Bandwidth Enhancement of Microstrip Patch Antenna

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Abstract—The design of microstrip rectangular patch antenna with resonant frequency at 5.8GHz for wireless application is presented. High bandwidth is one of the main requirements for wireless application. In this paper, two different possible techniques were used to enhance the bandwidth. The first technique is using different thickness of substrate. The second technique is addition of parasitic element into antenna structure. The simulation of the microstrip rectangular antenna done by using Computer Simulation Tool (CST) Microwave Environment software and fabricate on FR4 substrate. All the simulation and measurement results are presented in this paper to show its feasibility.

Keywords: patch antenna, CST microwave studio, fabrication, microstrip, simulation, substrate FR-4.

I. INTRODUCTION

In telecommunication, there are several types of microstrip antennas but the most common used is the microstrip patch antenna or patch antenna. Common microstrip antenna shapes are square, rectangular, circular and elliptical, but any continuous shape is possible. Microstrip patch antennas offer an attractive solution to compact and ease-low-cost design of modern wireless communication due to their many advantages as light weight and low volume, low profile, planar configuration which can be easily made conformal to host surface, low fabrication surface and capability of obtaining dual and triple frequency operation [1] - [2].

In designing microstrip rectangular antenna numerous substrates can be used to achieve good response. The dielectric constants are usually in the range of 2.2 up to 12 ($2.2 \leq \xi \leq 12$). The most desirable substrate used to enhance the bandwidth is normally thick substrate whereby the dielectric constant is at the lower end. The bandwidth is proportional to the thickness [3]. It is mean that when the thickness increase the bandwidth will also increase. However, the thicker the substrate of the antenna, the higher surfaces wave will be produced. Higher surface wave modes will result in serious degradations in antenna performance [4] - [5].

Besides using thicker substrate, another technique to improve the antenna bandwidth is by adding passive elements on the same patch layer [6] - [7]. This technique is the most popular method for bandwidth improvement. The basic idea is to introduce additional patches in antenna structure. However, this method invokes additional dissipative losses in antenna structure [4].

The objective of this paper is to enhance bandwidth of microstrip patch antenna based on those techniques. The first technique is by using different thickness of substrate and follow by adding passive element to the antenna structure. All the proposed idea will be simulated and measured on FR4 microstrip substrate.

II. BASIC ANTENNA STRUCTURE

In designing a patch antenna, the most important parameters need to be considered are width and length. An accurate value of the width and length affects overall performance of antenna [8]. The topology of the single patch antenna is depicted in figure 1.

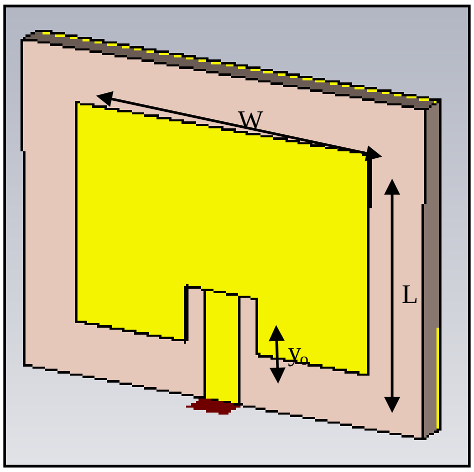

Figure 1: Topology of the single patch antenna without parasitic element.

In order to ensure the response can be realized, all element dimensions should be calculated first. Equations 1 can be used to determine the width of the microstrip patch antenna.

$$\text{Width} = \frac{c}{2fr}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

Where c = speed of light

f_r = the resonant frequency (equal to 5.8GHz)

The length of the antenna is calculated from equation 2.

$$L = \frac{C}{2fr\sqrt{\varepsilon_{reff}}} - 2\Delta L \quad (2)$$

From the equation 2, the effective relative permittivity is used to calculate the length of antenna. The effective relative permittivity is calculated from equation 3. The value of ΔL is calculated from equation 4.

