Design of transparent microstrip grid array antenna

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ABSTRACT

A transparent grid array antenna of 28 GHz frequency is presented. The radiating element of the antenna is made of ITO thin film and printed on glass as the dielectric 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. This antenna then compared to the rectangular microstrip patch antenna of the same operating frequency. The structural parameters of the proposed antenna were optimized based on parametric studies done. Grid array antenna gives better performance as it gives 35.7% lower return loss with -43.88 dB, better efficiency and gain with a gain of 7.358 dB, which is more than 40% increases.

1. INTRODUCTION

There are many types of antenna in the world. There are horn, helical, dipole, parabolic, and the most popular among them is microstrip antenna. The typical structure of a microstrip patch antenna consists of a thick metal layer as the radiating patch, and Ground, placed on a dielectric substrate. Transparent antenna normally designed by replacing the metal patch with Transparent Conducting Oxides (TCO) thin film, and clear glass [1-4] or PET film [5, 6] as the dielectric substrate.

Transparent Conducting Oxides (TCO) thin film is a very interesting material that optically transparent material and conductive electrically [7-10]. There are several types of TCO that commonly used; Indium Tin Oxide (ITO), Fluorine-doped Tin Oxide (FTO), silver conductive coated thin film AgHT-4 and AgHT-8. This remarkable combination of transparency and conductivity leads to a 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. Other than that, these features also caught researchers’ attention to be explored on and be considered in antenna designing. By replacing the typical thick metal layers of conductors with ITO thin film, the visual impact of the antenna in the system can be minimized [11-13].

Solar antenna is one of the technologies that have been explored by the researcher as it has an interesting benefit which is the ability to power itself by using natural resources. Several researches have been done to integrate the solar and antenna element and basically can be divided to three categories; non-transparent solar antenna, semi-transparent antenna, and transparent antenna.

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For non-transparent solar antenna, the problem is the design normally bulky in size and complicated design [14-16]. Some design of the category facing blockade effect [17, 18]. Normally for semi-transparent solar antenna, clear glass or plastic will be used as the substrate but still using solid metal as the radiating element. The structure of the patch improvised to permit sunlight to pass through to the solar cell that normally placed on the bottom as Ground [3, 19, 20] or as the reflector of the antenna [21]. One of the problems of these antennas is the shadowing effect that affecting solar performances as the structure of the antenna itself blocked the sunlight to reach the solar cell due to its material properties. For transparent antenna, all antennas elements are transparent but the design is complicated and the antenna performance is compromised [4, 22].

Grid array antenna was firstly introduced by Kraus in 1964 [23] and then the concept implemented on microstrip by Conti in 1981 [24]. This type of antenna has very interesting characteristics such as traveling wave, frequency scanning, the flexibility of tilting the beam, high gains, and ease of extension and fabrication [25, 26]. There are many techniques to improve the gain of antenna; array techniques, superstrate technique, slotted ground or patch technique, but considering the most suitable one to be implemented on the structure, Grid Array technique is used.

Grid array antenna consists of several grid cells as the radiating element on a dielectric and backed by a ground plane. Figure 1 shows the single element of the cells formed by combining two types of lines, long side, \( l \) and short side, \( s \), which act as the transmission line and the radiation element respectively [27].

![Figure 1. Single element of grid array](image)

In this paper, a design of transparent microstrip grid array antenna will be presented and discussed. The performance will be compared to a reference antenna which is a rectangular microstrip patch and both antennas are operating at 28 GHz frequency of 5G band application. The dielectric of the antenna is made of glass and the radiating element, as well as the ground plane, is made of Indium Tin Oxide (ITO) thin film.

### 2. RESEARCH METHOD

Figure 2 shows the rectangular microstrip patch antenna which as a reference antenna of 28 GHz operating frequency. ITO thin film with sheet resistance, \( R_s \) of 10Ω/sq used as the radiating patch material, and the thickness of the layer determined based on the equation discussed in [28-31]. The material of the substrate layer is glass with dielectric constant, \( \varepsilon_r \) and thickness of 4.82 and 1.10 mm respectively. Table 1 shows the optimized dimension of the reference design based on equations in [32].

![Figure 2. Reference antenna](image)

| Parameter | Length(mm) |
|-----------|------------|
| L         | 3.285      |
| W         | 4.235      |
| Wf        | 0.200      |
| Lt        | 1.805      |
| Wf        | 0.783      |
| Lf        | 1.958      |

Table 1. Optimized Dimensions of Rectangular Microstrip Patch Antenna
For grid array antenna, the loop dimensions are approximately half of guided wavelength vertically \((s=\frac{\lambda_g}{2})\) and one full guided wavelength horizontally \((l=\lambda_g)\) [27]. Figure 3 shows the front view of the transparent Grid Array Antenna with 8 optimized loops.

