Enhancement of Bandwidth through a Sandwich E-Shape between Multilayer Structure

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Abstract– **This paper presents a comparative study of the performances between single layer and multilayer with a sandwich E-shape patch antenna. The design process of these antennas were using Computer Simulation Technology (CST) Microwave Studio software. The type of substrate used for both antennas was R03003 substrate with the relative permittivity, ε_r= 3 and thickness, *h*= 0.5 mm and *h*= 0.75 mm. These antennas were designed to resonate at frequency 2.4 GHz. This study was focusing on enhancing the bandwidth and at the same time increased the value of return loss, gain and directivity of the antenna. The simulation results show that the bandwidth of multilayer with a sandwich E-shape patch antenna was increased by 61.74% compared to single layer patch antenna. The return loss, gain and directivity were also increased by 34.02%, 21.95% and 1.07% respectively. For multilayer with a sandwich E-shape patch antenna, the usage of thicker substrate was also enhanced those parameters by 6.66%, 37.34%, 21.68% and 5.08% respectively. Nevertheless, the usage of wider a sandwich E-shape dimension was only increased the values of return loss, bandwidth and directivity by 5.10%, 1.24% and 0.05% respectively but decreased the value of gain by 0.59%.**

Keywords– **Multilayer, E-shaped, Return loss, Bandwidth, Gain, Directivity.**

I. INTRODUCTION

In terms of the general point of view, antenna is known as a metallic conductor system that can radiates and captures the electromagnetic energy. The IEEE Standard stated that the antenna is used for transmitting and to gain the waves of radio [2]. Antenna is usually utilised to interface transmission line to the atmosphere or vice versa [1]. Antenna is also one of the vital component for the wireless communication systems. In addition, in terms of communication studies, antenna is one of the main active fields. In order to meet the specification required in these applications, the antenna with different properties is produced from a developed design techniques [3].

For wireless communication system, there are always a demand on the longer service life of the battery, high data bit rates and smaller devices. In terms of technical point of view, these demands indicate that the needs of smaller, more efficient and also broader bandwidth antennas [4].

Patch antenna is consisting of radiated patch which is commonly made of conducting materials like copper or gold. The feeding lines and radiating patch are generally photo etched on the dielectric substrate which have ground plane. It is also can take any shape [14]. Patch antenna also called planar antenna. It is due to its flat elements and three dimension (3D) structure [10]. There are a few advantages of the microstrip patch antenna which are lightweight, easy to fabricate, low profile and conformability to mount hosts due to the reduction of size and bandwidth [5]. A lot of extensive designs and characterizations of the microstrip patch antenna have been done. This is due to lower profile structure, lightweight and also has lower cost in terms of fabrication. These design techniques are developed in order to increase the radiation performance like the bandwidth and gain. Due to its small size, microsrip patch antenna is having very narrow frequency bandwidth, spurious feed radiation, poor polarization purity, low power and low efficiency [6].

The slot antennas like E-shape patch, U-slot patch with shorted patch, L-slot patch, double U-slot patch, annular slot and double C patch antennas are utilised for bandwidth improvement of microstrip patch antenna [13]. The other technique to enhance the bandwidth of antenna is by promoting the parasitic elements such as coplanar and multi-resonator of stack configuration. The other method is to modify the shape of patch antenna like E-shaped or U-shaped patch antenna. U-slot microstrip antenna gives the value of bandwidth up to thirty percent while E-shaped patch antenna will enhance the value of bandwidth to more than thirty percent. The major objective of designing E-shape patch antenna is to improvise the design base in order to achieve a broad bandwidth. This type of shape is easy to design by only adjusting its width, length and position of slots [12]. The E-shaped patch antenna has the highest bandwidth compare to U and H shaped antenna. This research also highlighted that the bandwidth value of the E-shaped and U-shaped patch antenna is much more higher compare to the conventional rectangular shape microstrip patch antenna [14].

