Multilayer Proximity Coupled Rectangular Patch Antenna

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Abstract—In this paper, a new invention of multilayer proximity coupled rectangular patch antenna operating at the frequency of 3.5GHz is presented. This frequency is applicable for WiMAX application. In designing antenna, there are four factors involved that need to be concentrate on which include dielectric constant ε_r of the substrate, thickness of the substrate, length and width of the feed line, and also the patch dimension calculation. The substrate used is RO 3003 for lower substrate while RT Duroid 5870 is used as the upper substrate. To analyze the performance of the antenna, CST software is used and the result of simulation determined by analyzing the return loss S_{11}, VSWR, bandwidth, and farfield. The results from electromagnetic simulation of the antenna are presented through this paper.

Keywords—**multilayer structure, proximity coupled, rectangular patch antenna, microstrip, wireless technology**

I. INTRODUCTION

Antenna is defined as metallic patch like rod or wire for radiating or receiving radio waves. In other words, the antenna is the transitional structure between free space and guiding device. The guiding device or known as transmission line carry electromagnetic energy from the transmitting source to antenna, or form antenna to receiver. This transmission line may be in forms of hollow pipe or coaxial cable [1].

Proximity coupled microstrip antenna also known as electromagnetically coupling microstrip antenna. This type of multilayer antenna is use to excite the patch on the top layer through the microstrip feed line in the bottom layer. There is no physical electrical contact between the feedline and the radiating patch since they are separated by two substrates. Energy is electromagnetically coupled from the feed to the radiating patch because their close proximity with each other [2]. The advantage of this coupled is that the microstrip feedline can be designed on a high dielectric constant so that the radiation from the feed dan be neglected.

Wireless broadband antenna has been widely used in the world. The need for wireless broadband communications has increased rapidly in recent years due to the need of quality service, security, handover, and increased performance in the system. The main aim for next generation wireless communication will be high speed network services for multimedia communication. The microwave wireless communication systems require compact and broadband antennas. There were various techniques attempted to increase the bandwidth but some of the methods could not totally solve the problem [3].

One example of wireless systems is WiMAX stands for Worldwide Interoperability for Microwave Access. WiMAX is standard based wireless technology which gives high-speed, last mile broadband connectivity to homes and business and thus for mobile networks. WiMAX can be use for many applications in communication system. The applications of WiMAX are as follow [4]:

- Residential of Home and Broadband Internet Access
- Medium and small size business
- Backhaul networks for cellular base stations

In this paper, a multilayer proximity coupled rectangular patch antenna is presented. The designed antenna should fulfill the specification of operating frequency of 3.5GHz. This frequency is applicable for WiMAX application. The return loss should be less than -20dB and VSWR should less than 1.5. The antenna specifications are summarized in Table 1.

TABLE I
Antenna Design Specification

Antenna Specification	Values
Operating Frequency	3.5GHz
Return Loss	<-20dB
VSWR	<1.5

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II. METHODOLOGY

This project deals with design, simulation, and result analysis. In designing this project, the substrate selection is the first step. This is because the type of substrate is the important factor affecting the performance of the antenna. The thinner and lower dielectric constant substrate will provide larger bandwidth and better efficiency [5].

For the antenna design, the substrate that being used is RO 3003, $\varepsilon_r = 3$ as feed substrate while RT Duroid 5870, $\varepsilon_r = 2.33$ as the patch substrate [6]. The substrate for bottom layer must be thinner than the top. The thickness *h* for RO 3003 is 0.75mm while RT Duroid 5870 is 0.5mm. The thickness of the substrate can be found from the data sheet. For the ground, feed line, and patch used perfect electrically conducting (PEC) as the substrate.

Then, the next step is to calculate the dimension of the antenna. This calculation is performs to obtain the dimension of ground, substrate and patch antenna. In design calculation, it is necessary to know the value of operating frequency and the speed of the light. After all the dimension needed being found, the next step is to design the antenna.

Proximity coupled rectangular patch microstrip antenna is use because this type of antenna is more practical and easy to manufacture. Rectangular patch is mostly use since it has attractive characteristic. Multilayer micostrip antenna used to enhance the bandwidth. The configuration of multilayer microstrip antenna is proximity coupled microstrip antenna and aperture coupled microstrip antenna [2]. Some parameters of feeder and patch adjusted to get better result.

