

## A planar antenna in LTCC for single-package ultrawide-band radio

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These results are best explained from the admittance charts. In each case, we note that the admittance of the unmatched antenna intersects the 20 mmho conductance circle at a frequency higher than the resonant frequency. By inserting the matching post, we add the equivalent of a parallel inductance at the input and this moves the admittance toward the center of the chart at that frequency. Although not exact, it does provide a qualitative explanation as to how the post behaves as a matching circuit.

As for other parameters, as is the case of all electrically small antennas, the radiation pattern approaches that of a point source; it has near hemispherical coverage. As mentioned in [1], the  $Q$ 's of the seven-wire and ten-wire antennas without the matching post were about 100 and 135, respectively. These antennas with the matching post are about the same. Finally, the efficiency of these antennas are close to 100%, since the input resistance is now near 50 ohms and the antennas do not have any losses other than the ohmic losses of the wire.

#### IV. CONCLUSION

Since these results have not been fully optimized, they are considered preliminary. They are, however, a strong indication that this method of using an inductive matching post near the input of an antenna, having a very low radiation resistance, is an excellent way to obtain a match to a 50-ohm coaxial line.

#### ACKNOWLEDGMENT

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## A Planar Antenna in LTCC for Single-Package Ultrawide-Band Radio

Chen Ying and Y. P. Zhang

**Abstract**—This correspondence presents a planar antenna in low-temperature cofired ceramic technology for a single-package solution of ultrawide-band (UWB) radio. The antenna has an elliptical radiator fed through a microstrip line. The radiator and the microstrip line share the same ground plane with the other UWB radio circuitry. The experiments have been conducted. Results show that the prototype antenna has achieved bandwidth of 110.9%, gain from  $-1.34$  to  $5.43$  dBi, broad patterns, and relatively constant group delay at frequencies from 3 to 10.6 GHz. Furthermore, it is also found that the normalized antenna radiated power spectrum density basically conforms to the FCCs regulation on the emission limit of indoor UWB systems.

**Index Terms**—Low-temperature cofired ceramic (LTCC), planar antenna, ultrawide-band (UWB).

#### I. INTRODUCTION

There is much interest today in developing ultrawide-band (UWB) radio for short-range high-speed wireless communication networks. UWB radio exploits an ultrawide bandwidth of 7.5 GHz to exchange information. With such a wide bandwidth, there exist some challenges in making UWB radio up to its full potential. One of the major challenges is the design of UWB antennas particularly for use in portable system. Good UWB antennas should have low return loss, omni directional radiation pattern, and high efficiency over the ultrawide bandwidth from 3.1 to 10.6 GHz. They should also meet FCCs regulations on emission limits. There are some UWB antennas such as the diamond dipole and the complementary slot antenna. They have been proven suitable for UWB radio [1]–[4]. A dielectric chip antenna has also been demonstrated by the Taiyo Yuden Research and Development Center of America (TRDA) for UWB radio recently [5], [6]. These UWB antennas are physically small but still discrete. Although the chip antenna developed by TRDA has a very small size, no investigations were carried out to integrate it with the radio circuitry ground plane in order to realize a single package solution. Furthermore, TRDA antenna relies upon Taiyo Yuden's ceramic-material and multilayer-stacking that may result in a higher cost in the mass production [7]. In this correspondence, a rather simple low-temperature cofired ceramic (LTCC) planar antenna is designed and tested. LTCC process can embed high-quality capacitors, resistors, and inductors in low loss ceramic substrates, while allowing active devices such as monolithic RF and microwave integrated circuits to be mounted on them [8]. LTCC process produces mechanically strong, hermetically sealed, thermally conductive, chemically inert, and dimensionally stable structures with high yield [9]. Therefore, LTCC process has recently become the choice of technology to realize single-package radio [10]. To examine the antenna performance when it is integrated with the other UWB radio circuitry in a single package, we have designed the LTCC planar UWB antenna that shares the same ground plane with the other UWB radio circuitry [11]. We describe the details of the LTCC planar UWB antenna in Section II. The

