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Design of Transparent Antenna for 5G Wireless Applications †

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Abstract: This paper presents the design of a compact size band patch antenna for 5G wireless communications. This wideband antenna was designed on a glass substrate ($12 \times 11 \times 2$ mm^3) and is optically transparent and compact. It consists of a radiation patch and a ground plane using AgHT-8 material. The antenna design comprises rectangular shaped branches optimized to attain the wideband characteristics. The calculated impedance bandwidth is 7.7% covering the frequency range of 25 to 27 GHz. A prototype of the antenna and various parameters such as return loss plot, gain plot, radiation pattern plot, and voltage standing wave ratio (VSWR) are presented and discussed. The simulated results of this antenna show that it is well suited for future 5G applications because of its transparency, flexibility, light weight, and wide achievable frequency bandwidth near the millimeter wave frequency band.

Keywords: transparent antenna; 5G communications; AgHT material; glass substrate; optical antenna

1. Introduction

Over recent decades, wireless mobile communication technology has developed significantly despite its relatively recent establishment. The fifth generation (5G) mobile communication system will be deployed on a large scale in the next decade, and it will bring us many advantages such as higher transmission rate, high bit rate with lower battery consumption, and shorter latency than the current 4G system [1,2].

Today, the modern telecommunication industries are already moving towards 5G enabled devices, and some are working on fully transparent and flexible devices [3]. Such cases create the need for flexible and transparent antennas to be designed in the 5G and millimeter wave frequency band.

Transparent antennas operating in the wireless frequency regions are useful in glass-mounted applications including automobiles, homes, and businesses where transmission and reception through or from a window is desired. Transparent antennas have been fabricated with AgHT materials, indium tin oxide (ITO) [4,5], and fluorine doped tin oxide on glass and polyimide. The use of a transparent conductor can pose challenges in fabrication and in application [6].

Among them are losses in films with lower conductivities, film thicknesses less than skin depth, and other complications, specifically additional losses and lower radiation efficiency posed by the presence of a transparent ground plane on thin substrates in standard, planar antennas.

The main objective of this work was to design and analyze a transparent antenna operating in the wide frequency band of 26 GHz. The frequency range extends from 25 to 27 GHz, which covers the band for 5G applications. The size of the compact antenna is ($12 \times 11 \times 2$ mm^3).

The article is organized as follows. Section 2 summarizes a literature review, and Section 3 describes the antenna design and its initial calculation. Results and discussion are presented in Section 4 followed by the conclusion in Section 5.

2. Literature Review

The antenna design is one of the most important factors to be considered in order to fully utilize the 5G technology. However, a few design issues can affect an antenna's performance. Aside from that, in fabrication process, mechanical inaccuracies and errors can affect the antenna performance [7]. As presented in Table 1, a number of transparent antenna designs have been proposed in literature such as dual-band [8,9] and ultra-wideband [10–13] characteristics, but very few cover millimeter wave applications. In Ref. [14], a semi-transparent flexible antenna working in the range of 7 to 13 GHz is proposed for 5G applications using polyethylene terephthalate (PET) and silver nanoparticles.

Table 1. Comparison of the proposed transparent antenna with other existing antennas.

Ref	Operating Bands (GHz)	Return Loss at Resonance (dB)	Gain (dB)	Transparent	Size (mm^2)
[14]	7–13	<10	5	Semi-transparent	60×75
[12]	2.2–12.1	<10	3–5	Yes	17×33.5
[11]	2–13	<10	1.5–3	Yes	20×20
Proposed antenna	25–27	40	5.5	Yes	12×11

This paper proposes a transparent patch microstrip antenna working at 26 GHz frequency with compact size, simple shape, and good performance.

3. Antenna Design and Parameters

This section describes in detail the geometrical configuration and a procedure for designing the transparent compact antenna for 5G applications. The concept of designing this antenna is based on the square ring monopole antenna structure.