There are two methods that can be used to enhance the performance of the design; firstly by adjusting the width and length of the feed line. While, secondly by adjusting the dimensions of the patch. From the simulation, the width of the rectangular patch has significant effect on the input impedance and bandwidth of the antenna. Consequently, the length of the patch can influence the value of voltage standing wave ratio, VSWR.

The last step is the simulation process. This was done using Computer Simulation Technology (CST) Microwave Studio software. The reason of using this software is because it provides more practical simulation and 3D design. The simulations that obtained are in term of return loss S_{11}, VSWR, bandwidth, input impedance, Zi = 50 Ω and farfield. As the result satisfies, the analysis is being done by comparing the simulation result and the expected result. The return loss S_{11} must be less than -20dB while VSWR less than 1.5.

The material for ground in this antenna is PEC. The same material is also used for feeder and patch of the antenna. To design multilayer antenna, two substrates with different material being used. The first substrate which located above the ground is using RO 3003. Then a feeder is put located on the first substrate followed by second substrate using RT Duroid 5870 as the material. The most upper part of the design is the patch antenna. The structure of the antenna showed in Figure 1.

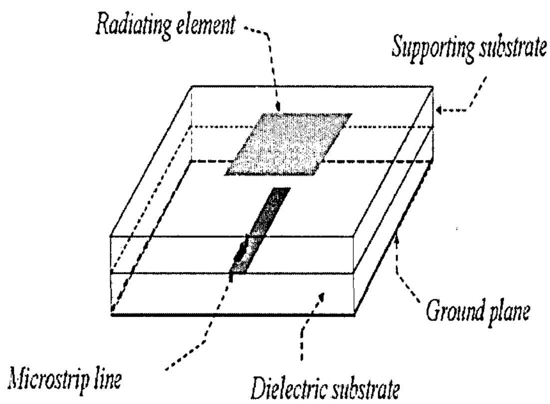

Figure 1: Structure of the Antenna

The parameters for every substrates used in this antenna are simplified in the Table II.

Parameters	Values
RO 3003 dielectric constant, ε_r	3
RT Duroid 5870 dielectric constant, ε_r	2.33
RO 3003 thickness, *h*	0.75mm
RT Duroid 5870 thickness, *h*	0.5mm
PEC thickness	0.017mm

TABLE II
Substrate Parameters and Properties

To design this multilayer proximity coupled rectangular patch antenna, some calculation has been made according to transmission line model of Derneryd [7]. Some formulas were used to calculate the width and length of patch antenna and also the feed substrate and the formula are as follow:

To obtain value of width, w of the antenna, equation (1) was used.

$$w = \frac{c}{2fo\sqrt{\frac{\varepsilon r + 1}{2}}} \qquad (1)$$

Where c = speed of light ($3x10^8$)
fo = operating frequency (3.5GHz)

From the calculation yield the width of 33.36mm.
Then, compute the value of effective permittivity ε_{eff} for microstrip line by using equation (2) for rectangular patch antenna,

$$\varepsilon reff = \frac{\varepsilon r + 1}{2} + \frac{\varepsilon r - 1}{2}\left(\frac{1}{\sqrt{1 + 12h/w}}\right) \quad (2)$$

So, $\varepsilon_{eff} = 2.28$ From the value of ε_{eff}, the value of fringe factor, ΔL was calculated using equation (3)

$$\Delta L = 0.412h\frac{(\varepsilon eff + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon eff - 0.258)(\frac{W}{h} + 0.8)} \quad (3)$$

The calculation yield ΔL = 0.261mm. To calculate the value for effective length L_{eff}, the equation is given by equation (4).

$$Leff = \frac{c}{2fo\sqrt{\varepsilon reff}} \quad (4)$$

So, L_{eff} = 28.38mm. Since the value for ΔL and L_{eff} were calculated, the value of actual length L can be obtain using equation (5).

$$L = L_{eff} - 2\,\Delta L \quad (5)$$

Calculation of L yield L = 27.86mm. To calculate for lower substrate or feed substrate, the same formulas were applied. The result tabulated in Table III.

