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Design of enhanced gain patch antenna at 2.4 GHz and 3.5 GHz for wireless application

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Abstract. In this work, the analysis of patch antenna design at the resonant frequency of 2.4 GHz and 3.5 GHz are presented. Both proposed antennas made of RT Duroid 5880 are designed and simulated using CST Studio Suite software. The antennas are designed, and their performances are examined. The antennas have been designed based on the size improvement technique to improve the fabrication tolerance. The characteristics of both antennas' including return loss, radiation pattern, surface current and directivity or gain were compared. The optimization of patch measurement to achieve the desired resonant frequency were also displayed.

1. Introduction

The implementation of microstrip patch antenna in wireless communication is popular due to its good performance despite having a low-profile configuration [1]. However, it subjected to experience a low gain and narrow bandwidth [2]. It is very crucial for a patch antenna to exhibit a low return loss (≤-10 dB) while having a high gain or directivity to attain excellent communication. Other than executing an array configuration, the gain of a patch antenna can also be amplified by increasing its dimensions [2].

Thus, in order to maximize the performance, the improvement design of microstrip patch antenna gain and bandwidth at high frequency is imitated and optimized for the ISM frequency band of 2.4 GHz. Moreover, the method is also enhanced to adapt the mid band frequency of 5G application at 3.5 GHz. The frequency band are favoured as the higher frequencies are more prone to precipitation losses due to weather [3,4]. In this research, the RT Duroid 5880 substrate is used for both design because of its excellent permittivity and conformal ability.

2. Antenna Design

These patch antennas are designed using RT Duroid 5880 substrate with a dielectric constant, $\varepsilon_r = 2.2$ [5] and thickness, t =1.57 mm at 2.4 GHz and 3.5 GHz frequency. In this research, the patch antennas will initially be designed according to size extension method, and it is optimized to obtain the desired resonant frequency and performance. Figure 1 shows the proposed CST antenna design. It consists of two patches, upper patch and lower patch connected by a microstrip line, ground plane and a microstrip feedline. This work is taken from [2] but modified at lower frequency range of 2.4 and 3.5 GHz.

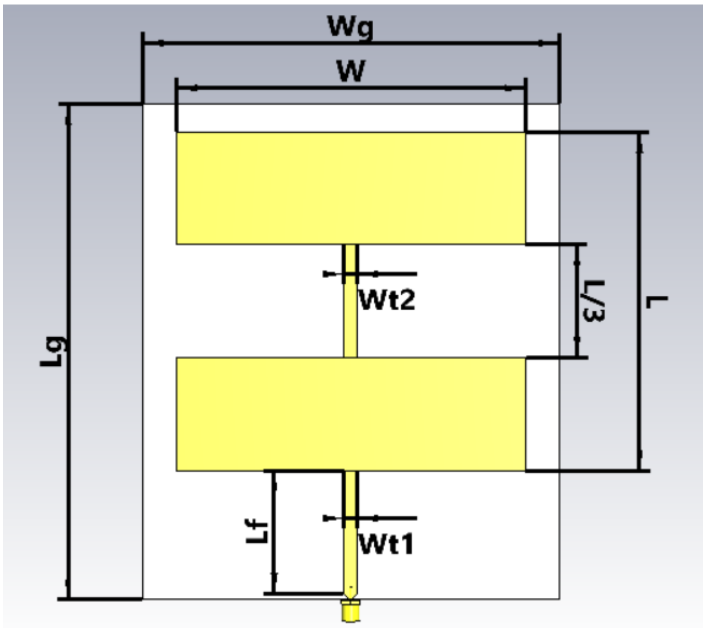


Figure 1. Patch antenna configuration (Top view)

The radiating patch width 'W' and length 'L' can be expressed as (1-2) [6]

$$W = \frac{(2N+1)}{\sqrt{(\varepsilon_r+1)/2}} \times \left(\frac{\lambda 0}{2}\right) \quad (1)$$

$$L = \frac{(2N+1)}{\sqrt{\varepsilon_{eff}}} \times \left(\frac{\lambda}{2}\right) - 2\Delta L \quad (2)$$