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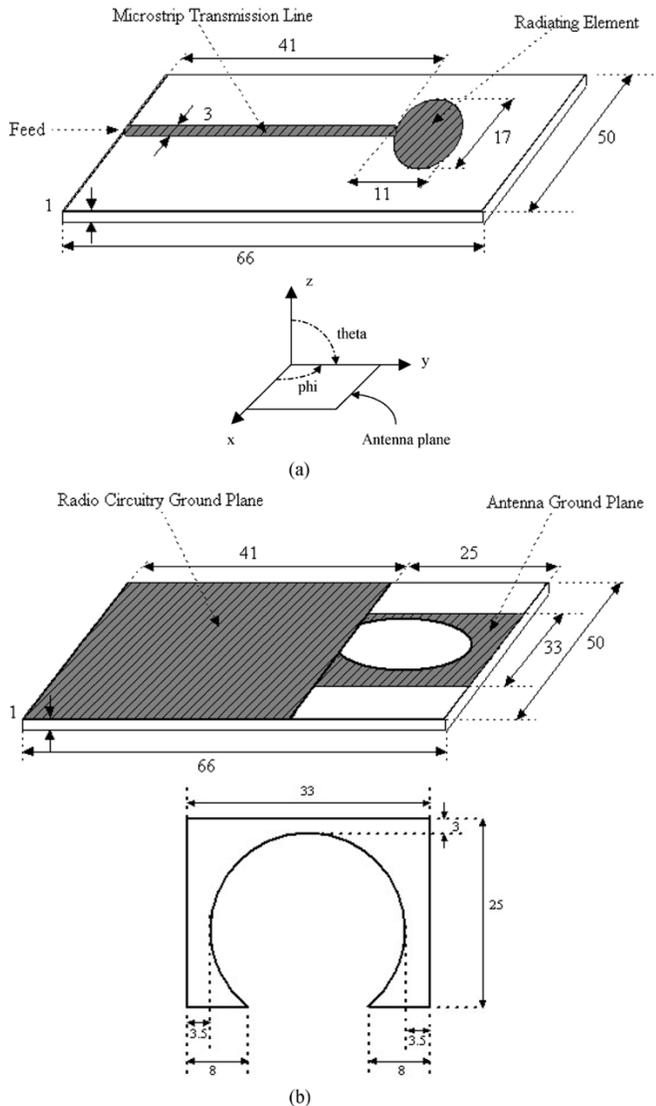


Fig. 1. Configuration of the LTCC planar UWB antenna (unit in millimeters): (a) top layer and (b) bottom layer.

performance of the LTCC planar UWB antenna is presented in Section III. Finally, the conclusions are summarized in Section IV.

## II. DESCRIPTION OF LTCC PLANAR UWB ANTENNA

There are numerous LTCC tapes that can be used for single-package UWB radio. We chose Dupont 951 LTCC tape for our work. Dupont 951 LTCC tape has a relative permittivity of 7.8 and loss tangent of  $0.001 \sim 0.002$  over the UWB band. Fig. 1(a) shows the top layer configuration of the LTCC planar UWB antenna. As shown, the antenna has a shape of ellipse with a short axis of 11 mm and a long axis of 17 mm. It is fed by a microstrip line with a length of 41 mm and a width of 3 mm. The single LTCC package has dimensions of  $66 \times 50 \times 1$  mm<sup>3</sup>. The antenna is positioned in such a way that the rest of the package surface can comfortably accommodate the other UWB radio circuitry. The outward orientation of the antenna allows the use of microstrip line to link the antenna with the RF front-end circuitry. Fig. 1(b) shows the bottom layer configuration of the LTCC planar UWB antenna. As shown, the antenna ground plane is connected with the other UWB radio circuitry ground plane. The antenna ground plane has a footprint of  $33 \times 25$  mm<sup>2</sup>. The other UWB radio circuitry ground plane has a rectangular shape of dimensions  $50 \times 41$  mm<sup>2</sup>.