The bandwidth enhancement of patch antenna will be improved by having multiple layer dielectric substrates. The microstrip antenna's bandwidth is small and differ with the patch size. In order to enhance the bandwidth, the patch size should be increased thus producing a larger antenna which is not preferable. In addition, to solve the bandwidth problem without changing the size of antenna, the multiple layer patch scheme is introduced to decrease dielectric constant. It is done in order to ensure that the bandwidth is greatly increase with no change of size [15]. The patch antenna of low dielectric has moderate bandwidth. But this antenna is having large size. Theoretically, the bandwidth is decrease with the increment of the substrate dielectric value. Thus, those substrates are combined in order to achieve both small size of patch and high value of bandwidth [7]. The usage of a truncated periodic structure in multilayer configuration in the substrate of the microstrip antenna will produce the gain enhancement mechanism [16]. The impedance bandwidth is one of the vital characteristics of microstrip patch antenna. It can be improved by utilising a multilayer dielectric configuration. They are also found that the bandwidth increase to 7.5% by using cover layer which the improvement over conventional multidielectric layer antenna for about thirty percent. The improved bandwidth with the minimization of surface wave losses is due to the offset impedance matching employed in feeding technique [17]. The gain and directivity can be improved by utilising the multilayer dielectric covered layer structure. It is also improve the patch dimension. Beside that, bandwidth and gain also can be improved by using the air gap and the parasitic patch between ground plane and feedline patch [18].

By definition, the bandwidth is the antenna operating frequency band which the antenna performs as desired. The bandwidth is also could be related to the antenna matching band if its radiation patterns do not change within the band [11]. There are a few methods to improve the patch antennas' bandwidth which are increasing the thickness of substrate, low dielectric substrate usage, the usage slot antenna geometry, cutting a resonant slot inside the patch, the usage of many impedance matching and feedline methods. On the other hand, the antenna's sizes and bandwidths are commonly mutual conflict characteristics which means the improvisation of one of the characteristic might degrade the other characteristics [8].

II. Methodology

At the initial stage of this study, the literature review that related to the types of substrate used and the bandwidth enhancement of multilayer with a sandwich E-shape patch antenna was reviewed. Before designing the antenna, a few calculations were done to obtain the needed parameters using the equation given. Then, this type of antenna was designed using Computer Simulation Technology (CST) Microwave Studio software. Next, this antenna was simulated also using CST software. These two steps were repeated until the optimum design of multilayer with a sandwich E-shape patch antenna was achieved. In this design, the substrate that was used was RO3003 substrate. The relative permittivity for this type of substrate was ε_r = 3.0. After achieving the optimum design of both single layer and multilayer antennas, the comparative study between them were done to indicate the performance in term of return loss, bandwidth, gain and directivity. Fig. 1 shows the framework structure of designing the antenna using CST software.