TABLE III
The Calculation Result for Feed Substrate

Parameters	Calculation Result
W	30.3mm
ε_{eff}	2.78
ΔL	0.37mm
L_{eff}	25.7mm
L	24.96mm

For calculation on the ground plane dimension, ground plane dimension is given as equation (6) and (7).

$Lg = 6h + L$ (6)

$Wg = 6h + W$ (7)

The calculation for ground dimension yield Lg =29.46 mm and Wg = 34.8 mm.

III. RESULT AND DISCUSSIONS

1. Return loss, S_{11}

The simulation has been done to see the performance of the designed antenna by using CST MWS to compute the required S-Parameter. From the simulation, it was found that return loss S_{11} resonates at frequency of 3.5GHz yield the value of -27.97dB. It was design and simulated at the range frequency of 1GHz to 6GHz. This result can be concluded that there is just slight reflected power and higher efficiency of the design. The result is shown in Figure 3.

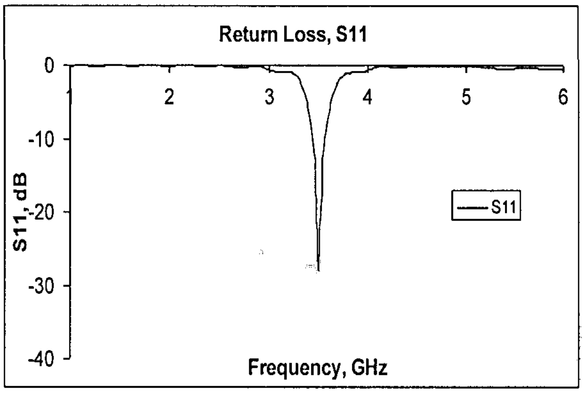

Figure 3: Return loss, S_{11} at 3.5GHz

2. VSWR

The value obtained for VSWR for the design of multilayer proximity coupled rectangular patch antenna is 1.0839. This also simulated at the range of 1GHz to 6GHz. From this, it found that only small mismatch and reflection occurred between antenna and transmission line. It is near to 1 which is ideal for the system. Figure 4 shows the result of VSWR.

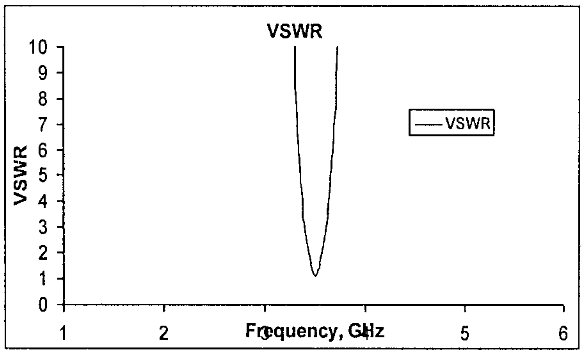

Figure 4: VSWR at 3.5GHz

3. Bandwidth

The bandwidth is the satisfactory VSWR value over the frequency range [8]. It was found that the bandwidth is about 132.64 MHz. The percentage bandwidth obtained from the antenna is about 3.79%. The bandwidth obtained from the simulation showed in Figure 5.

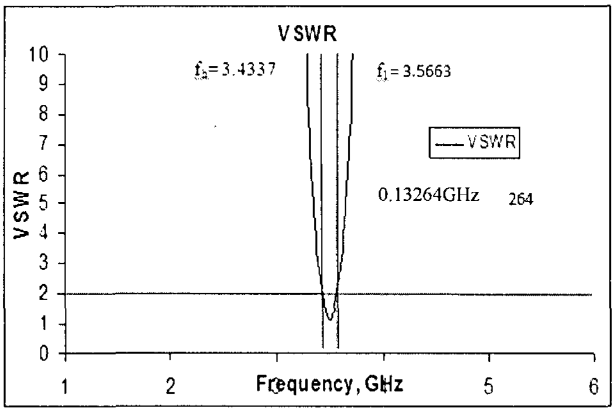

Figure 5: Bandwidth at frequency of 3.5GHz

4. Farfield

The farfield of the antenna at 3.5GHz displays based on the colours. The red colour indicates that the antenna gain is strong while the blue colour indicates that the gain of the antenna weak. From the farfield result, the gain of the antenna is 5.87dB. It shows colours vary almost in red indicates the strength of the EM field radiated from the antenna. This is shown in Figure 6.

