Bandwidth Enhancement in the Design of Triple Band Printed Dipole Antenna for LTE Base Station

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***Abstract*— In this research, the design of triple band printed dipole antenna is modified to enhance the antenna bandwidth and adjust its operating frequency range into the LTE allocated frequency band in Indonesia. The radiating elements of antenna are geometrically modified to adjust the bandwidth and resonant frequency range. The LTE frequency bands for Indonesia are taken as the reference frequencies. The design is initially assessed by using numerical simulation, then fabricated and empirically evaluated. The results shows that the proposed antenna can performs 81% in 900 MHz, 79% in 1,800 MHz, and 92% in 2,300 MHz which much better than previous reference design. The resonant frequency range of antenna also more compatible to allocated frequency bands.**

***Keywords*—LTE, printed antenna, printed dipole, triple-band, planar, antenna design, base station antenna.**

I. Introduction

An important issue related to the implementation of 4G LTE communication systems in Indonesia is the obligation to include local components in all telecommunication equipments. The government regulation states all equipments operated in Indonesian territory have to achieve at least 30% of domestic component level (DCN) [1] that show the procentage of local product components. A possible component in telecommunication devices to be domestically designed and fabricated is antenna. Consequently, the researches on LTE antenna become demanding topics and attract large attention among researchers and academia.

The microstrip becomes the most popular antenna type among the recent published designs because it is relatively easy to design and fabrication but has good radiation performance as in [2], [3]. The basic material of antenna is printed circuit board (pcb) that easy to find in Indonesia market, so it is also called as printed antenna. Previously, we have designed a kind of printed antenna for indoor base station on LTE systems. A printed dipole is preferable in this design to perform pure linear polarization [4], [5]. As results, double and tripple band have been carried out into antenna prototypes and match with frequency bands for LTE as reported in [6], [7], respectively. Unfortunately, the frequency response of antenna has some discrepancy with the frequency allocation in Indonesia. Therefore, a modification to match with bandwidth and frequency allocation is still required in further investigation.

This paper is proposed the bandwidth enhancement of printed dipole antenna with triple band at 900, 1,800, and 2,300 MHz frequencies band [7], [8]. The enhancement was carried out by adjusting the length and width of radiating element to match with the LTE frequency allocation in Indonesia.

II. Methodology

The design process is initiated by simulating antenna on antenna simulator software that allows multiple trials with almost no additional cost. The dimension of antenna is defined in this process and the radiating performance is evaluated as well. After completing the simulated design, antenna prototype can be fabricated and its performance is evaluated through measurement campaign.

A. Geometrical Structure of Antenna

The designed antenna is triple band printed dipole antenna. As depicted in Fig. 1, the antenna consists of three elements with different width and length to match with three different frequency bands. The initial dimension of each radiating element is calculated by the formula of basic dipole antenna [9]. There are three working frequency bands, i.e. 824-960 MHz, 1,710-1,880 MHz, and 2,300-2,400 MHz. The center frequency of each band can be easily calculated as 892 MHz, 1,795 MHz and 2,350 MHz. Then they are used for calculation antenna dimension by using the dipole antenna formulae [10]. After the initial dimension can be defined, the antenna simulation is carried out to optimize the radiation characteristic on antenna on three designate frequency bands. The calculations of initial dimension of radiating element length are listed below:

- First element (center frequency of 892 MHz)

$$\lambda_A = \frac{c}{f} = \frac{3x10^8}{8.92x10^8} \cong 0.336\, m = 336\, mm$$

$$h_A = \frac{336}{2} = 168\, mm$$

$$P_A = \frac{168}{2} = 84\, mm.$$

- Second element (center frequency of 1,795 MHz)

$$\lambda_B = \frac{c}{f} = \frac{3x10^8}{17.95x10^8} \cong 0.167\, m = 167\, mm$$

