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A Novel Optically Transparent Array Antenna Using Conductive ITO Film and Integrated in OLED for mm-Wave 5G Applications.

Mustapha El halaoui^{*,+}, Laurent Canale^{+,1}, Oussama Ben Abdellah^{*,+}, Adel Asselman^{*} and Georges Zissis⁺

Abstract – In this article, an optically transparent array antenna, integrated in organic light-emitting diodes (OLEDs), is proposed for mm-wave 5G applications. This antenna is designed by using the ITO film printed on a glass substrate with the measured optical transparency of 75 %. The proposed array antenna covers the 26 GHz (26.48 -- 28.16 GHz) for the mm-wave 5G applications. The peak gain is increased from 5.94 dB to 8.4 dB by applying the array antenna technique. The spectral power distribution (SPD) of the OLED with and without antenna is measured in the visible spectrum. The OLED luminance decreased by 34 % after antenna integration. Therefore, to solve this problem and increase the optical transparency, the mesh technique will be used.

Keywords – Optically transparent antenna, mm-wave band, array antenna, 5G applications, OLED.

1. INTRODUCTION

The new generations of wireless communication are being explored to solve the challenge of increasing demand and use of mobile devices and realize the concept of smart cities. The smart cities should offer a better quality of life through the development of Internet of Things (IoT) and the implementation artificial intelligence [1], [2]. One of the services that can be improved significantly in smart cities is the lighting system to reduce energy consumption [3]. Therefore, public lighting is one of the main factors in the comfort and safety of inhabitants in cities. However, the majority of public lighting network infrastructure weighs heavily on energy costs [4]. In this context, intelligent light emitting diode (LED) public lighting not only reduces energy consumption but also improves comfort, taking into account environmental protection while ensuring a feeling of security in public spaces [5]. Indeed, the use of Organic Light-Emitting Diodes (OLEDs) in public lighting can easily make it possible to mark out pedestrian areas by limiting light pollution and the integration of 5G antenna in this type of support can provide an answer in terms of network coverage wireless communication. The main objective of this work is to integrate the antenna into the structure of the OLEDs to be connected in the wireless network [6]. Transparent materials so as not to affect the light emission by OLEDs must manufacture this antenna.

In this context, the use of the optically transparent antenna is interesting, because they can be integrated in clear substrates placed in transparent surfaces such as LCD or OLED screens, glazing of vehicles, buildings and trains, street lighting lamps, bus stops, and solar panels to improve network coverage and to reduce their visual or spatial impact [1]. Hence, the implementation of these

antennas consists in depositing a material that is transparent in visible spectrum and has a high electrical conductivity on an optically transparent substrate. Transparent conducting oxides (TCOs), such as Indium Tin Oxide (ITO), Fluorine doped Tin Oxide (FTO) and Aluminum doped Zinc Oxide (AZO) are widely used in transparent antenna [7]-[12]. To increase the conductivity and the optical transparency, researchers have proposed to use the ultrathin metal films such as TCO/Metal/TCO multilayers materials and AgHT films (AgHT-4 and AgHT-8) [13]-[16]. Nevertheless, the thickness of the metal layers is lower than skin depth, then the propagation loss is generated. In [17]-[19], another solution consists in using mesh structures has been proposed.

This paper presents the design of an optically transparent antenna operates at mm-wave band for the next generation of wireless communication. Thus, this article discusses and analyzes the use ITO films to design transparent antennas and to be integrated in OLEDs light source. To increase the gain of the antenna, the antenna array technique is used. The proposed detailed antenna design is presented in Section II along with its electrical performances. An integration of the proposed optically transparent antenna in OLED light source with a performance comparison with and without OLED is detailed in Section IV. Finally, a conclusion is given in Section V.

2. OPTICALLY TRANSPARENT ANTENNA DESIGN.

2.1 Material characteristic

In this article, ITO films deposited on a glass substrate are used. These materials are identified by two main characteristics: their optical transparency in visible spectrum $T(\%)$ and their sheet resistance R_s ($\Omega=\text{sq}$) [20]-[21]. Therefore, a perfect transparent conductor would have an optical transparency of 100 % and infinite conductivity (zero sheet resistance).

