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Design and comprehensive testing a 2.4 GHz antenna for WiFi access point

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ABSTRACT

A small size patch antenna for replacing TP-LINK WA 701 ND access point (AP) internal antena for 2.4 GHz is proposed. Measurements are carried out on AP external antenna to get the basic parameter of the antenna i.e. return loss, bandwidth, radiation pattern, and polarization. The patch antenna is designed by using IE3D simulator on FR4 material with the thickness of 1.6 mm and the dielectric constant of 4.4. The 42×28×1.6 mm overall size of the designed antenna is printed on FR 4 substrate, measured and compared to external AP antenna. The measurement result shows good agreement between simulation and designed antenna. The printed antenna covers 2.4 GHz, the gain of 2.5 dBi, and has linier polarization. This antenna is much smaller than 190×15×15 mm conventional TP-LINK WA 701 ND AP antennas and allows it to be hidden and integrated on the AP printed circuit board. The comparation of the designed antenna and external AP antenna is also conducted by evaluating both antenna performance on TP-LINK WA 701 ND AP by accessing it on a laptop on different access distance.

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1. INTRODUCTION

Wireless local area networks (WLANs) are very popular for connecting various mobile communication devices such as cell phones and laptops in public areas, offices, homes, business centers, and industries [1]. WiFi, stand for wireless fidelity, is the main standard that used for WLANs. Wireless access point (AP) allows the mobile devices to be connected to local networks and internet. The AP antenna which is mounted on ceiling or wall needs omnidirectional [2] or unidirectional pattern [3], small (compact) size [4], cheap and simple design [5] as complies in 802.11 IEEE standards [6]. Mean while the AP antenna with significant gain does not necessary to occupy the low noise amplifiers (LNA) as in [7]. Generally, AP utilizes the dipole [8] or monopole [9] antenna which have the working frequency on 2.4/5.2/5.8 GHz. Consequently these frequency influence the antenna dimensions which reached 190×15 mm [5]. From an esthetic point of view that external antennas are not very comfortable to the end user [10]. thus the antennas size need to reduce the dimensions of the access point device.

The are some works on antenna design which has proposed for internal AP aplications. The 28.94×33.17×1.524 mm overall size of reconfigurable antenna are designed in [11] by using a microelectromechanical system (MEMS) switch for 2.4 and 5.2 GHz band. The fractal yagi-uda antenna that operating at 2.4 GHz frequency with overall size 93.75×55×1.6 mm are proposed in [12]. The multipolarize antennas with single circular patch radiating element are proposed to provide three coupled polarize APs with 150×150×10 mm dimension in [13]. Mean while, the antenna cylindrical dielectric resonator (cDRAs) for wireless access point application has dimension of 160x160 14.8 mm with metallic reflector [14]. In [3], the slot antenna is developed in the form of an exponential cross and parallel piped cavity with dimensions of 57×57×21 mm. All of these antennas have large dimensions in order to conceal in an access point device.

In this work, we developed a smaller compact patch antenna (42×28×1.6 mm overall size) with tappered slot and partial ground plane for 2.4 GHz WLAN frequency. The design procedure are the same as our previous works on [15, 16]. In order to validate the simulation results, several measurements were made on the printed antenna. Finally, the antenna apply directly to the AP TP-LINK WA 701 ND and conducting the connection test with various distances inside the building with several room; in this case at G building in the campus of Politeknik Negeri Padang. This work will contribute as an important consideration for the researchers who want to develop the testing of 2.4 GHz antenna in the future.

2. ANTENNA DESIGN

2.1. Target design

Generally, AP antenna used an external detachable antenna i.e. dipole or monopole antenna [17]. One of the popular AP in Indonesia is TP LINK WA-701 ND. In this work, the internal antennna will be designed to replace AP external antenna. Initially, the characteristics of the TP LINK WA-701 ND antenna is measured in order to have the reference on designing the AP antenna. The measurements are focused on the basic parameter of the antenna such as radiation pattern, working frequency, bandwidth and polarization.

