Yagi Biquad Antenna Design for 4G LTE in 2100 – 2400 MHz Frequency Band

R Adhita Mahardika[1], Suwasti Broto[2]
{suwasti.broto@budiluhur.ac.id[1]}

Faculty of Electrical Engineering Universitas Budi Luhur, Jl. Ciledug Raya, Jakarta, Indonesia[1,2]

Abstract. Long Term Evolution (LTE) technology is the latest standard of mobile network technology. The results showed that LTE was able to provide downlink speeds up to 100 Mbps and uplink speed up to 50 Mbps. In Indonesia, especially in Jabodetabek area, there were already provider of 4G LTE service. In practice, 4G LTE service was not yet stable, there were some areas that had not been reached 4G internet signal. This because of 4G signal that was easily influenced by the surrounding conditions, such as the presence of high buildings, trees, or rooms which block 4G signals. To solve this problem, an additional antenna for LTE 4G modem was required as a means to increase coverage areas that were not getting 4G LTE signal. One of the antenna made in this research was Biquad Yagi type antenna. The basis of this study, which aimed to create yagi antenna with biquad inside the director, used a working frequency of 2100 MHz – 2400 MHz. With a good Reflection Factor (S11) value used (<-10 dB) to provide additional signal coverage of 4G LTE. The designed system parts consisted of PCB, copper wire, and RP-SMA Connector. The design of this antenna was first simulated by using WIPL-D software and after the expected result obtained, then it was fabricated by using part of the designing system. The antenna worked by connecting the modem with the antenna as an external antenna of 4G LTE modem.

Keywords: yagi-uda antenna, biquad antenna, WLAN antenna, HSDPA, 4G LTE.

1 Introduction

The name 4G is widely used to cover several types of broadband wireless access communication systems, not just cell phone systems [1].

LTE is a 4G Wi-Fi broadband technology developed with reference to the previous generation of 3GPP [2],[3].

In Indonesia, especially in Jabodetabek area, there are already operators who provide 4G LTE service. In practice, 4G LTE service is not yet stable, there are some areas that have not reached by 4G internet signal. This is because the 4G signal is easily influenced by surrounding conditions, such as the presence of high buildings, trees, or rooms that block 4G signals.

To solve the above problem, an additional antenna needs to be made on 4G LTE modem as a means to increase coverage areas that are not getting the 4G LTE signal [4]. One of the antenna to be discussed in this research is biquad yagi antenna type. With its advantage of having a good directivity diagram antenna as well as the design of two squares (Biquad) on each antenna director, it is expected to enlarge the maximum bandwidth and reduce the decrease of radiation pattern at higher frequencies. From those advantages of yagi antenna, the

WMA-1 2018, January 20-21, Indonesia

DOI 10.4108/eai.20-1-2018.2281873

design of yagi antenna will use the frequency bands between 2100 – 2400 MHz where the frequency is benefitted by the operator x in 4G LTE service.

1.1 Waves Electromagnetic Waves

Electromagnetic waves are waves that have electrical properties and magnetic properties simultaneously. Radio waves are part of the electromagnetic waves in the radio frequency spectrum.

Waves are characterized by wavelength and frequency. The wavelength (λ) is related to the frequency (f) and the fast light velocity (c) as shown in Equation 1. [5]

$$\lambda = \frac{c}{f} \tag{1}$$

where:
λ = wavelength (m)
c = fast light velocity (m/s)
f = frequency (Hz)

One of the frequency spectrum of electromagnetic waves is radio waves. This radio frequency spectrum is required to know which bands enter in the design of yagi biquad antennas. The distribution of the radio frequency spectrum is shown in Table 1.

Table 1. Radio Frequency Spectrum.

Name of Band	Abbrevi-ation	ITU Band	Frequen-cy (f)	Wavelength (λ)
Extremely Low Frequency	ELF	1	3 – 30 Hz	10.000 km – 100.000 km
Super Low Frequency	SLF	2	30 – 300 Hz	1000 km – 10.000 km
Ultra-Low Frequency	ULF	3	300 – 3000 Hz	100 km – 1000 km
Very Low Frequency	VLF	4	3 – 30 KHz	10 km – 100 km
Low Frequency	LF	5	30 – 300 KHz	1 km – 10 km
Medium Frequency	MF	6	300 – 3000 KHz	100 m – 1 km
High Frequency	HF	7	3 – 30 MHz	10 m – 100 m
Very High Frequency	VHF	8	30 – 300 MHz	1 m – 100 m
Ultra High Frequency	UHF	9	300 – 3000 MHz	100 mm – 1 m
Super High Frequency	SHF	10	3 – 30 GHz	10 mm – 100 mm
Extremely High Frequency	EHF	11	30 – 300 GHz	1 mm – 10 mm