3.1. Design of Transparent Antenna for 5G

Figure 1 shows the stepwise design evolution of the proposed antenna, which was designed and optimized using CST Microwave Studio software simulator.

The optically transparent antenna comprises transparent glass with a dielectric constant of 4.82 and 2 mm thickness as the substrate material. Transparent conductive oxide AgHT-8 with a surface resistivity of 8 Ω/m, which is equivalent to the conductivity of 125,000 S/m, constitutes the patch radiator and ground. A feed line with a width of 3.58 mm is used to achieve 50 Ω impedance matching.

Front and rear views of the proposed antenna are shown in Figure 1a,b. A partial ground plane is used to increase the performance of the antenna and ensure the impedance matching. The optimized dimensions of the proposed transparent antenna are listed in Table 2.

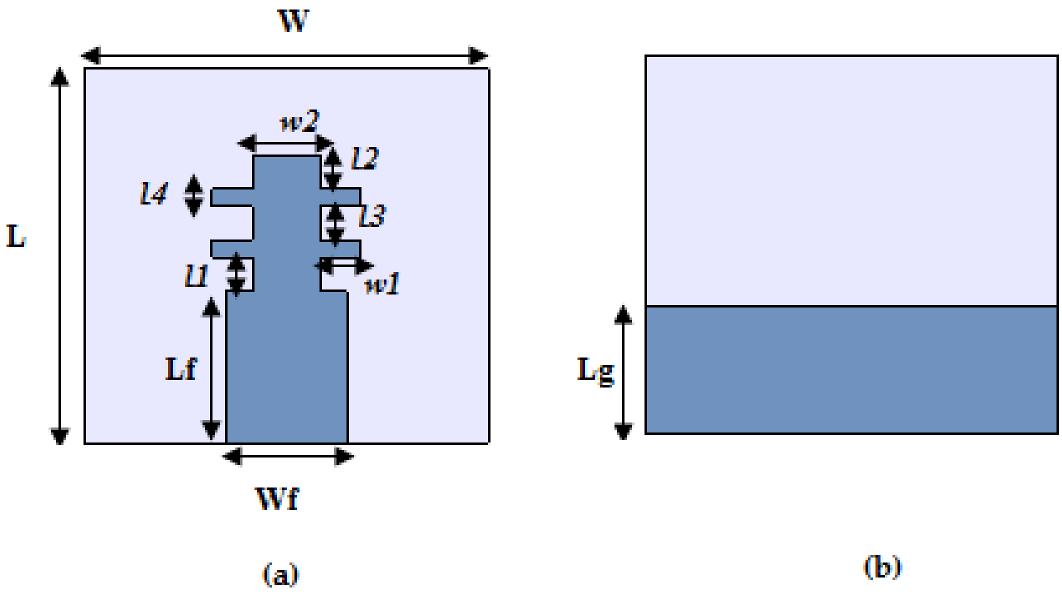


Figure 1. Geometry of proposed transparent antenna. (**a**) Front view; (**b**) rear view.

Table 2. Dimensions of the proposed antenna.

Parameters	Dimension (in mm)
L	11
W	12
Wf	3.58
Lf	4.45
L1	1
L2	1
L3	1
L4	0.5
w1	1.2
w2	2
Lg	4.4
tm	0.0177
hs	2

3.2. Parametric Study

Parametric investigation of the rectangular arm widths was performed to investigate the performance of the proposed antenna. In this study, rectangular arm width variations are given as terms w1 and w2.

Figures 2 and 3 show the performance of the proposed transparent antenna with the variations of w1 and w2. From Figure 2, it is seen that the return-loss performance is better for w1 = 1.2 mm. When w1 increases from 0.8 to 1.2 mm, the wide bandwidth ranges from 25 to 27 GHz, supporting the bandwidth requirements for 5G. The −10 dB reflection coefficient performance degrades with further decrease in the rectangular arm's width. From Figure 3, it can be seen that the best impedance matching is obtained as w2 = 2 mm. The center frequency is around 26 GHz, and the bandwidth covered is from 25 to 27 GHz.

