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A Transparent Curved Microstrip Patch Antenna

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Abstract— Microstrip antennas fabricated using transparent conductive oxides suffer from low efficiency and gain in the S band and lower. We propose here a modified version of the curved microstrip patch antenna, which has been designed with transparent materials. In this paper, we will show how this configuration is able to improve the radiation efficiency and gain of transparent microstrip antennas.

Keywords— curved microstrip antenna, microstrip antenna, transparent antennas

I. INTRODUCTION

Antennas manufactured using transparent conductive oxides (TCOs) have attracted increasing attention in recent times [1]. The antenna conductors are mostly based on indium tin oxide, sometimes with the addition of copper and silver, or weighted combinations of them [1]. These TCOs are usually deposited on glass or plastic substrates [1]. However, the antennas fabricated with this technology exhibit poor radiation efficiency due to the high losses of the TCOs (usually deposited with a surface resistance between 2 and 10 Ω/sq [1]) and this mainly occurs in the lower part of the S band [2]. In this paper, we exploit the characteristics of the curved patch antenna configuration presented in [3], to design a TCO curved microstrip patch antenna for solar panel applications [1]. The proposed antenna features a better radiation efficiency in comparison with the standard flat TCO microstrip patch antenna [2]. Actually, the latter, proposed in [2], exhibits a radiation efficiency lower than 15% with a TCO surface resistance around 4 Ω/sq . Moreover, the design proposed here ensures an improved frequency bandwidth. All the simulations have been performed using the commercial software Ansys HFSS at the center frequency at 2.15 GHz, considering a surface resistance of the TCOs between 1 Ω/sq and 10 Ω/sq (see Fig. 1).

To validate the performance of the proposed solution, a prototype of the curved antenna has been fabricated and measured. Good optical transparency and lightweight (about 8 g including the SMA connector) are achieved. We have used a commercial polyethylene terephthalate (PET) substrate with an In₂O₃/Au/Ag transparent conductive coating for the patch antenna and its ground plane, and 3D-printed polyethylene terephthalate glycol (PETG) to manufacture the dielectric gridded frame supporting the curved TCO-coated PET film (Fig. 1).

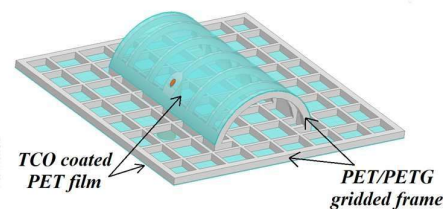


Fig. 1. 3D view of the proposed antenna.

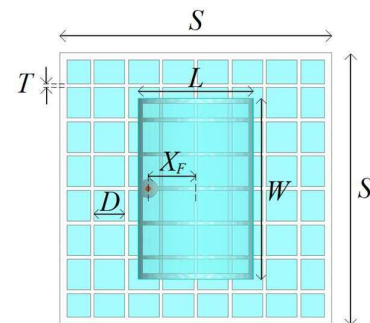


Fig. 2. Geometry of the curved antenna: top view. The grid spacing D is equal to 8 mm, and the width T is 1 mm.

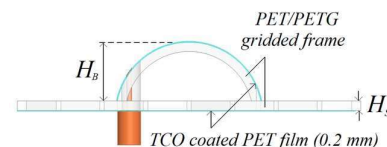


Fig. 3. Geometry of the curved antenna: side view.

II. ANTENNA DESIGN AND SIMULATIONS

A dielectric gridded frame (PET or equivalently PETG) of thickness 2 mm supports a 0.2 mm-thick curved PET film coated with a TCO (i.e., the patch antenna), with a radius of curvature equal to R_H . The antenna ground plane is provided by the same TCO deposited on a 0.2 mm-thick PET film (see Figs. 1, 2, and 3). The dielectric permittivity of both PET and

PETG is 2.5 with loss tangent 0.01. The geometrical parameters of the antenna are shown in Figs. 2 and 3.

