Fabricated AZO on Dual-Stacked Patch Transparent Antenna

M. Awalludin, M. T. Ali, R. A. Awang and M. H. Mamat

Abstract— **The development of a simple dual-stacked transparent patch antenna operating at 5 GHz is presented. A transparent conducting oxide material known as aluminum doped Zinc Oxide (AZO) for radiating patch and a transparent perspex acrylic for supporting substrate are used in this antenna design. The AZO thin film thickness of 200 nm has been deposited on the Perspex using RF magnetron sputtering technique. Employing an air gap in the antenna structure is proven to exhibit wider bandwidth compared to the single patch structure transparent antenna. The dual-stacked antenna is fabricated and measured to validate the simulation results. A measured return loss was slightly shifted to the lower frequency The proposed transparent material has the potential to be implementing in any transparent devices.**

Index Terms—**transparent antenna, AZO, air gap, stacked antenna**

I. INTRODUCTION

For decades, transparent conducting oxide (TCO) [1] such as tin oxide (SnO_2), indium tin oxide (ITO) and zinc oxide (ZnO) has been widely used in several semiconductor applications. It offers many advantages including good electrical and optical properties [2][3]. These advantages make it preferable choices for display devices applications for example in automated teller machines (ATMs), liquid crystal display (LCD) and mobile phone [4][5].

Recently, the TCO have also begun to take steps in antenna research field. Many studies have been conducted using the TCO in several transparent antenna applications such as radio-frequency identification (RFID) [6][7], and small satellites [8]. Among the TCOs, ITO is commonly used to create transparent antenna [9][10]. However, it has several disadvantages such as limited supplies of indium has led to higher cost, unstable and contains toxicity that might threaten the environment and humans [4][7].

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Alternatively AZO is believed a suitable materialin replacing ITO for transparent antenna design as it has good electrical conductivity properties, high transmittance in visible region. [4] and also non-toxicity material [11]. In addition, various well-established techniques such as magnetron sputtering [3][12], pulse laser deposition (PLD) [13], chemical vapor deposition (CVD) [14],and sol-gel process [15] have been employed in AZO thin film deposition process.

In this paper, transparent antenna design using AZO as a radiating patch and perspex acrylic as transparent substrates at operating frequency of 5GHz has been studied. A dual-stacked transparent patch antenna is fabricated using magnetron sputtering technique. In the final section, the fabricated antennas with their corresponding measurements such as return loss, radiation patterns and gain are presented. The implementation of air-gaps between the proposed stacked substrates will enhance the bandwidth of the single patch transparent antenna.

II. ANTENNA DESIGN

A. Single Patch Transparent Antenna

Figure 1 shows antenna design which consists of patch structure using AZO material as the radiating element and ground. To make it fully transparent device, a see-through perspex acrylic substrate is used. For simplicity in this design, the rectangular patch is chosen. A coaxial probe feeding technique has been used. The proposed antenna is designed and simulated using CST Microwave Studio software.

The conductivity (σ) of the AZO material was calculated based on the resistivity values of 6.11×10^{-4} Ω.cm as mentioned in paper [16]. The conductivity of Aluminum doped ZnO thin films were calculated using following equation;

$$\sigma = 1/\rho \qquad (1)$$

Thus, the conductivity of 1.6367×10^{5} S/m for AZO was used in the simulation.

The optimization process is carried out to achieve required resonant frequency and better performance results. The optimized parameters are tabulated in Table 1.

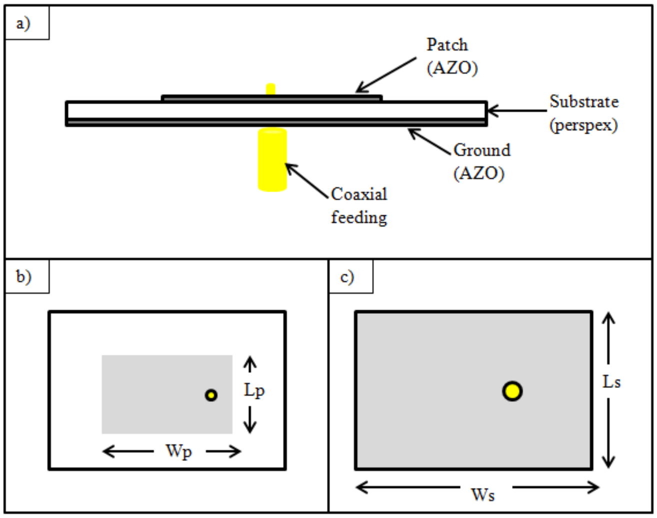

Fig . 1. Single patch transparent antenna: a) cross-sectioned view, b) front view and c) back view