The first studied properties of ITO films is sheet resistance. Typically, the sheet resistance is measured at d.c and is used to characterize thin films of conducting materials. This resistance is defined as the resistance of a

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material of thickness t deposited on a square surface [22]. The sheet resistance R_s and thickness t of ITO films are $8 \Omega/\text{sq}$ and 370 nm , respectively. The electrical conductivity, $\sigma \sim 3.5 \times 10^5 \text{ S/m}$, was calculated as follows:

$$\sigma = \frac{1}{R_s \times t} \quad (1)$$

An ITO film is coated on a 1.1 mm thick glass substrate (relative permittivity, $\epsilon_r = 5.5$ and loss tangent $\tan \delta = 0.0054$).

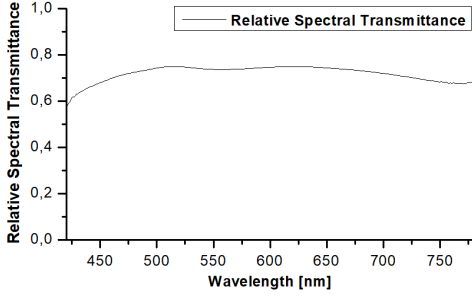


Fig. 1. Measured optical transparency in the visible spectrum.

The second studied parameters of ITO films is optical transparency in the visible spectrum. This parameter was measured using a MINOLTA-CS-1000 spectroradiometer. Fig.1 represents the measured optical transparency in the visible spectrum (380 to 780 nm) of the proposed transparent antenna. From this figure, an optical transparency of more than 75 % is obtained.

2.2 ITO patch antenna design

The aim of this article is to design an optically transparent array antenna to be integrated into OLED light source at mm-wave band for 5G applications. To achieve this objective, firstly, a single element of the array antenna is designed by ITO film. The geometry with the dimension values of the proposed ITO-antenna is presented in Fig.2. The top and bottom layers are radiating patch and ground plane. Both layers are coated on a glass substrate (with tick $h_s = 1.1 \text{ mm}$, relative permittivity, $\epsilon_r = 5.5$ and loss tangent $\tan \delta = 0.0054$). The single element array antenna occupies an area of $10 \times 10 \times 1.1 \text{ mm}^3$. The dimension values of the antenna were calculated with the equations presented in [23], so that the resonance frequency is 27 GHz.

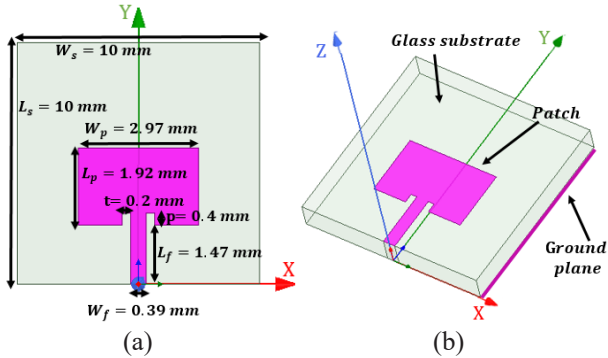


Fig. 2. Optically transparent antenna geometry, (a) top view, (b) 3-D view.

Anslys High Frequency Structure Simulator (Anslys-HFSS) software is used for simulating the antenna, in this paper. Fig.3 shows the simulated reflection coefficients of the proposed single antenna. It can be seen that ITO antenna has a simulated bandwidth of 7.98 % (with $S_{11} \leq -10 \text{ dB}$)

from 26.33 GHz to 28.51 GHz. A good impedance matching is obtained at operating band. To validate the proposed technique, this figure also represents a comparison between the simulated return losses for the transparent and non-transparent antenna. The difference between the two curves is justified by the difference in the sheet resistances for the two materials (copper and ITO).

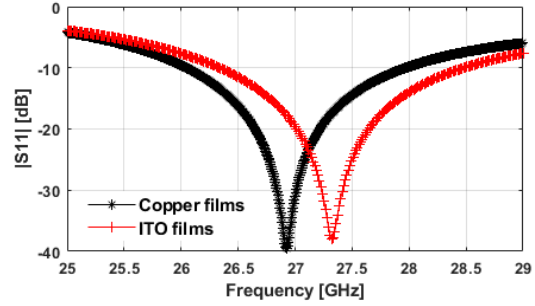


Fig. 3. The simulated return loss of the proposed antenna with ITO films (transparent) and copper films (non-transparent)

A comparison between the radiation patterns of the antennas with copper and ITO films is shown in Fig.4. They are simulated at the resonant frequency 27.33 GHz in the XZ-plane (Fig. 4(a)) and in the YZ-plane (Fig.4 (b)). The two curves are in good agreement, because the two antennas having the same dimensions. The peak gain is 5.94 dB at 27.33 GHz. The actual antenna gain value is not sufficient for 5G applications, hence, the antenna array technique is employed.

