Transparent Flexible Antenna for UWB Applications

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Abstract **─** In this paper, a flexible circular slot transparent antenna which can be used in ultra wideband applications is presented. A CPW-fed circular disc monopole is used to excite the circular slot aperture. The antenna is designed and fabricated using ITO coated on a flexible Polyethylene Terephthalate (PET) substrate. It can operate with different curvature angles at UWB frequencies with 125% bandwidth. Simulation and measurement results show that the radiation pattern does not change if the antenna is being rolled, and also confirm its effective performance as a flexible transparent antenna with low profile.

Index Terms **─** Coplanar waveguide (CPW) fed antennas, flexible antenna, Indium Tin Oxide (ITO), Polyethylene Terephthalate (PET), transparent antenna, transparent conductive.

I. INTRODUCTION

Due to the widespread development of wireless communication systems in recent years, particularly in wearable and smart coating systems, demand for small-size, light, and flexible antennas has increased. Once, for the first time in 2002, FCC (Federal Communications Commission) allocated frequency range of 3.1-10.6 GHz to UWB applications, numerous UWB antenna designs on inflexible and non transparent sub layers were proposed [1-4]. Soon after, various complex antennas with more flexible structures designed and implemented [5-6]. As literature survey confirms flexible microstrip antennas have significant impact on different wireless applications such as cellular phones, airplanes, satellite, and *etc*.

Most of flexible antennas investigated in the literature are fabricated on non-transparent conductors, for instance, copper, silver and gold; therefore in case of placing them on an electrical circuit such as solar cell, they will reduce the system efficiency and degrade the system functionality. Although the proposed flexible antenna in [7, 8] has been fabricated using PET substrate, it uses a non-transparent conductors such as copper layer. In the recent years, due to the extensive applications of transparent antenna in wireless industry, such as touch panel control, display panels of wireless communications equipment, car windshields, building windows, integrated solar cell systems with transparent antenna, the use of such antennas is becoming more attractive [9]. Transparent antennas are often made of transparent conductor films such as Indium Tin Oxide (ITO), Fluorine-doped Tin Oxide (FTO) and silver coated polymer (AgHT) films. Among them, ITO is more desirable as it offers reasonable trade-off between optical transparency and conductivity. [10]. Most of transparent antennas have rigid and inflexible substrate and those with less rigid substrates cannot be used in applications where flexible transparent antennas are required [11-14].

In this paper, we proposed a flexible transparent antenna with PET substrate and ITO transparent conductor, which not only is flexible and can be placed on curved surfaces, but also is light and its 85% optical transparency does not degrade the system functionality.

II. ANTENNA DESIGN

The geometry and parameters of the proposed antenna are given in Fig. 1. This antenna is a slotted

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circular patch with a CPW fed. This antenna is made of: 1) an ITO film with 100 nm thickness, 15 Ω/sq and above 85% transparency. 2) PET polymer with 0.28 mm thickness and dielectric constant of 3.4. To achieve high transparency and high flexibility, higher ITO sheet resistance than AgHT has been used. Although some transparent conductors such as AgHT-4 or AgHT-8 have lower sheet resistance, according to [12], in order to design an effective antenna from AgHT films, the transparency has to be sacrificed. Figure 2 shows the transparency of ITO at different wavelengths. As it can be seen the transparent conductor has 85% transparency at wavelength of 550 nm. The antenna is positioned in the xy plane and has a size of 40*40 mm^2. The fabricated antenna is depicted in Fig. 3. In order to achieve input impedance of 50 Ω, we have used CPW fed with width of W_f =1.3 mm, which is separated from the CPW ground by a gap of 0.65 mm. Once a conventional planar antenna is being rolled, impedance mismatch occurs within a frequency bands. The more the antenna is being rolled, the higher impedance mismatch can be seen. To overcome this problem, here we have tuned two key parameters, *i.e.*, L_s and R_1. Figure 4 shows the reflection coefficient of the antenna for different values of R_1 and L_s. Optimized dimension and characteristics of the antenna are given in Table 1.

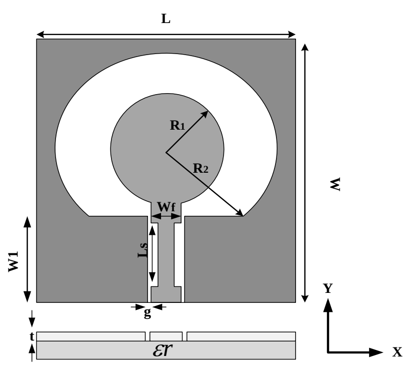


Fig. 1. Schematic of the antenna.

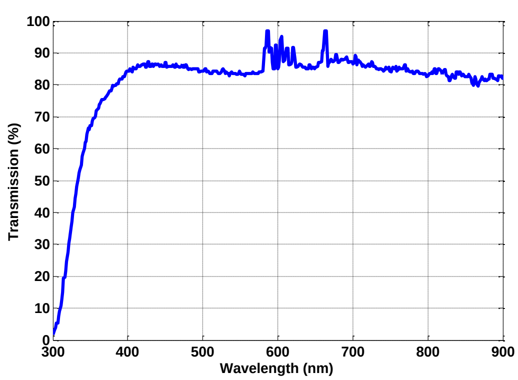


Fig. 2. Measured optical transparency of the antenna for various wavelengths.

