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TRANSPARENT ANTENNA DESIGN FOR WiMAX APPLICATION

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Abstract—A transparent monopole antenna operating at 2.30 GHz is presented in this paper. The radiating element and ground plane are both designed using AgHT-4, while the substrate is made of glass. The simulated and measured impedance bandwidths (BWs) are 41.89% (2.00–3.06 GHz) and 90.91% (1.5–4.00 GHz), respectively. These results were obtained by using a suitable arc-shape slot on the ground plane; and the BWs cover the IEEE 802.16e standard for WiMAX application in the 2.30 GHz band. The gain of proposed antenna is 3.16 dBi, and there is close agreement between measurement and simulation results, in terms of return loss and radiation patterns.

1. INTRODUCTION

Recently, there has been increasing interests on the investigations of the new types of antenna designs using transparent materials. Some of the early researches conducted on transparent antennas have been reported in the early 90s [1, 2]. These class of antenna designs, due to their transparent characteristics, are suitably implemented with clear substrates such as window glass for security, aesthetics [1, 3], and vehicles [4]. Other types also could be integrated with solar cells to reduce the surface area of small satellites [5]. Transparent conductive

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films allow the transmission of electric currents, while still retaining the optical transparency [6].

The previous researchers have used three main types of transparent conductive films for designing transparent antennas. These films are indium tin oxide (ITO), fluorine-doped tin oxide (FTO) and silver coated polyester film (AgHT) [7]. A number of slot shapes were introduced to enhance the antenna BW, particularly in monopole antenna designs such as Π-shaped slot [8], circular shaped slot [9], G-shaped slot [10], spherical slot [11], elliptical-ring slot [12], rectangular slot [13], square slot [14], step-slot antenna [15], a compact split-ring slot with EBG [16], SIW slot [17] and slotted ground structure [18]. As the proposed transparent antenna is manually made by cutting out the patch and the feed from the coated polyester sheet of AgHT-4, a simple shape of planar monopole antenna is preferred and a wide bandwidth (BW) can be obtained by properly designing a suitable arc shaped slot on the ground plane. The proposed antenna has been fabricated by using AgHT-4, with an operating frequency of 2.30 GHz for worldwide interoperability for microwave access (WiMAX) access point. Since the proposed antenna was made of thin conductive film, it therefore seems to be the best candidate to be placed on the glass such as building's glass, windows or mirrors for access point.

2. ANTENNA DESIGN

The dimensions of wideband transparent monopole antenna are shown in Figure 1. The radiating element and ground plane are both designed using AgHT-4 film of 0.175 mm thickness and conductivity of ($\sigma = 2.2 \times 10^5$ S/m) [7]. The transparent antenna is mounted on a 2 mm thick glass substrate which has dielectric permittivity of 7. The

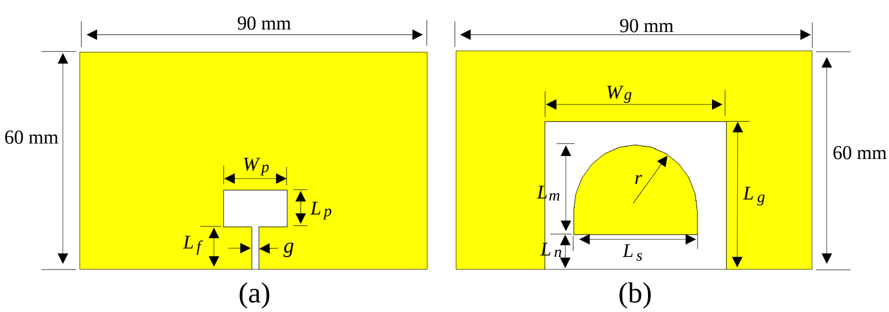

Figure 1. Layout of wideband transparent antenna. (a) Front view. (b) Back view.