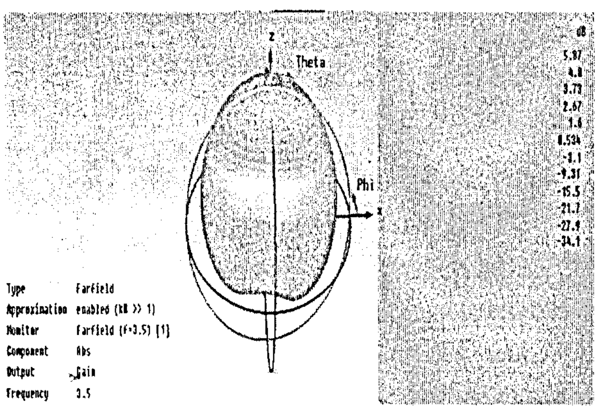

Figure 6: Antenna farfield at 3.5GHz

All the simulation results for multilayer proximity coupled rectangular patch antenna at 3.5GHz are summarized in the Table IV.

TABLE IV
Simulation Result at the Frequency of 3.5GHz

Simulation Result Characteristic	Values
Return loss, S11	-27.97dB
VSWR	1.0839
Bandwidth	132.64MHz
Antenna Gain	5.87dB

The design analysis divided to two parts. The first part has been done by investigate on the simulation result when some of the antenna parameters like feeder width, feeder length, patch width, and patch length values varies. Other than that, the investigation also had done by simulate the design by changing one of the substrate.

The analysis can be done by analyze on certain parameters that contribute major effects to the response. Increase the size of feeder and patch width will give effect on the value of S_{11} and VSWR. Besides, the operating frequency also will change, thus not operated at the desired frequency which is at 3.5GHz. This can be seen in Figure 7 and Figure 8.

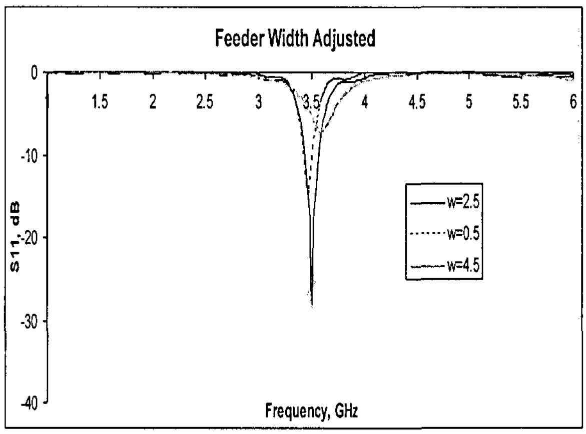

Figure 7: Parameter sweep of S_{11} on adjusted feeder width

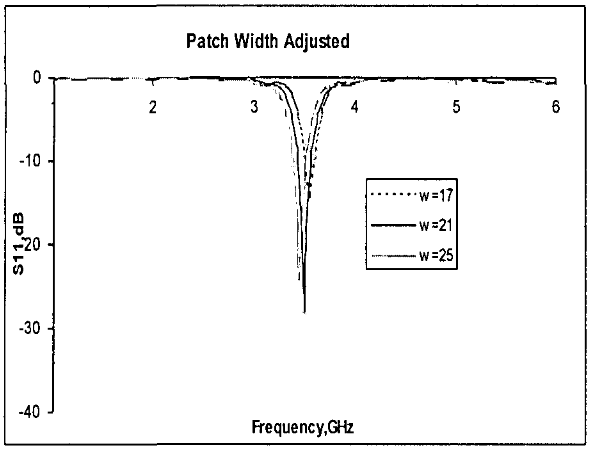

Figure 8: Parameter sweep of S_{11} on adjusted patch width

Adjust the feeder length also give some affects to the antenna performance whether it increase or decrease, the length will cause the value of S_{11} to increase. So, it can be said that the feeder length must be not too long or too short in order to get the best result. This can be shown in Figure 9.

