Circular Ring Optically Transparent Antenna for Ultra-Wideband Applications

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Abstract **─** This paper presents the results of a simple and novel optically transparent Ultra-Wideband (UWB) antenna consisting of a coplanar waveguide fed circular ring-shaped monopole that is constructed on a transparent conductive Indium Tin Oxide (ITO) film. The proposed antenna exhibits an impedance bandwidth of 163% between 2 to 20 GHz, which exceeds Federal Communication Commission's UWB frequency range, with a return-loss performance more than 10 dB. The antenna radiates omni-directionally in the *H*-plane and bi-directionally in the *E*-plane. The measured results confirm the antenna is a feasible proposition for integration with various ultra-wideband applications requiring transparent aesthetics. Details of the antenna design, simulation and measurement results are presented.

Index Terms **─** Coplanar Waveguide (CPW) fed antennas, Indium Tin Oxide (ITO), transparent antenna, transparent conductive, Ultra-Wideband (UWB) antennas.

I. INTRODUCTION

Optically transparent antenna are gaining prominence and becoming a very attractive proposition for various applications such as car windshields, building windows, touch panel controls, and display panels of wireless communications equipment. These antennas can enhance security and aesthetics of vehicles, and can be integrated within satellites' solar cell panels [1]. Such antennas can be constructed on transparent conductive film such as Indium Tin Oxide (ITO), Fluorine-doped Tin Oxide (FTO) and silver coated polymer (AgHT) films [2-4]. ITO is more desirable as it offers reasonable trade-off between optical transparency and conductivity. However, due to the difficulty of fabrication and lossy nature of the transparent materials, the R&D work on transparent antennas is limited and sparse in the literature [5-8]. In [5], the transparent antenna operates in 2.3 and 19.5 GHz, in [6], the AgGL meshed transparent antenna operates in 60 GHz and it has transparency above 80% in wavelength 550 nm. Katsounaros [7] has been presented an UWB Transparent antenna which works from 1 GHz to 8.5 GHz. The authors used an AgHT-4 optically transparent conductive coating on a clear polyester substrate.

After releasing by the Federal Communications Commission (FCC) for a bandwidth of 7.5 GHz (3.1-10.6 GHz) for UWB wireless communications, UWB is rapidly advancing as a high data rate wireless communication technology [9]. The UWB system has wide applications in short range and high speed wireless systems such as local area communications, radar, medical imaging and other military applications. This technology

Submitted On: July 27, 2013
Accepted On: September 27, 2014

requires antennas that are small in size with a wide bandwidth, possess omni-directional radiation patterns and exhibit minimum distortion in the received waveform. Although recently numerous planar broadband antenna configurations have been studied and reported [10-12], these antennas have not been implemented on the transparent media to date. In this paper, a new optically transparent antenna is proposed with a ring-shaped patch that is excited by CPW-fed structure and fabricated on ITO conductive film for UWB applications. Although the annular ring structure in opaque substrate is not new, in this paper we have studied various types of transparent substrates to achieve high transparency, higher bandwidth than nontransparent substrate and investigated the effect of them in antenna design. The antenna's impedance bandwidth of 163% extends between 2-20 GHz with return-loss better than 10 dB. This simulation result is compared with measurement which shows a good agreement.

II. ANTENNA CONFIGURATION

The geometry and parameters defining the proposed transparent UWB antenna are shown in Fig. 1. The antenna comprises of circular ring monopole patch with a CPW feed structure. It is fabricated on an ITO conductive film that has a thickness and surface resistance of 100 nm and 15 Ω/sq, respectively. Its transparency is also above 85% at a wavelength of 550 nm. Figure 2 shows the transparency of Antenna (ITO+substrate) for various wavelengths.

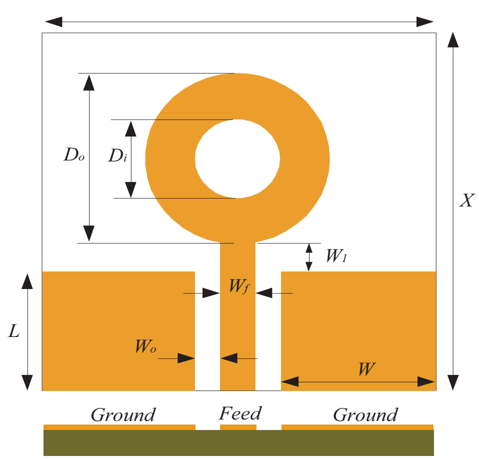

Fig. 1. Geometry and characterizing parameters of the proposed antenna.

