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Silver Nanowire based Flexible, Transparent, Wideband Antenna for 5G Band Application

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Abstract— A transparent, flexible antenna can be utilized on car windows, solar cells, and similar applications to make use of the existing space for communication. In this work, a flexible, transparent, and wideband mm-wave monopole antenna has been designed, fabricated and tested. The proposed antennas have been realized by inkjet printing of custom made silver nanowire (Ag NW) ink. The antenna shows ultra-wide bandwidth up to 26 GHz (from 18 GHz to 44 GHz), high radiation efficiency of 55% and a maximum gain of 1.45 dBi. In addition, more than 90% transparency has been obtained due to the high transparency of the Ag NW and the slot structure. The excellent performance enables the proposed antenna suitable for various applications.

Keywords—transparent antenna; silver nanowire; flexible; mm-wave

I. INTRODUCTION

The Internet of Things (IoT) based on wireless communication has become an inherent part of daily life. As the major part of the wireless communication, antennas are gaining more and more attention, especially the optical transparent antennas, which eliminating the visual impact and represents an attractive scheme in various applications of solar panel, satellite, and smart vehicle. 5G is one future application allowing faster data transfer by utilizing wider frequency bandwidth [1]. Previous works on triangular monopole have shown wide frequency bandwidth [2], making it suitable for 5G applications.

Generally, the conventional antennas showing optical transparency are made of transparent conducting oxides, for example, Indium Tin Oxide (ITO), which also shows high conductivity [3, 4]. However, the extensively studied ITO suffers from many drawbacks, such as high cost due to the rare material Indium, complex fabrication procedures and limited mechanical flexibility due to brittle behavior. Except for the conductive materials, the substrates widely used in the transparent antennas, are brittle [5], which also limit the potential applications in flexible and wearable devices.

In this work, a wideband monopole antenna with more than 90% transparency has been designed and fabricated with the help of inkjet printing technique. The proposed antenna is also flexible and bendable due to the flexible nature of the substrate and the silver nanowire (Ag NW) prepared in the lab.

II. ANTENNA DESIGN AND FABRICATION

The antenna designs are carried out using a 3D full-wave simulator CST Microwave Studio 2018. Flexible and low loss

dielectric substrate with a permittivity of $\epsilon = 2.6$ and a $\tan\delta = 0.0044$ at 24 GHz is selected as the substrate. The thickness of the substrate is 0.05 mm. The conductivity of the antenna is 10^5 S/m.

A. Antenna design

The proposed transparent antenna in this paper is a triangular monopole antenna with a microstrip line feeding. To obtain a wideband frequency range, a 60° angle has been chosen for the triangular monopole. The length of the antenna has been optimized to get center frequency around 30 GHz. The detailed geometry parameters and S -parameters of the transparent antenna has been shown in Fig. 1. The optimized transparent antenna shows a bandwidth of 26 GHz, radiation efficiency of $\sim 62\%$ and maximum gain of 1.5 dBi. The transparency of the antenna has been further increased by introducing slots in the antenna and ground plane. Due to the small size of the antenna, it is hard to connect SMA to this antenna. Thus, CPWG feed has been added to the antenna to make probing feasible.

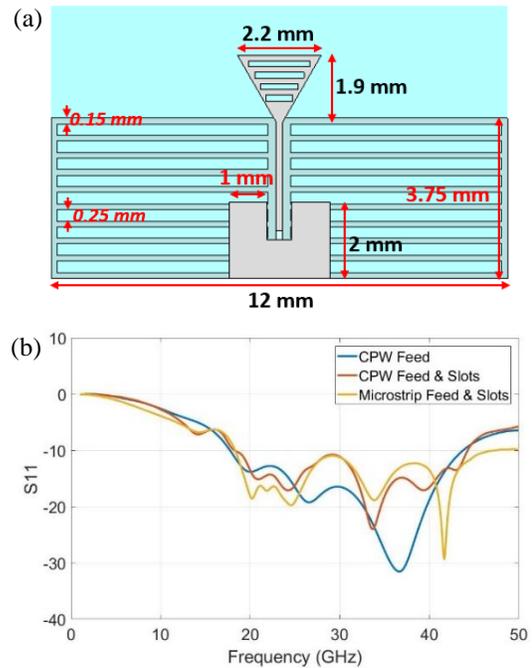


Fig. 1. (a) Structure of the triangle monopole antenna. (b) S -parameters of the transparent slotted and plane triangular monopole antennas with CPW and microstrip line feeds.