TABLE 1
DIMENSIONS Of SINGLE PATCH TRANSPARENT ANTENNA

Parameter	*Dimensions (mm)*
Wp	19.94
Lp	12
Ws	40
Ls	28

B. *Dual-Stacked Transparent Patch Antenna*

The dual-stacked transparent patch antenna design is the enhanced version of the single patch transparent antenna. The single patch antenna is stacked with another layer of perspex substrate introducing an air-gap separated between the stacking structures as shown in Figure 2. The purpose of adding air-gap in this design is to enhance the bandwidth of the antenna. Adding an air-gap between two perspex substrates decreases the effective permittivity and indirectly increases the total thickness of the transparent antenna. Thus, it is expected to exhibit wider bandwidth [17]. Figure 3 shows a parametric study of the effect of an air-gap thickness variation. The air-gap thickness was varied from 1 mm to 3 mm and all other parameters are kept constant. From the simulation plots, it is noticeable that the air-gap thickness of 2.5 mm thickness recorded the best result of highest bandwidth which is 0.351 GHz with return loss value of -30.07 dB. By increasing the thickness to 3 mm, the bandwidth and the return loss begin to decrease slowly. Hence, air-gap thickness (H_{airgap}) of 2.5 mm was chosen.

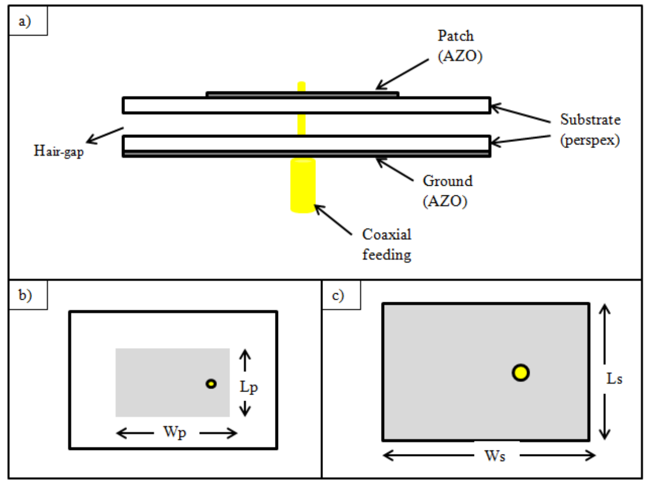

Fig . 2. Dual-stacked transparent patch antenna: a) cross-sectioned view, b) front view and c) back view

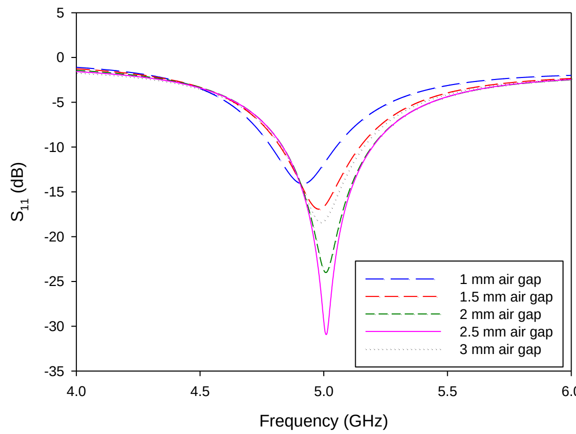

Fig . 3. Return loss response with different air-gap thickness

The parameter of the design need to beare optimized toachieve required resonant frequency and better results. The summary of the selected parameters is listed in Table 2.

TABLE 2
DIMENSIONS OF DUAL-STACKED PATCH TRANSPARENT ANENNA

Parameter	*Dimensions (mm)*
Wp	21.62
Lp	12
Ws	34
Ls	28
H_{airgap}	2.5

III. FABRICATION

The AZO films were deposited using magnetron sputtering as shown in Figure 4. The film is setup from a 5-inch diameter target consisting of 98 wt.% Zinc Oxide (ZnO) and 2 wt.% Aluminum Oxide (Al_2O_3). The composition was chosen based on [18] as it can produce higher transparent and conductive AZO thin film than other compositions. The film was made at room temperature and the deposition of the film was carried out with 100% argon atmosphere. The substrates were placed parallel to the target surface at 70 mm distance. The sputtering gas pressure was approximately 5 mTorr as investigated by [16] at different working pressures. A very good electrical and optical properties for AZO materials was obtained at working pressure of 5 mTorr. After 1-hour deposition, the samples were all self-cooled before were taken out of the chamber.