1.2 Important Quantity of Yagi Antenna

The maximum range of yagi antennas is largely determined by Driven, Reflector, and Director. Here is the important quantity of yagi antennas:

a. Driven is the supply point of the antenna cable. The formula for calculating the total length of yagi biquad Driven is as follows:

$$\mathbf{L = 1/4 \times K \times \lambda} \tag{2}$$

Where:
λ = the wavelength in air (m)
L = the length of Driven Element (m)
K = the velocity factor in the metal taken for 0.95 [6]

Modifying the Driven sections will cause changes in the frequency of reception power, maximization of the capture power is determined by metal material of this section.

b. The reflector is the back antenna that acts as a signal reflector, with a physical length of 7% longer than Driven Element.
Modifying the Reflector section will affect the signal capture direction, this will serve to reflect the signal to the Driven section. Modification in this section can be done by widening the area, but in the expansion, it needs adjustment by adding the length of the director also.

c. The director is which directing the antenna. Adding the director rod will increase the antenna gain, but it will make the antenna alignment pattern narrower. The more number of directors, the narrower the direction. The length of the director is 5% shorter than the Driven Element.

d. The boom is a driven part of the drive, the reflector, and the director. The boom is a metal or wooden rod that runs along the length of the antenna.

1.3 Parameter of Yagi Antenna

The parameters of Yagi antenna are as follows:

a. Radiation Patterns
The antenna radiation pattern is as a quantity to determine the angle in which the antenna emits its electromagnetic energy.

b. Polarization
An orientation description of electric field in the propagation direction. Polarization can also be interpreted as a form of electric field movement over time. The polarization of an antenna informs the direction in which the electric field has an orientation in its propagation

c. Gain
One of the important parameter to measure the antenna quality is gain. A gain of antenna is one of important quantity and characteristics in designing an antenna.

d. Reflection Factor
The reflection factor (return loss) is the ratio of the amplitude of reflected wave from the amplitude of transmitted wave. The value of a good return loss is below -9.54 dB, this value is obtained for VSWR ≤ 2 so that it can be said that the reflected wave value is not too large compared to the transmitted wave or in other words, the transmission line is matching. The value of this parameter becomes one of the reference to see whether the antenna has been able to work at the expected frequency or not.

e. Voltage Standing Wave Ratio (VSWR)
VSWR is the ratio between the maximum and minimum voltage on a standing wave due to the reflection of the wave caused by the difference of its antenna input impedance with the feeder channel. In general, the value of VSWR which is still considered to be good is VSWR ≤ 2.

f. Antenna Bandwidth
The bandwidth of an antenna is defined as the frequency interval, in which the antenna works in accordance with which specified by the given specification.

2 Antenna Design

In designing Biquad Yagi antenna, there will be some important steps that will be conduct to create an antenna that matches the expected specification. Some of the steps are described in the design flow diagram and the fabrication of Biquad Yagi antenna that will be used in this research as shown in Figure 1.

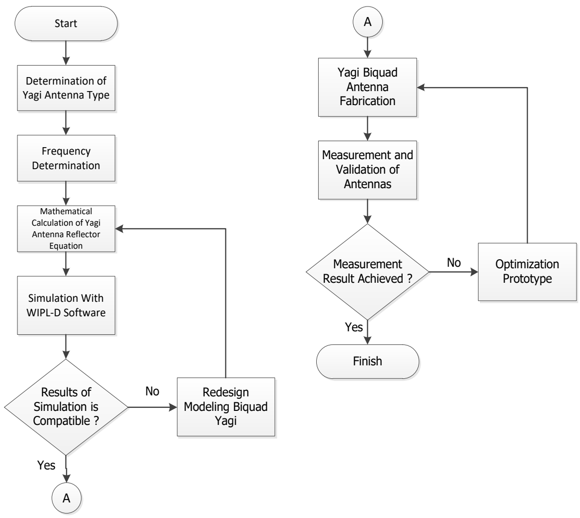

Fig. 1. Flowchart Design and Fabrication of Yagi Biquad Antenna.