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+12\left(\frac{h}{w}\right)}} \quad (3)$$

Where ε_{reff} = relative permittiviry

h = height (mm)

W = width (mm)

$$\frac{\Delta L}{h} = 0.412\,\frac{(\varepsilon_{reff}+0.3)(w/h+0.264)}{(\varepsilon_{reff}-0.258)(w/h+0.8)} \quad (4)$$

Where L = Actual length of the patch (mm)

W = width of the patch (mm)

ΔL = the extended patch length due to fringing effect

The feed mechanism also plays an important role in designing the patch antenna beside width and length. The microstrip patch antenna can be feed either coaxial probe or by an insert feed line. Both methods have their own advantage. Moreover, a simple analytical approach has been developed using the transmission-line model to find the input impedance of an insert-feed microstrip patch antenna. Using this approach, a curve-fit formula can be derived to find the inset length to achieve 50-Ω input impedance when using modern thin dielectric circuit-board materials [9].

The insert length is calculated from equation 5.

$$y_o = 10^{-4}(0.001699e_r^7 + 0.13761e_r^6 - 6.1783e_r^5 + 93.187e_r^4 - 682.69e_r^3 + 2561.9e_r^2 - 4043e_r + 6697)\frac{L}{2}$$

Where $2 \le e_r \le 10$ (5)

After completing the calculation of patch antenna dimension, the design antenna will be simulated using Computer Simulation Tool (CST) Microwave Environment software. The parameter S_{11} obtained from the simulation in CST. Figure 3 shows the ideal response for the S11 in dB. The impedance bandwidth needs to be measured at -10dB.

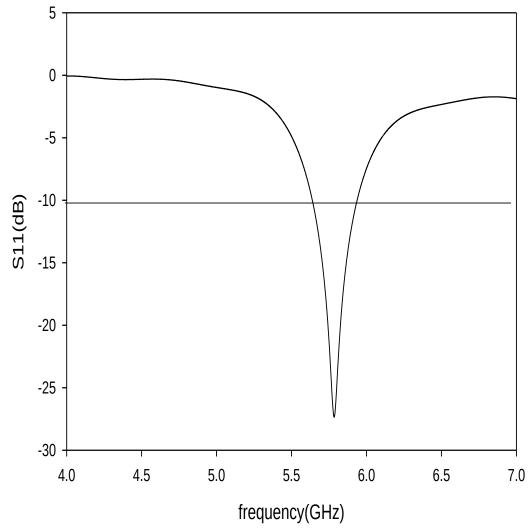

Figure 3: Ideal response of the single patch antenna

III. SIMULATION RESULT

A. BANDWIDTH ENHANCEMENT BY USING DIFFERENT THICKNESS

As mention in introduction in part 1, the first technique used to enhance the bandwidth of the antenna is by using different thickness. FR4 substrate with dielectric constant of 4.9 and 0.0025 tangent losses are used in designing the microstrip patch antenna. Four different thickness of substrate are 0.8mm, 1.6mm, 2.3mm and 4.6mm.

Based on the calculated dimensions, the frequency did not resonate at the designed frequency, so optimization is required to shift the resonant frequency back to 5.8GHz. The resonant frequency will change by controlling the length of the patch antenna as shown in table 1. When increased the size of patch antenna, the resonant frequency will decreased and otherwise.

Tables 2 show the simulated result after optimization. It shows the value of bandwidth and gain. Figure 4 and 5 shows the S_{11} result before and after optimization. It is clearly shown from table 2 that we can enhance the bandwidth of the antenna by using the thicker substrate of the patch antenna but the gain is decreased. The S_{11} parameter is affected when used thicker substrate.