![Figure 3. Top view of the transparent grid array antenna](image)

Figure 3. Top view of the transparent grid array antenna

Figure 4 and Figure 5 show the study of parameter \(W_L\) and \(W_S\) respectively. For the short arm, \(W_S\) is varied from 1.00mm with 0.05mm increment and shows that the resonance frequency, \(f_r\) shifted to the right side as the width of the short arm, \(W_S\) gets wider, whereas the effects on the return losses are insignificant. Contrary with the width of the long arm, \(W_L\), which varied starting from 0.5mm with the step size of 0.1mm, and as it increases, the return loss will be decreased together with the frequencies, \(f_r\) until it reaches 0.9mm, then the changes are minimal. Table 2 shows the optimized dimension of the design.

![Figure 4. Parametric study of short arm width, \(W_S\)](image)

Figure 4. Parametric study of short arm width, \(W_S\)

![Figure 5. Parametric study of long arm width, \(W_L\)](image)

Figure 5. Parametric study of long arm width, \(W_L\)
3. RESULTS AND ANALYSIS

Figure 6 shows the frequency response of both reference and transparent grid array antennas with a resonance frequency of 28GHz and Error! Reference source not found., shows the results summary of return loss and bandwidth of the design. From the results shown, the transparent grid array antenna gives better performance in terms of efficiency as it has 35.7%, lower return loss. Whereas, as predicted, the reference antenna gives wider bandwidth compare to the grid array as discussed in [33]. Besides that, the size of the reference antenna is also a concern as it will be difficult to do the realization due to its small size compare to the Grid Array antenna.

![Figure 6. Frequency response](image)

| Parameter | Length (mm) |
|-----------|-------------|
| \( l \)   | 4.814       |
| \( s \)   | 2.438       |
| \( W_L \) | 1.000       |
| \( W_S \) | 1.250       |

Table 2. Optimized Dimension of Transparent Grid Array Antenna

Figure 7 shows the 3D radiation pattern of both antennas designed and Table 4 shows the summarization of gain, VSWR, and the radiation efficiencies. As shown in the table, VSWR and radiation efficiency of both antennas are satisfactory which are near to 1 and higher than 50 percent respectively. But Grid Array antenna gives better efficiency compared to the reference one. The fact that grid array antenna is one of the methods used for enhancing gain, then, as expected the gain of the Transparent Grid Array antenna is almost 42% higher compared to the basic rectangular antenna.

![Figure 7. 3D radiation pattern](image)

| Parameters | Reference | Grid Array |
|------------|-----------|------------|
| Return loss | -32.335 | -43.88     |
| Bandwidth (GHz) | 4.018 | 1.253     |
| Bandwidth (%) | 14.35 | 4.48      |

Table 3. Return Loss & Bandwidth Results

| Result | Parameter | Reference | Grid Array |
|--------|-----------|-----------|------------|
| Gain (dB) | 5.192 | 7.358 |
| VSWR | 1.05 | 1.01 |
| Rad. Efficiency (%) | 77.38% | 83.68% |

Table 4. Gain, VSWR, and Radiation Efficiency
4. CONCLUSION

This paper compares two types of transparent antenna that operate in 28 GHz frequency, which are using ITO thin film as the radiating material. The designs that have been discussed are transparent microstrip grid array antenna and a basic rectangular microstrip patch antenna. Basic rectangular patch antenna gives wider bandwidth, but Grid Array antenna gives better performance in terms of higher radiation efficiency and gain with much lower return loss.