The measurement results of the antenna AP TP LINK WA-701 ND radiation pattern and return loss are shown in Figure 1. The radiation pattern of the antenna TP LINK WA-701 ND is omnidirectional as seen in Figure 1 (a). It is the 3D pattern of the antenna where the maximum field energy is on x-y plane. The 2D pattern is plotted in Figure 1 (b) where x-z pattern is bidirectional and y-z pattern is omnidirectional. The antenna gain is 5 dBi on 2.4 GHz. According to the antenna return loss in Figure 1 (c) the AP TP LINK WA-701 ND has the resonance frequency on 2.43 GHz. The polarization of the antenna is linear as shown in Figure 1 (d).

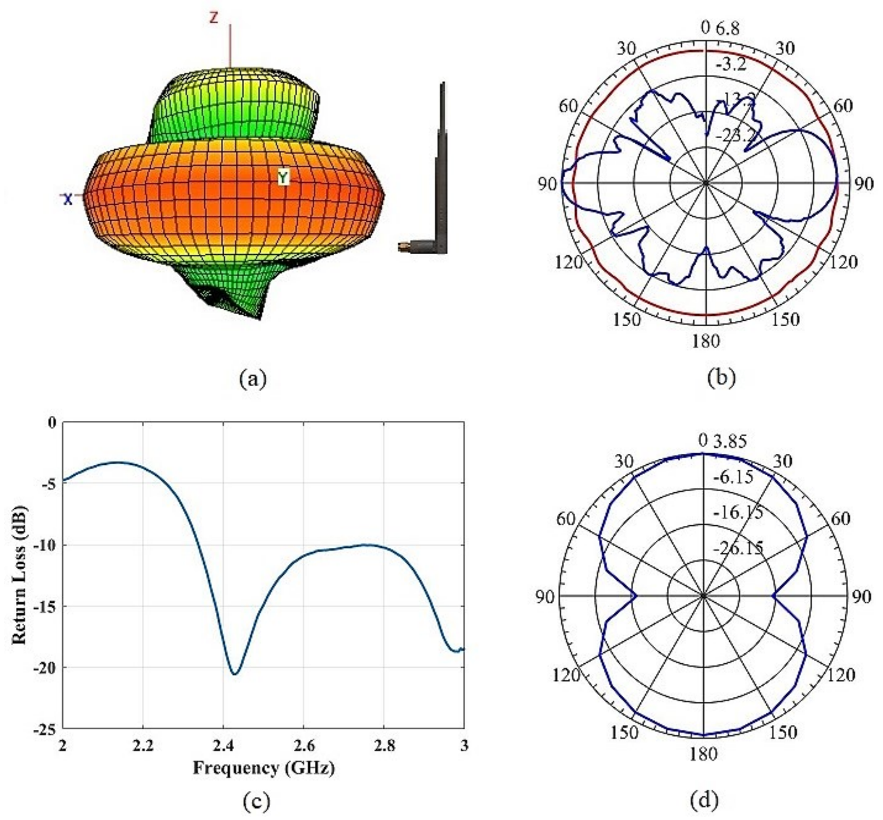


Figure 1. The measurement of TP LINK WA–701 ND, (a) 3D radiation pattern, (b) 2D radiation pattern (blue line = x-y plane, red line = x-z pattern), (c) return loss, (d) polarization

2.2. Patch antenna design for 2.4 GHz

Firstly, the preliminary length and width of the patch antenna is done by using the (1-4). The width W and length L of the patch determine using the [12]:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{\text{reff}}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \tag{2}$$

then :

$$\varepsilon_{\text{reff}} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{3}$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{reff}+0.258)\left(\frac{W}{h}+0.8\right)}, \tag{4}$$

whereε_r is the dielectric constant of the substrate, ε_{reff} is the effective dielectric constant of the substrate, h is the thickness of the susbtrate and f_r is the resonance frequency. For the patch antenna on 2.4 GHz using the FR4 substrate with the thickness is 1.6 mm and the dielectric constant is 4.4 resulting W = 38 mm and L = 29 mm as shown in Figure 2 (a). The design process of the antenna is conducted by using the method of moment based [18-20] full-wave electromagnetic simulator IE3D. The simulation result of the antenna return loss is shown in Figure 2 (b). It has minimum return loss on -8 dB at the frequency of 2.45 GHz. Furthermore, to optimize the design we do the parametric study on the patch dimension, feed line and ground to obtain the optimal performace as shown on Figure 3 (a). The optimization procedures are done as on [15, 16]. The working frequency can be adjusted by varying the W or using slots for multifrequency in order to improve the impedance matching [21-23]. Meanwhile the antenna occupy the partial ground plane [24] structure to get omnidirectional pattern.