$$h_B = \frac{167}{2} = 83.5\, mm$$

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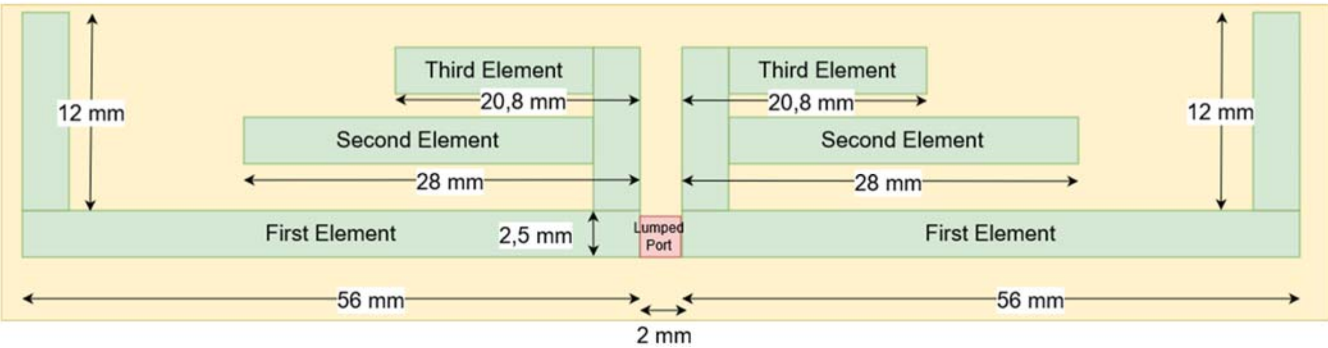


Fig. 1 Antenna design.

$$P_B = \frac{83.5}{2} = 41.75\ mm.$$

- Third element (center frequency of 2,350 MHz)

$$\lambda_C = \frac{c}{f} = \frac{3x10^8}{23.5x10^8} = 0.12765\ m = 127.65\ mm$$

$$h_C = \frac{127.65}{2} = 63.825\ mm$$

$$P_C = \frac{63.825}{2} = 31.9125\ mm.$$

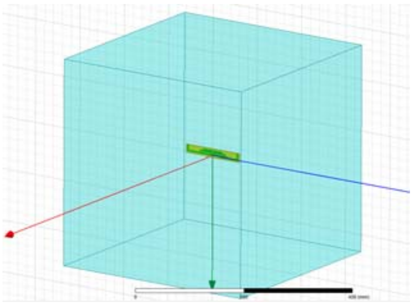


Fig. 2 Simulation design.

The antenna has three radiating element with different lengths. The element for 900 MHz frequency band is the longest one. To reduce to antenna size, it is formed in folded form as shown in Fig. 1. After defined the length radiation element, the simulation is conducted in which the spacing among elements have to be adjusted to match the impedance.

B. The Antenna Simulation

Numerical simulation is conducted in the antenna simulator by applying the calculated dimension as the radiating elements. Then the design is completed by adding substrate, port, and other supporting parameters.

First, the radiating element modelling is drawn according to the calculation, with the antenna shape as in Fig. 1. In the picture, substrate has 12 cm long and 1.6 cm wide. The substrate placed below the radiating element with port in its center.

In the design, antenna uses FR4 Epoxy type for substrate. This type is selected because it is easily found in the market and low cost. The susbtrate has thickness 1.6 mm and relative permitivitty 4.7 as the common value in the material in the market [11].

The next step, the radiation box is set to fit the air filled material. The box size is set at one wavelength of the low boundary of operating frequency, which is 900 MHz. The calculated length is $(37.5\ cm)/2 = 18.75\ cm$ or can be rounded to 20 cm or 200 mm as in [12]. Fig. 2 is the result of the antenna design along with the radiation box surrounding the antenna.

TABLE I
OPTIMIZED ANTENNA DIMENSIONS

Operating frequencies	Total length of radiating elements	Radiating element width
900 MHz	68 mm	2.5 mm
1,800 MHz	28 mm	2.5 mm
2,300 MHz	20.3 mm	2.5 mm

C. Optimation of Antenna Design

After drawing the antenna geometry, some simulation parameters should be determined such as sweep parameters, infinite sphere, etc. After accomplishing set-up, the simulation can be executed.

The successful design can be achieved if the antenna can work in the proper frequency band. Since it is triple band antenna, the antenna has to match in all designated frequency bands. Although, the antenna dimension is theoretically calculated on the assumption that antenna is independence and ideal shape. Since the antenna is modified and closely collocated among radiating elements, the resonant frequencies of antenna is possibly changed. However, this change is sophisticated in the theoretical analytics, so it is solve in this simulation works [13]. In the simulation, some adjustments on antenna dimension are made by trial and error.

Table I shows calculation results of radiating element antennas after adjustment in the simulatioan.

