Transparent solar antenna of 28 GHz using transparent conductive oxides (TCO) thin film

N I Mohd Ali¹,², N Misran¹, M F Mansor¹ and M F Jamlos³

¹Department of Electrical, Electronic and System Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia
²Faculty of Engineering Technology, Universiti Malaysia Perlis, Kampus UniCITI Alam, Sungai Chuchuh, 02100, Padang Besar, Perlis, Malaysia
³School of Computer and Communication Engineering, Universiti Malaysia Perlis, Kampus Tetap Pauh Putra, 02600, Arau, Perlis, Malaysia

E-mail: nurizzati@siswa.ukm.edu.my, bahiah@ukm.edu.my, m.mansor@ukm.edu.my, faizaljamlos@unimap.edu.my

Abstract. This paper presents the analysis of 28GHz solar patch antenna using the variations of transparent conductive oxides (TCO) thin film as the radiating patch. Solar antenna is basically combining the function of antenna and solar cell into one device and helps to maximize the usage of surface area. The main problem of the existing solar antenna is the radiating patch which made of nontransparent material, such as copper, shadowing the solar cell and degrades the total solar efficiency. Hence, by using the transparent conductive oxides (TCO) thin film as the radiating patch, this problem can be tackled. The TCO thin film used is varied to ITO, FTO, AgHT-4, and AgHT-8 along with glass as substrate. The simulation of the antenna executed by using Computer Simulation Technology (CST) Microwave Studio software demonstrated at 28 GHz operating frequency for 5G band applications. The performance of the transparent antennas is compared with each other and also with the nontransparent patch antenna that using Rogers RT5880 as substrate, operating at the same resonance frequency and then, the material that gives the best performance is identified.

1. Introduction
Throughout the years, the communication systems are rapidly developed. Typical antenna and microwave circuit are made of thick metal layers as conducting element and placed on a dielectric substrate, and then a thick metal layer as ground plane placed on the bottom of it. Recently, the communication system demanding antenna is with low profile characteristic. It is to minimize if not, eliminate the visual impact of antenna in the system [1, 2, 3]. Hence, transparent antenna has caught researcher attentions as one of the solutions. By implementing this feature, an antenna design can be more forgiven in terms of size, installation, and structure. There are other applications that also beneficial from this features, for instance, solar antenna.

Transparent Conducting Oxides (TCO) film is a thin film that is conductive electrically and transparent optically [4, 5]. This remarkable combination of transparency and conductivity leads to great development of electronic components and telecommunication devices, such as touch screens, solar cells, and electrodes for displays, as it can reduce the visual impact and flexibility in terms of installations.
Solar antenna is basically combining two applications in one device and it is mostly used on satellite as it helps to maximize the usage of satellite’s surface area, which is the main concern. The main problem of the solar antenna that have been designed using non-transparent material [6, 7, 8, 9, 10] and semi-transparent material [11, 12, 13, 14, 15, 16] are including bulky, have complicated design, and also experiencing shadowing effect that causing the degradation of total solar efficiency.

In this paper, transparent solar patch antennas for 5G band application with operating frequency of 28 GHz are designed. In order to investigate the performance, instead of using Copper, several types of TCOs have been used as the conducting patch of the antenna which is ITO, AgHT-4, AgHT-8, and FTO. The performance of the antennas are compared to each other and to the reference antenna which is nontransparent solar patch antenna at the same resonance frequency that made of copper and Rogers RT5880 as the patch and substrate respectively.

2. Design

The antenna design used in this paper is the basic rectangular microstrip patch antenna as shown in Figure 1 and based on the design specification in Table 1. It comprises of two parts which are the antenna part and the solar part. Figure 1(b) shows the design of the patch as the radiating element and (c) shows the structure of the solar cell which consists of three main layers, anode lattice, silicon, and cathode. The material used in this design for the anode and cathode layers are silver and aluminum respectively.

![Figure 1](image_url)

Figure 1. (a) Structure of designed antenna (b) top view of the patch design and (c) cross section of solar cells
Table 1. Design specification

| Operating freq. | Gain | Bandwidth | Rad. efficiency |
|-----------------|------|-----------|-----------------|
| 28 GHz          | >4 dB| >1.5 GHz  | >55%            |

For the nontransparent solar antenna which for reference purposes, Copper material used as the ground and the radiating patch material, whereas Rogers RT5880 used as the substrate with dielectric constant, $\varepsilon_r$ and thickness of 2.2 and 0.254 mm respectively. Table 2 shows the optimized dimension of the design.

Table 2. Optimized dimensions of nontransparent antenna

| Parameter | Length (mm) |
|-----------|-------------|
| L         | 3.357       |
| W         | 4.235       |
| $W_t$     | 0.2         |
| $L_s$     | 1.8046      |
| $W_f$     | 0.7826      |
| $L_f$     | 1.958       |
| s         | 2           |
| t         | 0.1         |

There are four transparent solar antennas have been designed and will be discussed in this paper. Glass materials have been used as the transparent substrate with dielectric constant, $\varepsilon_r$ of 4.82 and thickness of 1.1mm. As for the radiating patch and ground layer, TCO thin film are used and varied to Indium Tin Oxide (ITO) films, fluorine-doped tin oxide (FTO), conductive silver-coated thin film, AgHT-4, and AgHT-8 with sheet resistance, $R_s$ of 10$\Omega$/sq, 24$\Omega$/sq, 4.5$\Omega$/sq, and 8$\Omega$/sq respectively. Equation (1) below show the relationship between the sheet conductivity, $\sigma$ and sheet resistance, $R_s$ [1, 17, 18, 19].

$$R_s = \frac{\rho}{t} \quad \text{and} \quad \sigma = \frac{1}{\rho}$$

Table 3 shows the optimized width and length of each transparent antenna. Even though the properties of the conducting materials are varied, the optimized dimensions of all four transparent antennas are similar as the same substrate used. This is in line with the equation from [20] that shows the dimensions of a rectangular patch antenna are guided mainly by the properties of the dielectric substrate.

