Directional Ultra-Wideband Antennas in Planar Technologies

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Abstract — **Directional ultra-wideband antennas in various planar technologies are described. All designs feature a parabolic-shaped ground plane to accomplish high directivity and gain. Moreover, in comparison with a simple corner-shaped ground plane, the parabolic ground plane enhances bandwidth and improves input return loss. It also contributes to antenna compactness and efficiency in radar tracking applications. The salient features of the UWB antenna designs are demonstrated through two different full-wave simulation packages in the time and frequency domains.**

I. INTRODUCTION

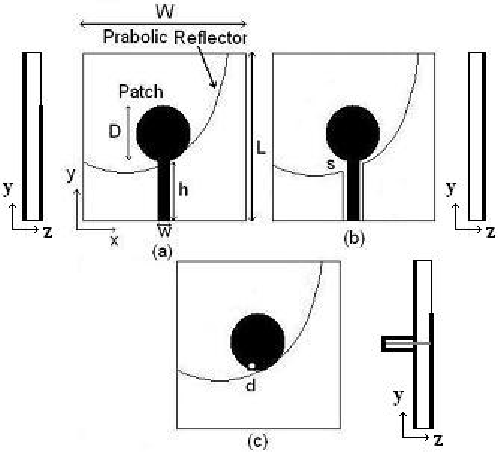
Ultra-wideband (UWB) communication systems promise high bandwidth, reduced fading from multipath propagation and low power requirements [1]. In the United States, the Federal Communications Commissions (FCC) has approved the license-free UWB usage within the frequency range of 3.1-10.6 GHz and power spectral density of -41.3dBm/MHz [2]. Therefore, low cost UWB systems are at the forefront of research for both military and commercial applications. One of the challenging tasks is the realization of effective UWB antennas that guarantee operation in terms of radiation properties, impedance matching and group delay within the band of interest [3].

The main focus of recent research is on compact UWB antennas in planar technologies as they are more practical in terms of manufacturing and integration with the entire system [4]-[7]. Typical configurations exhibit radiation similar to traditional monopole antennas with quasi-omni-directional patterns [4]. Although such features are desirable in UWB wireless communications, operation is limited in case of radar applications requiring high directivity at a specific angle. Therefore, a few efforts have been made to enhance the directivity of planar UWB antennas for specific applications such as radar systems [8]-[9]. The recent work on a directional UWB antenna in [9] consists of an additional corner ground plane operating as a reflector at center frequency to achieve directivity. However, due to the simplicity of the reflector used, the bandwidth, over which the antenna contributes to directional radiation patterns, reasonable group delay and impedance matching, is limited.

Therefore, in this paper, we propose new highly directional UWB antennas in various planar technologies including co-planar waveguide, and microstrip with regular and coaxial feeds. The proposed directional ultra-wideband antennas use disc monopoles printed on FR4 substrate. The shapes of the ground planes are carefully designed in order to increase both directivity and bandwidth for a UWB radar transceiver operating at a central frequency of 8GHz with more than 125 percent bandwidth.

II. ANTENNA STRUCTURE

All UWB antennas presented here are designed for fabrication on FR4 substrate with ε_r=4.4, thickness of 1.6mm and 35μm metallization thickness.



(a)

(b)

(c)

Fig. 1 Dark top and transparent ground-plane and side views of the proposed directional planar UWB antennas in microstrip technology (a), coplanar technology (b), and microstrip with coaxial feed (c).

Fig. 1 depicts the schematic views of the proposed UWB antenna structures in planar technology including the top and bottom metal layers. The top layer in Fig. 1a consists of a centered circular patch element with 50Ω microstrip feed. The parameters *D*, *w* and *h* are the diameter of the patch, and the width and length of the feed line, respectively. The transparently shown metallization on the bottom of the substrate is recognized as a parabolic reflector of which the patch is located in the focal point based on

$$y - y_0 = \frac{1}{4f}(x - x_0)^2 \qquad (1)$$

where x_0 and y_0 are the displacements in the Cartesian coordinate system, and f is the focal length, which is assumed to be one half of the patch diameter. Fig. 1b and Fig. 1c illustrate the respective antenna structures in coplanar waveguide technology as well as with a coaxial feed. The parameter *s* in Fig. 1b is the gap between the ground reflector and the patch for 50Ω input matching. The parameter *d* in Fig.