For comparison, the same antenna has been studied with a silver nanoparticle (Ag NP) ink which has higher conductivity (10^7 S/m), but much lower transparency. Attributing to the high conductivity, the Ag NP antennas show higher efficiency (more than 90%) and larger maximum gain (more than 3 dBi) comparing to the Ag NW antennas (see Table I).

B. Antenna fabrication

An inkjet printing technique has been used to fabricate the antennas. For the non-transparent antennas, Ag NP ink was directly deposited onto the substrate to form the desired monopole antennas and ground layers. For the Ag NW antennas, a polymer ink was printed onto the substrate with desired patterns. Then, Ag NW ink was deposited through spin-coating. Finally, the fabrication process was completed by immersing the sample into an organic solvent to remove the polymer layer. Fig. 2 shows the fabricated antennas and Ag NW antenna under different bending conditions, demonstrating the flexibility.

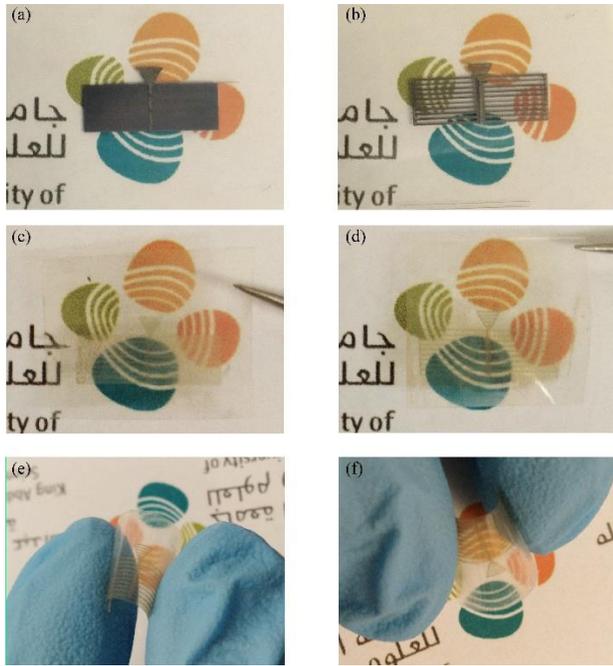


Fig. 2. (a) Antenna with Ag NP ink, (b) antenna with Ag NP ink and slots, (c) antenna with Ag NW ink, and (d) antenna with Ag NW ink and slots. (e) The Ag NW antenna under bending convex condition. (f) The Ag NW antenna under bending concave condition.

III. ANTENNA TRANSPARENCY CHARACTERIZATION

For the Ag NP-based antennas, the transmittance is equal to the area of the Ag divided by the total area [6]. For the Ag NW antennas, the transmittance has been measured in the visible light wavelength (Fig. 3). The results are compared and shown in Table I. It is reasonable to find that the Ag NW antenna with slots both in monopole antenna and ground layer shows the best transparency, which could be as high as 91.2%.

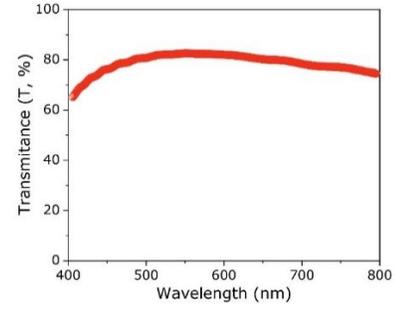


Fig. 3. UV-Vis spectra of the Ag NW antenna without slot structure.

TABLE I. COMPARISON FOR THE FABRICATED ANTENNAS

Antenna type	Bandwidth (GHz) ^a	Efficiency (%) ^a	Max Gain (dBi) ^a	Transmittance (%)
Ag NP	17	92	3.4	0
Ag NP with slot	6.8	90	3.2	42.3
Ag NW	26	62	1.5	82.4
Ag NW with slot	26	55	1.45	91.2

^a. Simulated results. The measured results will be provided.

IV. CONCLUSION

In this work, a wideband, flexible, and transparent triangular monopole antenna has been designed for 5G applications. The Ag NW ink has been prepared to be used in the fabrication of the transparent antennas with the help of inkjet printing technique. The Ag NW based antenna shows ultra-wide bandwidth up to 26 GHz, high radiation efficiency of 55% and a maximum gain of 1.45 dBi. Notably, more than 90% transparency has been obtained for the Ag NW antenna.

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