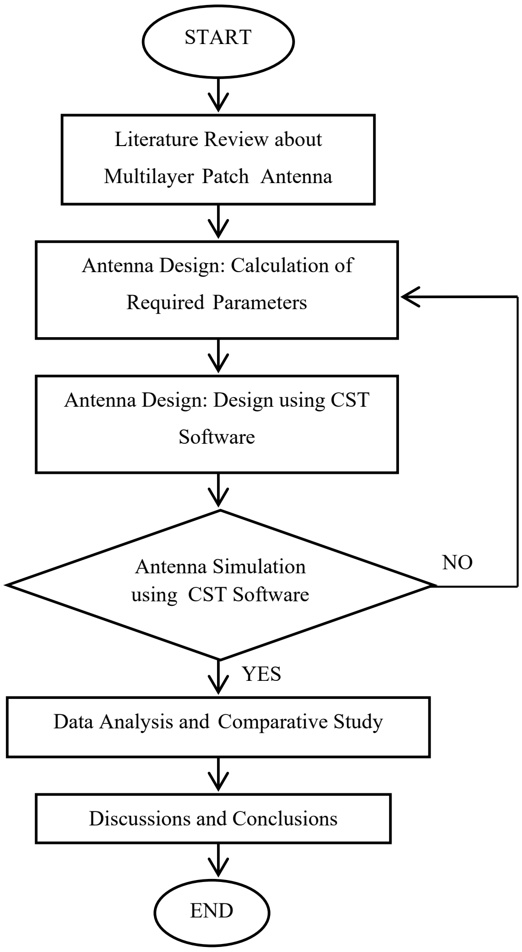

Fig. 1. Flowchart of Methodology.

A. Project Research

This project was started with researching the multilayer patch antenna. This project was using patch antenna with a sandwich E-shape between two layer of substrates and ground structure. The previous research proved that the usage of E-shape and multilayer patch antenna can enhance the bandwidth. Hence, this particular project was done in order to verify whether the multilayer with a sandwich E-shape patch antenna can enhance the bandwidth of the antenna.

TABLE I: Rogers RO3003 Substrates Characteristics

Characteristic	Value
Permittivity, ε_r	3.00
Thickness, h (mm)	0.5 and 0.75
Copper (Annealed) Thickness (mm)	0.035

Table I shows the characteristics of RO3003 substrate that was used in the design. The CST Microwave Studio Software was not only used to draw the design, but it was also used to simulate and analyze the designed antenna. All parameters had been calculated using the specific equations for designing this type of antenna.

B. Microstrip Patch Antenna Calculation and Design

Width of the patch,

$$W = \frac{c}{2f\sqrt{\frac{(\varepsilon_r + 1)}{2}}} \quad (1)$$

where;

speed of light, c = 3 x 10^8 m/s

Effective dielectric constant of patch,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \quad (2)$$

Extension of length,

$$\Delta L = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left(\frac{w}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{w}{h} + 0.8\right)} \quad (3)$$

Actual length of patch,

$$L = \frac{c}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (4)$$

Inset feed,

$$y = \frac{10^{-4}L}{2}\begin{pmatrix} 0.001699\,\varepsilon_r^{7} + 0.13761\,\varepsilon_r^{6} - \\ 6.1783\,\varepsilon_r^{5} + 93.187\,\varepsilon_r^{4} - \\ 682.69\,\varepsilon_r^{3} + 2561.9\,\varepsilon_r^{2} - \\ 4043\,\varepsilon_r^{1} + 6697 \end{pmatrix} \quad (5)$$

Ground plane dimension and substrate,

$$Lg = L + 6h, \quad (6)$$

$$Wg = W + 6h \quad (7)$$

After calculation process, the antenna was designed and simulated using CST Software. The simulation was done in order to prove the generalized S-parameters of the designed antenna.

TABLE II: DIMENSIONS OF SINGLE LAYER AND MULTILAYER WITH A SANDWICH E-SHAPE PATCH ANTENNA

Parameter	Design 1: Single Layer (h=0.5mm)	Design 2: Multilayer with a Sandwich E-Shape (h=0.5mm)	Design 3: Multilayer with a Sandwich E-Shape (h=0.75mm)	Design 4: Multilayer with Wider E-Shape Dimension (h=0.5mm)
W (mm)	44.1940	46.1940	44.1940	46.1940
L (mm)	35.9660	35.4880	35.3867	35.4880
W_g (mm)	47.1940	47.1940	47.1940	47.1940
L_g (mm)	38.9660	38.9660	38.9660	38.9660
W_f (mm)	1.26750	2.8100	4.16395	2.8100

Table II above shows the dimensions for all types of designed antenna in this study, while Fig. 2, Fig. 3 and Fig. 4 illustrate the patch antenna for single layer and multilayer design.

