Design of a Dual Band Printed Dipole Antenna for WIFI Application

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***Abstract*— Simulation and measurement of 2.4 GHz dipole antennas with baluns are presented and discussed. The design was made to study the characteristics of a dipole antenna before converting its configuration from wire to printed configuration. As a wire dipole antenna is prone to break, a printed dipole antenna with integrated via-hole balun printed on FR-4, Rogers TMM 4, and Rogers RT6002 substrates are presented. The study also focuses on improvement from a single band printed dipole antenna by adding another resonance frequency making it dual band. The simulated printed dipole antenna was made to resonate at 2.4 GHz and 5 GHz. Simulation was performed using CST Microwave Studio (CST MWS) to analyze the antenna performance. The proposed designs on RT6002 have the best return loss values of 13.2dB and 23.4dB with bandwidth of 17.2% and 33.9% respectively. Fabrication on Rogers RT6002 was selected for both single and dual band antenna. Measurements taken are in good agreement with the simulated results. From the results, it is demonstrated that the proposed antenna can be used for dual band Wi-Fi applications.**

***Index Terms*— Dual-Band; Integrated Balun; Printed Dipole; Wi-Fi Application.**

I. Introduction

Dipole is a versatile antenna that can be made in different configuration. It is well known that a dipole needs a balance feed such as a quarter-wavelength coaxial balun [1]. Without balun, the connection between dipole arms and coaxial cable introduces current on the outer side of the outer conductor of the coaxial line. Quarter-wavelength balun was presented in [2]. The connection of a dipole with a balun eliminates undesirable radiation leaking from the coaxial cable. In this paper, a few design of practical dipole antennas with baluns at 2.4 GHz is simulated and fabricated to study its performance.

In recent years there have been rapid development that demand for antenna which is compact in size, low profile, and multiband. The addition of 5 GHz band to 2.4 GHz band for Wi-Fi applications enable users to transmit higher amounts of data since 5 GHz band is less congested in comparison with 2.4 GHz band. The 2.4 GHz band is an unlicensed spectrum band thus has been shared with many devices such as microwaves, laptops, phones and tablets. This will lead to sudden drop of connections and low data throughput. However, a 5 GHz band is suitable for short range communications (such as indoor) and less able to penetrate through walls. On the other hand, 2.4 GHz band can be used for longer range and able to penetrate the walls and solid objects. The advantages and disadvantages of both bands complement each other and highly desirable. Thus, instead of having antenna operating at only one frequency, a dual band antenna is preferable. Printed antennas are popular due to their low profile, compact and ease of integration.

In this paper, a simulation of wire dipole antenna for single band has been performed at 2.4 GHz. Then, it has been compared with measured results [3] for verification. However, as wire dipoles are prone to break lead to the printed dipole antennas design at 2.4GHz. For printed dipole, the coaxial balun can be replaced with an integrated balun as presented in [4]. The open circuited-stub in the J-shaped balun [4] was then modified and improved with a via-hole balun [5]. The via-hole balun can eliminate undesired radiation, coupling effect, and power losses from the stub [5]. However, in [4] and [5], they only presented dipole antenna working only at single resonant frequency. There are several dual band printed dipole antenna reported [6-8]. The proposed printed antenna design uses Marchand balun [6], incorporating Yagi technique [7], and bended stripline [8]. This paper proposes both single (2.4 GHz) and dual band (2.4 GHz & 5 GHz) printed dipole designed on three substrates with via-hole balun. The dual band printed dipole is introduced and highlighted in this paper by simply manipulating the dimension of the same antenna geometry.

II. Antenna Structure and Design

A. Wire Dipole Antenna

Simulation of a wire dipole antenna (without balun) at 2.4 GHz was performed in CST MWS. A cylinder made of annealed copper was used to model the dipole arms. The length of the dipole is approximately 0.464λ. After both dipole arms were created, a discrete port with gap was placed in between them to feed the antenna as in Figure 1. The dimension of a simple wire dipole antenna is presented in Table 1. In practical, a discrete port does not exist thus a balun is required in order to balance between coaxial cable and dipole antenna. This antenna was simulated for comparison of its performance with a wire dipole antenna with balun. The antenna resonates at 2.4 GHz with return loss of 14.533 dB. It has the bandwidth equivalent to 7.6% of the resonant frequency.

Table 1
Dimension of simple wire dipole (without balun).