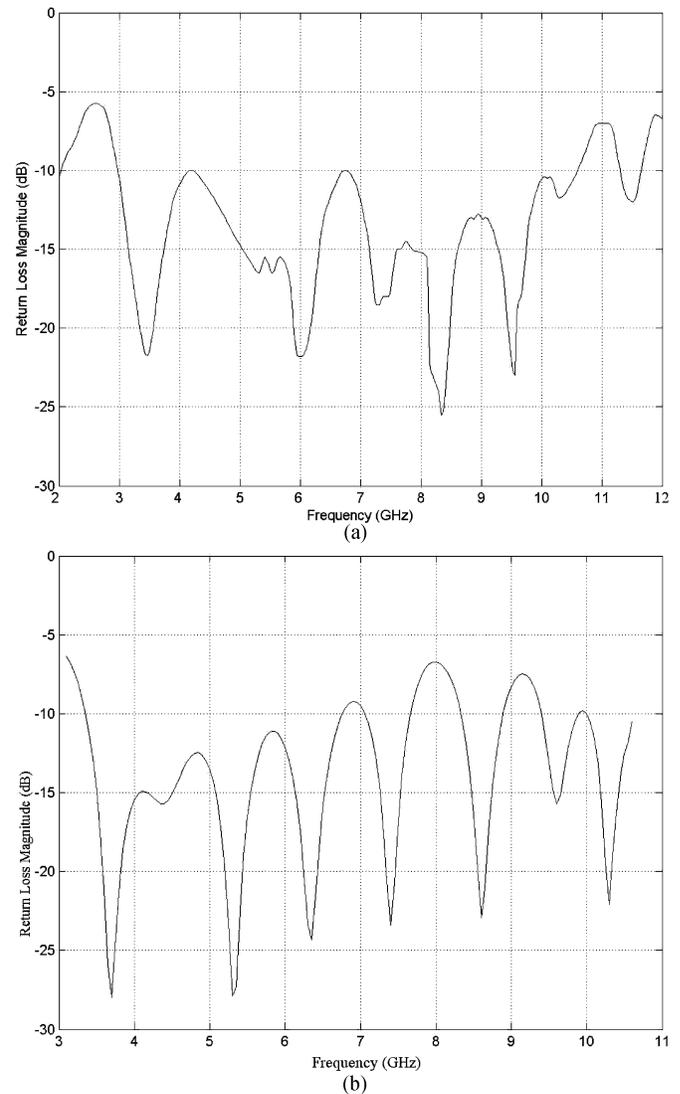


Fig. 2. Measured return loss versus frequency: (a) with the antenna ground plane and (b) without the antenna ground plane.

## III. RESULTS AND DISCUSSIONS

In this section, the measured performance of the LTCC planar UWB antenna is examined. All the measurements were carried out using an HP 8722ES network analyzer in an anechoic chamber over the frequency range of 2 to 12 GHz.

### A. Return Loss and Radiation Characteristics

As shown in Fig. 2(a), the measured return loss magnitudes fall below the threshold of  $-10$  dB from 3 to 10.6 GHz indicating that the antenna has achieved bandwidth 7.6 GHz ( $7.6/6.85 = 110.9\%$ ).

Figs. 3–5 show the measured far-field radiation patterns at 3.5, 6.85, and 10.1 GHz for the two principal cuts ( $\phi = 0^\circ$  and  $\phi = 90^\circ$ ). For all the three frequencies, the radiation patterns at  $\phi = 0^\circ$  cut have the strongest radiation at  $0^\circ$  and  $180^\circ$  and the weakest radiation at  $90^\circ$  and  $270^\circ$ . For all the three frequencies, the radiation patterns at  $\phi = 90^\circ$  cut have nulls at  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$ , and  $270^\circ$ . This indicates that the LTCC planar UWB antenna has very similar radiation patterns over the ultrawide bandwidth. Due to the finite ground plane used in the measurements the measured radiation patterns have shallow nulls at both  $90^\circ$  and  $270^\circ$ . The measured results demonstrate that the LTCC planar UWB antenna has quasi omni-directional radiation patterns in the azimuthal plane.