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1c is the diameter of the via hole through the substrate, which is equal to the inner diameter of the coaxial feed line at the bottom of the substrate.

III. ANTENNA DESIGN AND CHARACTERIZATION

The design of the UWB antennas is centered at 8 GHz with more than 120 percent bandwidth. The fundamental design goals are a low reflection coefficient, enhanced radiation pattern in the desired direction as well as good group delay performance. The diameter of the disc is calculated as *D*=18mm for 8GHz center frequency and remains the same for all antenna structures presented in Fig. 1.

A. Microstrip Technology

Fig. 2 shows the input reflection coefficient of the directional microstrip antenna as obtained from CST Microwave Studio [10] and Ansoft HFSS [11]. Good agreement is observed, thus verifying the design process. The width of the input line is *w*=3mm for a characteristic impedance of 50Ω. In order to find a good trade-off between all desired properties, the width and the length of the substrate were varied and finally identified as *W*=50mm and *L*=46mm. The predicted return loss is better than 9.5dB between 3.1GHz and 12.6GHz. Note that this includes a coax-to-microstrip transition as shown in the inset of Fig. 2.

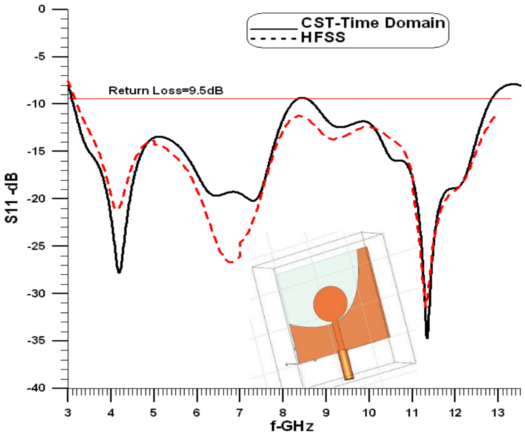

Fig. 2 Input reflection coefficient performance of the directional UWB antenna in microstrip technology according to Fig. 1a.

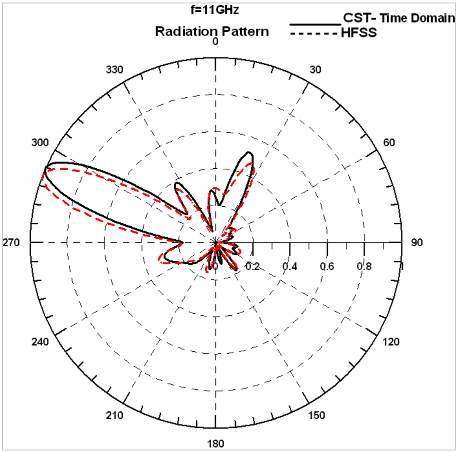

Fig. 3 Radiation pattern (linear scale) of the directional UWB antenna in microstrip technology at 11 GHz.

The radiation patterns have been computed with both simulation packages at various frequencies. The largest differences between the two results are observed at 11 GHz, and these patterns are shown in Fig. 3 as an example and representative of largest variation of radiation patterns obtained for all antennas to follow.