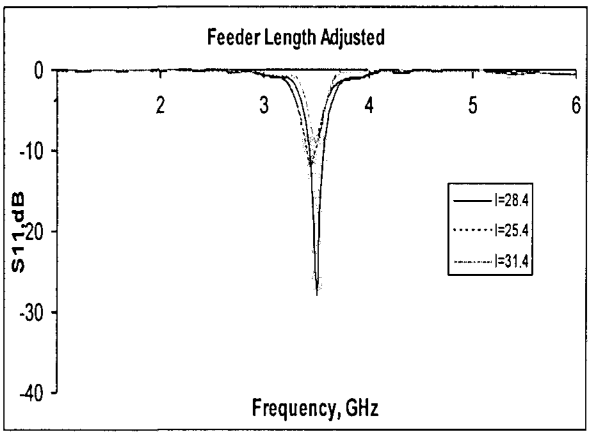

Figure 9: Parameter sweep of S_{11} on adjusted feeder length

Increasing the length of the patch also decreased the resonant frequency and this response work in vice versa where decreasing the length made the resonant frequency increased. This is proven by Figure 10.

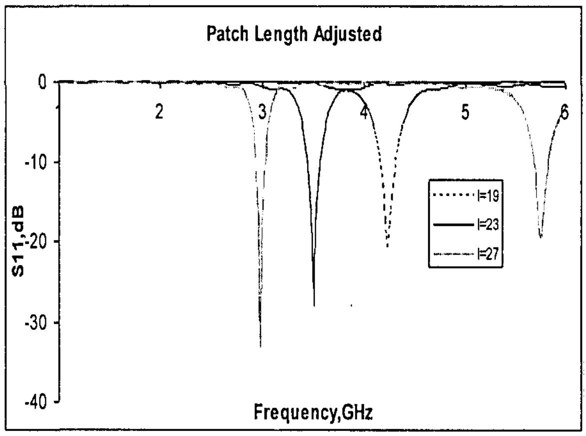

Figure 10: Parameter sweep of S_{11} on adjusted patch length

The second part of the analysis was done by changing one of the substrate used in the antenna design. The substrate changed was between RO 3003 with FR-4.

A comparison has been made between the coupling of RT Duroid 5870 and RO 3003 with RT Duroid 5870 and FR-4. Both operate at the frequency of 3.5 GHz. From the simulation result above, the value for S_{11} is higher but it still acceptable because the value is less than -20dB.For VSWR, the value is higher. VSWR for the design with the coupling of RT Duroid 5870 and RO 3003 is better since the value is close to 1 which is the ideal value. The bandwidth value is better since it has higher value. For the gain of the antenna, it is lower. So, it can be conclude that the design of RT Duroid 5870 with RO 3003 is better than the design of RT Duroid 5870 with FR-4 in term of return loss, VSWR and gain. The comparison between both substrates is shown in Table V.

TABLE V
Simulation Result Using FR-4 and RO 3003

Simulation Result Characteristic	FR-4	RO 3003
Return loss, S_{11}	-21.24dB	-27.97dB
VSWR	1.1955	1.0839
Bandwidth	149.94MHz	132.64MHz
Gain	4.99dB	5.87dB

IV. CONCLUSION

The combination of these two substrates; RO 3003 and RT Duroid 5870 are suitable and reliable since the dielectric constant of RO 3003 is greater than RT Duroid 5870. RO 3003 is assigned to be at the bottom and RT Duroid 5870 is at the top layer. This type of structure is known as proximity-coupled or electromagnetic coupled.

A multilayer proximity coupled rectangular patch microstrip antenna at the frequency of 3.5GHz has been presented. The performance of this antenna from the simulation showed that this antenna has been designed successfully. According to the result obtained, it was discovered that the combination of RO 3003 as the feed substrate and RT Duroid 5870 as the patch substrate are suitable and matched to each other. From the analysis, the performance of the antenna which resonates at the frequency of 3.5GHz is proven to be applied for the WiMAX application.

V. RECOMMENDATION

In future, this design of multilayer can be improve the performance by replace the configuration of substrate like polymide and gallium arsenide. Besides, increase the thickness of feed substrate and patch substrate can improve antenna input impedance. Other than that, replacing the proximity coupled patch antenna with aperture coupled patch antenna can improve input impedance and the bandwidth.

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