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Performance Comparison of Transparent and Non-Transparent Wineglass-Shaped Antenna at 28 GHz

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Abstract: This paper discussed the performance of a wineglass-shaped antenna fabricated on transparent (indium tin oxide on glass) and non-transparent (Rogers RT6006) substrates. Simulated and measured results of coefficient reflection, VSWR, and radiation patterns are compared and analyzed. Both antennas are well matched at the designed frequency with good reflection coefficient. The non-transparent antenna minimum coefficient reflection is -35.45 dB, and the transparent antenna reached the value of -19.71 dB. The non-transparent antenna has higher gain and exhibits symmetrical radiation. The study demonstrates the feasibility of both transparent and non-transparent wineglass antennas at 28 GHz, with the non-transparent offering higher gain and better impedance matching from a better conductivity compared to the transparent material used.

Keywords: Antenna, wineglass, transparent antenna, Indium tin Oxide

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1. INTRODUCTION

The advent of 5G communication has garnered significant interest from both industrial and research institutions regarding mm-wave technology. To transmit or receive communications, an antenna is a vital component of the radio frequency system; without one, the receiver is incapable of detecting any signal. Even though the mm-wave bands have a much wider absolute bandwidth than the sub-6 GHz bands, people are still looking for wideband antennas because different 5G bands are used in different areas or for different purposes[1]. Wideband antennas have become increasingly popular among the general population and have quickly become a preferred means of wireless communication. The main benefits of this technology include low power usage, increased bandwidth, and higher transmission speeds.[2].

Traditionally, antennas are constructed out of metallic materials, which might be opaque and impede the individual's ability to see well. On the other hand, the development of transparent antennas has been spurred by the increased need for applications such as smart windows, wearable gadgets, and invisible communication networks. A significant disadvantage of transparent antennas is their lower efficiency as compared to traditional metal antennas. This is due to the inherent conductivity distinction between metals and transparent materials.

Transparent materials, such as ITO (Indium Tin Oxide) and metal meshes, exhibit reduced conductivity, leading to increased signal losses throughout the process of transmission and reception. Less efficiency can show up as weaker messages being received, a shorter range, and a higher chance of interference[3].

This research investigates the performance of wineglass-shaped antennas made from both transparent and non-transparent materials. Specifically, the study examines antennas fabricated for a frequency of 28 GHz using two types of materials: indium tin oxide (ITO) coated on glass and Rogers RT6006. This study contributes to understanding how these materials impact antenna performance, particularly in the context of their transparency and electrical properties.

2. DESIGN AND SIMULATION

Wineglass-shaped antennas are commonly chosen for their advantageous properties in several domains, especially in millimeter-wave communication systems, radar systems, and other high-frequency applications. As an antenna, the smooth curvature of the wine glass's shape transforms it into a structure resembling one that propagates-wave[4]. The wine-glass design provides a wider frequency range in comparison to traditional patch antennas. The distinctive shape of the object enables a more consistent distribution of the field, resulting in an expanded bandwidth [7].

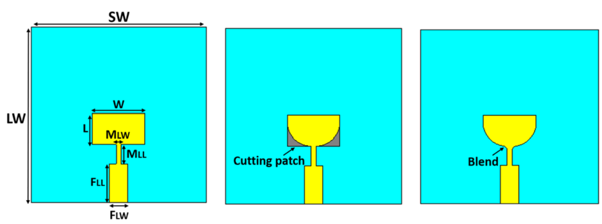


Figure 1. Design stage of proposed antenna.

The design stage of wineglass-shaped antenna is shown in Figure 1. The form of the antenna is essentially a basic rectangular shape with incisions created on the sides, imitating the outline of a wine glass. The antenna is fed using a quarter-wave transformer, microstrip feed line, and an input impedance of 50 ohms operating at a frequency of 28 GHz.

The ITO material has a sheet resistance of 6 to 8 Ohms/sq, a thickness of 185 nm, a transmittance greater than 84%, and a conductivity of approximately 900,000 S/m. The glass substrate has a relative permittivity between 4.8 and 5.6 and a tangent loss ranging from 0.001 to 0.003. In contrast, Rogers RT6006 features a thickness of 1.127 mm, a relative permittivity of 6.15, and is clad with 0.035 mm of copper foil on both sides. The properties of antenna are tabulated in Table 1.