Where N is non-negative integer (N=1), $\lambda 0$ is the operating wavelength and ε_r is the relative dielectric constant. The effective dielectric constant 'ε_{eff}' and 'ΔL' value is obtained through following formulas (3-4) [7]

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

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \left(\frac{\varepsilon_r-1}{2}\right)\left(1 + 12\frac{W}{h}\right)^{-1/2} \quad (4)$$

For this antenna structure, the width of upper and lower patch connector is set to be equal to the width of the feedline ($W_{T2} = W_{T1}$). The ground length 'Lg' and ground width 'Wg' were set to Lg=L+12h and Wg=W+12h respectively. The length of the patch 'L' is optimized to ensure the designed antennas resonate at the desired frequency, 2.4 and 3.5 GHz. The width of patch 'W' and width of feedline 'Wf' are improvised to minimize the return loss. The final optimized parameters are shown in table 1. The fabricated antennas is shown in figure 2. Figure 3 displays the experimental setup to measure the characteristics of the antennas.

Table 1. Design Parameters for antennas at 2.4 GHz and 3.5 GHz

	Dimensions (mm)	
Parameter	**2.4 GHz**	**3.5 GHz**
Length of patch (Lp)	119.5	80.3
Width of patch (Wp)	123.23	90
Length of ground plane (Lg)	175.19	134.586
Width of ground plane (Wg)	147.07	108.84
Width of substrate (h)	1.57	1.57
Thickness of radiating patch (t)	0.035	0.035
Length of feedline (Lf)	45.69	44.286
Width of feedline (Wf)	4.837	4.837

Figure 2. Fabricated antennas

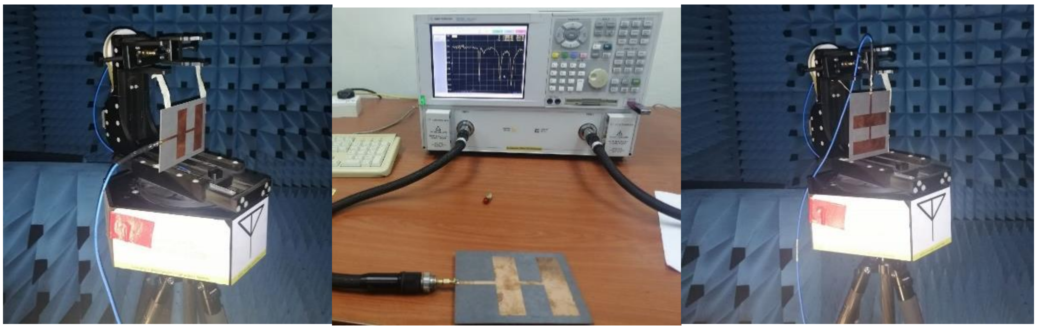


Figure 3. Experimental setup of the fabricated designed antennas

3. Results And Discussion

The return losses of 2.4 GHz and 3.5 GHz patch antenna are shown in figure 4. Based on the measured result, the resonant frequency of the 2.4 GHz antenna shifted by 20 MHz from the simulated result. The measured antenna's return loss is -13.23 dB, 8% higher compared to the simulated S11. Apart from that, the measured antenna's bandwidth is 29.4 MHz, which is 8% lower than the simulated results.

The measured 3.5 GHz patch antenna resonates at 3.55 GHz, shifted by 50 MHz from the simulated resonant frequency. The antenna's return loss is almost identical between the measured and simulated results which is around -14 dB. Meanwhile, the measured antenna’s bandwidth is 50 MHz, which is 4% higher than the simulated results. The shift in resonance frequency might happen due to fabrication tolerance during the manufacturing process [8]. Both antennas exhibit low return losses across resonant frequency, ≤ 10 dB which is relevant for patch antenna [9].