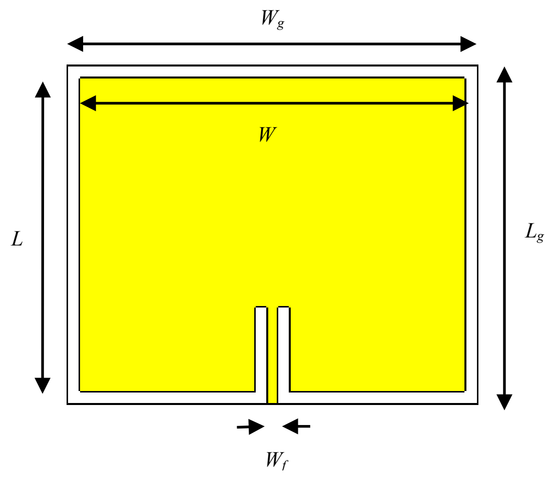

Fig. 2. Patch Antenna for Design 1.

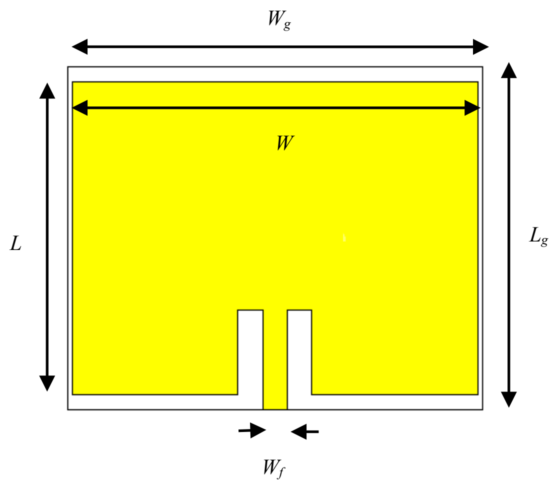

Fig. 3. Patch Antenna for Design 2 and 4.

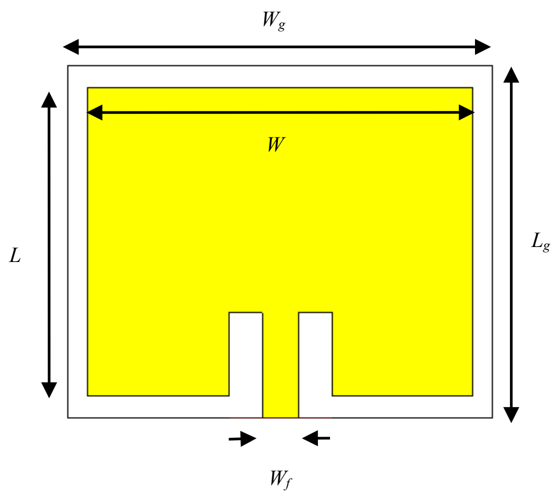

Fig. 4. Patch Antenna for Design 3.

C. Designing E-Shape

TABLE III: DIMENSIONS OF E-SHAPE

Parameter	Design 2 & Design 3	Design 4
W_{main} (mm)	31.2500	41.6667
L_{main} (mm)	15.6250	15.6250
W_{arm} (mm)	7.8125	7.8125
W_{slot} (mm)	3.90625	9.1146
L_{slot} (mm)	10.4167	10.4167

Table III above shows all the dimensions of a sandwich E-shape for Design 2, 3 and 4. Fig. 5 and 6 show the E-shape for multilayer antenna. This E-shape was placed between two substrates. The width of E-shape for Design 4 was wider compared to Design 2 and 3 as illustrated below. This was done in order to evaluate the changes of bandwidth when changing the width of E-shape. Fig. 7 and Fig. 8 show the schematic diagram of this antenna.

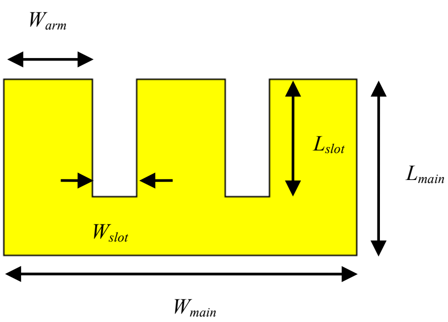

Fig. 5. E-Shape for Design 2 and 3.