Parameter	Value
Length of the dipole, L	57.9448
Gap of the antenna, g	0.289724
Radius of the wire, R	0.125

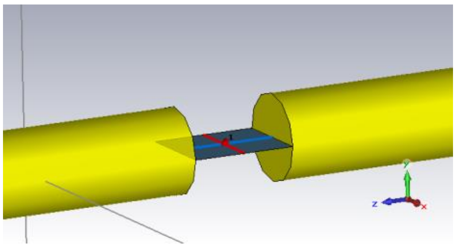
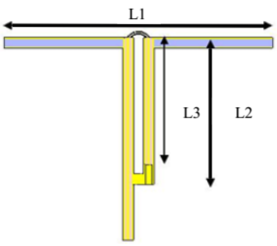


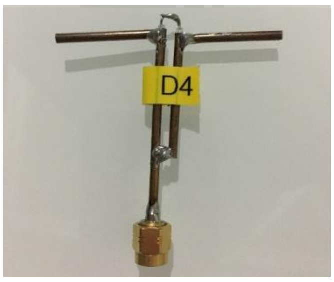
Figure 1: A simple wire dipole with discrete port

The feeding port (discrete port) that has been used is already balanced with a simple dipole antenna (without balun). However, the situation does not exist in practical due to unbalanced coaxial cable that is connected to the dipole antenna. A practical dipole antenna requires a balun in order to avoid RF radiation leaking out towards coaxial cable and thus disturb the characteristics of dipole antenna. The simulation for the fabricated antenna from previous work [3] was performed to validate the measured result. Figure 2 shows the simulation of a wire dipole (with balun) together with the parameters and antenna dimension depicts in Table 2. The simulation and measurement results of S11 are shown in Figure 3; 1) modified, 2) measurement, 3) simulation with balun and 4) simulation without balun. It is observed that the return loss of the simulation (with balun, Figure 2) and measurement results are in closer agreement compared to the simulation without balun (Figure 1).

The modified dimension was proposed in Table 2 to improve the S_{11} and bandwidth. The comparison of all wire dipole antennas performance are shown in Figure 3 and Table 3. The modified version produced a better return loss and improved bandwidth compared to the simulated and measured wire dipole with balun. The bandwidth is better than other curves even though the simulation (without balun) has the best return loss since it is directly fed at the center. This is due to the usage of coaxial cable in which the dipole might experience loss from the transmission line itself. The numerical performance of those are presented in Table 3.



(a)



(b)

Figure 2: (a) Simulated antenna using CST (b) Fabricated dipole antenna with balun at 2.4 GHz.

Table 2
Dimension of the simulated and modified wire dipole antenna (with balun)

Parameter	Simulation	Modified
L1	53.12 mm (with 2 mm feed gap)	52.75 (with 2 mm feed gap)
L2	29 mm	32 mm
L3	25 mm	25 mm
Diameter	2.06 mm	2.06 mm

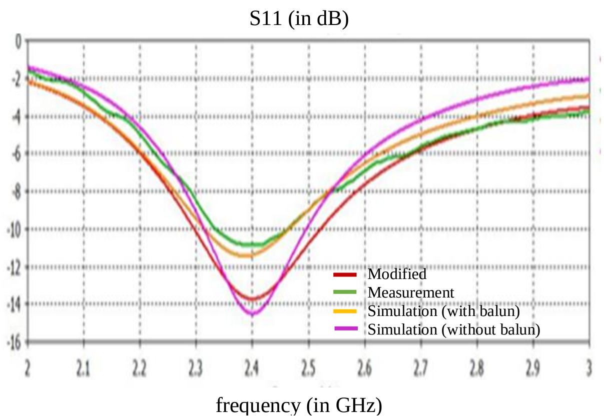


Figure 3: Return loss graph of all wire dipole

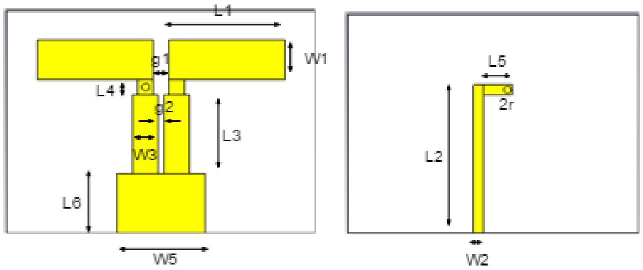
Table 3
Performance of wire dipole antenna