In the antenna simulator, it is necessary to display return loss (S11), VSWR, Smith chart, and radiation patterns. The result parameters are used in comparison analysis and made it is easier to find a good value on the design when adjusting the antenna parameters.

D. Antenna Fabrication

After accomplishing the simulation, the antenna design is sent to printing press for etching it on the PCB. As defined in the simulation, the PCB is made from FR4. In addition, the fabricated antennya also equipped by SMA connector as antenna input feeder [14], [15], as shown in Fig. 3.

E. Measurement Campaign

Measurement campaigns are conducted to assess the performance of fabricated antenna. They are carried out at the High Frequency System Lab. at the Department of Electrical and Information Engineering, Universitas Gadjah Mada.

Fig. 3 Results of antenna fabrication.

Fig. 4 Antenna testing.

Fig. 4 is condition of meausurement. The test consists of two parts, i.e. reflection and transmission [16]. Reflection tests are done to measure return loss, VSWR, and Smith chart. While transmission tests are acquiring antenna radiation patterns. Data were stored and then combined to obtain radiation patterns.

III. Results and Discussion

In this section, the results of measurement are discussed and analysed. The comparison between the proposed antenna and prior design is also analysed.

A. Return Loss Analysis

Fig. 5 shows the reflection coefficients of antenna gained from the simulation. The graph of reflection coefficient represents the resonant frequency and bandwidth of antenna. The resonant frequency of each radiating element calculated from measuremen data is listed in Table II. The table also contains the frequency allocation of 4G in Indonesia for the frequency design reference. The performance of antenna before optimization published in [7] and written in Table II as comparison for evaluation the optimization performance.

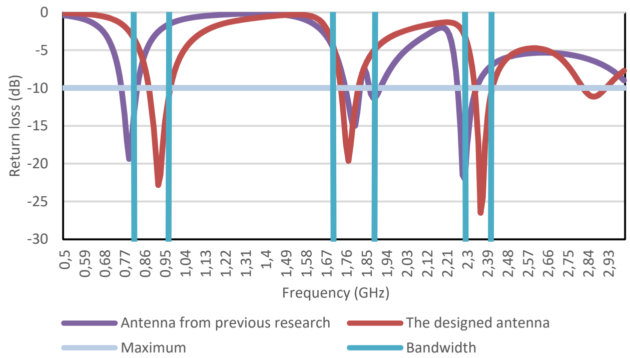


Fig. 5 Graph of return loss simulation results.

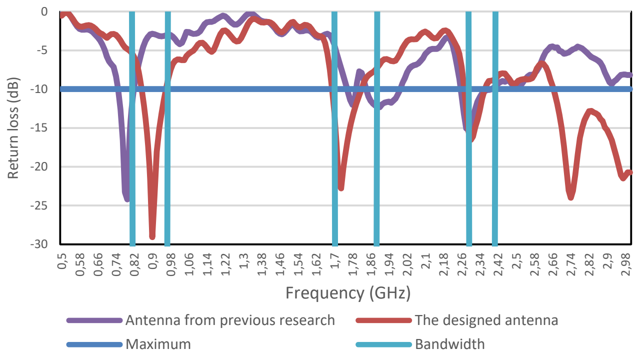


Fig. 6 Graph of return loss test results.

From data in Table II, it can be seen that the bandwidth enhancement perform improvement on two channel of 900 and 1,800 MHz, whilts in 2,300 MHz the performance is a bit decreased, but it still above 80% bandwidth coverage.

Fig. 6 depicts the return loss acquired by measurements. In the graph, it appears that the measurement results have irregular return loss and bandwidth results and much fluctuated than simulation since the measurement is not in radio anechoic chamber where the uncontrollable interferenceis may appearred. The measured resonant frequency and bandwidth from measurement campainn are summarized in Table III. It can be found that the prior design [7] still has some discrepancies with the allocated frequency of LTE systems. The resonant frequency can be found in all designated band, but the bandwidth is not totally covered by the antenna. Especially the 1,800 MHz band, it is only about 23.5% covered by the design. Somehow the 2,300 MHz band coverage is excellent up to 138%.