Figure 2. Antenna prototype.

size of the glass substrate is designed large enough (90 mm × 60 mm) in order to stabilize such antenna properties as gain, after increasing the dimension of the glass substrate [19, 20]. The feedline width, $g = 2$ mm was obtained, thereby yielding a characteristic impedance of 50 Ω. A ground frame (50 mm × 40 mm) is necessary in order to have a bi-directional radiation pattern. In addition, the wide slot on the ground plane ensures that the antenna has a wider BW. The proposed transparent monopole antenna is designed and optimized using the CST Microwave Studio simulation tool. The antenna prototype is shown in Figure 2, and the logo of UTM can be seen through the antenna. This implies that the antenna is visibly transparent. The main objective of having such an antenna is to utilize the windows or mirrors in the modern buildings to harvest the solar energy and at the same time, to provide some signal coverage in the building. The antenna can be made thin and transparent so that it will not disturb an outside view. The dimensions of the proposed antenna are as follows: $W_p = 18$ mm, $L_p = 10$ mm, $L_f = 12$ mm, $g = 2$ mm, $L_m = 23$ mm, $L_n = 11$ mm, $L_s = 34$ mm, $W_g = 50$ mm, $L_g = 40$ mm, and $r = 17$ mm.

3. RESULTS AND DISCUSSIONS

The parametric studies have been done to investigate the effects of varying some parameters on the proposed antenna performance. The analysed parameters include the effects of varying arc-shape, radius of the arc-shape, size of the ground frame and length of the patch. Figure 3 shows the comparison of the return loss between arc-shaped slot and without arc-shaped slot on the ground plane. It can be seen that a wide impedance BW of 41.89% (2.00–3.06 GHz) can be obtained by introducing a suitable arc-shaped slot on the ground plane, which covers the WiMAX application in the 2.30 GHz band. This is because

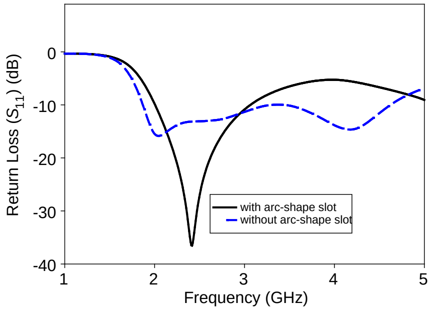

Figure 3. Comparison of simulated return loss for proposed antenna with and without arc-shaped slot.

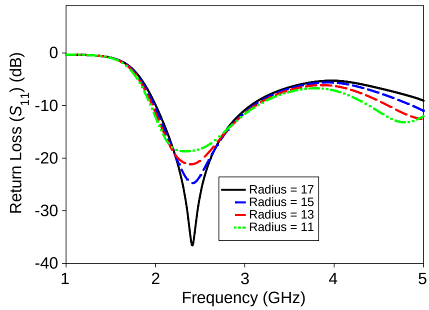

Figure 4. Comparison of simulated return loss for different slot radius.

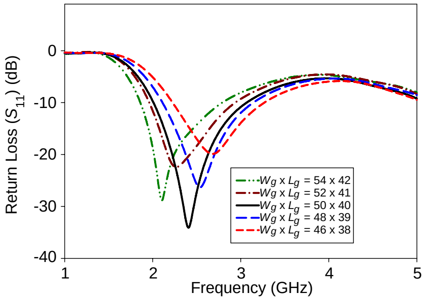

Figure 5. Comparison of simulated return loss for different sizes of ground frame.

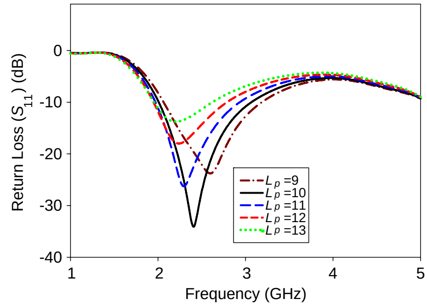

Figure 6. Comparison of the simulated return loss for different values of patch length.

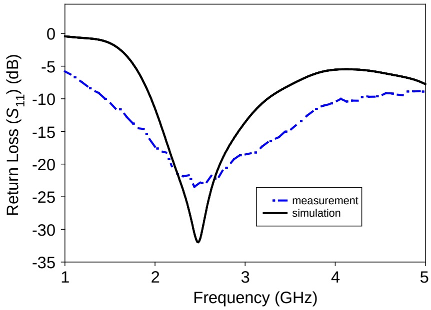

Figure 7. Measured and simulated return losses of the proposed antenna.