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REFERENCES

[1] S. Sheikh, M. Shokoosh-Saremi, and M.-M. Bagheri-Mohagheghi, “Transparent microstrip patch antenna based on fluorine-doped tin oxide deposited by spray pyrolysis technique,” IET Microwaves, Antennas Propag., vol. 9, no. 11, pp. 1221–1229, 2015.
[2] M. J. Roo-Ons, S. V. Shynu, M. J. Ammann, S. J. McCormack, and B. Norton, “Transparent Patch Antenna on a-Si Thin-Film Glass Solar Module,” Electron. Lett., vol. 47, no. 2, pp. 85–86, 2011.
[3] O. Yurduseven, D. Smith, and M. Elsdon, “A Transparent Meshed Solar Monopole Antenna for UWB Applications,” 8th Eur. Conf. Antennas Propag. (EuCAP 2014), pp. 2145–2149, Apr. 2014.
[4] T. Peter, T. A. Rahman, S. W. Cheung, R. Nilavalan, H. F. Abutarboush, and A. Vlckes, “A Novel Transparent UWB Antenna for Photovoltaic Solar Panel Integration and RF Energy Harvesting,” IEEE Trans. Antennas Propag., vol. 62, no. 4, pp. 1844–1853, 2014.
[5] M. S. A. Rani et al., “Electromagnetic Behaviors of Thin Film CPW-Fed CSRR Loaded on UWB Transparent Antenna,” IEEE Antennas Wirel. Propag. Lett., vol. 13, pp. 1239–1242, 2014.
[6] C.-T. Lee, C.-M. Lee, and C.-H. Luo, “The Transparent Monopole Antenna for WCDMA and WLAN,” in 2006 IEEE Annual Wireless and Microwave Technology Conference, 2006, pp. 1–3.
[7] T. J. Coutts, T. O. Mason, J. D. Perkins, and D. S. Ginley, “Transparent Conducting Oxides: Status and Opportunities in Basic Research,” in 195th Meeting of the Electrochemical Society, 1999, no. August.
[8] Y. Augarten, A. Wrighley, U. Rau, and B. E. Pieters, “Calculation of the TCO sheet resistance in thin film modules using electroluminescence imaging,” 2017 IEEE 44th Photovolt. Spec. Conf. PVSC 2017, no. 4, pp. 1–5, 2018.
[9] J. George et al., “Optimization of Electrical and Optical Properties in Multilayer TCO Thin Film Structures,” in 2009 34th IEEE Photovoltaic Specialists Conference (PVSC), 2009, pp. 440–444.
[10] A. Selamat, K. Mat, N. Misran, M. T. Islam, and M. F. Mansor, “Bandwidth performance analysis of different glass’s dielectric permittivity on reflectarray radiating element,” in 2016 International Conference on Advances in Electrical, Electronic and Systems Engineering, ICAEES 2016, 2017.
[11] J. Hautcoeur, F. Colombel, M. Himdi, X. Castel, and E. M. Cruz, “Large and Optically Transparent Multilayer for Broadband H-Shaped Slot Antenna,” IEEE Antennas Wirel. Propag. Lett., vol. 12, pp. 933–936, 2013.
[12] J. Hautcoeur, L. Talbi, K. Hettak, and M. Nedil, “60 GHz optically transparent microstrip antenna made of meshed AuGl material,” IET Microwaves, Antennas Propag., vol. 8, no. 13, pp. 1091–1096, Oct. 2014.
[13] G. Sun, B. Munecr, and Q. Zhu, “A study of microstrip antenna made of transparent ITO films,” 2014 IEEE Antennas Propag. Soc. Int. Symp., pp. 1867–1868, Jul. 2014.
[14] E. H. Lim, K. W. Leung, C. C. Su, and H. Y. Wong, “Green antenna for solar energy collection,” IEEE Antennas Wirel. Propag. Lett., vol. 9, pp. 689–692, 2010.
[15] O. Yurduseven, D. Smith, N. Pearsall, and I. Forbes, “Design of a highly efficient wideband suspended solar array antenna,” Proc. 2012 IEEE Int. Symp. Antennas Propag., no. 1, pp. 1–2, Jul. 2012.
[16] S. Yoshida et al., “7/8-GHz band 2x2 circular patch active integrated array antenna for solar sail applications,” in 2013 IEEE Antennas and Propagation Society International Symposium (APSURSI), 2013, pp. 1278–1279.
[17] M. J. Roo-Ons, S. V. Shynu, M. Seredynski, M. J. Ammann, S. J. McCormack, and B. Norton, “Influence of solar heating on the performance of integrated solar cell microstrip patch antennas,” Sol. Energy, vol. 84, no. 9, pp. 1619–1627, Sep. 2010.
[18] S. V. Shynu, M. J. R. Ons, M. J. Ammann, S. Gallagher, and B. Norton, “Inset-Fed Microstrip Patch Antenna with Integrated Polycrystalline Photovoltaic Solar Cell,” in The Second European Conference on Antennas and Propagation EuCAP 2007., 2007, pp. 1–4.
[19] T. W. Turpin and R. Baktur, “Meshed Patch Antennas Integrated on Solar Cells,” IEEE Antennas Wirel. Propag. Lett., vol. 8, pp. 693–696, 2009.
[20] O. Yurduseven, D. Smith, N. Pearsall, I. Forbes, and D. Johnston, “A meshed multiband solar patch array antenna,” in LAPC 2012 - 2012 Loughborough Antennas and Propagation Conference, 2012, pp. 1–5.
[21] S. V. Shynu, M. J. R. Ons, G. Ruvio, M. J. Ammann, S. McCormack, and B. Norton, “A Microstrip Printed Dipole Solar Antenna Using Polycrystalline Silicon Solar Cells,” in 2008 IEEE Antennas and Propagation Society International Symposium, 2008, no. 1, pp. 1–4.
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