The proposed optimized model has better performance than previous design. It has coverage 81%, 79%, and 92% for 900 MHz, 1,800 MHz, and 2,300 MHz respectively. The return loss in resonant frequency is also lower than prior

TABLE II
RETURN LOSS DATA FROM ANTENNA SIMULATIONS

4G Frequency in Indonesia [1]				Resonance frequency of previous research antenna [7]				Resonance frequency of designed antenna			
FL (MHz)	FH (MHz)	Df (MHz)	%	FL (MHz)	FH (MHz)	Df (MHz)	%	FL (MHz)	FH (MHz)	Df (MHz)	%
824	960	136	100	731	786	55	40.44	**878**	**974.5**	**96.5**	**70.95**
1,710	1,880	170	100	1,731	1,785	54	31.76	**1,735.5**	**1,814.5**	**79**	**46.47**
2,300	2,400	100	100	**2,264**	**2,352**	**88**	**88**	2,332.7	2,413.5	80.8	80.8

TABLE III
RETURN LOSS DATA FROM ANTENNA MEASUREMENTS

4G Frequency in Indonesia [1]				Resonance frequency of previous research antenna [7]				Resonance frequency of designed antenna			
FL (MHz)	FH (MHz)	Df (MHz)	%	FL (MHz)	FH (MHz)	Df (MHz)	%	FL (MHz)	FH (MHz)	Df (MHz)	%
824	960	136	100	750.24	820.36	70.11	51.55	**852.41**	**962.60**	**110.18**	**81.01**
1,710	1,880	170	100	1,757.92	1,797.99	40.067	23.56	**1,689.81**	**1,824.03**	**134.22**	**78.95**
2,300	2,400	100	100	**2,256.76**	**2,394.99**	**138.23**	**138.23**	2,272.78	2,364.94	92.15	92.15

TABLE IV
VSWR DATA FROM ANTENNA SIMULATIONS

Resonance frequency of previous research antenna [7]					Resonance frequency of designed antenna				
FL (MHz)	**FH (MHz)**	**Df (MHz)**	**max**	**min**	**FL (MHz)**	**FH (MHz)**	**Df (MHz)**	**max**	**min**
824	960	136	20.30	4.85	**824**	**960**	**136**	**4.55**	**1.15**
1,710	1,880	170	10.60	3.10	**1,710**	**1,880**	**170**	**3.46**	**1.23**
2,300	2,400	100	8.09	2.32	**2,300**	**2,400**	**100**	**4.44**	**1.09**

TABLE V
VSWR DATA FROM ANTENNA MEASUREMENTS

Previous research [7]					Design results				
FL (MHz)	**FH (MHz)**	**Df (MHz)**	**max**	**min**	**FL (MHz)**	**FH (MHz)**	**Df (MHz)**	**max**	**min**
824	960	136	6.12	1.97	**824**	**960**	**136**	**3.08**	**1.07**
1,710	1,880	170	3.41	1.66	**1,710**	**1,880**	**170**	**2.44**	**1.16**
2,300	2,400	100	**1.95**	1.47	2,300	2,400	100	2.13	**1.35**

design. It can be concluded that the optimation can improve the antenna performance.

From the analysis, the proposed antenna is capable of performing greater bandwidth than the previous design in the 900 MHz frequency field and 1,800 MHz for both in simulation and in real implementation. However, at a frequency of 2,300 MHz the designed antenna has less he bandwidth than the previous one.

The results of simulation and measurement show that the proposed antenna has better performance than the reference one. However, further modification is still required to have bandwidth that covers all LTE frequency bands.

B. VSWR Analysis

The performance of antenna can also be represented by voltage standing wave ratio (VSWR) that can be computed by simulation or measured by vector network analyser. The VSWR in simulation and measurement are shown by Fig. 7 and Fig. 8 respectifully. The graph only shows the VSWR up to 5 for clarity of graph.

As reminder, the VSWR has expected in range between 1-2 for good power transfer from transmitter for transmitting antenna to the air or from the air to receiver for receiving antenna.