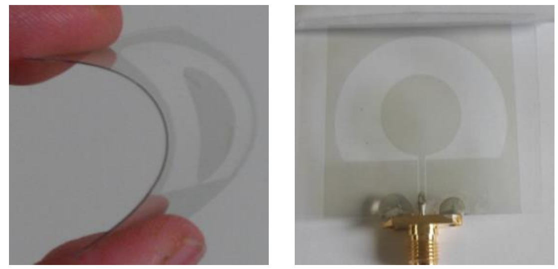
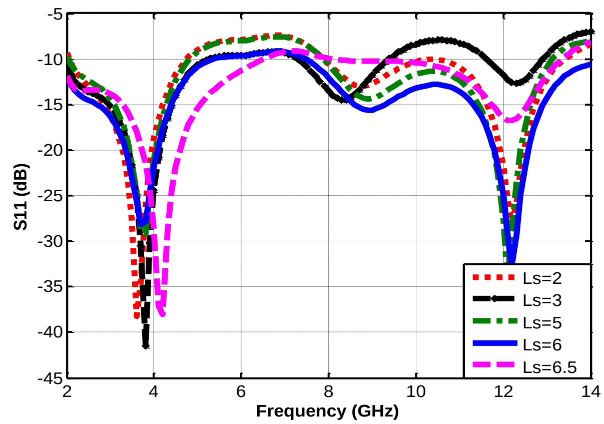
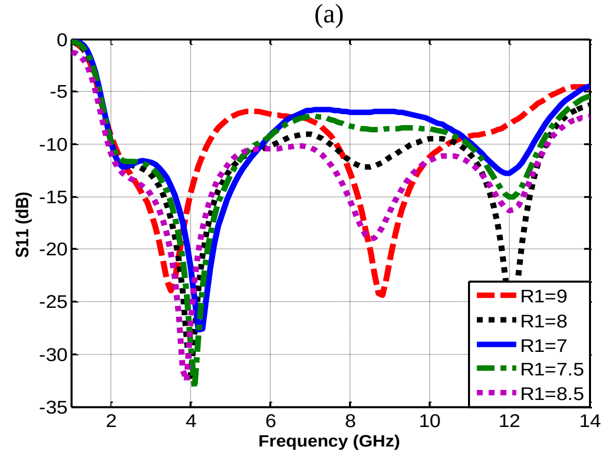


Fig. 3. Schematic of the fabricated antenna.



(a)



(b)

Fig. 4. Reflection coefficient of the antenna for: (a) different values of L_s, and (b) different values of R_1.

Table 1: Antenna parameters

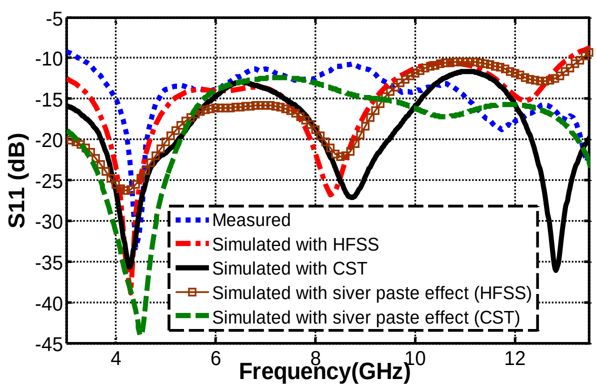
Parameter	L	W	W_1	L_s	R_1	R_2	R_s
Units (mm)	40	40	11.1	6.5	8.5	18	0.8

III. SIMULATION AND FABRICATIONS

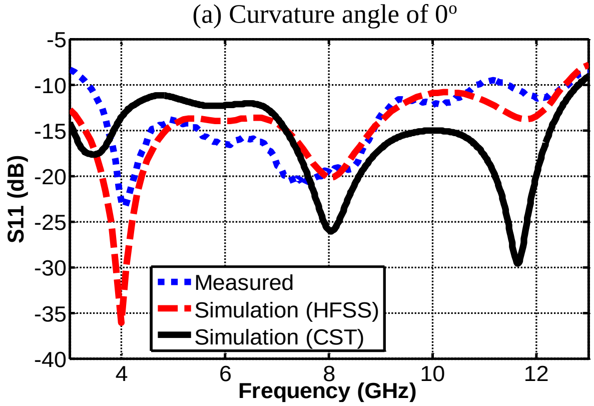
The antenna shown in Fig. 1 is fabricated using parameter values given in Table 1. The antenna is simulated with Ansoft's High-Frequency Structure Simulator (HFSS™). The reflection coefficient (S_{11} dB) is measured by Agilent 8722ES network analyzer (50 MHz-40 GHz). To ensure the antenna performance, it has been assessed for three curvature angles: 0º, 45º, 90º in the z-axis.