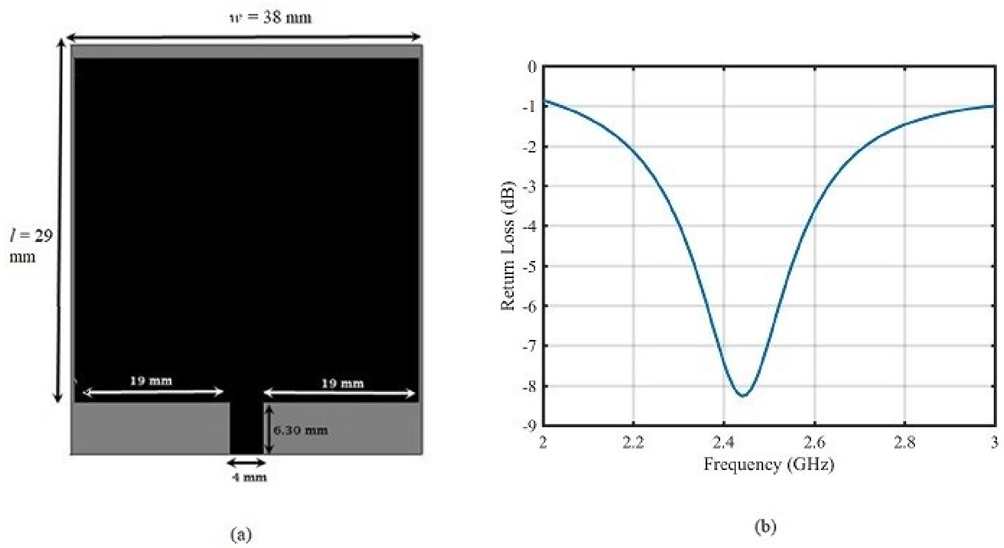


Figure 2. Antenna design, (a) initial design, (b) optimization

The optimization procedure on having optimal dimension of the antenna design are described in Figure 3. Figure 2 (a) shows the geometry of the antenna based on the initial dimension which is obtained from the previous calculation. To reduce the size of the antenna, the optimization of the patch size is conducted and the optimum 25×25 mm at the frequency of 2.4 GHz as in Figure 3 (b). Variation of the feedline width w and length l will change return loss value and thus control the impedance matching. feedline width W 4.5 mm and length l 16.6 mm are the optimum size as show in Figures 3 (c) and 3 (d). Furthermore the optimization on the size of the antenna ground are shown in Figure 3 (e) for w_2 (ground width) and in Figure 3 (f) for l_2 (ground length) variations. Finally the antenna is simulated using all of the optimum dimension and Figures 3 (g) and (h) shows the omnidirectional radiation pattern for 2D and 3D plots respectively which is good agreement to the premilinary result of the AP TP LINK WA-701 ND antenna radiation pattern measurement.