The substrate extension S is set to 75 mm, the thickness H_S of the flat and curved gridded substrate is equal to 2 mm (Fig. 3), and the width W of the patch is equal to 50 mm. As remarked in [3], the first step of the antenna design is the selection of the bending radius R_H , which is set here to 16 mm. Then L and, consequently, the corresponding value of H_B (see Fig. 3) are chosen to get the resonance at 2.15 GHz. Finally, the position of the coaxial connector X_F is selected to match the antenna to the 50 Ω coaxial connector.

All the simulations presented in the following have been performed using Ansys HFSS. To demonstrate the capability of the propose configuration to achieve a good radiation efficiency even when the metallization exhibits relatively high values of R_S , in Table I, the radiation performance of the TCO curved antenna is reported, showing an improved radiation efficiency in comparison with a reference TCO flat patch antenna, obtained with the same geometry shown in Figs. 2 and 3, for a bending radius $R_H = \infty$ (compare results of Table I and II). For example, for surface resistance R_S equal to 2 Ω /sq the TCO curved patch exhibits 73% efficiency against 16% of the TCO flat counterpart.

TABLE I. GEOMETRICAL PARAMETERS AND ELECTROMAGNETIC PERFORMANCE OF THE TRANSPARENT CURVED ANTENNA AT 2.15 GHz

R_S (Ω /sq)	Geometrical Parameters			EM performance		
	H_B (mm)	X_F (mm)	L (mm)	G_R (dBi)	η (%)	B (MHz)
1	11.9	11.2	31.34	5.61	83.5	250
2	12.1	11.6	31.45	5.16	73.3	280
3	12.2	12.0	31.50	4.70	66.5	320
4	12.4	12.3	31.60	4.12	60.0	360
5	12.5	12.5	31.64	3.68	54.4	400
6	12.6	12.8	31.68	3.28	49.7	445
7	12.8	13.1	31.76	2.84	45.6	500
8	12.8	13.2	31.76	2.47	42.3	540
9	12.8	13.2	31.76	2.13	39.5	565
10	12.8	13.3	31.76	1.78	36.9	605

TABLE II. GEOMETRICAL PARAMETERS AND ELECTROMAGNETIC PERFORMANCE OF THE REFERENCE TRANSPARENT FLAT ANTENNA AT 2.15 GHz

R_S (Ω /sq)	Geometrical Parameters			EM performance		
	H_B (mm)	X_F (mm)	L (mm)	G_R (dBi)	η (%)	B (MHz)
1	0	16.7	54.2	2.27	28.2	145
2	0	26.6	54.6	-0.21	16.2	237
3	0	26.6	54.6	-2.01	11.2	270

From the comparison of the results in Table I and II, it can also be observed that the projected length L of the curved antenna [3-5] is significantly reduced (from $\sim 54/55$ mm to $\sim 31/32$ mm) in comparison with the flat counterpart.

III. EXPERIMENTAL VERIFICATION

A prototype of the curved antenna has been fabricated (see Fig. 4) to assess the simulated results presented in Section II. For the realization of the TCO, we have selected a commercial $\text{In}_2\text{O}_3/\text{Au}/\text{Ag}$ coated 0.2 mm-thick PET film by Delta Technologies that exhibits a nominal surface resistance (provided by the supplier) less than 10 Ω /sq and ensures good transparency in the visible spectrum (about 90% at 550 nm measured using a PerkinElmer Lambda 900 UV/VIS/NIR

Spectrometer).

For the sake of simplicity, in this work, we have used 3D-printed PETG to realize the antenna substrate (see Fig. 1). It should be noted that when PETG is employed for 3D-printing, it results translucent, with a transmittance that is strongly dependent on the printing fill density and pattern.

In our case, the PETG transmittance, measured using the spectrometer, is about 50% in the visible spectrum.

Finally, the conductivity of the $\text{In}_2\text{O}_3/\text{Au}/\text{Ag}$ coating on the 0.2 mm-thick PET film has been estimated. Since the thickness of this coating is proprietary, we have directly measured the static surface resistance of several samples to verify the exact value in the range provided by the supplier (4-10 Ω /sq). We have found that the surface resistance of this material is about 8 Ω /sq. The latter will be assumed as the value to be used for the experimental verifications.