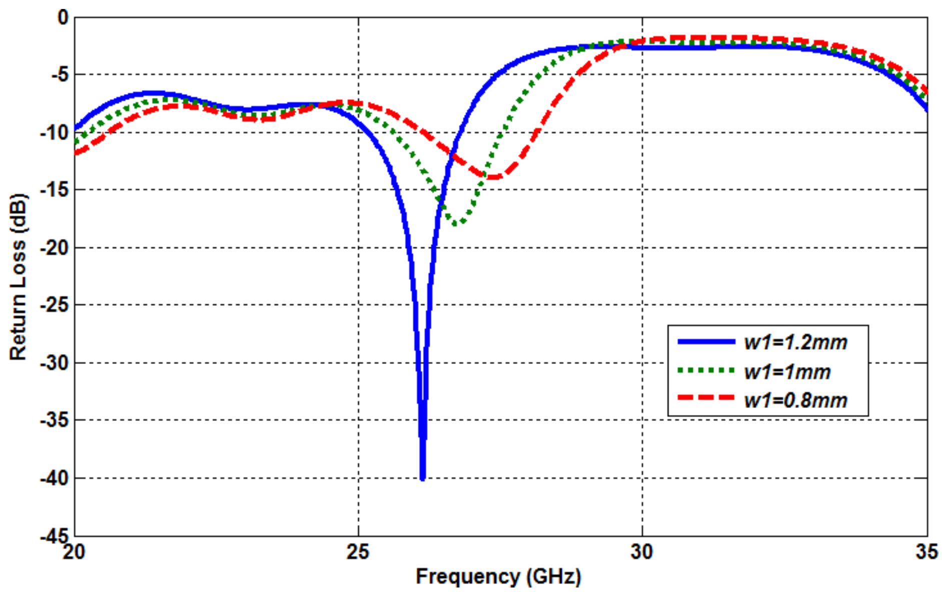


Figure 2. Antenna performance with the variations in term w1.

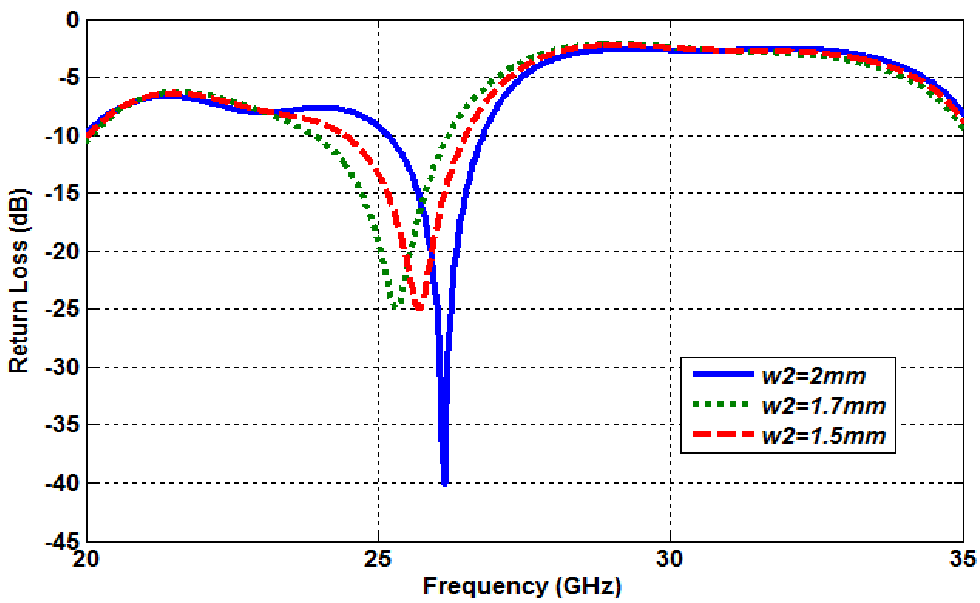


Figure 3. Antenna performance with the variations in term w2.