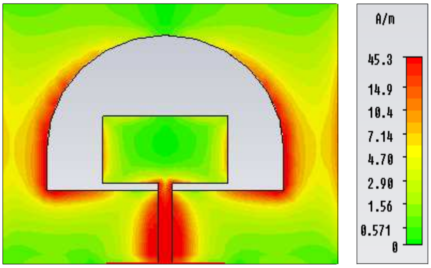

Figure 8. Simulated Current distribution of the transparent antenna.

the arc-shaped slot enables the surface current to flow much longer, and consequently makes the antenna to be tuned at the lower frequency (2.30 GHz). The effect of varying radius of the arc-shaped slot, r is illustrated in Figure 4, where the arc radius has been varied from 11 to 17 mm. It can be seen from Figure 4 that, the wider the antenna arc slot, the higher is the frequency. However, the slot radius depends on the overall size of the ground frame (L_g and W_g). The optimized value of 17 mm has been used in this design. Note that 18 mm radius would not be compatible with the size; and the overall size of the antenna would otherwise need to be increased if this radius were to be chosen. As a result, the antenna becomes bigger and the resonance frequency will be detuned to lower frequency.

The variation of return loss with different sizes of ground frame, $W_g \times L_g$ is shown in Figure 5. It can be observed that, when the size of the ground plane becomes smaller, the return loss will shift to

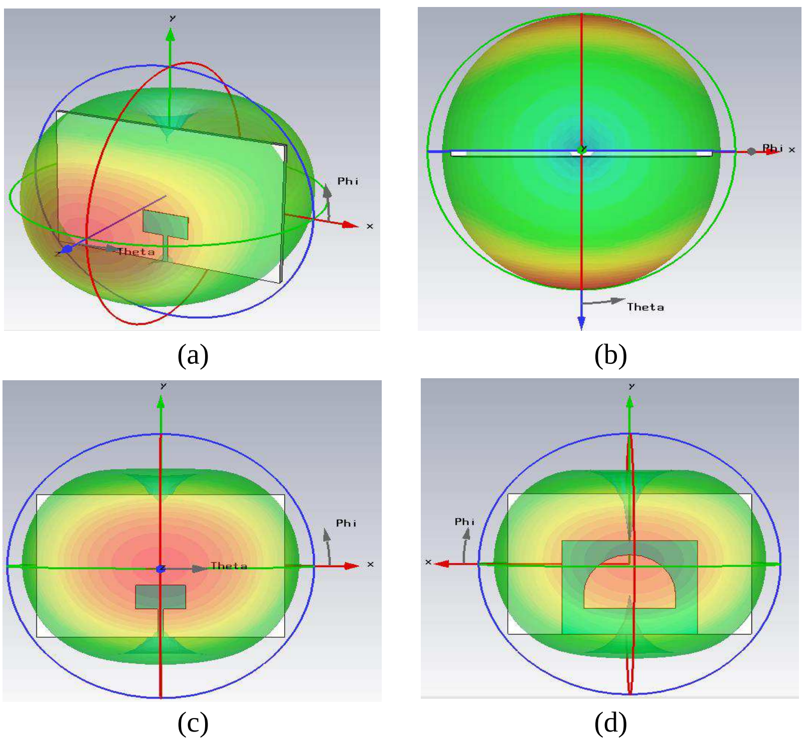

Figure 9. Simulated 3D Radiation pattern of the proposed transparent antenna. (a) Perspective view. (b) Top view. (c) Front view. (d) Back view.

higher frequency and vice versa. However, when the dimensions of ground plane were 50 mm × 40 mm, the lowest value of return loss has been obtained and this tuned the antenna to 2.30 GHz, which is the frequency of interest for WiMAX application. The patch length L_p has been varied from 9 to 13 mm, as shown in Figure 6. And it can be observed from Figure 6 that, the optimum value of patch length, $L_p = 10$ mm gave the return loss covered at 2.30 GHz.

Figure 7 shows the measured and simulated return loss for the proposed antenna. It can be observed that both simulation and measurement have produced the resonance frequency at approximately 2.30 GHz. The simulated and measured BWs are 41.89% (2.00–3.06 GHz) and 90.91% (1.5–4.00 GHz) respectively. The discrepancy noted in the two BWs may be due to fabrication process, since the antenna prototype was handmade and fabricated by cutting out the patch and the feed from the coated polyester sheet, AgHT-4. In addition, an adhesive material was used between the glass and coated polyester sheet, AgHT-4, resulting in an air-gap between them. The air-gap will increase the overall height of the transparent antenna and thus widening the BW [21, 22]. The material itself (AgHT-4) has high sheet resistance, and by applying a layer of highly conductive coating