Wire dipole	Resonant Frequency (GHz)	Return loss (dB)	Bandwidth (MHz)
Simulation (without balun)	2.40	14.533	182.2 (7.59%)
Simulation (with balun)	2.39	11.467	152.1 (6.34%)
Measurement	2.39	10.902	128.5 (5.37%)
Modified	2.40	13.758	225.2 (9.38%)

B. Printed Dipole Antenna (with balun) for Wi-Fi Applications

Wire dipole antenna is prone to break which leads to the printed dipole antenna design as in [9]. The geometry of a printed dipole antenna (with balun) is shown in Figure 4 from [9]. It is compact and low profile in comparison to the wire dipole antenna as in Figure 2. The antenna with integrated balun is printed on both side of the dielectric substrate. The microstrip feed line with the integrated balun is on the top strip layer, while the dipole is printed at the bottom layer. A microstrip via-hole balun acts as an unbalance-to-balance transformer from the coaxial feed line to the two dipole arms.

Printed dipole antenna made for Wi-Fi application is simulated using three different materials: FR-4, Rogers TMM 4 and Rogers RT6002. For single band antennas, they were made to resonate at 2.4 GHz, while for dual band antenna, the resonant frequencies are 2.4 GHz and 5 GHz. Improvement from single band antenna to dual band antenna is introduced by manipulating the dimension of the same antenna geometry. Six printed dipole antennas are presented in this study using the three substrates mentioned. The geometrical dimensions of the antennas are optimized using CST MWS to produce single and dual band antennas. The design parameters of the single band printed dipole antenna with via-hole balun are listed in Table 4.



(a) (b)

Figure 4: Geometry of a single band printed dipole antenna at 2.4GHz. (a) Top and (b) Bottom

Table 4
Dimension of single band printed dipoles using three different substrates.

Parameter	Value (FR-4)	Value (Rogers TMM 4)	Value (Rogers RT6002)
Dipole arm	L1 = 20.8 mm W1 = 6 mm g1= 3 mm	L1 = 20.7 mm W1 = 6 mm g1= 3 mm	L1 = 24.2 mm W1 = 6 mm g1= 3 mm
Microstrip balun	L2 = 30.5 mm L3 = 16 mm L4 = 3 mm L5 = 6 mm W2 = 2 mm W3 = 5 mm W4 = 3 mm g2 = 1 mm	L2 = 30.5 mm L3 = 16 mm L4 = 3 mm L5 = 6 mm W2 = 2 mm W3 = 5 mm W4 = 3 mm g2 = 1 mm	L2 = 30.5 mm L3 = 16 mm L4 = 3 mm L5 = 6 mm W2 = 2 mm W3 = 5 mm W4 = 3 mm g2 = 1 mm
Via-hole radius	r = 0.375 mm	r = 0.375 mm	r = 0.375 mm
Ground plane	L6 = 12 mm W5 = 17 mm	L6 = 12 mm W5 = 17 mm	L6 = 12 mm W5 = 17 mm
Overall size (mm)	37 × 44.6	37 × 44.4	37 × 51.4

FR-4, Rogers TMM 4, and Rogers RT6002 have permittivity (ε_r) equal to 4.3, 4.5, and 2.94, respectively. In reference to equation (1), the dimension of the antenna depends on the ε_r and the length needed for a resonant antenna is proportional to $1/(f\sqrt{\varepsilon_r})$. Since Rogers RT6002 has the lowest ε_r, the dipole arm's length need to be increased in order to resonate at 2.4 GHz. The overall size is notably increased in comparison to the other two.

$$\lambda = \frac{c_0}{f\sqrt{\varepsilon_r}} = \frac{\lambda_0}{\sqrt{\varepsilon_r}} \qquad (1)$$

In achieving dual band operation from a single band antenna, the test on widening the dipole arms width and changing other parameters are conducted. The modified and optimized parameters for dual band antennas (at 2.4 GHz and 5 GHz) are presented in Table 5.

Dual band dipole antenna printed on FR-4 and Rogers RT6002 can be achieved only by increasing the width of the dipole arm (W1). Increment in the dipole length (L1) was made in Rogers TMM 4 and RT6002 as compared to Table 4 in order to maintain the lower resonant frequency at 2.4 GHz. Printed dipole using Rogers TMM 4 need further optimization by reducing the length of ground plane (L6) and microstrip line (L2) to make it resonates below -10 dB at 5 GHz. The antenna printed on Rogers RT6002 has the largest overall size followed by FR-4 and Rogers TMM 4. By having all the parameters optimized, the dual band antennas are produced.