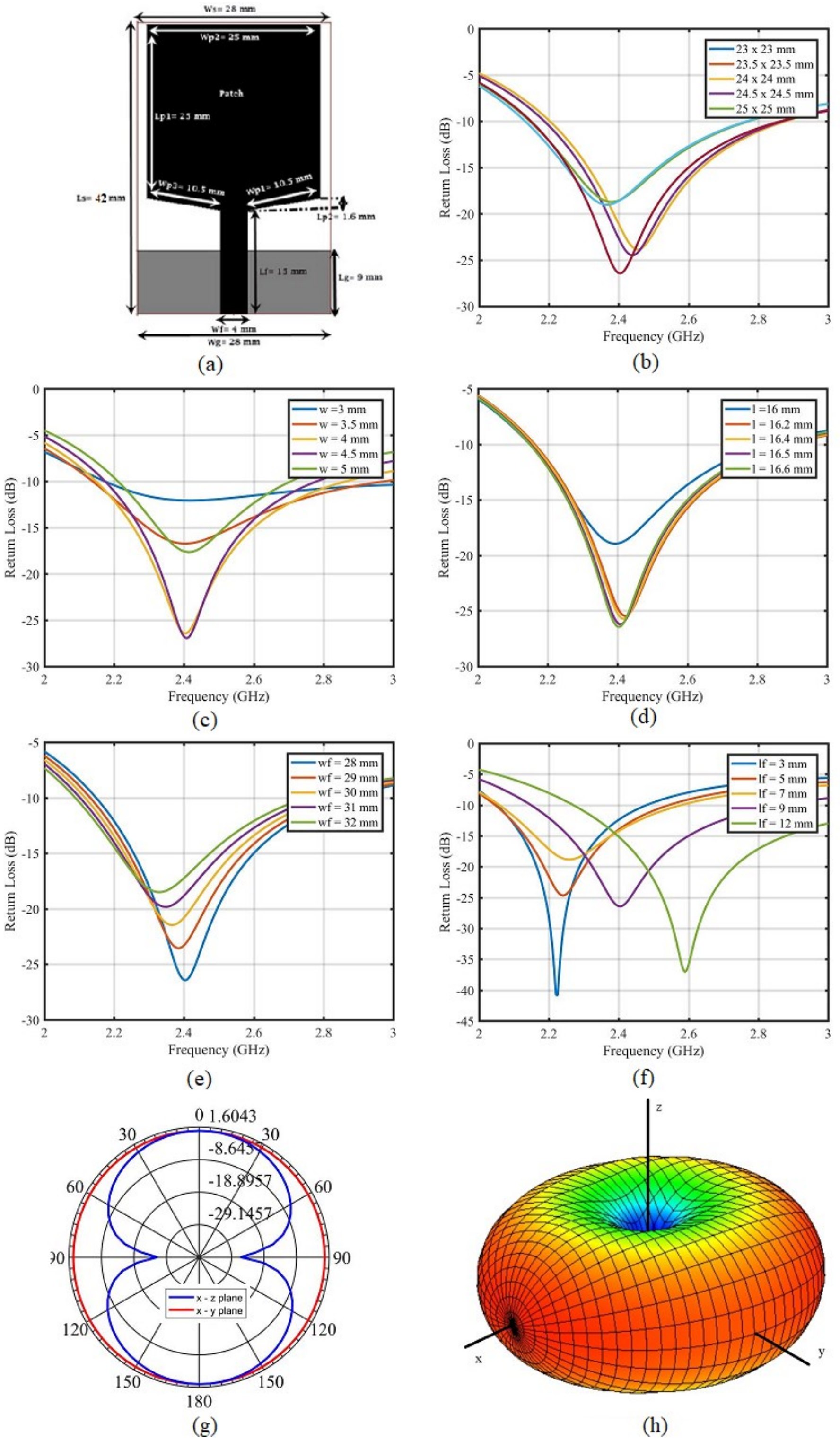
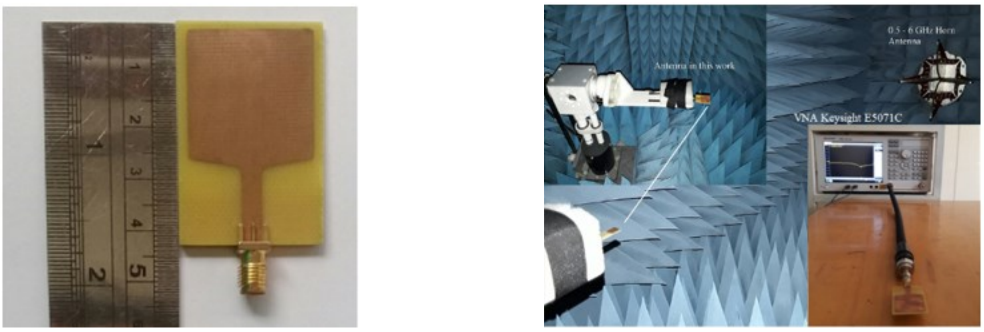


Figure 3. Parametric study of the antenna design geometry, (a)initial design, (b) patch size, (c) feed width w, (d) feed length l, (e) ground width w_f, (f) ground length l_f

3. RESULT AND DISCUSSION

The prototype of optimal dimension of the AP antenna is fabricated onFR4 material with 4.4 dielectric constant as depicted in Figure 4 (a). In order to validated the simulation result then the measurement has been conducted for the printed antenna and followed by performance test of the antenna on TP LINK WA-701 ND. The performance of the antenna is measured in the anechoic chamber equipped with keysight E5071C vector network analyzer (VNA), a dual polarize 0.7-6 GHz horn antenna, a turn table, a control for the turn table and RP3D sofware to run the measurement. The return loss of the printed antenna is measured directly to the VNA where the measurement setup is shown in Figure 4 (b).