Table 1: optimization of parameter length with thickness of 1.6 mm

Length (mm)	Resonant frequency(GHz)
10.6	5.95
10.8	5.85
11.0	5,81
11.2	5.73

Table 2: simulated result after optimization

Thickness(mm)	F_L(GHz)	F_H(GHz)	BW(%)	Gain(dBi)
0.8	5.6799	5.9228	4.2	6.38
1.6	5.6454	5.9703	5.6	6.232
2.3	5.5995	6.0239	7.3	6.134
4.6	5.5435	5.9967	7.9	4.926

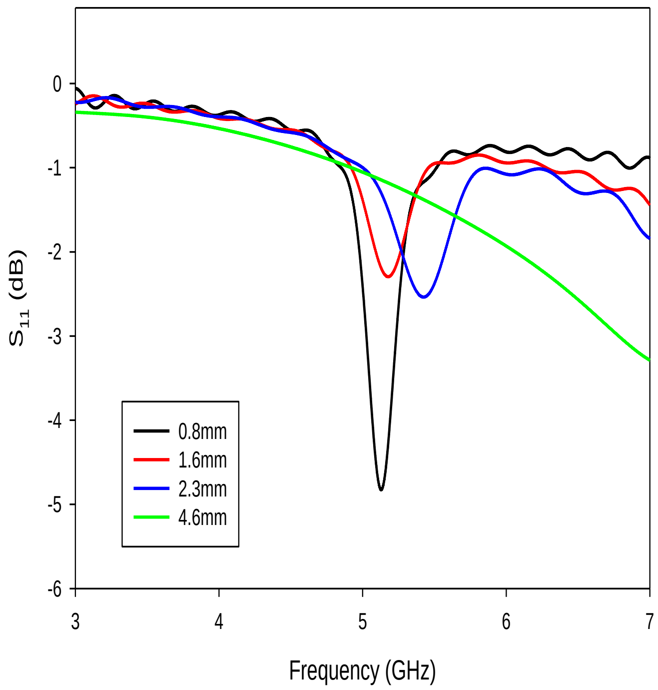

Figure 4: simulated S11 for the antenna with different thickness before optimization.

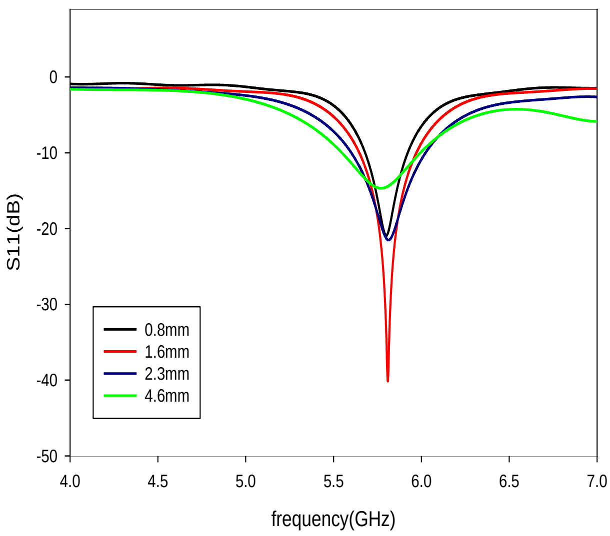

Figure 5: simulated S11 for the antenna with different thickness after optimization.

B. BANDWIDTH ENHANCEMENT BY ADDING PASSIVE ELEMENT

The second technique used to enhance the bandwidth of the antenna is by adding passive element. Passive element used is same type with the patch antenna. There are many ways to add the passive element into the antenna structure. Figure 6 shows two ways to add passive element into the antenna structure which is beside the patch and below the patch.

Table 3 shows the bandwidth, gain and parameters of S_{11} for the patch antenna with and without passive element while figure 7 show the S_{11} response. It is shows that bandwidth of the antenna was enhancing when adding passive element. A 5.71% bandwidth enhancement has been achieved with the passive element beside the patch and 9.3% for passive element below the patch. It shows that the bandwidth was enhancing about 0.1% to 3.7% when adding passive element. Moreover, the dual frequencies have been provided by adding the passive element below the patch line as shown in figure 7.

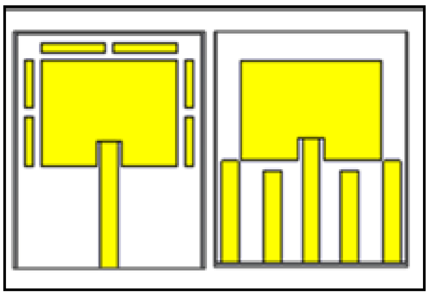

Figure 6: two ways to add passive element into the antenna structure.