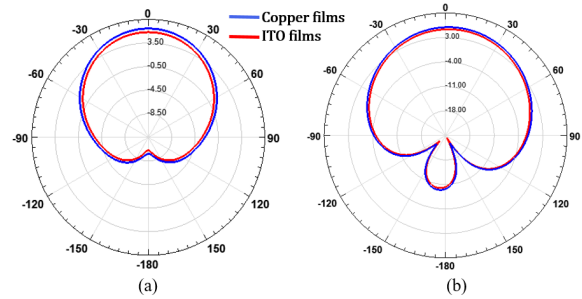


Fig. 4. The radiation patterns of the ITO and copper antennas at 27.33 GHz and 26.97GHz respectively; (a) in the XZ-plane and (b) in the YZ-plane.

2.3 array antenna design

To increase the gain, an optically transparent array antenna is realized after carrying out the analysis of a single element as presented in Fig.5. To increase the gain more, an array antenna design of 2, 4, 8, 16, 32 ... elements is necessary [24]. In this article, to validate the array technique, an array antenna of 2 elements is designed. Therefore, this paper represents an introduction to other publications seeking the developing of transparent array antenna integrated in OLEDs light source.

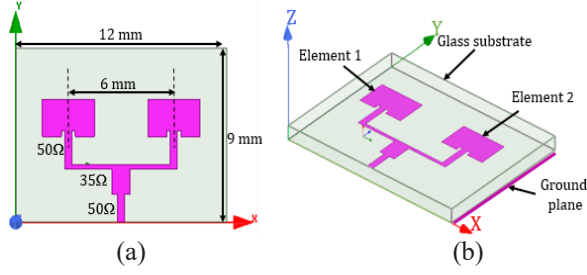


Fig. 5. The geometry of the optically transparent array antenna; (a) top view, (b) 3-D view.

The geometry of the array antenna is shown in Fig.5 with their dimensions. The array antenna is feed by 50 Ω transmission line along with the 1 \times 2 power divider, to ensure that the power is distributed in an equivalent manner in each element. To decrease mutual coupling, the distance between the two elements of the array antenna is 6 mm translating to 0.52λ at 26 GHz. The dimension values of the single element are the same for all.

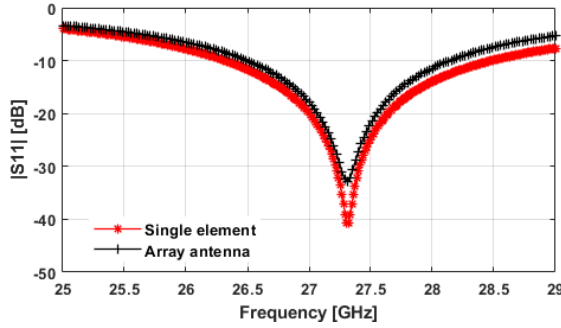


Fig. 6. The comparison between the return loss of the single and array antenna.

Fig.6 shows the comparison between the return loss of the single element and array antenna. From this figure, we can notice that the return loss of the antenna is not affected too much after using the array antenna, and it's well adapted in 26 GHz band. An array antenna bandwidth of 6.12 % from 26.48 GHz to 28.16 GHz is obtained. The antenna has been designed to operate in the 26 GHz band for mm-wave 5G applications.

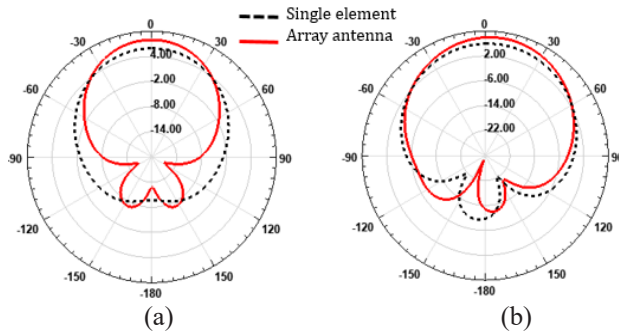


Fig. 7. The comparison between the radiation patterns of the single and array antenna at 27.33 GHz; (a) in the XZ-plane and (b) in the YZ-plane.