Considering the frequency ranges of LTE allocation, the VSWR's of antenna on those frequencies are summarized in Table IV and Table V. Table IV is VSWR obtained from the simulation and compared to the reference antenna. It can be seen, the VSWR value for all bands does not entirely satisfy with the requirement of 1-2. However, the proposed antenna optimation can give improvement. The minimum and maximum VSWR of proposed antenna is significantly lower than the reference antenna. To get more convicting results, it can be analyzed from the measured data acquired in the measurement campaign as listed in Table V. The new design has minimum VSWR closed to unity and much lower than the reference antenna. However, it can be found some values more than 2 that still higher than the standard operating VSWR. From the analyses, it can be concluded that the proposed optimation can improve the VSWR but it still needs

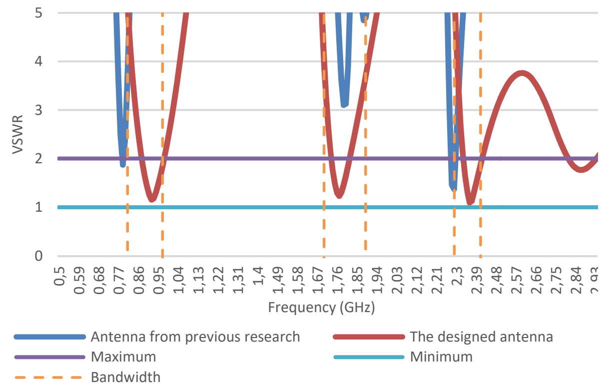


Fig. 7 Antenna VSWR simulation results.

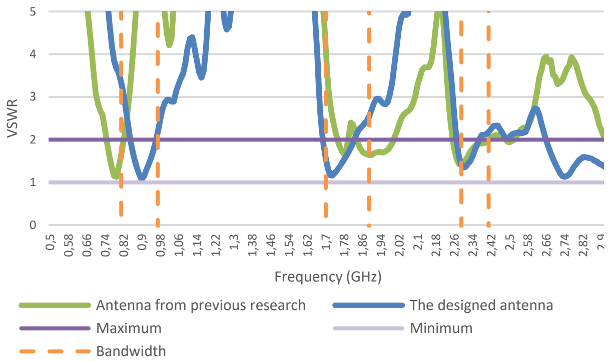


Fig. 8 Antenna VSWR test results.

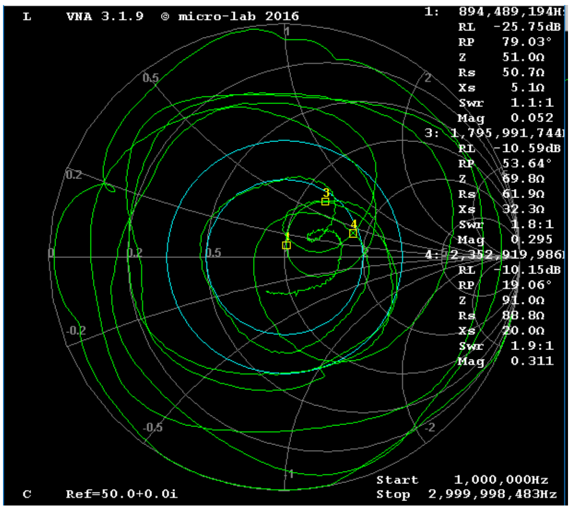
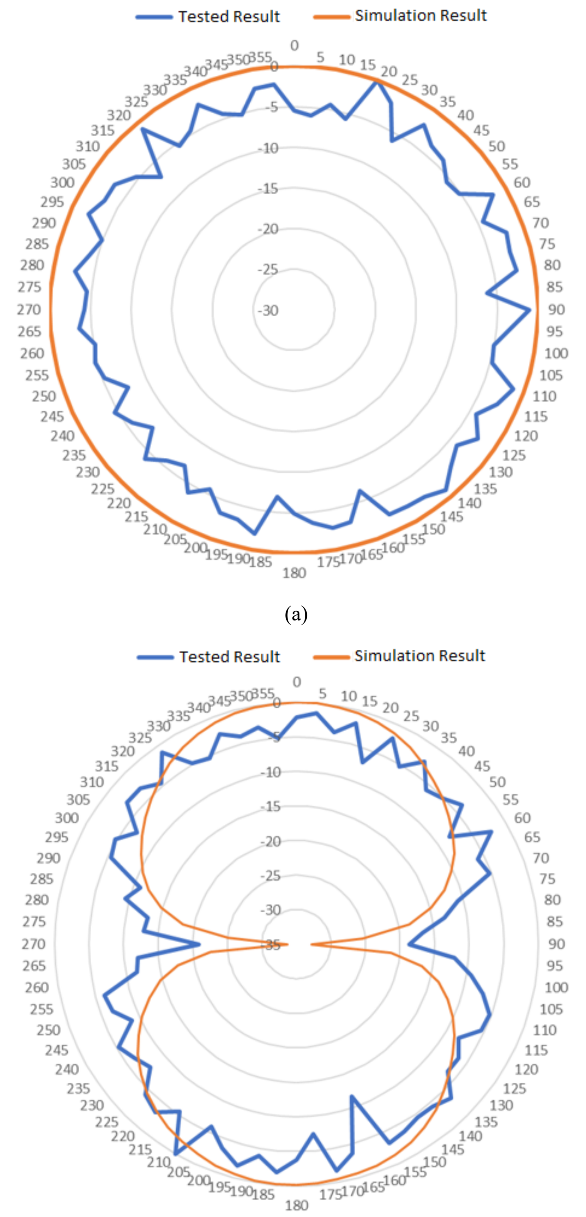