The measurements have been performed in an anechoic environment by using the Anritsu MS46322B two-port vector network analyzer (VNA). In Fig. 5 and 6, the return loss and the realized gain are plotted, respectively. The slight difference in the return loss bandwidth (511 MHz-measured against 540 MHz-simulated) is probably due to the small uncertainty of the surface resistance of the $\text{In}_2\text{O}_3/\text{Au}/\text{Ag}$ coating. The agreement between simulated and measured realized gain is good as well, with a measured gain at 2.15 GHz equal to 2.56 dBi (see Table I for a comparison).

Finally, since the bandwidth of this resonant antenna is quite large, the far-field pattern of the manufactured prototype has been measured at selected frequencies in the operating bandwidth, i.e., at 2.0 GHz, 2.15 GHz, and 2.30 GHz.

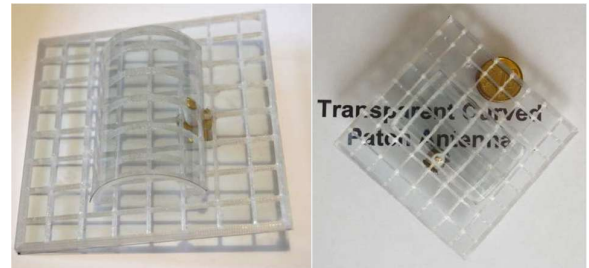


Fig. 4. Manufactured prototype of the proposed antenna.

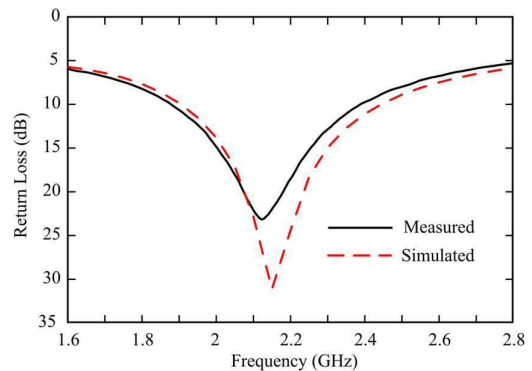


Fig. 5. Comparison between simulated and measured return loss of the manufactured prototype.

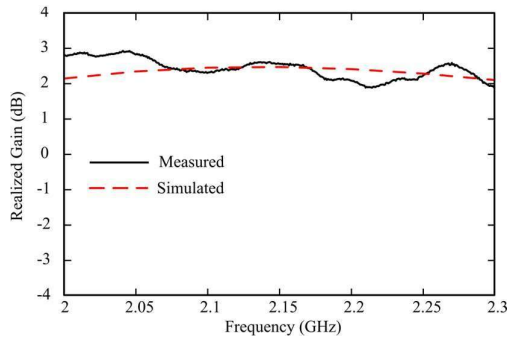


Fig. 6. Comparison between simulated and measured realized gain of the manufactured prototype.

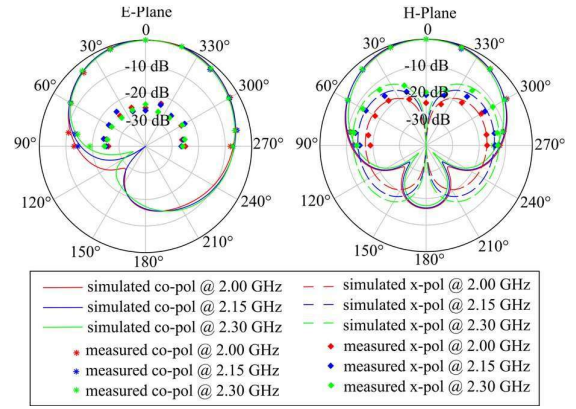


Fig. 7. Comparison between simulated and measured normalized radiation pattern.

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