(a) (b)

Figure 4. Measurement of fabricated antenna, (a) fabricated antenna, (b) measurement setup

3.1. Measurement of printed antenna

The measured of printed antenna, APs antenna, and simulated return loss are plotted in Figure 5 (a). That three curves show the minimum value on 2.4 GHz. This printed antenna shows good matching impedance with minimum return loss is -46 dB which is better than AP antenna and simulation return loss-it mean this antenna suitable for both transmitter and receiver. Antenna bandwidth also depicted in Figure 5 (a). The bandwidth of the AP antenna, the simulation and the printed antenna are 500 MHz, 715 MHz, and 755 MHz respectively. Thus, the printed antenna can cover all ofthe frequency bandwhich can covered by AP antenna.

The plots on Figures 5 (b, c, d, e and f) are the measured radiation pattern of the printed antenna and the AP antenna. In can be seen the antennas show omnnidirectional pattern. Antenna in this work more stable omnidirectional than AP antenna. Figures 5 (b) and (c) are the 3D plot of radiation pattern of the printed antenna and the AP antenna respectively where the printed antenna is close to isotropic antenna. The comparation of 2D radiation pattern of both antenna are shown in Figures 5 (e) and (f). Mainly, the printed antenna pattern are distributed almost uniformly for both x-z and y-z planes. Based on Figure 5 (f), we found 2.5 dBi gain of the printed antenna since gain the AP antenna is 5 dBi. The measurement of antenna polarization are carried out as polarization measurements procedure on [25] (see chapter 17). The measurement results show the polarization for both of the antenna is linear (vertical) in which the direction of wave propagation is parallel to the y axis as shown in Figure 5 (d).

3.2. Antenna performance on TP-LINK WA 701 ND

In this case, the printed antenna as the prototype of the AP antenna is mounted on the TP-LINK WA 701 ND device access point in order to investigate the performance of the designed antenna. Access point testing is done by comparing the conventional antennas, the designed antenna and without an antenna as in Figure 6. The test was carried out on the 3rd floor of the G building at the campus of the Politeknik Negeri Padang, Indonesia. The site plan of the building is shown in Figure 6 where the access point is located in the G 307 room. The access point connection testing is conducted by means of speed test software. The performance test is implemented in all rooms, corridors, and terraces of G building by using a laptop which will be connected to the access point.

The test results are shown in Figure 7 which indicate the signal strengths at the time of testing. Table 1 summarized the data of time on pinging the access point as well as the download and upload speed. It is seen that the ability of the laptop on accessing the device by using the printed antenna mainly as good as the AP conventional antenna. There are only three rooms at the farthest distance has lower level in receiving power. Furthermore, when there is no antenna connected to the laptop then the connection only occurs if AP the laptop and AP is placed in the same room closely. Thus, the antenna in this work is a good candidate as an internal AP antenna.

