure and ideally it has no resonant frequency. However the feed structure can have resonance. A finite size TEM antenna has multiple reflections from the end edge and quasi-TEM nature of the present antenna has modal energy storage. The modified aperture fields at frequencies 3 and 6 GHz are shown in Fig. 8. Both the multiple reflections and energy storage cause resonance that gives undesired ringing in the transmitted pulse shown in Fig. 7. Fig. 4(a) shows the resonance in the CPW-fed monopole with two additional higher frequency resonances. The proposed antenna has more resonances than the monopole due to presence of horn. Its first resonance occurs at about 3 GHz which is reflected in gain peak (6 dBi) in Fig. 4(b). In similar fashion, other gain peaks of Fig. 4(b) can be co-related to the response shown in Fig. 4(a). At higher frequencies, there is some variation in such correspondence as aperture field and monopole fields are not properly co-polarized.



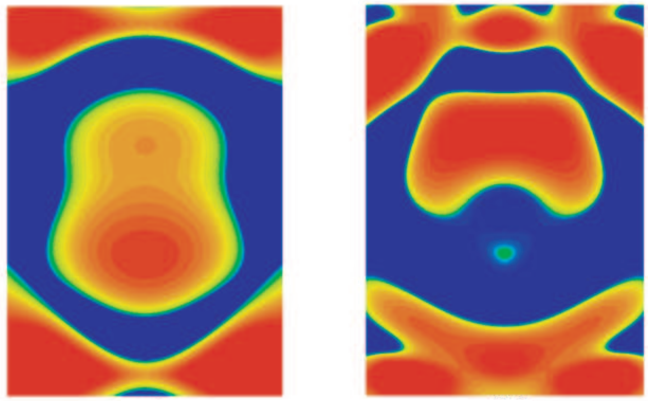
(a) (b)

Figure 6. Pulse correlation of the new antenna and the reference semicircular disc monopole antenna, where theta is varying from Y to Z in yz-plane and phi is variation from X to Z in xz-plane.



(a) (b)

Figure 7. (a) Pulse performance of antenna. (b)Transmission phase of the new antenna for face to face and side to side arrangements.



(a) (b)

Figure 8. Field distribution at aperture of quasi TEM horn. (a) 3 GHz. (b) 6 GHz.

4. CONCLUSION

A CPW-fed semicircular disc monopole has been integrated with a short horn, mounted on surface of the monopole, to create a new ultra-wideband antenna that operates from 2.5 GHz to 15 GHz with enhanced gain. The measured peak gain of the antenna is nearly constant at 5.5 dBi $\pm$ 0.7 dB from 2 GHz to 15 GHz. The measured radiation patterns demonstrate broad beam coverage in the azimuth plane. The antenna has nearly linear phase response with frequency and its pulse fidelity is better than that of the reference monopole antenna in nearly all directions considered.

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