Table 5
Dimension of dual band printed dipole.

Parameter	Value (FR-4)	Value (Rogers TMM 4)	Value (Rogers RT6002)
Dipole arm	L1 = 20.8 mm W1 = 8.1 mm g1= 3 mm	L1 = 22.45 mm W1 = 8.1 mm g1= 3 mm	L1 = 24.8 mm W1 = 10.6 mm g1= 3 mm
Microstrip balun	L2 = 30.5 mm L3 = 16 mm L4 = 3 mm L5 = 6 mm W2 = 2 mm W3 = 5 mm W4 = 3 mm g2 = 1 mm	L2 = 21.5 mm L3 = 16 mm L4 = 3 mm L5 = 6 mm W2 = 2 mm W3 = 5 mm W4 = 3 mm g2 = 1 mm	L2 = 30.5 mm L3 = 16 mm L4 = 3 mm L5 = 6 mm W2 = 2 mm W3 = 5 mm W4 = 3 mm g2 = 1 mm
Via-hole radius	r = 0.375 mm	r = 0.375 mm	r = 0.375 mm
Ground plane	L6 = 12 mm W5 = 17 mm	L6 = 3 mm W5 = 17 mm	L6 = 12 mm W5 = 17 mm
Overall size (mm)	39.1 × 44.6	30.1 × 47.9	41.6 × 52.6

III. Results And Discussion

A. Single Band Antenna

Simulation results of the single band printed dipole antennas using three different substrates are shown in Figure 5. All single band antennas resonate at 2.4 GHz. From the graph, the S_{11} value of FR-4 is the best followed by Rogers TMM 4 and RT6002. The return loss values are listed in Table 6. The antenna printed using substrates of FR-4, Rogers TMM 4 and RT6002 exhibit 22.9%, 20.6%, and 17.7% of bandwidth, respectively.

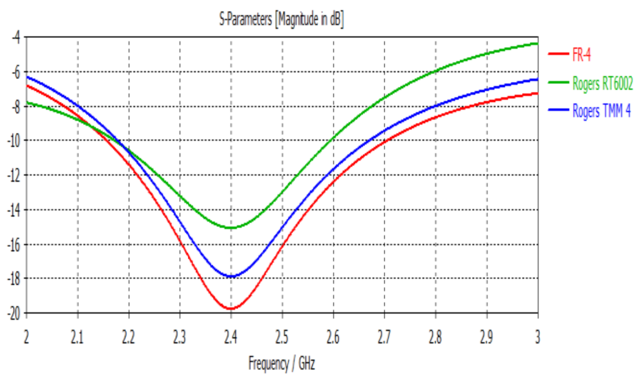
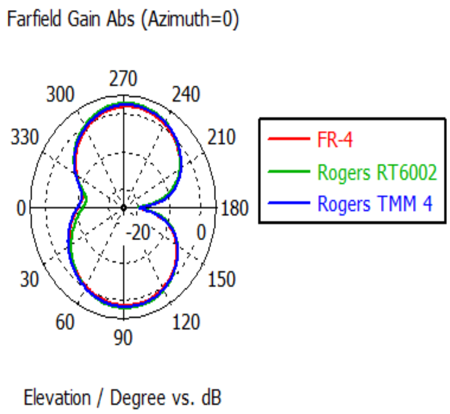
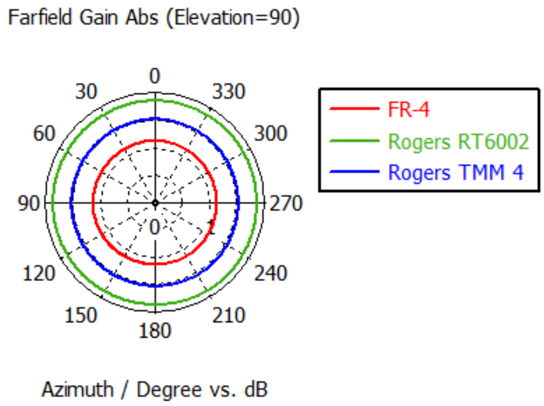


Figure 5: Return loss graph of single band printed dipole antennas.