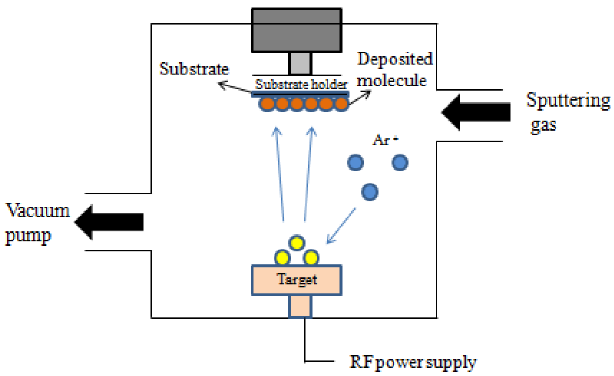

Fig . 4. Schematic diagram of a magnetron sputtering system [19]

IV. RESULTS AND DISCUSSIONS

A. *Simulation Results of Transparent Antenna*

Figure 5 shows a simulation graph of return loss, S_{11} for both transparent antennas. The S_{11} is a parameter that describes how much of power is reflected by an impedance discontinuity in the transmission medium. Both antennas are operated at frequency of 5 GHz. The simulated S_{11} for single patch and dual-stacked patch transparent antenna is -32.22 dB and -30.07 dB, respectively. The dual-stacked patch antenna produces 351 MHz 10-dB bandwidth which is 160 % increment from the bandwidth of single patch transparent antenna. As the stacked patch transparent antenna achieved wider bandwidth, it has been chosen for fabrication.

The antenna radiation pattern is a graphical representation of the antennas radiated electrical performance. The simulated radiation pattern for both transparent antennas are shown in Fig.6. From this figure, it can be seen that this antenna structure produce the directional pattern which radiates its energy in one direction.

The simulated gain for dual-stacked patch transparent antenna is 6.998 dB which is significantly higher than single patch (4.047 dB). The simulated gain value is acceptable for a microstrip antenna. For directivity results, single patch and dual-stacked transparent antenna achieved 7.211 dBi and 7.467 dBi respectively.