The optimum values of w1 and w2 were selected as 1.2 and 2 mm, respectively.

4. Simulation Results and Analysis

Simulations of the proposed antenna were performed using Computer Simulation Technology (CST) Microwave Studio. An antenna parameter of significant importance in the antenna is the reflection coefficient (S11), which defines the bandwidth and the impedance matching characteristic. The simulated result of the return loss for transparent antenna is depicted in Figure 4. The simulated results show that the single element antenna has a reflection coefficient (S11) of −40 dB, less than −10 dB in the frequency range of 25 to 27 GHz. More than 2 GHz of impedance bandwidth was obtained.

Another imperative parameter beside the reflection coefficient and input impedance that reflects the antenna performance is the voltage standing wave ratio (VSWR). The antenna is only able to operate at frequencies where the values of VSWR are less than 2 (Figure 5).

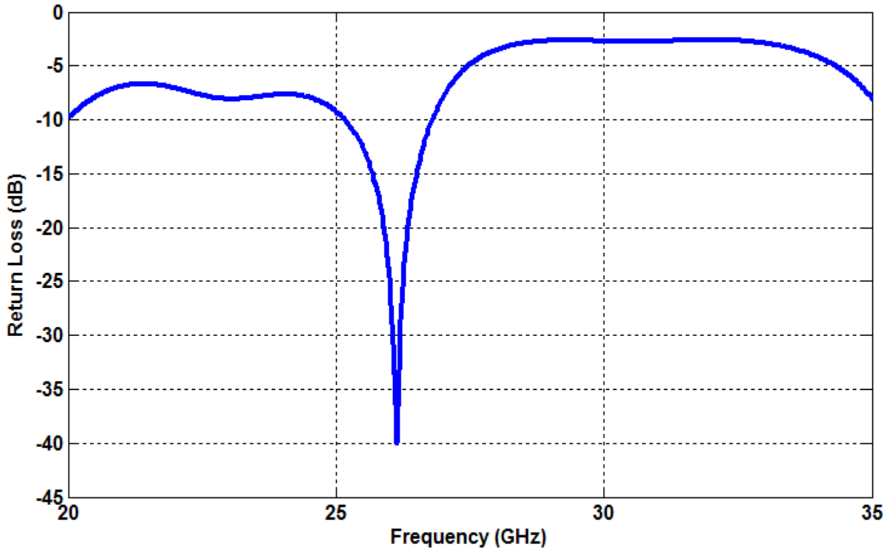


Figure 4. Simulated return loss (S11) for proposed antenna.