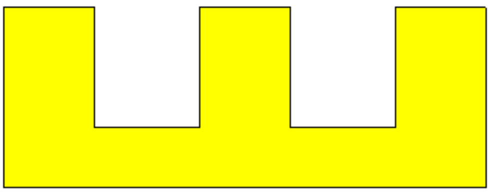

Fig. 6. E-Shape for Design 4.

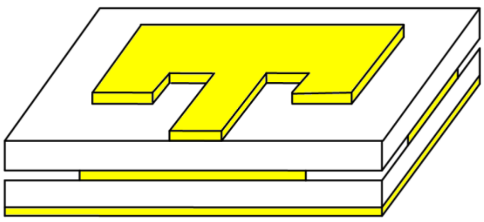

Fig. 7. 3D View of Antenna Structure.

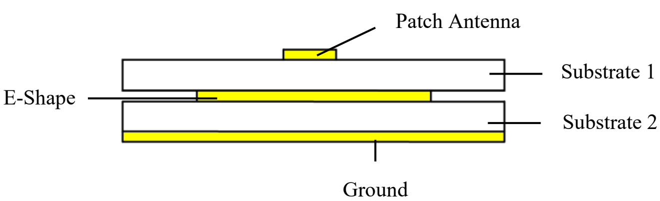

Fig. 8. Cross Section of Antenna Structure.

III. RESULT AND DISCUSSION

In this project, the comparison between the performances of single layer and multilayer with a sandwich E-shape patch antenna were investigated through simulation process. All the simulation results were obtained from the CST software.

Fig. 9 until Fig. 12 show the return loss, S_{11} result for all the designed antenna. Based on the result, S_{11} for Design 1 was -14.213735 dB, Design 2 was -19.048614 dB, Design 3 was -20.317036 dB and lastly Design 4 was -20.020777 dB. The bandwidth for Design 1 was 0.0149 GHz, Design 2 was 0.0241 GHz, Design 3 was 0.0331 GHz and Design 4 was 0.0244 GHz. Based on the results, it shows that the value of return loss and bandwidth for multilayer with a sandwich E-shape patch antenna was greater than single layer patch antenna. It was proved that the multilayer with a sandwich E-shape patch antenna enhanced the performance of the antenna in terms of its return loss, S_{11} and the bandwidth.

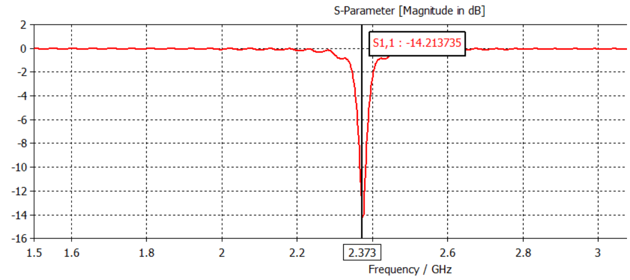

Fig. 9. Return Loss, S_{11} for Design 1.

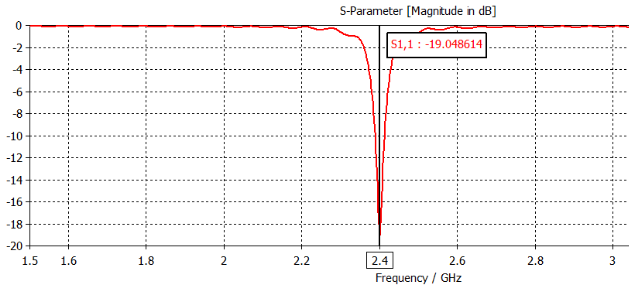

Fig. 10. Return Loss, S_{11} for Design 2.