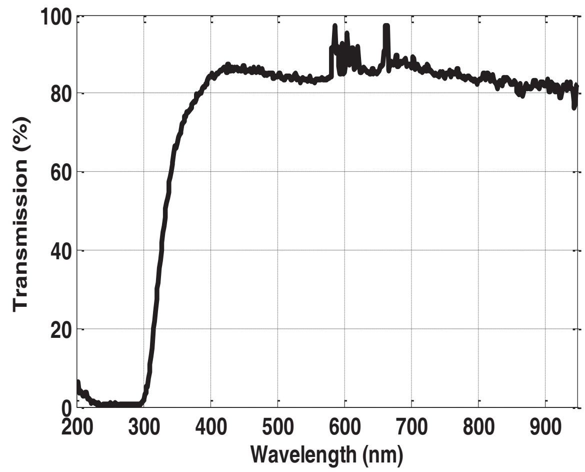

Fig. 2. Measured transparency of the antenna for various wavelengths.

The antenna is mounted on a 1.3 mm thick glass substrate with ε_r=4.6. The antenna located in the *x-y* plane, has a total substrate size of 50×50 mm^2. The antenna characterizing dimensions are given in Table 1. A photograph of the fabricated antenna is shown in Fig. 3. In order to obtain 50 Ω input impedance, a CPW feed-line is used, which has width, W_f of 2.0 mm and is separated from the coplanar ground-plane with gap, W_o of 0.34 mm.

Table 1: Characterizing parameter values of the antenna

Parameters	*X*	*W*	*L*	*W1*	*D0*	*Di*
Units (mm)	50	23.45	18.7	1	25.2	11

Fig. 3. Photograph of the fabricated antenna.

III. SIMULATION AND MEASURMRNT RESULTS

The proposed antenna in Fig. 1 is fabricated using parameter values given in Table 1. The antenna design was conducted using Ansoft High-Frequency Structure Simulator (HFSS™). The return-loss was measured in an anechoic chamber using the Agilent 8722ES network vector analyzer (50 MHz - 40 GHz). Simulated and measured reflection coefficient (S_{11}) presented in Fig. 4, are in good agreement.

The measured response is better than the simulated one. The discrepancy is attributed to a lesser extent of the fabrication tolerance and the effect of Ag adhesive applied to mount the antenna on the glass substrate. Also, the dielectric constant of the substrate in the measurement may be different than one used in the simulation.

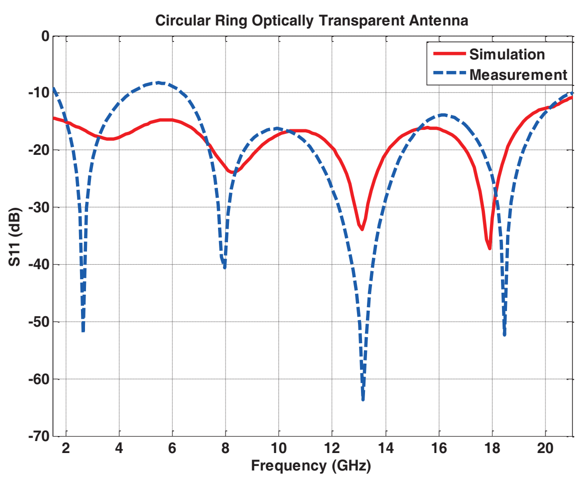

Fig. 4. Simulated and measured reflection coefficient of the proposed antenna.

The bandwidth of the fabricated antenna is 163% across the frequency range of 2-20 GHz for S_{11} <-10 dB. The normalized radiation patterns of the proposed antenna at three spot frequencies, i.e., 3, 8 and 13 GHz, are shown in Fig. 5. The results show that the *H*-plane radiation pattern of the antenna is omni-directional, while the *E*-plane one is bi-directional. The frequency range of this antenna exceeds the UWB frequency region defined by FCC (3.1-10.6 GHz), which validates the effectiveness of the proposed antenna. Table 2 compares the proposed transparent antenna using ITO coated glass with copper plate antenna.

Figure 6 shows the effect of antenna dimension on the reflection coefficient. As it can be seen, by reducing the external diameter and increasing the internal one, antenna bandwidth can be improved. Figure 7 shows variation of dielectric constant of the transparent antenna using various transparent materials. As it can be seen, the use of PEC allows achieving maximum bandwidth while preserving the transparency.