2.1 Determination of Yagi Antenna Type and Specification

In the determination of this yagi antenna type is including the number of yagi antenna elements to be create and the shape of the antenna. It is intended that the antenna is made in accordance with the working frequency of 4G LTE 2100 – 2400 MHz. In designing this yagi antenna, 7 elements will be used consist of reflector, driven element, and 5 director by using type biquad with length of element $\lambda / 4$.

The Biquad Yagi antennas that will be create is in the following specifications:
- ❖ Frequency : 2100 MHz – 2400 MHz
- ❖ Impedance : 50 Ω

- ❖ VSWR : ≤ 1.3
- ❖ Radiation Pattern : Bi-directional
- ❖ Polarization : Linier (Vertical)
- ❖ Gain : ±10 dB

The material used in creating Yagi Biquad antenna is copper wire, which has the following specifications:

- ❖ Goods relitivity s (εr) : 1
- ❖ Wire thickness : ± 1.5mm

2.2 Determination of Work Frequency of Yagi Biquad Antenna

In Indonesia region, the work frequency of 4G LTE which is currently held by the government is at frequency of 2300 MHz. Thus on this design the frequency 2100 – 2400 MHz will be made.

2.3 Mathematical Calculations for Determining Wavelength and Yagi Biquad Antenna Dimensions

Before conducting further design, at first determine the λ (wavelength) value, which can be obtained from equation (1) with the value of c (3 x 108) and f of 2100 MHz.

$$\lambda = \frac{c}{f} = \frac{3.10^8}{2,1.10^9} = 0.14 \text{ m} = 14 \text{ cm}$$

where:
λ = Wavelength in air (m)
c = fast light velocity (m/s)
f = frequency (Hz)

In creating antenna Yagi Biquad, each side of the antenna has a length of l/4. According to Antenna System Engineering book (2013: 104) on the Yagi antenna, it can generally be summarized as follows:

a. Driven Element on biquad type has a length of ¼ λ (lambda). To calculate the total length of a Yagi Driven Element, it can be found using equation (2).
   L = 1/4 x K x λ
   where:
   λ = the wavelength in air (m)
   L = the length of Driven Element (m)
   K = the velocity factor in the metal taken for 0.95 [6]
   Thus the length of Driven Element is:
   L = ¼ x K x λ = ¼ x 0,95 x 14 cm = 3,325 cm

b. Reflector length is made approximately 7% longer than Driven Element. Thus the length of Reflector is:
   L + (7% x L) = 3,325 + (7% x 3,325) = 3,55 cm

c. The length of Director 1 is made 5% shorter than Driven Element. Thus to create Yagi that has more than 3 elements, the next Director (Director 2) is usually cut a little shorter than Director 1. Similarly with Director 3, Director 4, and so on.
Hence, the length of Director 1 – 5 is as follows:
Director 1 = 3,325 – (5% x 3,325) = 3,2 cm
Director 2 = 3,325 – (7% x 3,325) = 3,1 cm
Director 3 = 3,325 – (9% x 3,325) = 3 cm
Director 4 = 3,325 – (11% x 3,325) = 2,9 cm
Director 5 = 3,325 – (13% x 3,325) = 2,8 cm
To determine the distance of each element is as follows:
– To obtain the greatest gain is if the distance between Driven Element with Reflector is about 0.2 λ - 0.25 λ
– To obtain a good coupling between Driven Element with Director 1, then Director 1 should be placed as far as 0.1 λ - 0.15 λ from Driven Element.
– For Director 2 is placed as far as 0.15 λ - 0.2 λ from Director 1.
– For Director 3 is placed as far as 0.2 λ - 0.25 λ from Director 2. And so on for Director 4 and 5.

Table 2. Length of Each Yagi Element Based on Calculations.

Element Name	Symbol	Length of Element (cm)	Distance Between Element (cm)
Reflector	R	3,55	1,9
Driver Element	DE	3,325	1,7
Director 1	D1	3,2	1,7
Director 2	D2	3,1	1,7
Director 3	D3	3	1,7
Director 4	D4	2,9	1,7
Director 5	D5	2,8	1,7

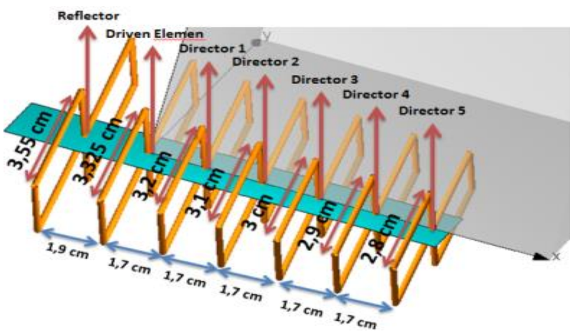

Fig. 2. The Dimensions of Each Yagi Element Based on the Calculations.