Table 1. Properties of Proposed Antenna

Substrate Parameters	ITO on Glass	Rogers RT6006
Substrate		
- Thickness (mm)	0.7	1.5
- Tan Loss	0.02	0.0027
- Relative Permittivity	5.6	6.15
Conductor		
- Thickness (um)	0.185	35
- Conductivity (S/m)	9.0e+05	5.8e+07

The patch width (W) and patch length (L) were determined using the following equations [5]:

$$W = \frac{c}{2f_{res}\sqrt{\frac{2}{\varepsilon_r+1}}} \tag{1}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\sqrt{1+12\left(\frac{h}{W}\right)}\right)^{-0.5} \tag{2}$$

$$\Delta L = 0.412h\left(\frac{(\varepsilon_r+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_r-0.258)\left(\frac{W}{h}+0.8\right)}\right) \tag{3}$$

$$L = \frac{c}{2\sqrt{\varepsilon_{reff}}}-2\Delta L \tag{4}$$

where ε_r is relative permittivity of substrate, ε_{reff} is relative permittivity effective of substrate, h is thickness of substrate, and ΔL is fringing length.

The impedance of edge patch, feedline, and quarter-wave transformer is calculated using following equation [5]:

$$ZA = 90\frac{\varepsilon_r^2}{\varepsilon_r-1}\left(\frac{L}{W}\right)^2 \tag{5}$$

$$\mathrm{Zo} = \sqrt{(\mathrm{zin} * \mathrm{ZA})} \tag{6}$$

$$\mathrm{wf} = \frac{7.48*h}{e^{\left(\mathrm{zo}\frac{\sqrt{\varepsilon_r+1.41}}{87}\right)}} - (1.25t) \tag{7}$$

where *ZA* is impedance edge of the patch, *Zo* is impedance of quarter-wave transformer, and *zin* is input impedance. While *wf* is width of feed line and *t* is conductor thickness of the patch. The dimensions of all antenna components were computed and refined using CST Studio Suite, as depicted in Table 2.

Table 2. Design Parameter of Antenna

Symbol	Meaning	Dimension (mm)	
		ITO	RT6006
ε_r	Relative permittivity	5.6	6.15
t	Thickness of conductor	0.000185	0.035
W	Patch Width	5.68	5.62
L	Patch Length	3.84	3.81
F_{LW}	Feed Line Width	1.2	2.11
F_{LL}	Feed Line Length	4	3.84
M_{LW}	Matching Line width	0.50	1.12
M_{LL}	Matching Line length	1.51	1.51
SW	Substrate width	12	11.9
LW	Substrate Length	13.5	12.5

3. FABRICATION AND MEASUREMENT ANTENNA

The design wineglass-shape antenna using indium tin oxide on glass substrates and Rogers RT6006 substrate (non-transparent) and indium tin oxide on glass substrates (transparent) is fabricated on respective material as shown in Figure 2.

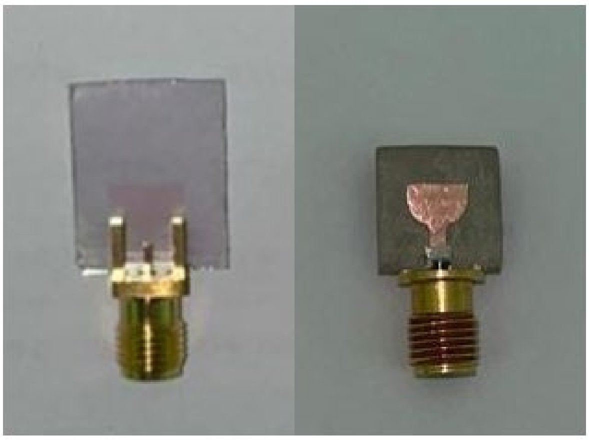


Figure 2. Proposed wineglass-shape antenna

The antenna is fabricated using dry film photoresist with maskless photolithography method [6]. The stages of fabrication are shown in Figure 3.