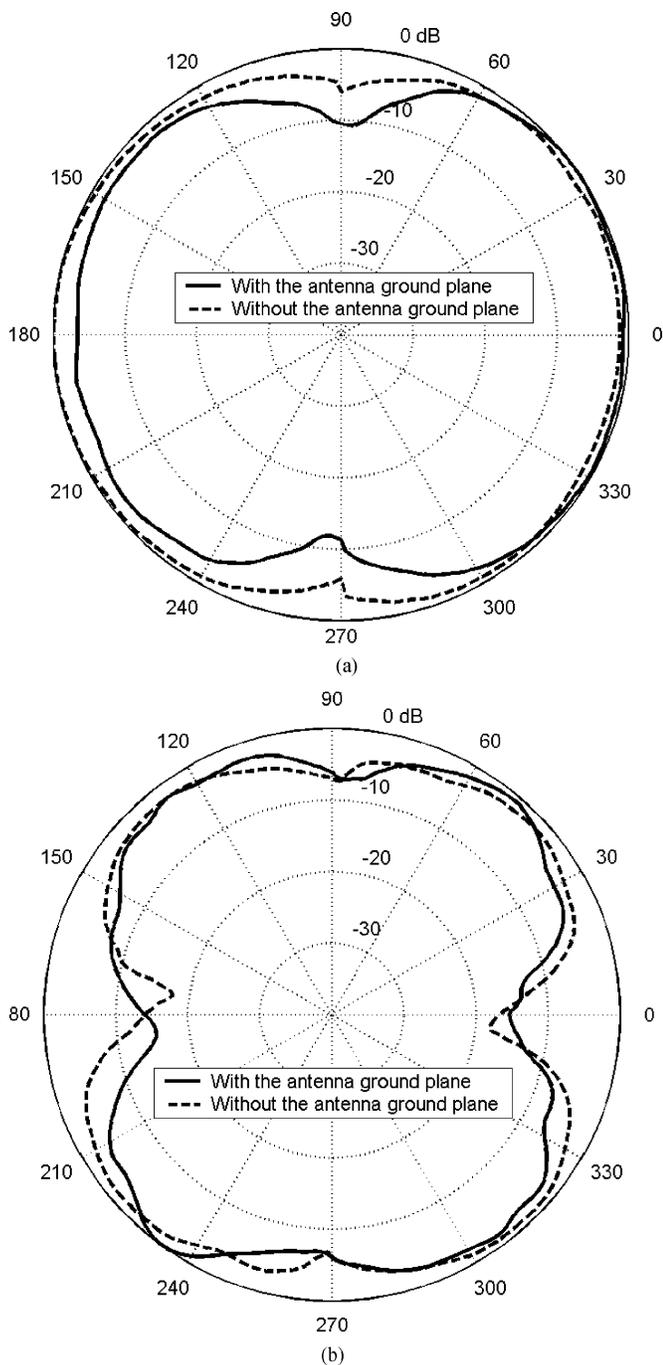


Fig. 3. Measured radiation patterns at 3.5 GHz: (a)  $\phi = 0^\circ$  and (b)  $\phi = 90^\circ$ .