Fig. 9 Smith chart of designed antenna.

further improvement to achieve impedance match in all designated frequency band.

The other representation of design result is Smith chart as depicted in Fig. 9. Basically the chart graphically shows impedance and resonant characteristic of antenna. The low VSWR can be easily observed by line near the chart center. Since it is triple band antenna, the graph contains many circles that somehow give some difficulty on analysis. However, in the Smith chart on the interface of VNA can help the designer to adjust the resonant zone of antenna. In the Smith cart in Fig. 9, it is ulized markers to pop up the value of any desired point.



(a)

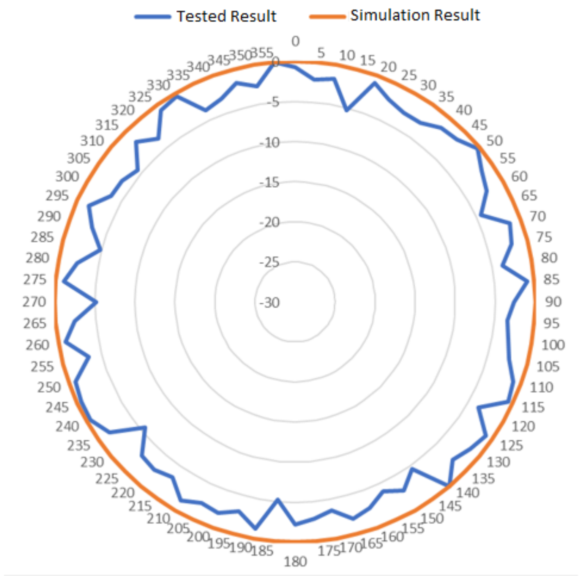
(b)

Fig. 10 Results of the 900 MHz frequency radiation pattern, (a) H-plane, (b) E-plane.

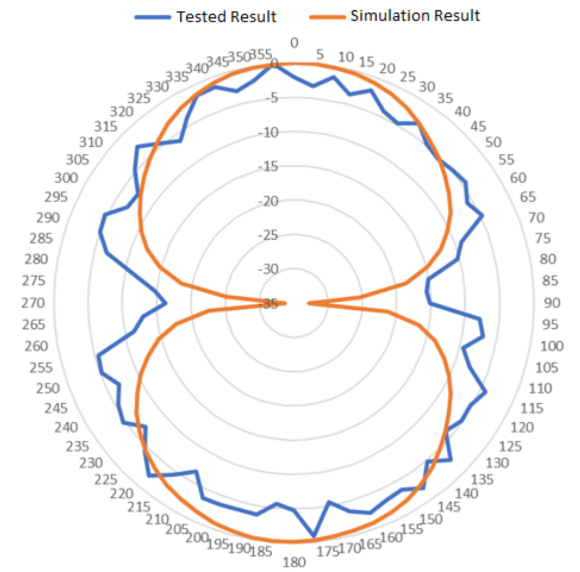
Three markers in figure show the resonant zone with frequency 894.5 MHz, 1,795.9 MHz, and 2,352.9 MHz.

C. *Radiation Pattern Analysis*

Radiation pattern analysis is carried out by comparing the simulation to measurement results. The pattern for frequency bands 900 MHz, 1,800 MHz, and 2,300 MHz are shown in Fig. 10, Fig. 11, and Fig. 12, respectively. It should be noticed that the radiation patterns are always normalized to their maximum value to easy the understanding of pattern comparisons. In each frequency, there are two types of pattern that are E-plane and H-plane. E-plane is defined as the plane parallel to the length of radiating elements, while H-plane is perpendicular plane to length of radiating elements.