At 2.4 GHz, the antennas produced simulated radiation patterns as shown in Figures 6 (a) and (b). All three antennas have an omni-directional pattern and a doughnut shaped pattern on elevation and azimuth. However, the gains are different in each material. The low loss properties of both Roger materials made the gains to be significantly higher than in FR-4. The overall performance of the single band antenna can be seen in Table 5.



(a)



(b)

Figure 6 Simulation radiation pattern of single band printed dipole antennas. (a) Elevation plane (b) Azimuthal plane

Due to the good performance of antenna design on Rogers RT6002, the material has been chosen for antenna fabrication (Figure 7). The simulation and measurement results of single band antenna at 2.4 GHz has been observed in Figure 8. It is observed that the simulation and measurement of S11 at 2.4 GHz are -15.0 dB and -13.7 dB respectively. However, the bandwidth of the fabricated antenna increased from 17.5% (simulation result) to 25% (measurement result).

Table 6
Performance of single band printed dipole antennas on three different substrates.

Substrate	S_{11} (dB)	Bandwidth (MHz)	Radiation pattern	Gain (dB)
FR-4 $\varepsilon_r = 4.3$ Loss tangent = 0.025	-19.787	550.2	Omni-directional	1.930
Rogers TMM 4 $\varepsilon_r = 4.5$ Loss tangent = 0.002	-17.908	493.3	Omni-directional	2.379
Rogers RT6002 $\varepsilon_r = 2.94$ Loss tangent = 0.0012	-15.094	423.6	Omni-directional	2.854

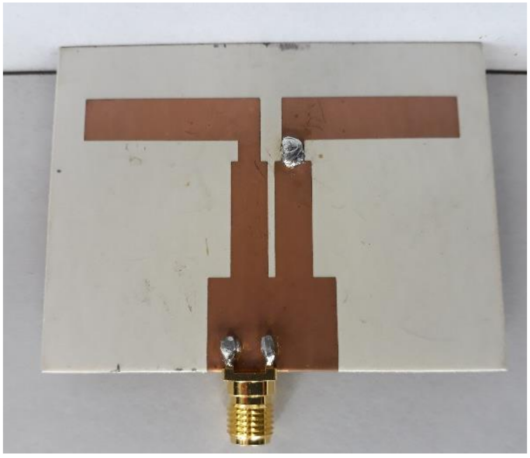


Figure 7: Fabricated of single band printed dipole antenna at 2.4GHz on Rogers RT6002 substrate.

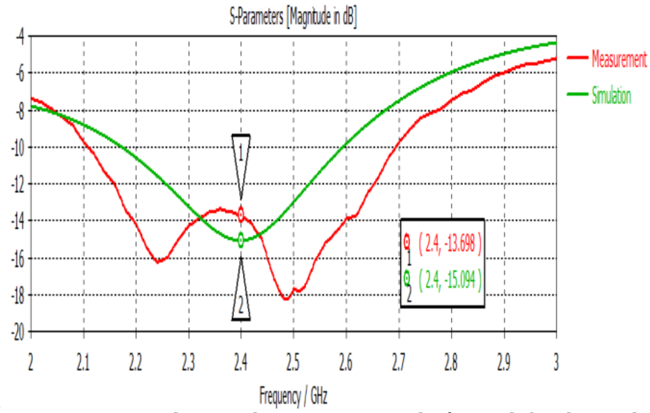


Figure 8: S11 simulation and measurement results for single band printed dipole antenna on Rogers RT6002 substrate.

B. Dual Band Antenna

The optimization of antenna dimension from single band (Table 4) to dual band (Table 5) produced the simulation results as shown in Figure 9. The dual band antennas operate at 2.4 GHz band and 5 GHz band based on three different substrates of FR4, Rogers TMM 4 and RT6002 using antenna dimension presented in Table 5. It is observed that antenna on FR-4 works best at lower frequency, while at 5 GHz Rogers RT6002 has better performance compared to FR-4 and TMM 4. Bandwidth performance at 2.4 GHz on FR-4, Rogers TMM 4 and RT6002 are 24.6%, 23.7% and 17.2%, respectively. It is observed that it follows the same trend in bandwidth performance as in single band antenna. While at 5 GHz, the bandwidth for FR-4 is 14.9%, Roger TMM 4 is 17.8% and RT6002 is 33.9%. At higher frequency, Roger RT6002 shows the largest bandwidth compared to FR-4 and Roger TMM 4.