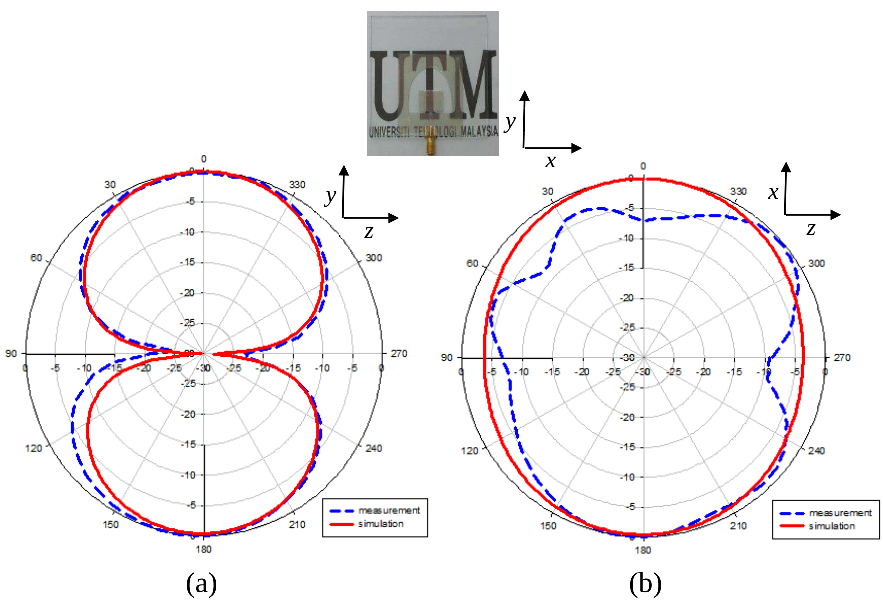

Figure 10. Measured and simulated radiation patterns. (a) E-plane. (b) H-plane. (NB: the antenna prototype is shown in the inserted figure).

or metallization at high current density, which is at the arc-shaped slot, will improve the antenna performance [7].

Figure 8 shows the surface current distribution at 2.30 GHz, where the currents are more concentrated along the arc-shaped slot of the antenna. This shows that the slot acts as a resonator which generates the resonance frequency of 2.30 GHz.

The simulated bi-directional radiation pattern of the transparent antenna is shown in Figures 9(a)–(d). The bi-directional radiation pattern makes the proposed antenna suitable for indoor access point applications. The antenna can easily be mounted against glass in order to receive signals from both sides. Note that the simulated antenna directivity is 3.40 dBi.

Figures 10(a) and (b) show the measured and simulated E-plane and H-plane radiation patterns of wideband transparent antenna at 2.30 GHz frequency. It is observed that the proposed transparent antenna has bi-directional radiation pattern in the E-plane and omni-directional radiation pattern in the H-plane over the entire working bands.

4. CONCLUSIONS

A wideband monopole transparent antenna for WiMAX access point application has been presented in this article. The transparent antenna has bi-directional radiation pattern and a wide impedance BW of 41.89% (2.00–3.06 GHz) and 90.91% (1.5–4.00 GHz) obtained for simulation and measurement respectively that covers WiMAX applications in the 2.30 GHz operation band. The transparent antenna gain and directivity are 3.16 dBi and 3.40 dBi respectively. The transparent antenna is suitable for WiMAX access point applications.

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REFERENCES

1. Ito, K. and M. Wu, "See-through microstrip antennas constructed on a transparent substrate," *IEE Seventh International Confer-*