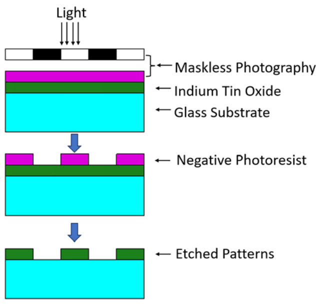


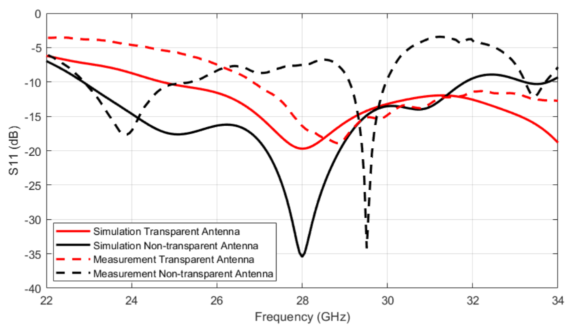
Figure 3. Stages of antenna fabrication

The antenna feed line soldered to SMA connector before the performance is measured using an Anritsu MS46322A Vector Network Analyzer (1 MHz–43.5 GHz). The performance is observed in term of the resonance frequency, reflection coefficient (*S11*) and voltage standing wave ratio (*VSWR*) were then measured.

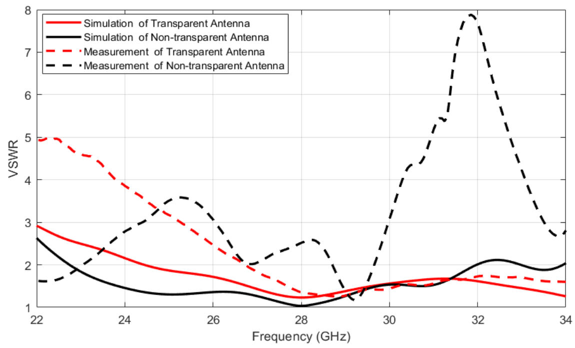
4. RESULT AND DISCUSION

The performance of a wineglass-shaped antenna using Rogers RT6006 (non-transparent) and indium tin oxide on glass (transparent) substrates is characterized and compared to the simulation results.

Figure 4 shows the simulated and measured responses of the antenna in term of reflection coefficient (*S11*) and the voltage standing wave ratio (*VSWR*). The performance of antenna on non-transparent material at 28 GHz is better with reflection coefficient of -35.45 and VSWR 1.03, compared to antenna on transparent material with reflection coefficient of -19.71 and VSWR 1.23. Both have VSWR values below 2, indicating good impedance matching. However, the non-transparent antenna has a lower VSWR, indicating less power loss due to mismatch. The comparison is tabulated in Table 2.



(a)



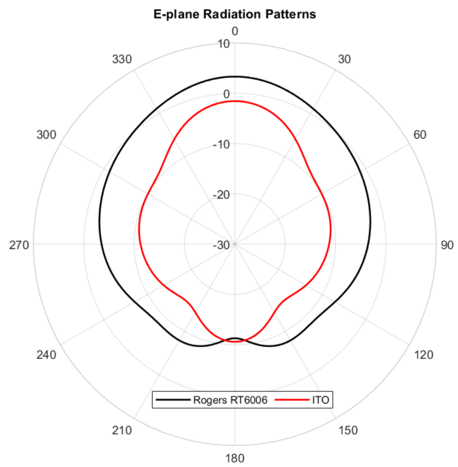
(b)

Figure 4. (a) simulation and measurement results of coefficient reflection (S11) of transparent and non-transparent antenna (b) simulation results of VSWR of transparent and non-transparent antenna.