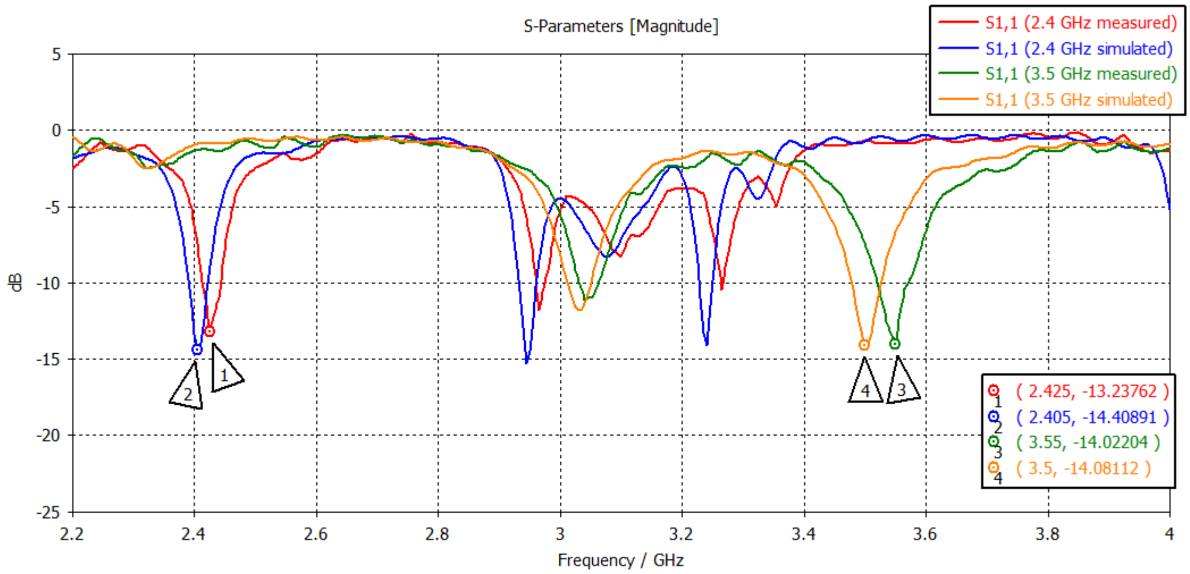
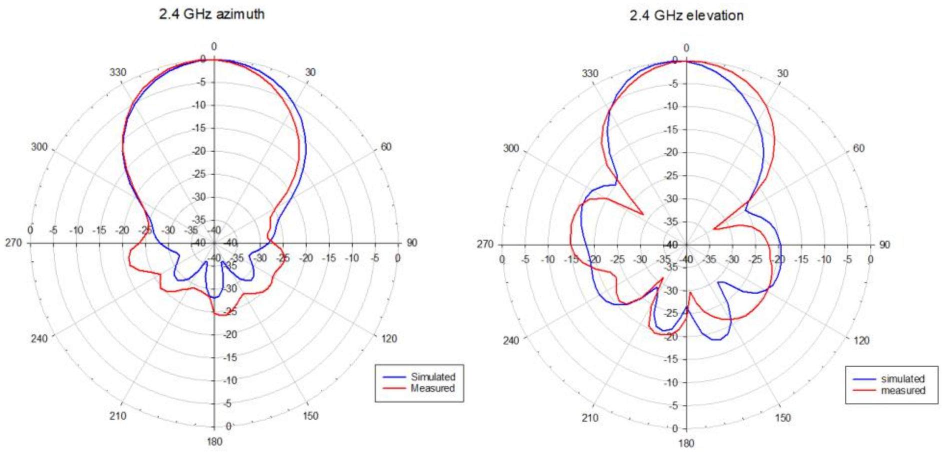


Figure 4. Simulated and measured S11 of 2.4 GHz and 3.5 GHz patch antenna



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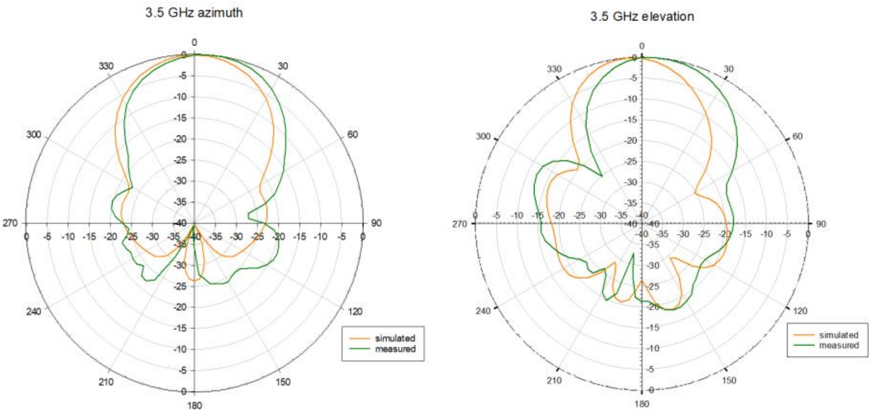
(a) (b)