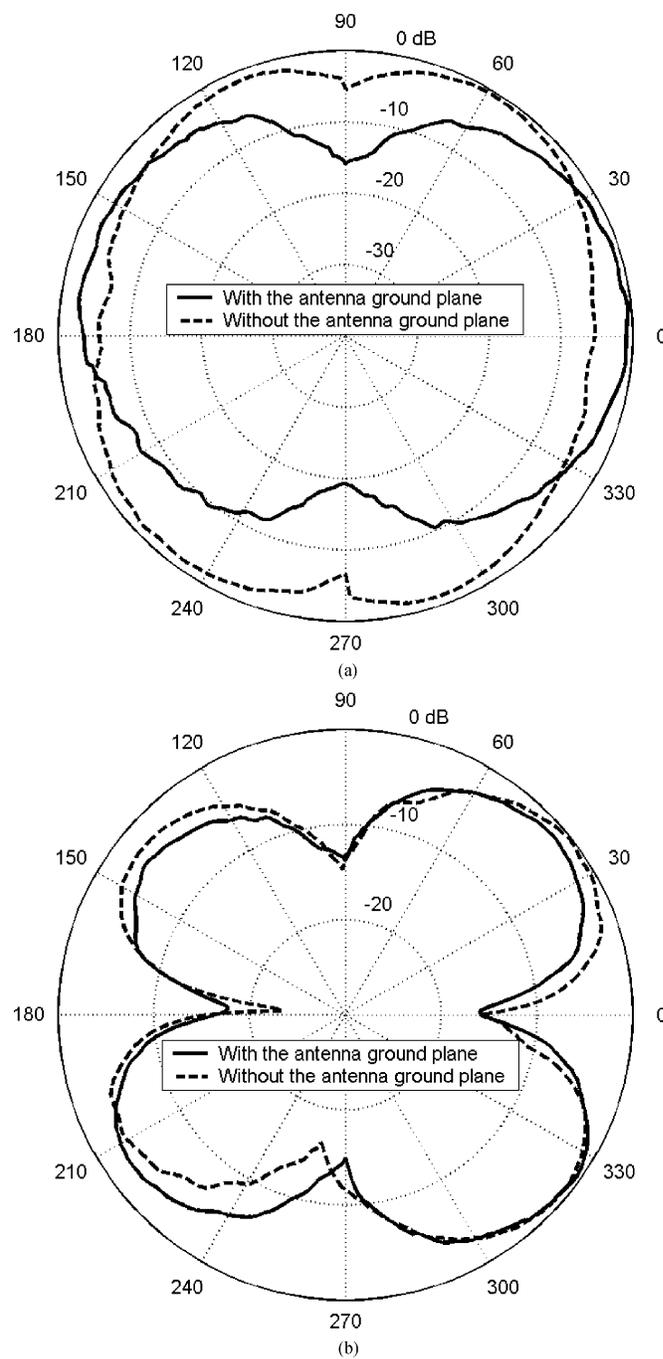


Fig. 4. Measured radiation patterns at 6.85 GHz: (a)  $\phi = 0^\circ$  and (b)  $\phi = 90^\circ$ .

Fig. 6 shows the measured antenna gain values at  $\phi = \theta = a = 0^\circ$  direction. The measured gain is  $-1.34$  dBi at 3.1 GHz, 4.2 dBi at 6.85 GHz, and 1.76 dBi at 10.6 GHz.

Fig. 7 shows the measured group delay versus frequency. As shown, the group delay difference is within 3.5 ns throughout the whole band from 2 to 12 GHz. The small group delay differences ensure the good performance of the antenna against waveform distortion during the transmission.

*B. Effect of the Antenna Ground Plane*

Planar monopole antenna has been proved to yield wide-impedance bandwidth [12]. The removal of the antenna ground plane modifies

the planar slot antenna into a planar monopole antenna. The effect of the removal of the antenna ground plane is worth of investigating.

The measured return loss plotted versus frequency from 3.1 to 10.6 GHz is shown in Fig. 2(b). It also indicates very wide impedance bandwidth over the UWB band. The return loss can be further improved by adjusting the dimension of the radiating element. The measured radiation patterns at 3.5, 6.85, and 10.1 GHz without the antenna ground plane are also plotted in Figs. 3–5 for both the  $\phi = 0^\circ$  and  $\phi = 90^\circ$  cuts. The shapes of radiation patterns for both cases with and without the antenna ground plane are also very similar.