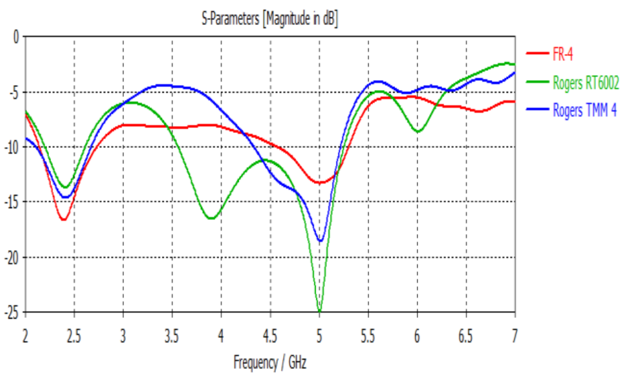
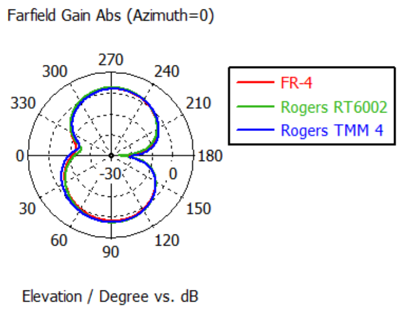
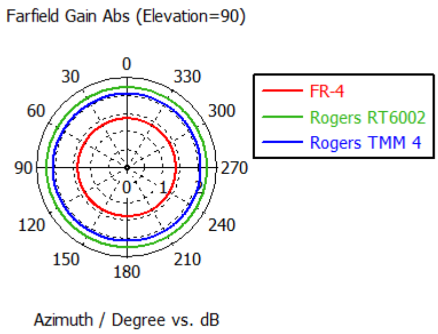


Figure 9: Return loss of dual band printed dipole antennas.

At 2.4 GHz, all three antennas have an omni-directional and doughnut shaped pattern with increasing gains when Rogers substrates are used (Figures 10(a) and (b)). However, at 5 GHz, the pattern becomes directive for all substrates (Figures 11(a) and (b)). The gain generally becomes better when using Rogers, but having decrement at 5 GHz when RT6002 is used. The overall performance of the dual band antennas can be seen in Table 7.

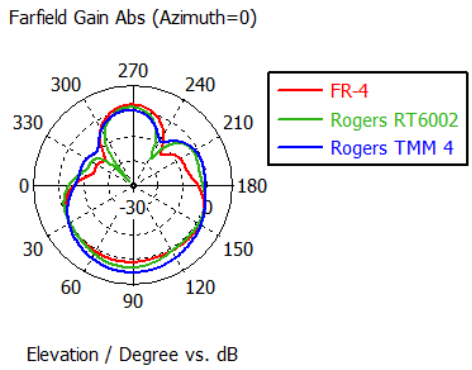


(a)

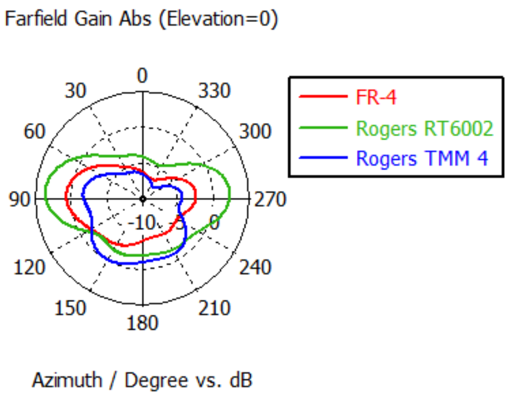


(b)

Figure 10: Simulated radiation pattern of dual band printed dipole antennas at 2.4 GHz (a) Elevation and (b) azimuthal plane



(a)



(b)

Figure 11: Simulated radiation pattern of dual band printed dipole antennas at 5 GHz. (a) Elevation and (b) azimuthal plane

Due to the good performance of antenna design using Rogers RT6002, the material has been chosen for antenna fabrication (Figure 12). The simulation and measurement results of dual band antenna at 2.4 GHz and 5.0 GHz bands has been observed in Figure 13. It is observed that the simulation and measurement results of dual band printed dipole antenna are in good agreement at 2.4 GHz. However, it is observed that the antenna also resonates at 4 GHz and 5.3 GHz which is 6% difference than the desired resonance at 5 GHz. The mismatch is maybe due to the fabrication error due to the soldering of the connector. However, the measurement result follows similar pattern as the simulation result. The bandwidth at high frequency (simulation and measurement results) also larger as compared to the lower frequency which cover both 4 GHz and 5 GHz band. Table 8 compares the simulation and measurement results for dual band antenna and its performance with design from [9].