The comparison between the radiation patterns of the single element and the array antenna is shown in Fig.7. This figure shows that the radiation pattern becomes directive after array antenna design. From this figure, it can be seen also that the gain value is increased to 8.4 dB for array antenna. The literature indicates that the gain can be increased as the number of network elements increases [24]-[26].

3. INTEGRATION OF TRANSPARENT ARRAY ANTENNA IN OLEDs.

Organic Light Emitting Diodes (OLEDs) are becoming one of the most interesting technologies in the lighting systems. In addition to the lighting system, OLED technology is used to create digital displays in devices (television, computer and smartphone screens). Therefore, OLEDs is the technology of the future for display and lighting. Park et al discuss the potential benefits for optically transparent antennas for smart city concepts to resolve infrastructure and network capacity problems in 5G application systems [18], [19], [25], [26]. However, adding transparent antennas to the smartphone OLEDs screen would reduce the visual pollution for individuals [1], [2]. This paper discusses an original technique for the transparent antenna integration in OLEDs light source to implement this device in the wireless network.

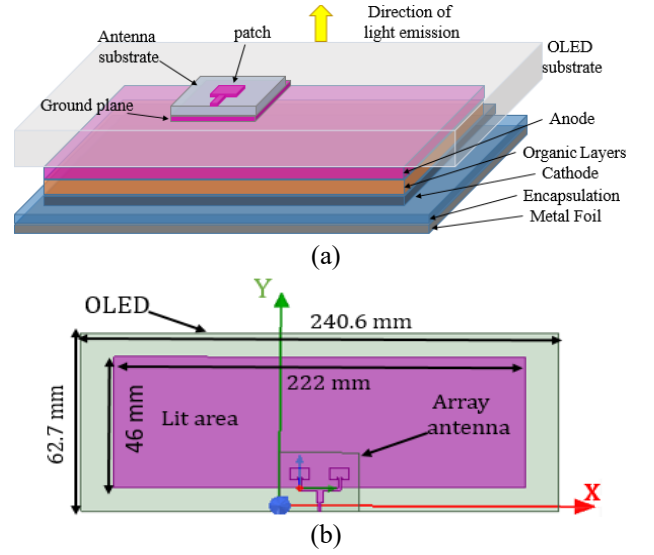


Fig. 8. The transparent array antenna integration in OLED light source; (a) 3-D view (b) top view.

Fig.8 presents the integration method of the optically transparent array antenna in OLED light source [17]. In the Fig.8 (a), the 3-D view of the OLED structure with the array antenna is presented. Several organic layers are located between two electrodes (Anode and cathode). The OLED glass substrate is the first layer with a thickness of 0.7 mm. The second layer is ITO anode with a thickness of 150 nm. The organic layers (Hole Transport Layer-HTL, Electron Transport Layer-ETL and emissive layer) with a thickness of 270 nm (the third layer) are located below the anode. After, the fourth layer is the aluminum cathode (thickness of 120 nm). Then, the thin-film encapsulation (the fifth layer) is implemented to the back of the cathode to protect organic layers from oxidation. Finally, the heat spreader made from a layer metal foil (the sixth layer) is attached to the encapsulation layer. The overall size of the OLED is presented in [27]. Fig.8 (b) shows the array antenna position on OLED; it is located in a small part in the front face (light emission direction) to minimize undesired degradation of OLED layers.

To validate the technique, the Fig.9 represents a comparison between the return loss of the transparent

array antenna with and without OLED. The impedance matching becomes more suitable for 50 Ω . In addition, at the resonant frequency 27.33 GHz, the minimum return loss is increased from -33.15 dB to -50 dB.