ence on Antennas and Propagation, ICAP 91, Vol. 1, 133–136, 1991.
2. Wu, M.-S. and K. Ito, "Basic study on see-through microstrip antennas constructed on a window glass," *IEEE Antennas and Propagation Society International Symposium, AP-S. 1992 Digest, Held in Conjuction with: URSI Radio Science Meeting and Nuclear EMP Meeting*, Vol. 1, 499–502, 1992.
3. Simons, R. N. and R. Q. Lee, "Feasibility study of optically transparent microstrip patch antenna," *IEEE Antennas and Propagation Society International Symposium, 1997 Digest*, Vol. 4, 2100–2103, 1997.
4. Song, H. J., "Challenges in glass integrated optically transparent antennas," *International Symposium on Antennas and Propagation (ISAP)*, Jeju, Korea, 2011.
5. Turpin, T. W. and R. Baktur, "Meshed patch antennas integrated on solar cells," *IEEE Antennas and Wireless Propagation Letters*, Vol. 8, 693–696, 2009.
6. Kawashima, T., H. Matsui, and N. Tanabe, "New transparent conductive films: FTO coated ITO," *Thin Solid Films*, Vol. 445, 241–244, 2003.
7. Song, H. J., T. Y. Hsu, D. F. Sievenpiper, H. P. Hsu, J. H. Schaffner, and E. Yasan, "A method for improving the efficiency of transparent film antennas," *IEEE Antennas and Wireless Propagation Letters*, Vol. 7, 753–756, 2008.
8. Teng, X. Y., X.-M. Zhang, Z. X. Yang, Y. Wang, Y. Li, Q. F. Dai, and Z. Zhang, "A compact CPW-fed omni-directional monopole antenna for WLAN and RFID applications," *Progress In Electromagnetics Research Letters*, Vol. 32, 91–99, 2012.
9. Xie, J.-J., Y.-Z. Yin, S.-L. Pan, and L. Sun, "A novel circular slot antenna with two pairs of T-shaped slots for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 32, 49–57, 2012.
10. Kang, L., Y.-Z. Yin, H. Li, W.-J. Huang, and S.-F. Zheng, "Dual-wideband symmetrical G-shaped slotted monopole antenna for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 17, 55–65, 2010.
11. Ng Mou Kehn, M., "Spherical slotted antenna coated with double layyer of materials having combinations of singly and doubly negative parameters and consequences of mode resonance," *Progress In Electromagnetics Research B*, Vol. 45, 223–249, 2012.
12. Wang, M.-Z. and F.-S. Zhang, "A circular polarized elliptical-

ring slot antenna using and L-shaped coupling strip," *Progress In Electromagnetics Research Letters*, Vol. 35, 29–35, 2012.

13. Sagnard, F., "A compact coplanar braodband rectangular slot antenna with E-shaped feeding structure for GPR applications," *Progress In Electromagnetics Research B*, Vol. 4, 241–260, 2012.
14. Joseph, R. and T. Fukusako, "Bandwidth enhancement of circularly polarized square slot antenna," *Progress In Electromagnetics Research B*, Vol. 29, 233–250, 2011.
15. Sog, K., Y.-Z. Yin, B. Chen, S.-T. Fan, and F. Gao, "Bandwidth enhancement design of compact UWB step-slot antenna with rotated patch," *Progress In Electromagnetics Research Letters*, Vol. 22, 39–45, 2011.
16. Alam, M. S., M. T. Islam, and N. Misran, "A novel compact split ring slotted electromagnetic bandgap structure for microstrip patch antenna performance enhancement," *Progress In Electromagnetics Research*, Vol. 130, 389–409, 2012.
17. Cheng, Y. J., "Substrate integrated waveguide frequency-agile slot antenna and its multibeam application," *Progress In Electromagnetics Research*, Vol. 130, 153–168, 2012.
18. Chen, Z., Y.-L. Ban, J.-H. Chen, J. L.-W. Li, and Y.-J. Wu, "Bandwidth enhancement of LTE/WWAN printed mobile phone antenna using slotted ground structure," *Progress In Electromagnetics Research*, Vol. 129, 469–483, 2012.
19. Yasin, T., R. Baktur, and C. Furse, "A study on the efficiency of transparent patch antennas designed from conductive oxide films," *2011 IEEE International Symposium on Antennas and Propagation (APSURSI)*, 3085–3087, 2011.
20. Yasin, T., R. Baktur, and C. Furse, "A comparative study on two types of transparent patch antennas," *2011 XXXth URSI General Assembly and Scientific Symposium*, 1–4, 2011.
21. Kasabegoudar, V. G. and A. Kumar, "Dual band coplanar capacitive coupled microstrip antennas with and without air gap for wireless applications," *Progress In Electromagnetics Research C*, Vol. 36, 105–117, 2013.
22. Benmeddour, F., C. Dumond, F. Benabdelaziz, and F. Bouttout, "Improving the performances of a high TC superconducting circular microstrip antenna with multilayered configuration and anisotropic dielectrics," *Progress In Electromagnetics Research C*, Vol. 18, 169–183, 2011.