Table 7
Performance of dual band printed dipole antennas (simulation) using three different substrates.

Substrate	**S_{11} (dB)**		**Bandwidth (MHz)**		**Radiation pattern**		**Gain (dB)**	
	2.4 GHz	5 GHz	2.4 GHz	5 GHz	2.4 GHz	5 GHz	2.4 GHz	5 GHz
FR-4 ε_r = 4.3 Loss tangent = 0.025	-16.651	-13.339	589.4	745.3	Omni-directional	Directional	1.883	3.010
Rogers TMM 4 ε_r = 4.5 Loss tangent = 0.002	-14.682	-18.576	568.7	888.6	Omni-directional	Directional	2.041	4.908
Rogers RT6002 ε_r = 2.94 Loss tangent = 0.0012	-13.723	-24.948	413.2	1696.7	Omni-directional	Directional	2.548	3.798

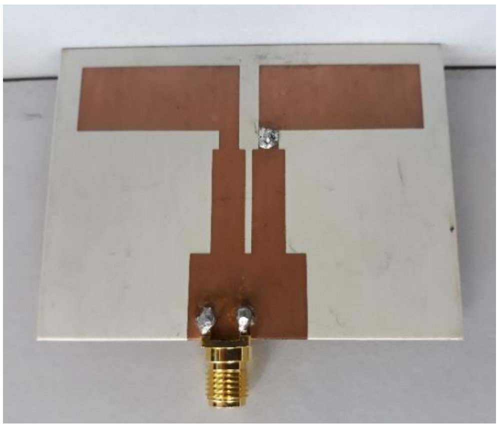


Figure 12: Fabricated of single band printed dipole antenna at 2.4GHz on Rogers RT6002 substrate

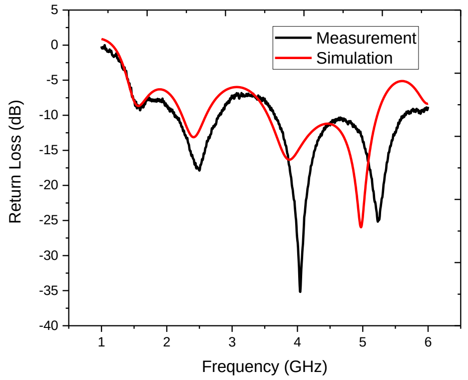


Figure 13: S11 simulation and measurement results for single band printed dipole antenna on Rogers RT6002 substrate.

Table 8
Performance of dual band printed dipole antennas and comparison with [9]

Design	S_{11} (dB)			Bandwidth (MHz)		
	2.4 GHz	4 GHz	5 GHz	2.4 GHz	4 GHz	5 GHz
Simulation	-13.7	-14.8	-24.95	12%	38.55%	
Measurement	-18.1	-35.8	-13.25	24%	44.4%	
Simulation from [9]	-15	-10	Not available	14.5%	7.5%	Not available
Measurement from [9]	-25	-11.5	Not available	20.8%	6.8%	Not available

IV. Conclusion

The simulation based on simple dipole antenna (without balun) has been performed. The simulation of wire dipole antenna with balun is then conducted based on the previous work. The dimension was taken directly from the fabricated antenna. Though the simulated and measured results agree each other well, further improvement was proposed and new dimension was presented in this study. Thus it validates the necessity of simulation of dipole antenna with balun in order to prevent the radiation leakage to the coaxial cable in practice.

However, the wire dipole are fragile and prone to break. Thus, the design and optimization of the printed dipole antenna for Wi-Fi applications have been discussed. The printed dipole antennas were simulated using different material of substrate to study its behavior. A novel work from single band antennas to dual band antennas has been introduced in this research by manipulating the dimension of the same antenna geometry. The proposed designs have return loss less than 10 dB at required resonant frequency with moderate gains. Measurement of antennas fabricated on RT6002 are in good agreement with the simulated results. From the results, it is demonstrated that the proposed antenna can be used for dual band Wi-Fi applications.

The future works of this research including the radiation pattern measurement will be conducted especially at high resonance frequency.

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