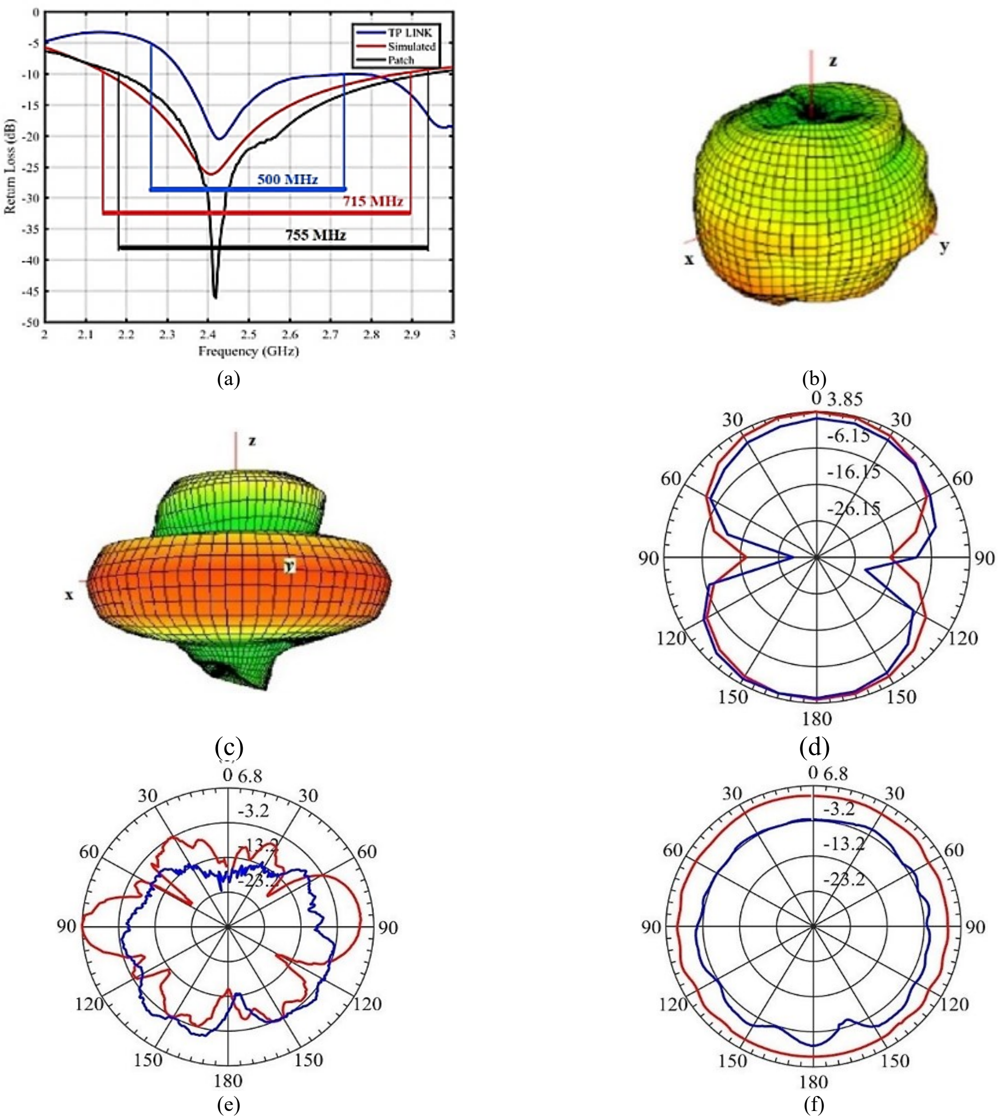


Figure 5. Comparison of the patch antenna and the TP-LINK atenna

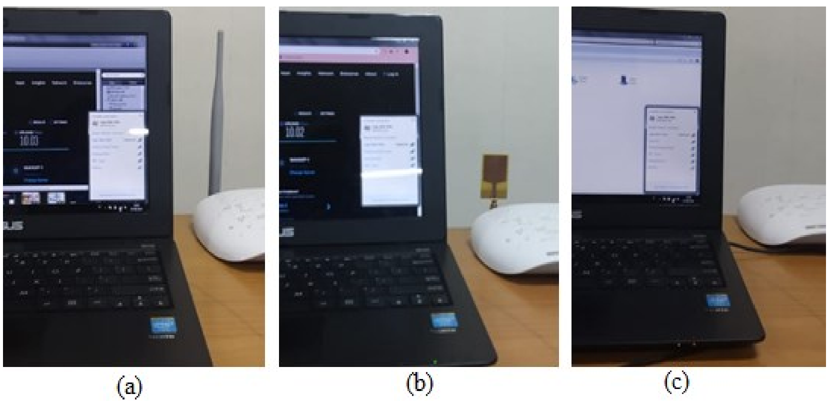


Figure 6. Testing scenario, (a) AP TP-LINK antenna, (b) patch antenna, (c) without antenna