2.4 Simulation of Biquad Yagi Antenna with WIPL-D Software

In the initial design according to Table 2, then it compares to several different element length and spacing elements. It is necessary to determine the element's length and distance of the element based on the measurement of best reflection factor. In Table 3 there are four simulations of different elements lengths.

Table 3. Simulation Table of Yagi Biquad Antenna Calculations.

SIMULATION 1				SIMULATION 2			
Element Name	Symbol	Length of Element (cm)	Distance Between Element (cm)	Element Name	Symbol	Length of Element (cm)	Distance Between Element (cm)
Reflector	R	3,55	3,5	Reflector	R	3,55	1,9
Driver Element	DE	3,325	2,1	Driver Element	DE	3,325	1,7
Director 1	D1	3,2	2,8	Director 1	D1	3,2	1,7
Director 2	D2	3,1	3,5	Director 2	D2	3,1	1,7
Director 3	D3	3	3,5	Director 3	D3	3	1,7
Director 4	D4	2,9	3,5	Director 4	D4	2,9	1,7
Director 5	D5	2,8	3,5	Director 5	D5	2,8	1,7

SIMULATION 3				SIMULATION 4			
Element Name	Symbol	Length of Element (cm)	Distance Between Element (cm)	Element Name	Symbol	Length of Element (cm)	Distance Between Element (cm)
Reflector	R	3,8	1,9	Reflector	R	4	1,9
Driver Element	DE	3,6	1,7	Driver Element	DE	3,6	1,7
Director 1	D1	3,4	1,7	Director 1	D1	3,3	1,7
Director 2	D2	3,3	1,7	Director 2	D2	3,3	1,7
Director 3	D3	3,2	1,7	Director 3	D3	3,3	1,7
Director 4	D4	3,1	1,7	Director 4	D4	3,3	1,7
Director 5	D5	3	1,7	Director 5	D5	3,3	1,7

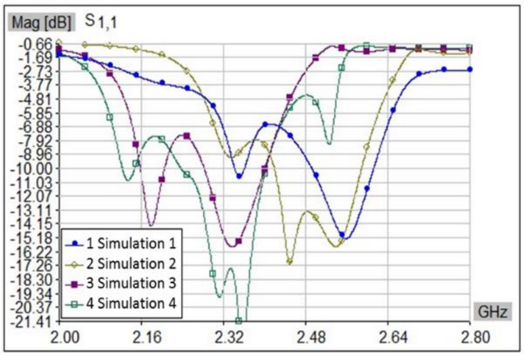

Fig. 3. Comparison of return loss simulation of Yagi Biquad antenna.

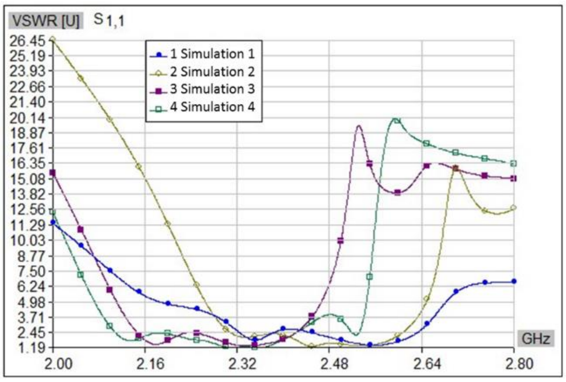

Fig. 4. Comparison of VSWR simulation of Yagi Biquad antenna.

The simulation results in Figures 3 and 4 show that from the simulation of the four types of Yagi Biquad antennas, the best return value and VSWR at 2100 – 2400 MHz are available in simulation 3 and simulation 4, this is because the return loss value <-10 dB and VSWR <2 at the work frequency that will be used. From the simulation result of the radiation pattern in Fig. 5, the most stable emission is found in simulation 3 with the gain as author's specification is ± 10 dB.