Figure 5 compares the measured and simulated reflection coefficient of the antenna for different curvature angles using HFSS and CST Microwave studio. As the reflection coefficient plots show, rolling the proposed flexible antenna causes less impedance mismatch compared to the planar one. More importantly, considering optimized parameter values for the antenna, it can sustain its 10 dB bandwidth over the whole UWB range for different curvature angels. The slight deviation of the simulation and measurement results can be due to the impact of fabrication process, for instance, silver paste used to attach the connector to the antenna. In spite of this slight deviation, it is a good candidate because it does not suffer from low efficiency of common flexible antennas. Also, the effect of the silver paste has been shown for the curvature angles of 0º in Fig. 5 (a).

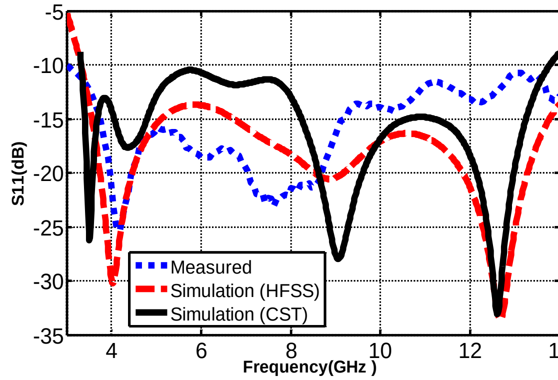
Figure 6 shows radiation patterns of the proposed antenna at two frequencies of 4 GHz and 8 GHz, for both co- and cross-polarizations and three curvature angles of: (a) 0º, (b) 45º, and (c) 90º. As can be seen, it is omni-directional on the *H*-plane while it is bi-directional on the *E*-plane. Moreover, for different curvature angles its radiation patterns do not change significantly.



(a) Curvature angle of 0º



(b) Curvature angle of 45º



(c) Curvature angle of 90º

Fig. 5. Reflection coefficient of the antenna for several curvature angles.

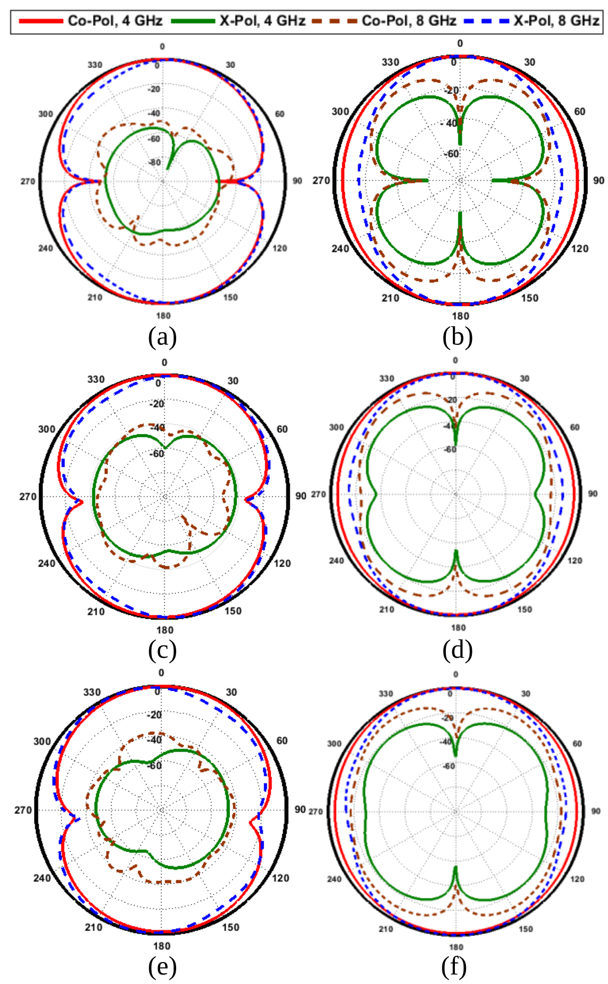


Fig. 6. Co-polar and cross-polar normalized radiation patterns at 4 GHz and 8 GHz for: (a) *E*-plane at 0º, (b) *H*-plane at 0º, (c) *E*-plane at 45º, (d) *H*-plane at 45º, (e) *E*-plane at 90º, and (f) *H*-plane at 90º.

IV. CONCLUSION

In this paper, a flexible transparent circular slot antenna excited by a circular disc CPW-fed monopole, is proposed. This antenna which is fabricated using ITO on a transparent, very light, and flexible PET substrate, can be used for UWB applications. Simulation results are validated with measurement, and confirm that the proposed antenna has a bandwidth of 125% and is omni- directional in the *H*-plane and bi-directional in *E*-plane. Its great features such as being light, low profile, highly transparent, and flexible have made it a suitable candidate for applications where an antenna needs to be placed on non coplanar surfaces or wearable electronic systems.

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