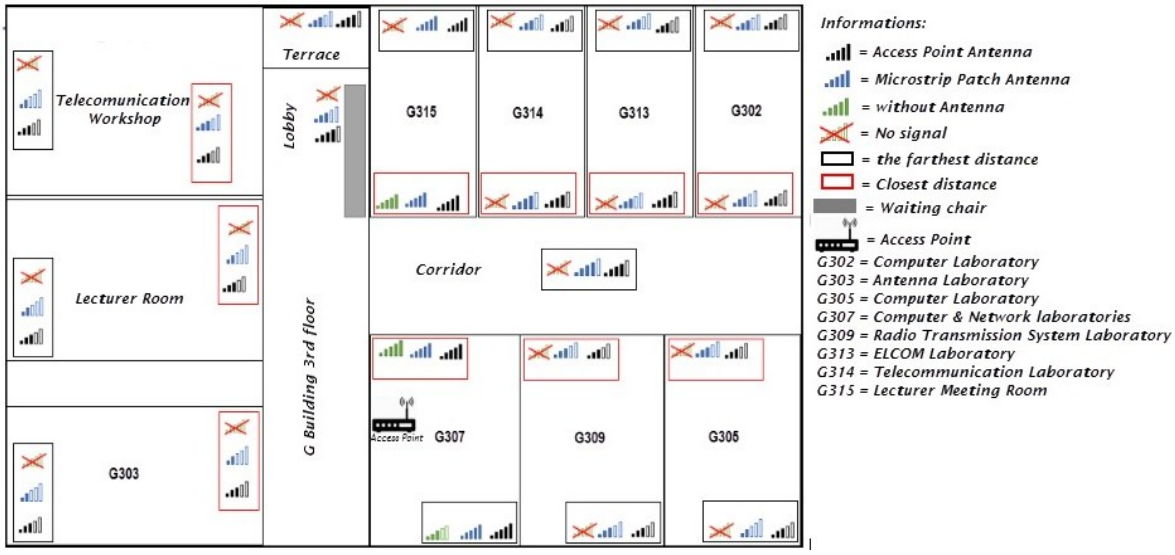


Figure 7. Third floor of G building where the antenna in this work is tested

Table 1. Comparison of TP LINK ND APs antenna to patch antenna

Location	Antenna	Distance* (m)	Signal Bar	Speed test measurement		
				Ping (ms)	Download (Mbps)	Upload (Mbps)
	APs Antenna	3	Full	24	10.12	9.76
G 307	Patch	3	Full	23	10.12	9.99
	Without Ant.	3	Full	23	9.94	10.05
	APs Antenna	6	Full	26	9.87	9.56
G315	Patch	6	Full	23	9.36	9.46
	Without Ant.	6	Full	24	9.85	9.73
	APs Antenna	10	4 bar	24	9.31	9.46
G314	Patch	10	4 bar	27	10.28	9.73
	Without Ant.	10	No	No	No	No
	APs Antenna	12	3 bar	25	10.1	4.69
G309	Patch	12	3 bar	23	4.77	6.42
	Without Ant.	12	No	No	No	No
	APs Antenna	11	4 bar	35	2.13	1.42
G313	Patch	11	3 bar	23	8.9	9.65
	Without Ant.	11	No	No	No	No
	APs Antenna	15	3 bar	26	3.52	5.76
G 302	Patch	15	3 bar	27	4.36	4.79
	Without Ant.	15	No	No	No	No
	APs Antenna	15	3 bar	22	2.01	5.21
G305	Patch	15	3 bar	24	3.75	4.19
	Without Ant.	15	No	No	No	No
	APs Antenna	10	3 bar	28	5.24	7.86
Workshop	Patch	10	3 bar	22	4.56	7.72
	Without Ant.	10	No	No	No	No
	APs Antenna	8	3 bar	28	9.13	10
Lecturer room	Patch	8	2 bar	33	5.13	7.79
	Without Ant.	8	No	No	No	No
	APs Antenna	8	3 bar	28	9.13	9.43
G303	Patch	8	2 bar	33	1.76	4.68
	Without Ant.	8	No	No	No	No

4. CONCLUSION

A small antenna patch for internal access point operating in 2.4 GHz band is proposed. Antenna have stable omnidirectional pattern and linier polarization. The measured -10 dB bandwidth is 755 MHz, and 2.5 dBi gain. Test results show the antenna performance is still below conventional antennas, but the antenna able to cover the entire area in the G building which is a typical building on the office, school or university. The dimensions of the antenna is 42x28x1.6 mm which allowingthe antenna to be hidden in the access point device by integrating it with the printed circuit board.

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