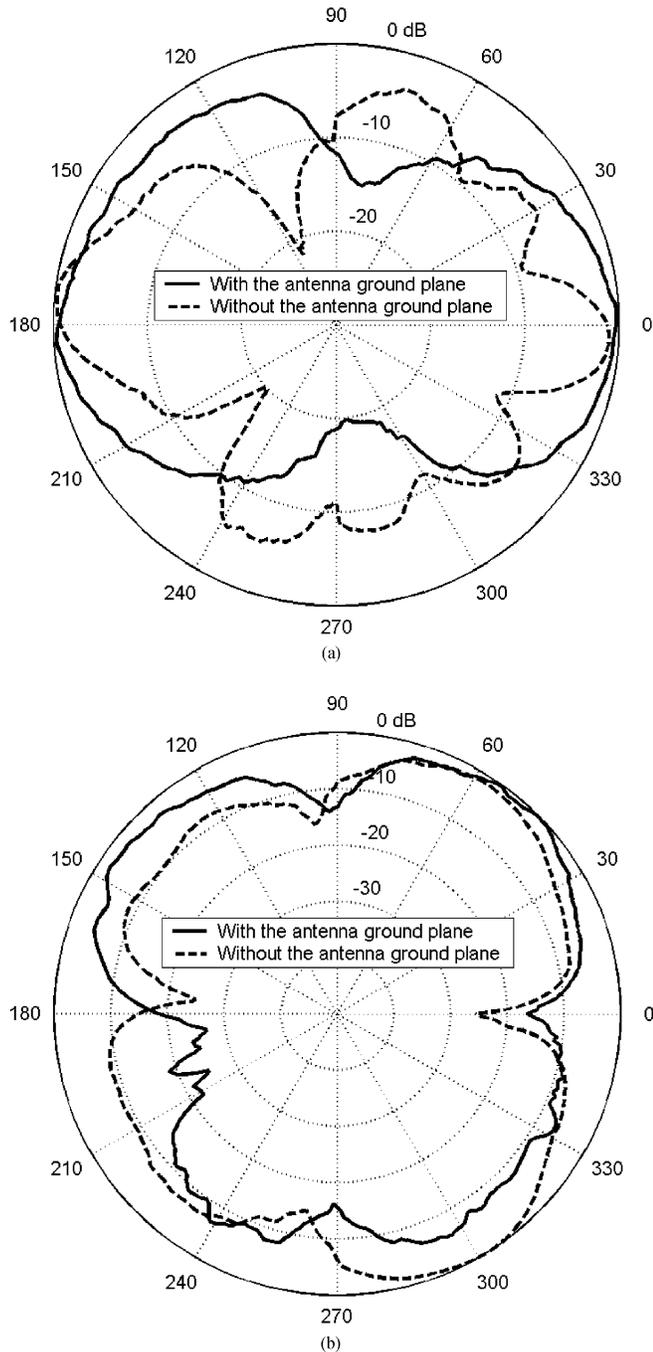


Fig. 5. Measured radiation patterns at 10.1 GHz: (a)  $\phi = 0^\circ$  and (b)  $\phi = 90^\circ$ .

#### IV. CONCLUSION

The LTCC planar UWB antenna that shares the same ground plane with the other radio circuitry has been studied for the single-package solution of UWB radio. It has been demonstrated that the antenna has achieved an ultrawide bandwidth of 7.6 GHz from 3 to 10.6 GHz. It has been also demonstrated that the antenna has relatively omnidirectional radiations over the ultrawide bandwidth in the azimuthal plane. It was found that the normalized radiated power spectrum density of the LTCC planar UWB antenna was within the FCC's regulation on emission limit of indoor UWB systems except from 2.6 to 3 GHz [13]. The measured antenna gain was  $-1.34$  dBi at 3.1 GHz, 4.2 dBi at 6.85 GHz, and 1.76 dBi at 10.6 GHz. The measured group delay fluctuated within 3.5 ns from 2 to 12 GHz. Further investigations and developments are being