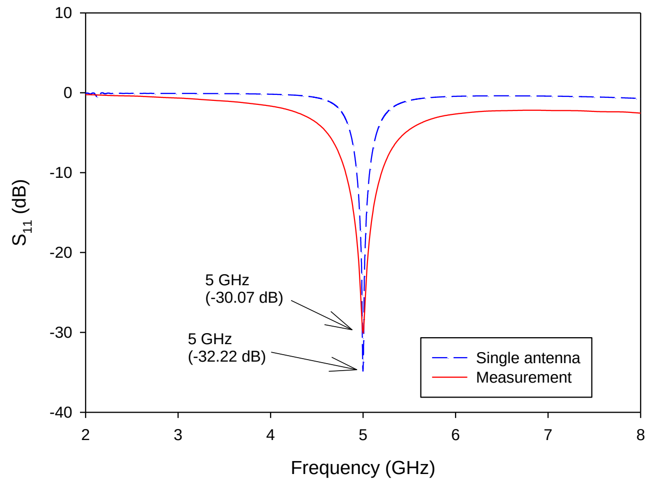

Fig . 5. Simulated return loss for single and dual-stacked transparent antenna

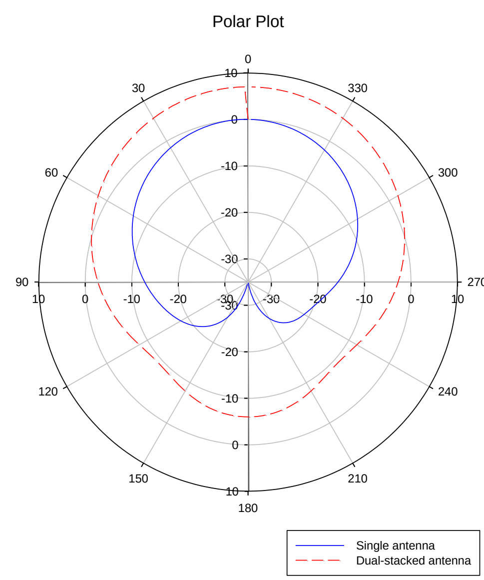

Fig .6. Simulated radiation pattern for both transparent antenna

B. *Measurements Results of Dual-Stacked Transparent Patch Antenna*

Based on the good performance of simulation results that has been discussed earlier, the dual-stacked patch transparent antenna has been constructed into prototype as shown in Figure 7. The measured S_{11} of the dual-stacked transparent patch antenna is presented in Figure 8. The measured S_{11} is slightly shifted to the lower frequency (4.24 GHz) could be mainly affected due to fabrication tolerances. In addition, the transparent substrate used also contributes to the performance antenna. The chosen transparent perspex acrylic substrate might contribute in this shifting result as it can melt in high temperature during deposition process. As stated in [12], AZO thin film deposited on unheated substrates lead to deprive electrical properties. Therefore, the shifting results are expected.

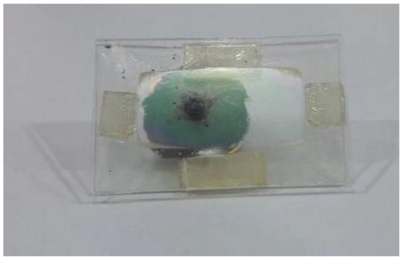

Fig . 7. The fabricated dual-stacked transparent patch antenna

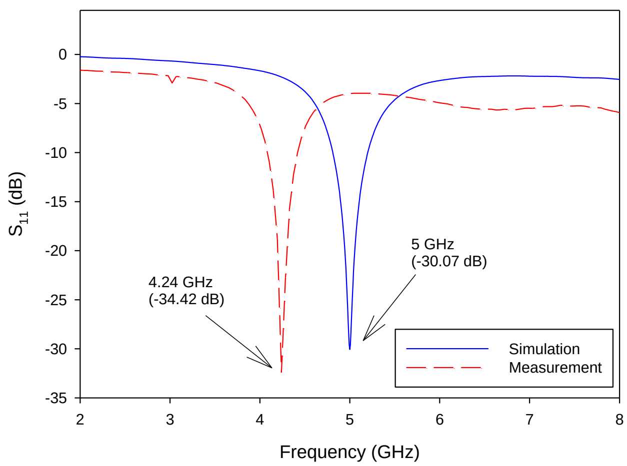

Fig . 8. Simulated and measured results of return loss for dual-stacked transparent patch antenna

The simulated and measured radiation pattern of dual-stacked transparent patch antenna at frequency response of 5 GHz is presented in Figure 9. The radiation pattern was measured in the anechoic chamber environment. The measured directivity and gain value at 5 GHz are 4.25 dBi and -8.56 dB, respectively while measured directivity and gain at 4.24 GHz are 5.61 dB and -9.08 dBi. The negative measured gain is expected because of low conductivity of the AZO and lossy nature of the transparent material [20].

V. CONCLUSION

A dual-stacked transparent patch antenna based on transparent materials is successfully presented. Creating air-gap between the stacked substrates produces higher gain and much wider bandwidth than a single patch transparent antenna. The stacked transparent antenna has been simulated, fabricated and measured. Due to fabrication tolerance, the measured return loss is slightly shifted to the lower frequency compared to the simulated result. Based on the successfully performances, the AZO material can be a potential candidates for transparent antenna design applications.

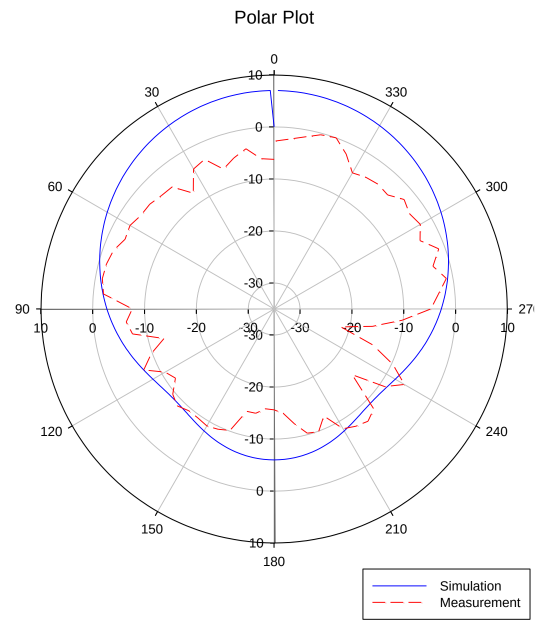

Fig . 9. Simulated and measured radiation pattern illustrated on polar plot

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