Table 3: Value of bandwidth, gain and parameters of S_{11} for the patch antenna with and without passive element

Antenna structure	S_{11}(dB)	BW(%)	Gain(dBi)
Without passive element	-40	5.6	6.232
With passive element (beside the patch)	-45	5.71	6.253
With passive element (below the patch)	-13	9.30	6.40

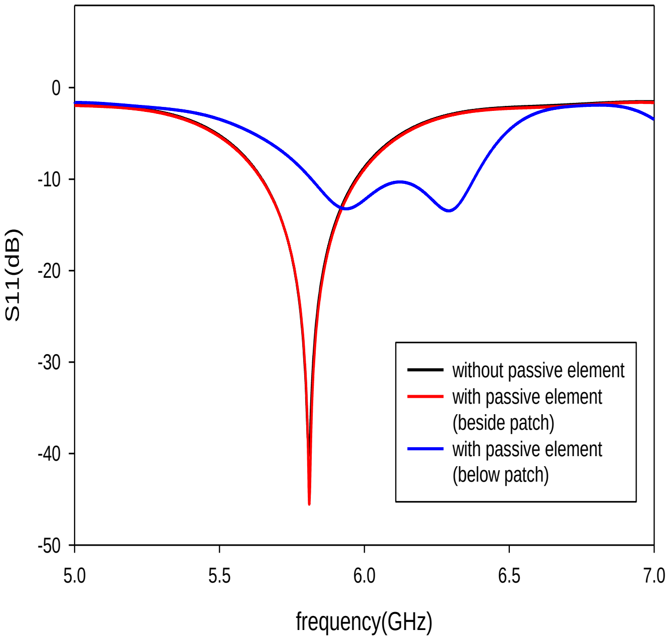

Figure 7: simulated S11 for the antenna with and without passive element

IV. MEASUREMENT RESULT

After completing the simulation using Computer Simulation Tool (CST) Microwave Environment software, three microstrip antennas were fabricated as shown in figure 8. Thickness of substrate used for fabrication is 1.6mm. In this measurement process, a vector network analyzer (VNA) used to obtain the result from fabricated devices. Table 4 shows the measurement result for the patch antenna with and without passive element while figure 9 shows the S_{11} response.

Figure 10 shows the comparison S_{11} response for the simulation and measurement part. The graph measurement 1 and simulation 1 is referring to the MPA without passive element while the graph measurement 2 and simulation 2 represent to the MPA with passive element beside the patch. The graph measurement 3 and simulation 3 is representing to the MPA with passive element below the patch. The measured result is different with the simulation result. The resonant frequency for measurement is increased about 0.3 to 0.7 GHz. This may due to different dimension used during the simulation and fabrication part.

The other parameters affects the response during fabrication is the permittivity of the substrate. The substrate may be not suitable for the frequency range used due to high loss at the microwave frequency. It is often found that the dielectric losses in FR4 are too high at microwave frequencies. Besides, FR4 has higher dissipation factor than laminates for high frequency used [10].