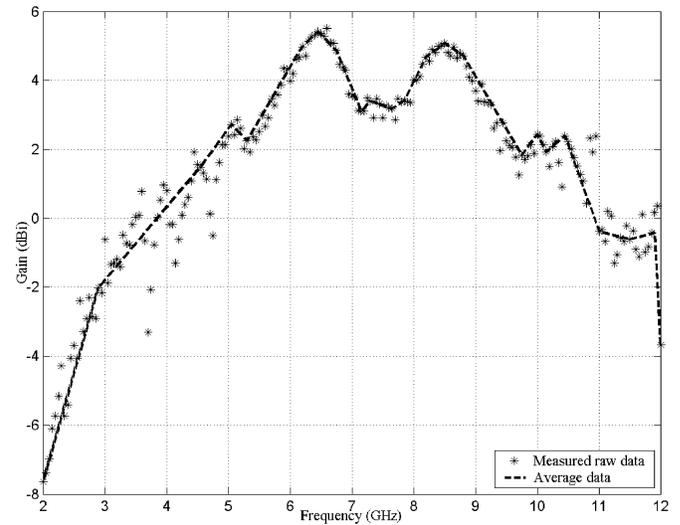


Fig. 6. Measured antenna gain ( $\phi = \theta = 0^\circ$ ) versus frequency.

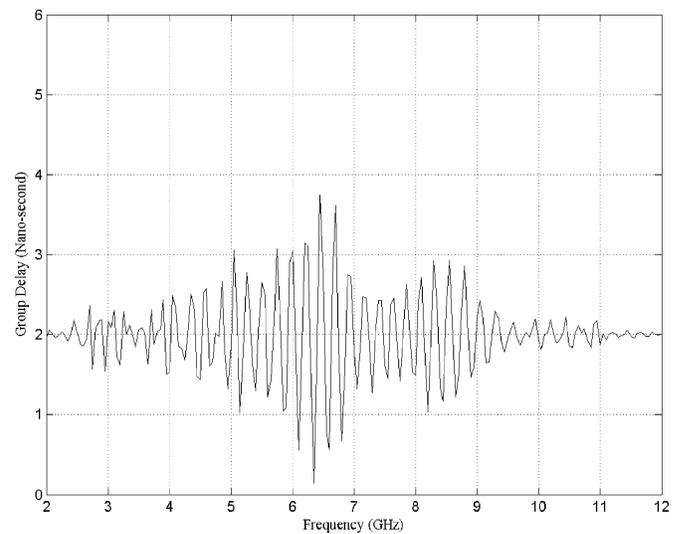


Fig. 7. Measured group delay versus frequency.

carried out in our laboratory on the effect between the LTCC planar UWB antenna and the other UWB radio circuitry.

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## Dual-Polarized Omnidirectional Planar Slot Antenna for WLAN Applications

Ezzeldin A. Soliman, Magdy S. Ibrahim, and Alaa K. Abdelmageed

**Abstract**—A novel planar slot antenna is presented in this paper. The antenna provides dual-polarization and omnidirectional radiation patterns. Hence, it is suitable for hand-held equipments of wireless systems. The proposed antenna is optimized for operation at 5.2 GHz. The antenna, without ground plane extension, occupies an area of  $2.17 \times 2.17 \text{ cm}^2$ . An impedance bandwidth of 10.6% is obtained, with a very good isolation between the two excitation ports. Appealing omnidirectional radiation patterns are maintained over the entire impedance bandwidth. The gains of the two polarizations are 2.59 and 3.52 dB, while the radiation efficiencies are 93% and 99.8%.

**Index Terms**—Cusp antenna, dual-polarization, omnidirectional, planar slot antennas, Wireless Local Area Network (WLAN).

### I. INTRODUCTION

Planar antennas are gaining a lot of interest recently, owing to their low cost, low profile, and possible conformity to the supporting structures. They can be classified into two main classes, the microstrip and the slot types. A representative example for the first type is the microstrip patch antenna which has been studied intensively in the literature in the past two decades [1]. Slot type antennas have advantages over the microstrip antennas as they provide wider impedance bandwidth, higher radiation efficiency, and the possibility of obtaining both bi-directional [2], and uni-directional radiation patterns [3].