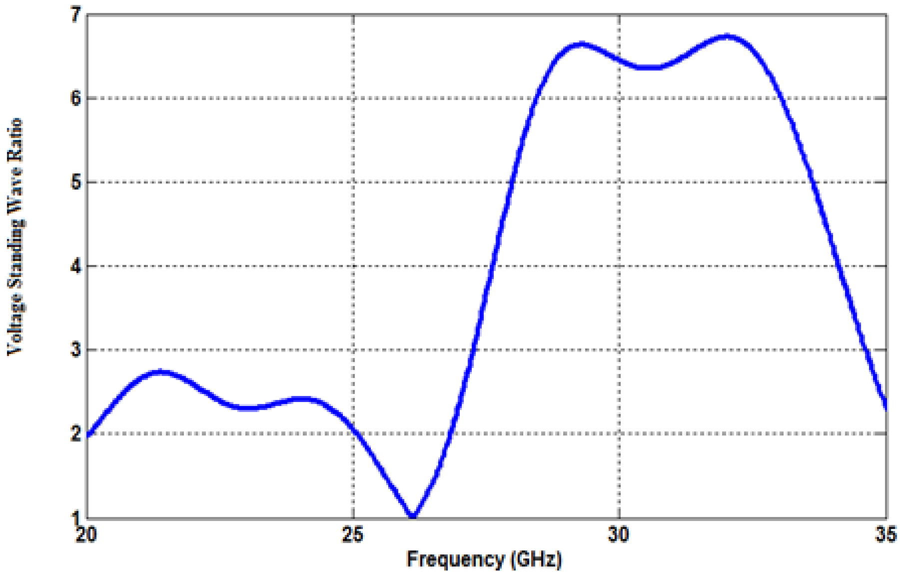


Figure 5. Voltage standing wave ratio (VSWR) values of the single element antenna.

The gain performance of the proposed transparent antenna is shown in Figure 6. The high positive gain performance is observed all over the working frequency band. The peak gain of about 5.5 dB is observed at 26 GHz. This positive gain and widespread radiation pattern ensure the stable performance of the antenna for 5G applications.

The radiation patterns in terms of E-plane and H-Plane are shown in Figure 7. It can be noticed that the E plane radiation pattern appears bi-directional at 26 GHz, and the H plane pattern covers a wide aperture angle with three main orientations.

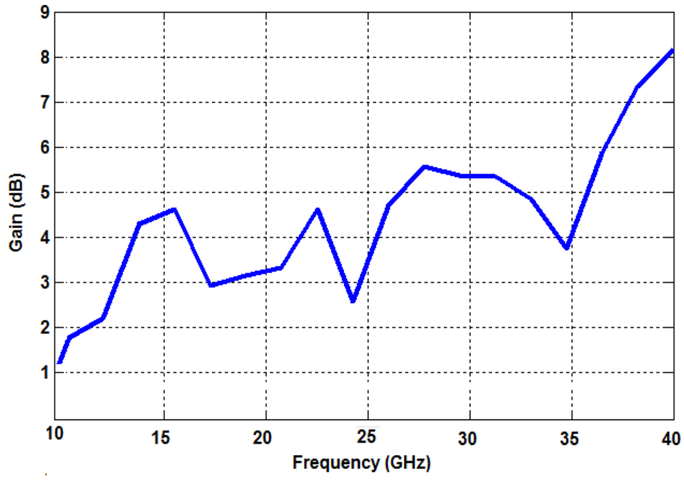
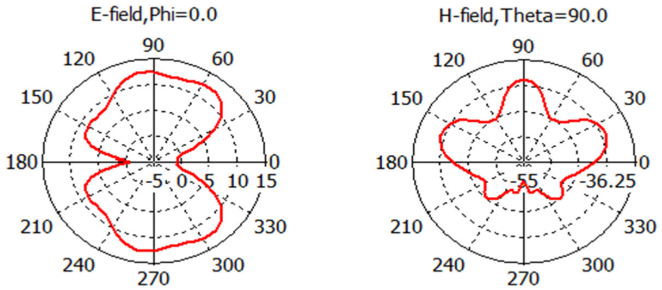


Figure 6. Simulated peak gain of the proposed antenna.



(**a**) (**b**)

Figure 7. (**a**) E-plane radiation pattern at 26 GHz; (**b**) H-plane radiation pattern at 26 GHz.

5. Conclusions

With the development of 5G communication, the integration of transparent antennas on glass surfaces or OLED lighting sources will become a necessity in the next decade. In this study, transparent antennas of simple shape and miniaturized structure were investigated. The proposed antenna is potentially a good option for fifth generation (5G) wireless systems that require high gain topology and low profile. The simulated results show a reflection coefficient of −40 dB with an S11 of less than −10 dB in the frequency range 25 to 27 GHz and an impedance bandwidth of more than 2 GHz. In the future, we will try to manufacture the proposed antenna and compare the radiation pattern and reflection coefficient of the simulated and measured results.

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