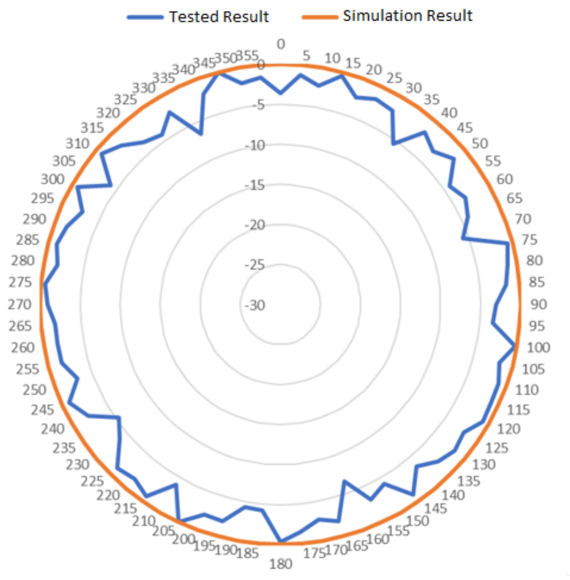


(a)

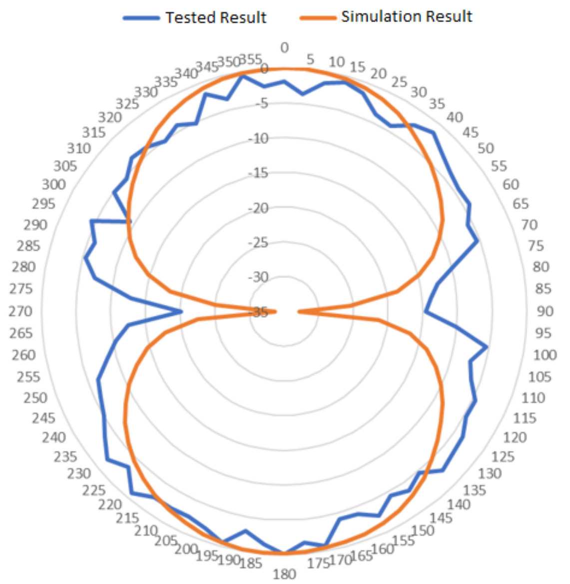


(b)

Fig. 11 Results of the 1,800 MHz frequency radiation pattern, (a) H-plane, (b) E-plane.



(a)



(b)

Fig. 12 Results of the 2,300 MHz frequency radiation pattern, (a) H-plane, (b) E-plane.

Since the antenna is basically a dipole antenna, so the pattern is analogous to dipole antenna pattern. The E-plane pattern of dipole antenna is theoretically directional and has two main lobes in the direction of antenna tips, whilst the H-plane is omnidirectional.

The radiation patterns in all frequency bands as depicted in Fig. 10 to Fig. 12 are agree with the theoretical patterns. The simulated patterns are smooth line but the measured patterns have ripples. They are probably caused by the low power of the transmitted power of VNA and large distance of transmitter and receiver so that the effect of interference has strong to measurement results. It should be noticed that the measurements are done in the laboratory room that is not equipped with any radio absorbers. However, the patterns are tended to agree with the simulation and theoretical patterns as well.

In general, the triple antenna is properly designed and bandwidth enhancement is successfully achieved. However, the frequency coverage cannot cover all range of designated bands. Thus further improvement is still required, and it remains for future works.

IV. Conclusion

The triple-band printed dipole antenna has been successfully designed by considering the allocated frequency band for LTE systems in Indonesia, i.e. 824 MHz - 960 MHz, 1,710 MHz – 1,880 MHz, and 2,300 MHz – 2,400 MHz. The antenna structure consists of three dipole elements with different length to obtain resonance in each frequency band. The radiating element for the lowest frequency is the longest one and it is folded to reduce the antenna size. The size of radiating elements has also been modified to enhance the antenna bandwidth. As results, the antenna bandwidths can cover up to 81%, 79%, and 91% for 900 MHz, 1,800 MHz, and 2,300 MHz respectively frequency. Those bandwidths are larger than the reference antennas with similar structures, except for the 2,300 MHz, but it still has good frequency coverage. In addition, the simulated and measured radiation patterns agree with the theoretical patterns of dipole antenna.

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