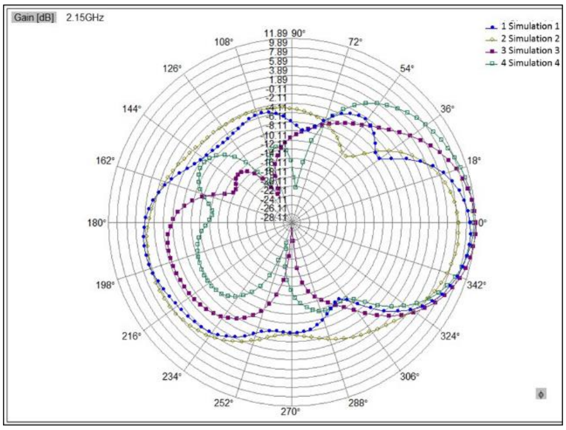

Fig. 5. Diagram of Yagi Biquad radiation at 2.15 GHz frequency.

Here is obtained the detail size of the Yagi Biquad antenna simulation in the *wipl-d* application

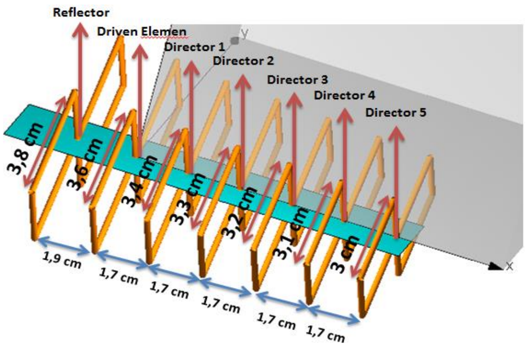

Fig. 6. Yagi Biquad Antenna Design on WIPL-D Viewed from Top.

2.5 Fabrication of Yagi Biquad Antenna

The design will then be fabricated with copper type material. Selection of copper material because it is good enough in terms of conductor and also resistant to rust. Other equipment for fabrication of this antenna is PCB as antenna boom and RP-SMA connector as feeding of an antenna.

This fabrication is done according to the size of the simulation results 3 in Table 3. The preparation of this antenna is done several stages:

1. Making Boom with 3mm size as media of Yagi Biquad placement
2. Creating Element, Reflector, and Director Driver based on the simulation size with four-sided shape like parallelogram, after that the copper pieces are soldered in boom which already made.
3. . Preparing the hole before the reflector for a feeding with size 3 mm.

The results from the antenna fabrication from the top side and side are shown in Figure 7.

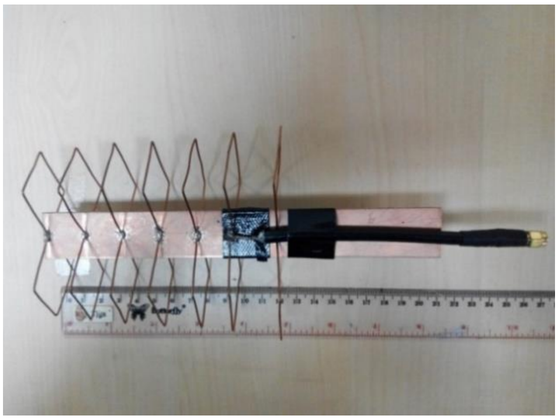

Fig. 7. Yagi Biquad Antenna from The Upper Side.

3 Test and Analysis of Yagi Biquad Antenna

3.1 Measurement of Return Loss and VSWR

The measurement data is obtained by measuring yagi biquad antenna by using spectrum analyser, while the measurement step is as follows:

a. Calibrate the spectrum analyzer along with the coaxial cable used with the calibration kit so that the return loss value is close to zero for all frequencies. This calibration step is very important to get the validity of measurement value as possible, without being affected by the presence of cable attenuation,
b. Connect the yagi biquad antenna to port 1 spectrum analyser using 1m jumper cable.
c. Displays each parameter that wanted to know through the format buttons, then note and record the graph of the measurement results.

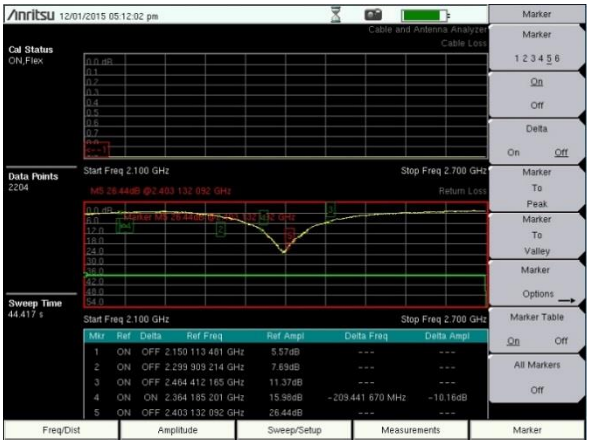

Fig. 8. VSWR Measurement Results of Yagi Biquad Antenna.