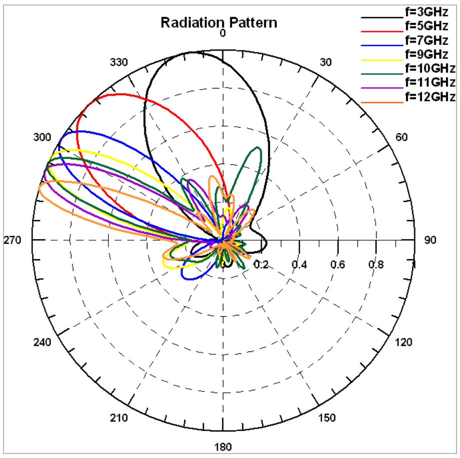

Fig. 4 Beam variation versus frequency for the directional UWB antenna in microstrip technology (Fig. 1a).

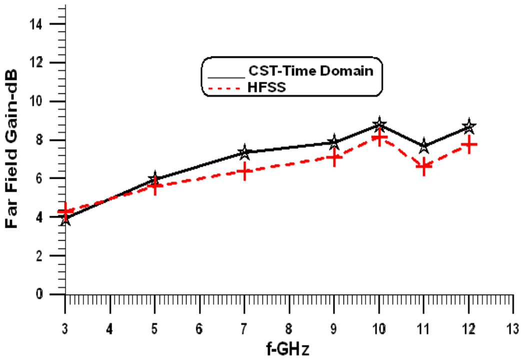

Fig. 5 Maximum antenna gain for the directional UWB antenna of Fig. 1a.

Fig. 4 shows that the direction of the beam moves between 348 and 285 degrees between 3GHz and 12.6GHz. In addition, the half-power beamwidth of the main lobe varies between 75 and 25 degrees. The maximum gain versus frequency is shown in Fig. 5 and is around 8dB at mid-band frequency. Good agreement is observed between the simulation packages. The increase of the side lobes specifically in the upper frequency range (c.f. Fig. 3) is due to the influence and impact of the proposed ground plane in microstrip technology. This can be improved by different feeds as reported in the next sections.

B. Coplanar Technology

In coplanar technology, the ground plane reflector and disk patch are both on the top layer of the substrate. The resulting two parts of the ground plane in Fig. 1b are therefore connected by a coax-to-coplanar transition as depicted in the inset of Fig. 6. The gap between the input transmission line and the reflector is *s*=35mm for 50Ω input impedance. The same gap is maintained between the disc and the reflector, which is achieved through shifting the reflector along the y-axis. The substrate dimensions are *W*=50mm and *L*=48mm.

Fig. 6 shows the reflection coefficient of the coplanar UWB antenna in Fig. 1b. A return loss better than 9.5dB from 3.1GHz to 13.6GHz is obtained, which is approximately 10 percent more than that achieved in microstrip technology. Fig. 7 illustrates that the beam variation is between 342 and 285 degrees from 3GHz to 14 GHz. The 3-dB beamwidth varies between 90 degrees at 3GHz and 18 degrees at 14GHz.

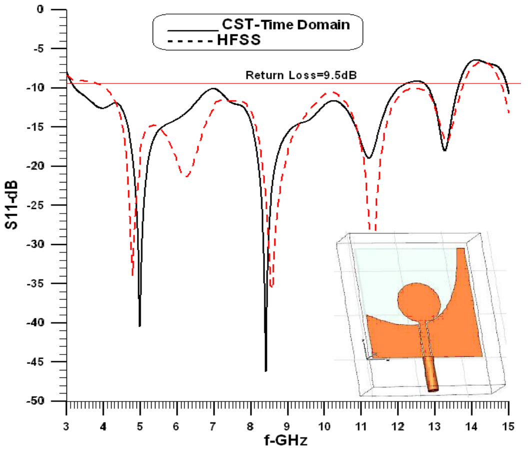

Fig. 6 Input reflection coefficient performance of the directional UWB antenna in coplanar technology according to Fig. 1b.