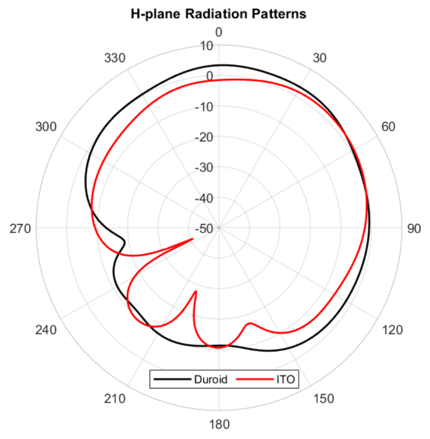
Table 2. Measurement and simulation results of proposed antenna

Antenna Parameters	Simulation		Measurement	
	ITO on Glass	Rogers RT6006	ITO on Glass	Rogers RT6006
Freq	28 GHz	28 GHz	28.56 GHz	29.2 GHz
S11	-19.71 dB	-35.45 dB	-18.25 dB	-18.49 dB
VSWR	1.23	1.03	1.39	1.33

The measured performance shows as shows a shift of operating frequency to higher band. This might be due to error in fabrication process.



(a)



(b)

Figure 5. (a) Simulation results of the E-plane radiation pattern of transparent and non-transparent antenna; (b) Simulation results of H-plane radiation pattern of transparent and non-transparent antenna.

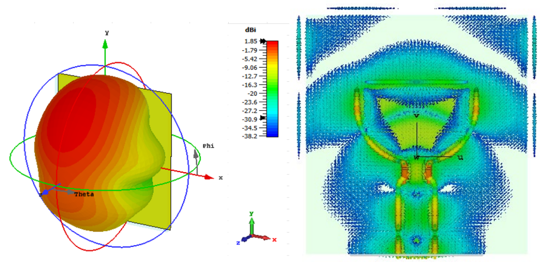
Figure 5 illustrates a simulation of the radiation patterns of proposed antennas for E-Plane and H-plane. The transparent antenna has a main lobe value of -0.16 dBi in the 0 degrees direction, while the non-transparent antenna has a main lobe value of 3.38 dBi in the 5 degrees direction. The H-plane radiation pattern shows a main lobe value of 1.28 dBi in the 37 degrees direction, while the non-transparent antenna has a main lobe value of 3.28 dB in the 0 degrees direction. The half power beam width (HPBW) for each antenna is calculated to be 51.6 degrees at E-Plane and 77.3 degrees at H-Plane, and 65 degrees and 95.4 degrees respectively.

The non-transparent antenna has higher gain, suggesting stronger signal transmission in its main lobe direction. Both antennas have similar HPBW in the E-plane and wider HPBW in the H-plane, suggesting similar directivity. The non-transparent antenna's main lobes align in both planes, while the transparent antenna's main lobes are misaligned. Table 3 shows a simulation of the radiation patterns of the proposed antenna.

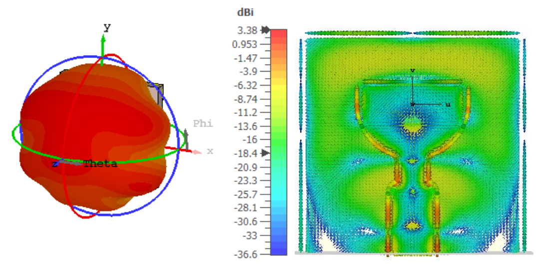
Table 3. Farfield simulation results of proposed antenna

Far Field	ITO on Glass		Rogers RT6006	
	E-Plane	H-Plane	E-Plane	H-Plane
Main lobe	-0.16 dBi at 0^o	1.85 dBi at 40^o	3.29 dBi at 0^o	3.38 dBi at 5^o
HPBW	48.6^o	76.7^o	95.4^o	77.3^o

The 3D simulation results of the 3D farfield and surface current of the proposed antenna are shown in Figure 6.



(a)



(b)

Figure 6. (a) Simulation results of the 3D far filed and surface current of transparent antenna; (b) Simulation results of 3D far filed and surface current of non-transparent antenna.

5. CONCLUSION

Wineglass-shaped antennas fabricated on both transparent and non-transparent substrates demonstrate good performance at 28 GHz. While the non-transparent substrate offers higher gain and better impedance matching, the transparent option presents a viable alternative where visibility is crucial. Further research could explore optimization techniques for improved transparency and alignment of radiation patterns. The superiority of the non-transparent antenna fabricated on RT6006 material is due to the better conductivity of the copper clad compared to the ITO material. Despite of the drawback, the transparent antenna still shows a good working performance at the designed frequency.

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