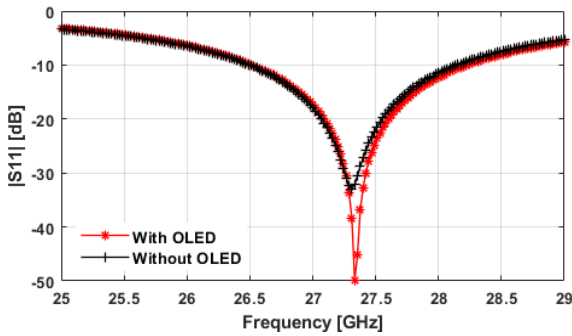


Fig. 9. The Comparison between return loss of the transparent array antenna with and without OLED

For a better explanation, the radiation of the array antenna integrated in OLED has been studied. Fig. 10 shows the radiation patterns of the array antenna with and without OLED. This diagram is simulated at the resonant frequency 27.33 GHz and represented in the two planes XZ-plane (Fig.10(a)) and YZ-plane (Fig.10(b)). The discrepancy between the two diagrams (with and without OLED) is attributed to the effect of OLEDs layers, because they are placed in the back side of the array antenna.

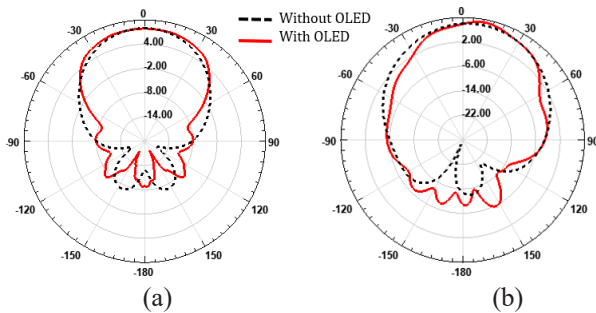


Fig. 10. The comparison between the radiation patterns of the transparent array antenna with and without OLEDs layers at 27.33 GHz; (a) in the XZ-plane and (b) in the YZ-plane.

Fig. 11 illustrates the SPD (spectral power distribution) of a Warm White OLED with a CCT (Correlated Color Temperature) of 3000 K (Solid Line), and the SPD of the same OLED measured through the antenna. The measurements were realized with a Minolta CS-1000 Spectroradiometer, allowing radiance measuring in the visible field [380, 780 nm] with a 1 nm step. The SPD, in both cases (OLED versus OLED through the antenna) was repeated twenty-one times in order to verify the precision of the apparatus.

Table.1 shows the impact of the antenna on the photometric and colorimetric factors. In fact, the luminance decreased by 34 %, and this alteration will lead to a non-uniformity regarding the screen luminosity. The CCT decreased by 2 %, which will probably not degrade the visual comfort of the user according to [28].

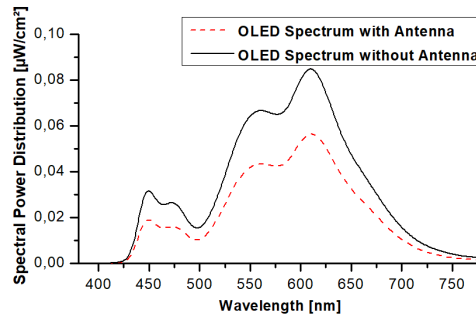


Fig. 11. The spectral power distribution of the OLED with and without antenna integration.

Table 1. The measured luminance and CCT through the Minolta CS-1000.

| Photometric and colorimetric parameters | OLED | OLED through the antenna |
|---|------------|--------------------------|
| Luminance [cd/m ²] | 4155 ± 2.6 | 2737 ± 0.8 |
| CCT [K] | 3052 ± 0.5 | 3000 ± 0.5 |

4. CONCLUSION

In this article, an optically transparent array antenna have been designed and analyzed. This antenna is designed by using the ITO film printed on a glass substrate. To validate this idea, the characteristics of transparent (with ITO films) and non-transparent (with copper films) antennas are compared. This transparent antenna covers the 26 GHz band from 26.33 GHz to 28.51 GHz, with a good impedance matching. The peak gain is increased from 5.94 dB to 8.4 dB by applying the array antenna technique of two elements. The measured optical transparency in visible spectrum more than 75 % is obtained. The ITO film is chosen so to achieve high optical transparency and low sheet resistance so that the proposed antenna is integrated into the OLEDs. To study the effect of this integration on the colorimetric characteristics of the OLED, the SPD is measured through the antenna. In fact, the luminance decreased by 34 %, and this alteration will lead to a non-uniformity regarding the screen luminosity. Therefore, to improve these colorimetric performances of the OLED, a detailed study will be discussed in the future works. The mesh technique will be used to further increase the optical transparency of the antenna and will be no-visible to the naked eye.

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