Table 3. Optimized dimension of transparent antennas

| PARAMETERS       | ITO | FTO | AgHT-4 | AgHT-8 |
|------------------|-----|-----|--------|--------|
| Length of patch (mm) | 1.594 | 1.57 | 1.57   | 1.57   |
| Width of patch (mm)   | 3.90  | 3.90 | 3.90   | 3.90   |

3. Result and Analysis

3.1. Return Loss and Bandwidth
Figure 2 shows the frequency response of transparent and non-transparent antenna with resonance frequency of 28GHz, and Table 4 shows the results summary of return loss and bandwidth of the design.

![Figure 2. Frequency Response](image)

**Table 4. Return Loss and Bandwidth Results.**

| Conducting material | PEC   | ITO   | FTO   | AgHT-4 | AgHT-8 |
|---------------------|-------|-------|-------|--------|--------|
| Return loss         | -25.729 | -35.437 | -31.123 | -33.833 | -31.573 |
| Bandwidth (GHz)     | 0.7395  | 7.2808 | 7.5964 | 7.4912 | 7.584  |
| Bandwidth (%)       | 2.64%   | 26.00% | 27.13% | 26.75% | 27.09% |

As predicted, the bandwidth of the transparent and non-transparent antenna shows great difference due to its substrate thickness which is more than 4 times thicker than the non-transparent. Transparent antenna that gives the highest bandwidth is the FTO whereas ITO gives the best performance in terms of return loss.

### 3.2. Surface Current Density

Results as depicted in Figure 3 shows the surface current of each element of the conducting material. As foreseen, copper gives the highest maximum surface current with 230.4 A/m as copper have the highest conductivity. Same goes to the transparent antenna, maximum current density of ITO is the highest with 125.1 A/m as it have the highest conductivity compare to the other thin films.

![Figure 3. Surface current density of (a) non-transparent (Copper) (b) ITO, (c) FTO, (d) AgHT-4 and (e) AgHT-8](image)
3.3. Gain, Radiation Pattern, VSWR, and Radiation Efficiency

Figure 4 shows the radiation pattern of the non-transparent antenna and all transparent antenna on both $\phi=90^\circ$ and $\theta=90^\circ$ planes. From the figures, it shows that all antennas have directional radiation pattern on both planes.

![Radiation Pattern Diagrams](image)

**Figure 4.** Radiation Pattern of (a) non-transparent antenna on $\phi = 90^\circ$ planes and (b) $\phi = 90^\circ$ planes, (c) ITO on $\phi = 90^\circ$ planes (d) ITO on $\phi = 90^\circ$ planes, (e) FTO on $\phi = 90^\circ$ planes, (f) FTO on $\phi = 90^\circ$ planes, (g) AgHT-4 on $\phi = 90^\circ$ planes (h) AgHT-4 in $\phi = 90^\circ$ planes, (i) AgHT-8 in $\phi = 90^\circ$ planes and (j) AgHT-8 in $\phi = 90^\circ$ planes.

Table 5 shows the summarization of gain, VSWR, and the radiation efficiencies. As shown in the table, all transparent antennas give similar results of gain, but ITO gives slightly better value than others, and then followed by AgHT-4. The VSWR and radiation efficiency of all antennas are satisfactory which are nearly to 1 and higher than 50 percent respectively. But again, ITO gives the best efficiency compare to the other transparent antennas.

**Table 5.** Gain, VSWR, and radiation efficiency results

| Conducting material | PEC | ITO | FTO | AgHT-4 | AgHT-8 |
|---------------------|-----|-----|-----|--------|--------|
| Gain (dB)           | 7.066 | 4.883 | 4.263 | 4.412 | 4.299 |
| VSWR               | 1.109 | 1.102 | 1.057 | 1.042 | 1.054 |
| Rad. Efficiency (%)| 86.49% | 81.05% | 73.08% | 75.54% | 73.72% |
4. Conclusion

Transparent solar antenna of 28 GHz operating frequency has been designed with radiating patch and ground material are made of Transparent Conductive Oxides thin film which varied to ITO, FTO, AgHT-4, and AgHT-8. These antennas are then compared to the nontransparent solar antenna and to each other. From the result obtained, it shows that transparent antenna can be designed using TCO thin film as all designs give satisfactory results and fulfilling the design specification. As for comparison, transparent antenna that made of ITO thin film gives the best performance with highest current density, gain, and efficiency but with minor differences compared to each other. Transparent antenna also shows great performance in terms of bandwidth when comparing to the nontransparent antenna with more than 20 percent of differences. It is due to higher thickness of substrate used for the transparent antenna.

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