In a previous work, a wideband planar slot antenna has been introduced [4], [5]. This antenna is referred to as the cusp antenna. It has been demonstrated that such antenna possesses a wide impedance bandwidth behavior. For feeding this antenna, a coplanar waveguide (CPW) is used. It is well known that the CPW has two fundamental modes, namely the coplanar and the slotline modes. The coplanar mode is more attractive in circuits owing to its less dispersion and less radiation losses at discontinuities. However, for antennas the slotline mode can be also attractive.

In [6] the authors used both modes of the CPW to excite the cusp antenna. It has been demonstrated that for such antenna, the polarization of the copolar component of the coplanar mode is normal to that of the slotline mode. In other words, a dual polarization operation is possible via switching between the two modes of excitation. However, there are two main problems in the preliminary study in [6]. These problems prevent the practical use of the proposed method for achieving dual polarization operation. The first problem is that the working impedance

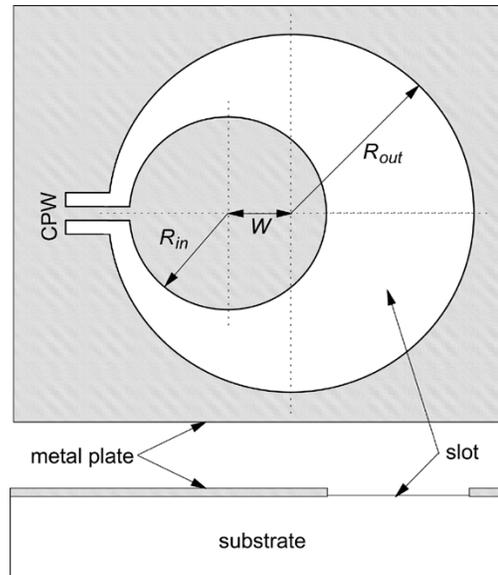


Fig. 1. CPW-fed planar slot cusp antenna.

bandwidths of the two modes are not overlapped. This means that there is no common bandwidth for which the antenna is matched to both modes. The second problem comes from the difficulty in bringing the two modes simultaneously at the feeding CPW line. In this paper, we present the practical solutions for these problems.

The application selected for performing our research, is the antenna of the hand-held equipment of the Wireless Local Area Network (WLAN) systems operating at 5.2 GHz. Such systems require omnidirectional radiation patterns from both sides of the substrate. They also require dual-polarization operation. Wideband behavior is desired in order to be compatible with the evolution of the wireless systems toward transmitting video signals. Finally, the size reduction for such systems becomes an important issue. For example, the antenna with its ground plane extension must fit inside the PC card which occupies an area of  $5.2 \text{ cm} \times 4.3 \text{ cm}$ . It will be demonstrated that our proposed design and feeding mechanism are able to satisfy all these requirements.

Section II presents the magnetic current distribution of the two radiating modes of the cusp antenna. The proposed excitation mechanisms of the two modes are introduced in Section III. The optimized dimensions of the cusp antenna for operation at 5.2 GHz are also given in Section III. The complete set of simulation results for the proposed antenna are presented and discussed in Section IV. The main conclusions are drawn in Section V.

### II. RADIATING MODES

As demonstrated in [4]–[6], the cusp antenna has a single slot layer deposited on top of a dielectric substrate, as shown in Fig. 1. There are two circular boundaries present in the geometry of the cusp antenna. A large circle with radius  $R_{out}$ , and a smaller circle with radius  $R_{in}$ . The centers of the two circles are separated from each other by a distance  $W$ . Consequently, there are three design parameters for the slot of the cusp antenna:  $R_{out}$ ,  $R_{in}$ , and  $W$ . These design parameters are optimized in order to achieve the desired input impedance behavior versus frequency. No dimensions are provided in Fig. 1, because the discussion presented in this section is quite general and not associated to a specific frequency band or layer structure.

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