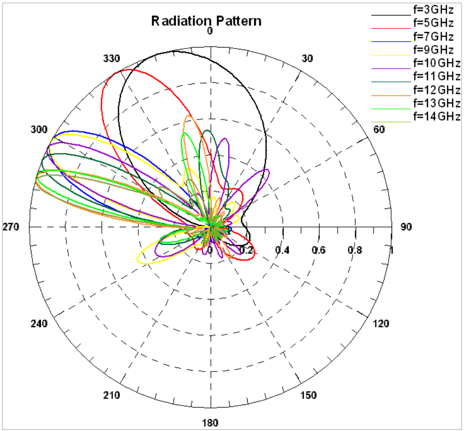

Fig. 7 Beam variation versus frequency for the directional UWB antenna in coplanar technology (Fig. 1b).

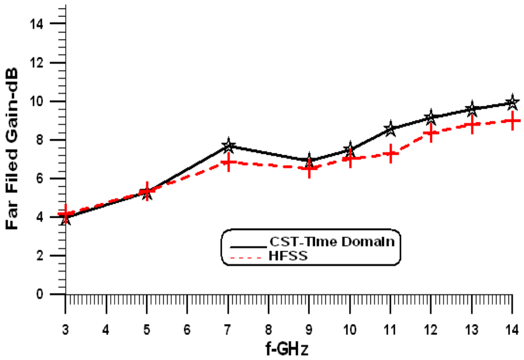

Fig. 8 Maximum antenna gain for the directional UWB antenna of Fig. 1b.

The maximum gain is depicted in Fig. 8 and shows a variation between 4 dB and 10 dB. Good agreement is observed between the CST and HFSS results, specifically in the upper frequency range where side lobes increase significantly (c.f. Fig. 7).

C. *Microstrip Technology with Coaxial Feed*

The 3D view of the directional UWB antenna in microstrip technology with coaxial feed is shown in Fig. 9 together with the response of the input reflection coefficient. The parameter d (c.f. Fig. 1c) is 1.2mm and equals the inner diameter of the coaxial cable. The location of the coax connection on the disc patch are v_x=-1mm and v_y=-8.4mm, where the center of this coordinate system is located at the center of the circular patch. The substrate dimensions are W=48mm and L=50mm.

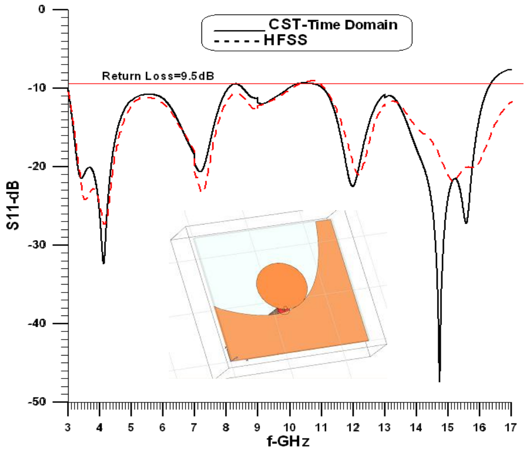

Fig. 9 Input reflection coefficient of the directional UWB antenna in microstrip technology with coaxial feed according to Fig. 1c.

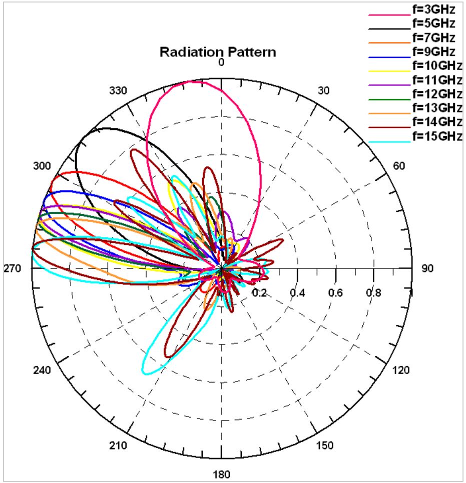

Fig. 10 Beam variation versus frequency for the directional UWB antenna in microstrip technology with coaxial feed (Fig. 1c).