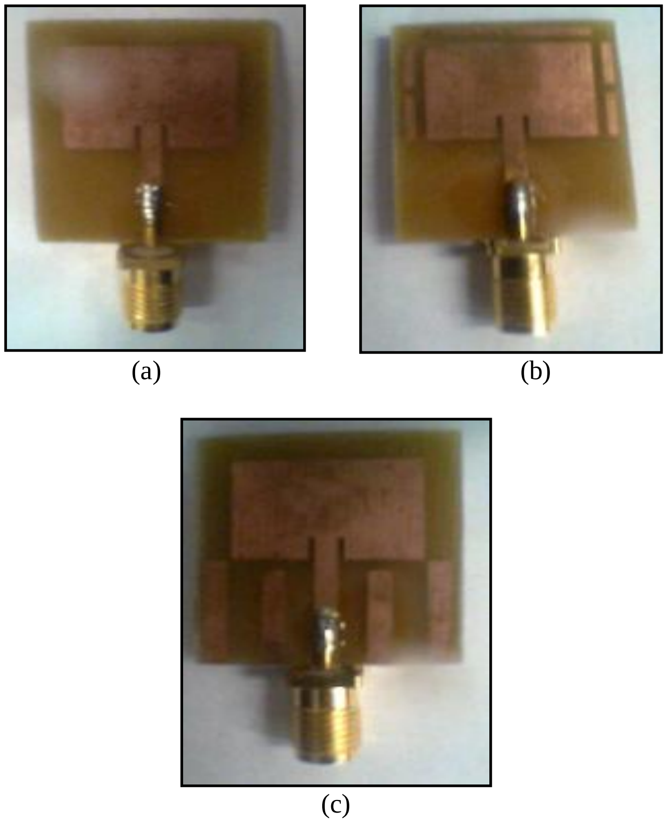

Figure 8: (a) fabricated MPA without passive element, (b) fabricated MPA with passive element beside the patch, (c) fabricated MPA with passive element below the patch

Table 4: measurement result using VNA

Antenna	F_L(GHz)	F_H(GHz)	BW(%)	S_{11}(dB)
Without passive element	6.02	6.50	7.67	-6.330
With passive element(beside patch)	5.92	6.42	8.11	-7.470
With passive element(below patch)	6.40	6.94	8.10	-5.593

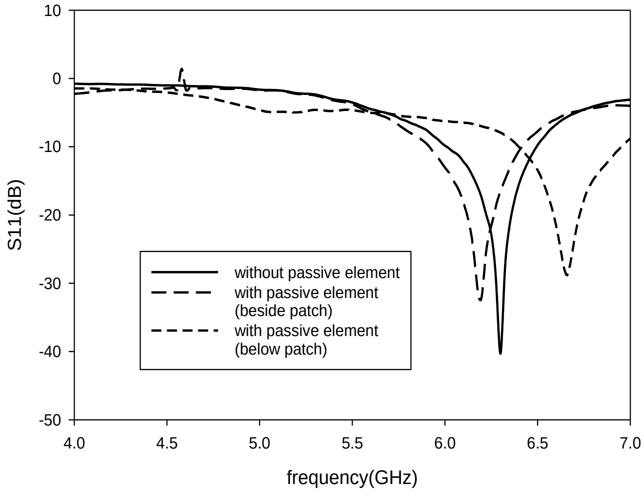

Figure 9: measurement result for the microstrip patch antenna

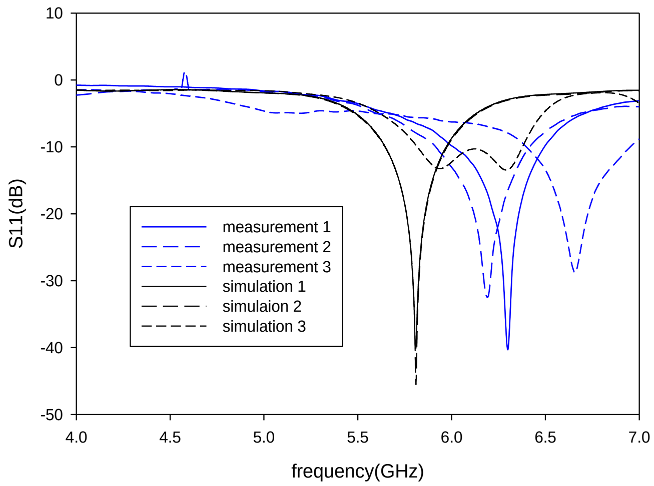

Figure 10: comparison between measurement and simulation.

V. CONCLUSION

The different thickness and using passive element techniques for enhancing bandwidth of microstrip patch antenna is successfully designed in this research. Simulation results of a patch antenna covering 0.8 to 4.6 mm thickness have been presented. The improvement of bandwidth is clear when added passive element below the patch in the design. The bandwidth enhancement achieve up to 9.3%. The maximum achievable gain of the antenna is 6.4dbi. With an adding passive element beside the feed, the wide bandwidth with dual frequency can be produced. The measurement of the antenna design have been measure by fabricated the antenna on the FR4 substrate. The wide bandwidth antenna is a good candidate for many wireless communications.

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