Figure 5. Simulated and measured (a) H-plane and (b) E-plane pattern at 2.4 GHz

Figure 5 shows simulation and measured results of far-field patterns in both E and H planes of 2.4 GHz antenna. From simulation, the gain simulated is 12.41 dB. Meanwhile, the measured gain for the antenna is close to 12.2 dB or 1.67% lower compared to simulated gain.



(a) (b)

Figure 6. Simulated and measured (a) H-plane and (b) E-plane pattern at 3.5 GHz

Figure 6 shows simulation and measured results of far-field patterns in both E and H planes of 3.5 GHz antenna. The gain simulated for 3.5 GHz patch antenna is 13.14 dB. As for the measured result, the gain obtained is around 13.03 dB, less than 1% difference to the simulated gain.

The gain comparison method is applied to measure the patch antenna gain by using broadband horn antenna as the reference. This antenna can operate from 1 GHz to 18 GHz. The gain of reference horn is shown in figure 7. The gain of patch antenna is calculated using the formula (5) [7]

$$G_M = G_R + \Delta G \tag{5}$$

where G_M is the gain of measured antenna, G_R is the gain of reference antenna and ΔG is the difference between them. Based on the figure 7, the standard gain at 2.4 GHz and 3.5 GHz horn antennas are around 13.7 dB and 13.5 dB respectively.

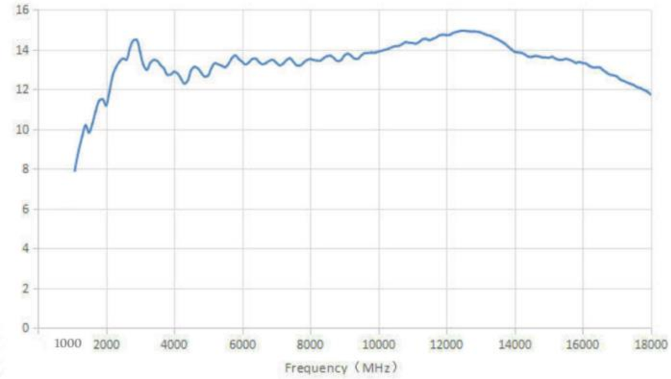


Figure 7. The gain of standard horn antenna [10]

The measurement of antenna gain is presents in table 2 with the comparison to the simulated antenna gain. Overall, the performances of the design antennas are concluded in table 3.

Table 2. The comparison table between simulated and measured gain

Antenna types	Max patch power density measured	Max horn power density measured	Difference between horn and patch	Gain measured (dB)	Gain simulated (dB)
2.4 GHz	-33.299	-34.8	1.501	12.2	12.41
3.5 GHz	-34.848	-35.315	0.467	13.03	13.14

Table 3. Design antennas' performances

Antenna types	Bandwidth (MHz)	Gain (dB)	S11 (dB)	Radiation Efficiency (%)
2.4 GHz	29.4	12.2	-13.21	96.7
3.5 GHz	50.0	13.03	-14.02	97.9

4. Conclusion
Both patch antennas were designed and simulated using CST Studio software. The simulated results of the two different antennas resonate at 2.4 and 3.5 GHz were analyzed and compared to find out the performances in terms of return loss, radiation pattern and surface current. It was observed that the characteristics obtained at 3.5 GHz frequency does not have significant difference to 2.4 GHz antenna despite having a smaller overall patch size. The antennas will be fabricated to verify the simulated results. In addition, the antenna design will be further fabricated using 3D printing using PLA or ABS substrate to be applied to other wireless communication purposes.

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