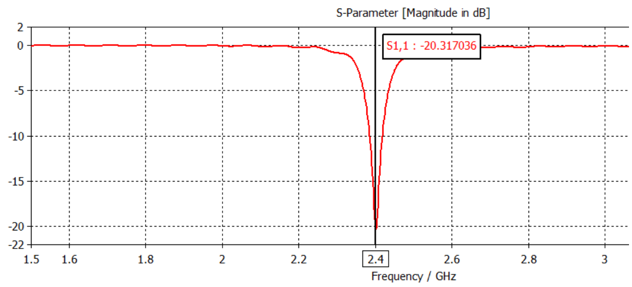

Fig. 11. Return Loss, S_{11} for Design 3.

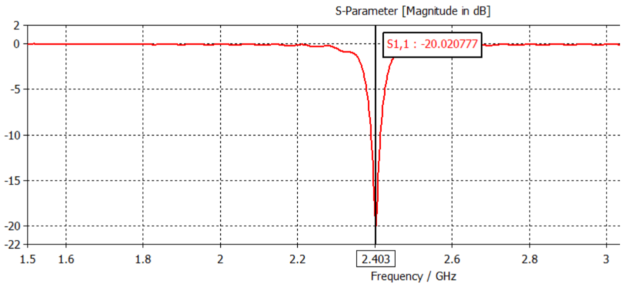

Fig. 12. Return Loss, S_{11} for Design 4.

Fig. 13 until Fig. 16 present the 3D polar plot of antenna gain for single layer patch antenna (Design 1) and multilayer with a sandwich E-shape patch antenna (Design 2, 3 and 4). Design 2, 3 and 4 produced higher gain with a value of 4.3720 dB, 5.3200 dB and 4.3460 dB respectively compared to Design 1 with a value of 3.5850 dB. It shows that the multilayer with a sandwich E-shape patch antenna enhanced the antenna gain.

Fig. 13 until Fig. 16 were also present the directivity for both single layer patch antenna and multilayer with a sandwich E-shape patch antenna. The multilayer with a sandwich E-shape patch antenna also produced higher directivity with a value of 5.9700 dBi, 6.2730 dBi and 5.9730 dBi for Design 2, 3 and 4 while the single layer patch antenna (Design 1) was 5.9070 dBi.

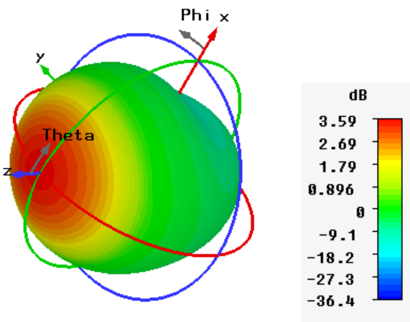

Fig. 13. 3D Polar Plot for Design 1.

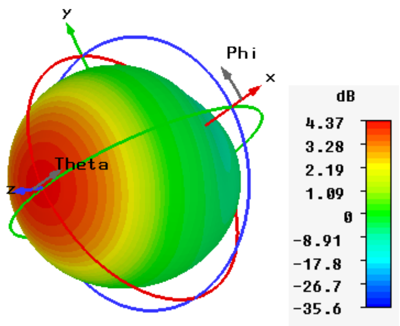

Fig. 14. 3D Polar Plot for Design 2.

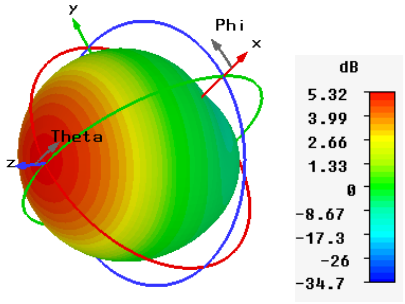

Fig. 15. 3D Polar Plot for Design 3.