The reflection coefficient in Fig. 9 is better than 9.5dB over a bandwidth extending from 3GHz to 16.35GHz. This is more than 30 percent additional bandwidth in comparison with the previously discussed directional UWB antennas. Fig. 10 shows that the direction of the maximum radiation in x-y plane varies between 348 and 278 degrees between 3GHz and 16GHz, respectively. In addition, the half-power beamwidth changes between 60 and 20 degrees. Fig. 11 illustrates the maximum gain versus frequency. The average gain in the mid and upper band is approximately 8dB.

The advantages of utilizing coaxial line feeding rather than microstrip or coplanar feeds is mainly an increase of more than 30 percent in bandwidth. Secondly, the variation of the 3-dB beamwidth is smaller for coaxial line feeding than for those in the previous structures. The disadvantage, of course, lies in the heavy influence (not shown here for lack of space) of the feeding coaxial cable on the radiation pattern in the yz plane (c.f. Fig. 1c).

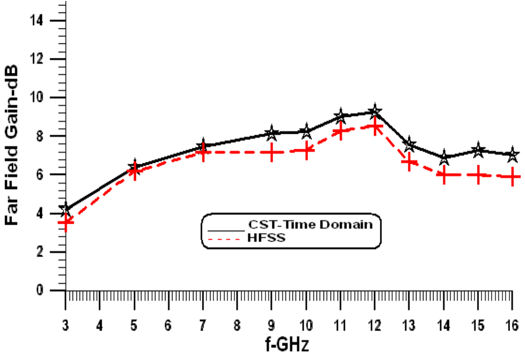

Fig. 11 Maximum antenna gain for the directional UWB antenna of Fig. 1c.

D. Group Delay

The key in UWB antenna design is to obtain a good linearity of the phase of the radiated field in order to minimize pulse distortions. Fig. 12 shows the group delay results for all three directional UWB antennas as calculated from the time-domain responses, e.g. [12], in CST Microwave Studio.

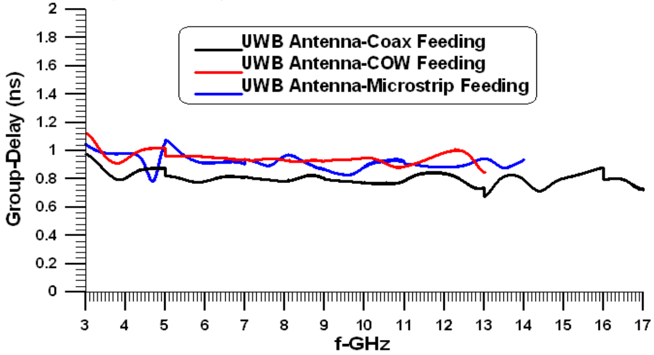

Fig. 12 Group delay performance for the three proposed directional UWB antennas in Fig. 1.

The group delay variation of all three directional UWB antennas is less than 0.2ns. Apparently, smaller variations of the group delay occur for the antenna with coaxial line feeding in Fig. 1c. The microstrip antenna of Fig. 1a exhibits the largest group delay variation which is attributed to the fact that the polarization is required to rotate at the transition between the microstrip feed and the circular disc.

IV. CONCLUSIONS

The properties of directional UWB antennas have been investigated. The designs use monopole disc patches and parabolic-shaped ground planes mounted on a planar substrate with various feeding technologies. The key feature of the new ground plane shape is to operate mainly as a reflector within the UWB frequency range in order to maximize antenna directivity as well as minimize side lobes. It is obvious that such a planar parabolic reflector can be implemented on any existing printed circuit UWB antenna. It is also illustrated that implementation of coaxial line feeding through the substrate rather than microstrip/coplanar feeding contributes to more than 30 percent of achievable bandwidth, less variation of the angular directivity and beamwidth and a slightly flatter group delay response over the entire bandwidth. The performances of the three proposed directional UWB antennas are verified by two commercially available software packages in the time and frequency domains.

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