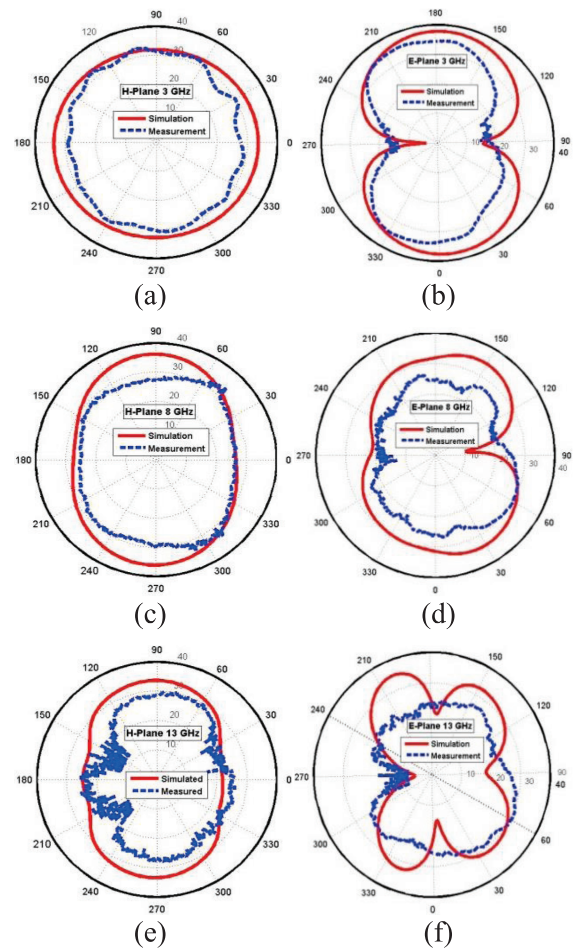

Fig. 5. Simulated and measured E- and H-plane radiation patterns: (a) H-plane 3 GHz, (b) E-plane 3 GHz, (c) H-plane 8 GHz, (d) E-plane 8 GHz, (e) H-plane 13 GHz, and (f) E-plane 13 GHz.

Table 2: Measured gain and parameters of antenna

Frequency (GHz)	3	5	8	13	T (%)	BW (%)
ITO+glass (dB)	-4	-2	0.5	2	88	163
Copper+FR4 (dB)	0.5	3	5	5.2	0	138

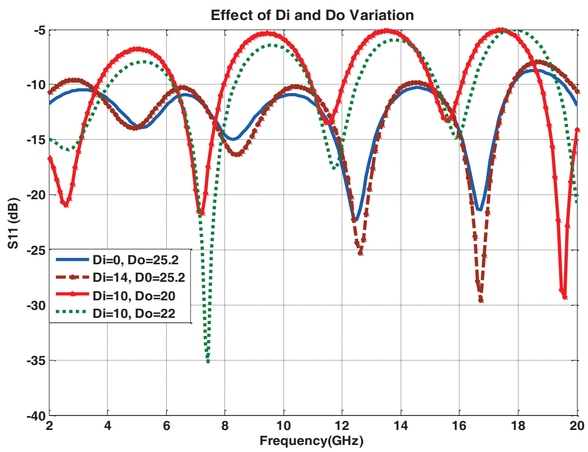

Fig. 6. Effect of Di and Do variation.

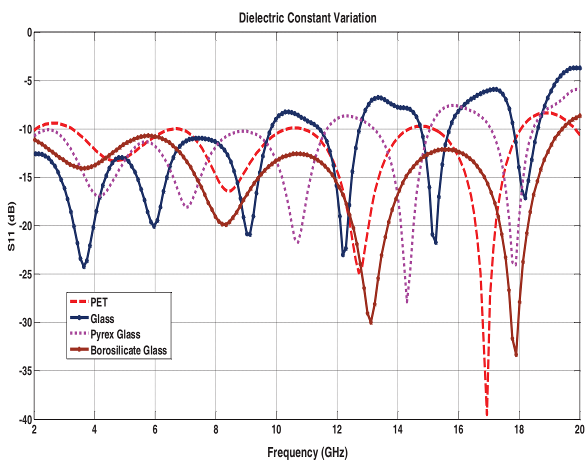

Fig. 7. Effect of dielectric constant variation.

IV. CONCLUSIONS

An optically transparent monopole antenna consisting of a circular ring patch, which is excited through a coplanar waveguide is proposed. This antenna exhibits return-loss performance exceeding FCC's ultra-wideband frequency range. Its performance is assessed by simulation and verified experimentally. The antenna is fabricated on a transparent conductive ITO film and mounted on a glass substrate with dimension of 50×50 mm^2. Its bandwidth is 163% (2-20 GHz) for a return-loss better than 10 dB (VSWR<2). In addition, the antenna radiates omni-directionally in the *H*-plane and bi-directionally in the *E*-plane. The compact size, low profile and transparent feature of the proposed antenna allows it to be integrated in a mini solar panel or cell for harnessing solar energy to provide backup power for efficient management and use of the battery in the compact UWB devices.

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