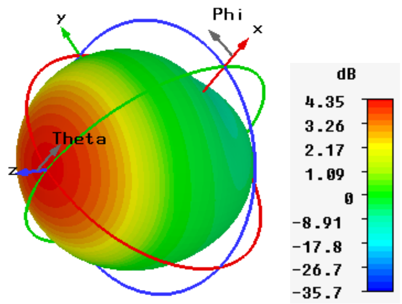

Fig. 16. 3D Polar Plot for Design 4.

Fig. 17 until Fig. 20 present the radiation pattern for all the designed antenna. For single layer patch antenna, the main lobe magnitude and direction were 5.9 dBi and 2.0 degree while the angular width for 3dB and side lobe level were 97.9 degree and -6.2 dB. The main lobe magnitude, main lobe direction, angular width for 3dB and side lobe level for multilayer with a sandwich E-shape patch antenna Design 2 were 6.0 dBi, 2.0 degree, 96.9 degree and -7.0 dB. For Design 3, those values were 6.3 dBi, 2.0 degree, 95.2 degree and -9.1 dB while for Design 4, those values were 6.0 dBi, 2.0 degree, 96.9 degree and -7.0 dB. This proved that multilayer with a sandwich E-shape patch antenna improved the radiation pattern than the single layer patch antenna.

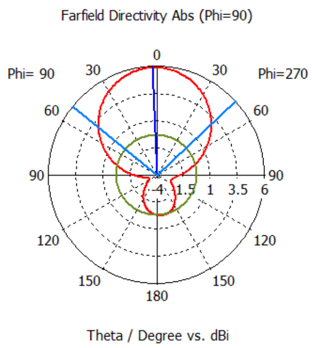

Fig. 17. Radiation Pattern for Design 1.

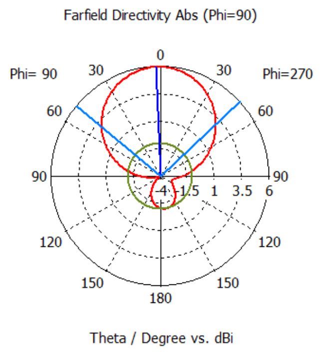

Fig. 18. Radiation Pattern for Design 2

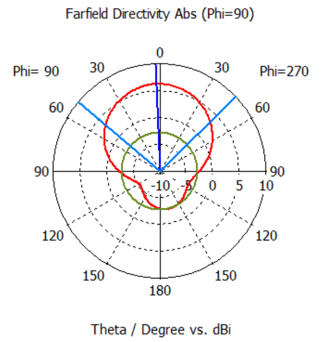

Fig. 19. Radiation Pattern for Design 3.

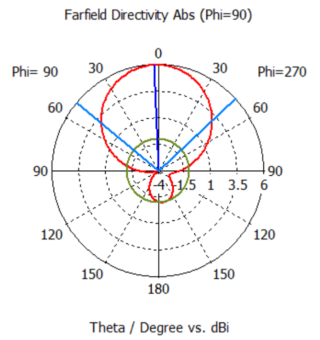

Fig. 20. Radiation Pattern for Design 4.

TABLE IV: COMPARISON BETWEEN SIMULATION PERFORMANCES OF SINGLE LAYER PATCH ANTENNA AND MULTILAYER WITH A SANDWICH E-SHAPE PATCH ANTENNA (H=0.5MM)

Parameter	Design 1	Design 2	Difference (%)
Return Loss, S_{11} (dB)	-14.2137	-19.0486	34.02
BW (GHz)	0.0149	0.0241	61.74
Gain (dB)	3.5850	4.3720	21.95
Directivity (dBi)	5.9070	5.9700	1.07

Table IV shows the comparisons between simulation performances of Design 1 and Design 2. Design 2 produced better performance compared to Design 1 in terms of its return loss, bandwidth, gain and directivity. Table above stated that the return loss, S_{11} for Design 2 improved by 34.02%, 61.74% for bandwidth, 21.95% for gain and 1.07% for directivity. It shows that multilayer with a sandwich E-shape patch antenna was having better performance compared to single layer patch antenna. A study by the other researcher also indicated that the usage of multilayer antenna increased the bandwidth value by 15% [7].

TABLE V: COMPARISON BETWEEN SIMULATION PERFORMANCES OF MULTILAYER WITH A SANDWICH E-SHAPE PATCH ANTENNA FOR H=0.5MM AND H=0.75MM

Parameter	Design 2	Design 3	Difference (%)
Return Loss, S_{11} (dB)	-19.0486	-20.3170	6.66
BW (GHz)	0.0241	0.0331	37.34
Gain (dB)	4.3720	5.3200	21.68
Directivity (dBi)	5.9700	6.2730	5.08

Table V shows the comparisons between simulation performance of Design 2 and Design 3. Design 3 produced better performance compared to Design 2 in terms of its return loss, bandwidth, gain and directivity. Table above stated that the return loss, S_{11} for Design 3 improved by 6.66%, 37.34% for bandwidth, 21.68% for gain and 5.08% for directivity. It shows that the usage of thicker substrate can enhance the performances of multilayer with a sandwich E-shape patch antenna.

TABLE VI: COMPARISON BETWEEN SIMULATION PERFORMANCES OF MULTILAYER WITH A SANDWICH E-SHAPE PATCH ANTENNA AND MULTILAYER WITH A SANDWICH E-SHAPE PATCH ANTENNA WITH WIDER A SANDWICH E-SHAPE DIMENSION (H=0.5MM)

Parameter	Design 2	Design 4	Difference (%)
Return Loss, S_{11} (dB)	-19.0486	-20.0208	5.10
BW (GHz)	0.0241	0.0244	1.24
Gain (dB)	4.3720	4.3460	-0.59
Directivity (dBi)	5.9700	5.9730	0.05

Table VI summarizes the different between simulation performance of Design 2 and Design 4. Design 4 produced better performances compared to Design 2 in terms of its return loss, bandwidth and directivity. Table above stated that the return loss, S_{11} for Design 4 improved by 5.10%, 1.24% for bandwidth and 0.05% for directivity. The gain value for Design 4 was lower than Design 2 by 0.59%. It shows that the usage of wider E-shape dimension can enhance the performance of multilayer with a sandwich E-shape patch antenna in terms of its return loss, bandwidth and directivity but decrease the value of gain.

IV. CONCLUSION

After the simulation and data analysis stages, it can be concluded that the aim and objectives were achieved. Early hypothesis which stated that "the usage of multilayer with a sandwich E-shape patch antenna will broaden the bandwidth" was true. At the same time, the usage of multilayer with a sandwich E-shape patch antenna also enhanced the performance of antenna in terms of return loss, gain and directivity. The value of return loss for multilayer with a sandwich E-shape patch antenna (Design 2) was improved by 34.02% compared to single layer patch antenna (Design 1). For bandwidth, gain and directivity, the values were increased to 61.74%, 21.95% and 1.07% respectively. This research was also proved that the usage of thicker substrate enhanced the bandwidth of multilayer with a sandwich E-shape patch antenna. For multilayer with a sandwich E-shape patch antenna, the usage of thicker substrate (Design 3) was also enhanced those parameters by 6.66%, 37.34%, 21.68% and 5.08% respectively. Nevertheless, the usage of wider E-shape dimension (Design 4) were only increased the values of return loss, bandwidth and directivity but decreased the value of gain.

V. FUTURE RECOMMENDATION

After completing this research, there are a few recommendations that can be done for future work in order to enhance the performance of the antenna. It is encourages to design a new shape of patch structure instead of using conventional or E-shape structure. Then, the fabrication of multilayer with a sandwich E-shape patch antenna should be done to obtain the actual value of antenna's performances. The different types of substrate is also can be done in order to investigate the difference performance between them.

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