Similarly, the measurement of return loss, in Figure 8, a good value of VSWR according to the standard is <2 which at the working frequency of 2364 MHz up to 2464 MHz. The result of return loss measurement and VSWR on Yagi Biquad antenna as a whole is recorded in table 4.

Table 4. Table Measurement of Return Loss and VSWR

	Measurement Standard	Actual Measurement				
		2150 MHz	2300 MHz	2364 MHz	2400 MHz	2464 MHz
VSWR	<2	2,68	3,22	1,51	1,27	1,79
Return Loss	<-10 dB	-5.57 dB	-7.69 dB	-15.98 dB	-26.44 dB	-11.37 dB

3.2 Measurement of Antenna Gain

In this Measurement, the antenna used as a reference antenna is a 4cm dipole antenna that is assumed to have a large gain on isotropes on a conversion value of ± 1.5 dB. The method used in this measurement is referred as the method of comparison with the reference antenna which is using two antennas such as the dipole reference antenna which has a known gain and its antenna to be tested. This test is conducted in Indosat. The antenna gain measurement scheme is shown in figure 9.

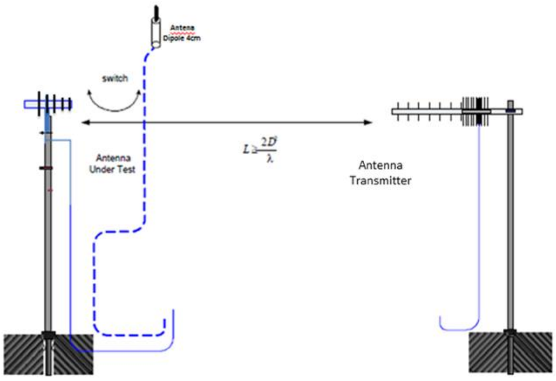

Fig. 9. Gain Measurement Scheme.

Measurement steps of antenna gain:

a. The test antenna is placed as a receiver in the interference-free or lowest interference area. Navigate to the main axis of the radiator pattern. Record the power on the spectrum analyser (dB).

b. Replace the test antenna with dipole antenna as a reference antenna. Record the power on the spectrum analyser.
Compare the two results, then the measured result of the antenna gain is calculated by using the formula:

$$GAUT\ (dBm) = P_{AUT}\ (dBm) - P_{REF}\ (dBm) + 1.5\ (dB) \qquad (4.1)$$

where:
$G_{AUT(dbm)}$ = gain of the measured antenna
$P_{AUT(dbm)}$ = AUT power level received
$P_{REF(dbm)}$ = power level received of the reference antenna

Table 5 is the result of recorded gains that analyse 10 times to obtain more accurate results. The gain is 9.23 dB, which is in a simulated gain is 11.80 dB. This is possible due to the measurement is not on the anechoic chamber.

Table 5. Measurement Results of Gain.

Sample	AUT	REF
1	-35,47	-44,33
2	-34,88	-42,25
3	-35,23	-43,66
4	-36,24	-44,18
5	-36,17	-43,73
6	-37,33	-42,55
7	-36,17	-43,82
8	-35,67	-43,24
9	-35,5	-43,58
10	-35,23	-43,93
Average	**-35,789**	**-43,527**
Gain = P_{AUT} (dBm) - P_{Ref} (dBm) + 1.5 dB		
Gain = 9.23 dB		

3.3 Analysis of Measurement Result

In the above measurement results, it is obtained the reflection factor is in accordance with the standard that the working frequency is 2364 MHz - 2464 MHz where the return loss value of 11.37 dB – 26 dB with a good VSWR value of 1.27. From the actual measurement results, there is change in the frequency simulation, this is caused by several factors such as:

1. Cable impedance, this input impedance value is very important to achieve a matching conditions when the antenna is connected to a voltage source, so that all signals sent to the antenna are properly transmitted.

2. Differences in the distance between elements that have different millimetres and solder in each element to the boom is not neat and clean.

3.4 Yagi Biquad Antenna Testing

The test conditions are performed on an empty field to find out how far the reach increase of a portable modem after using yagi biquad antenna by pairing a yagi biquad antenna to an external antenna port on a portable modem. The modem used in this test is the Huawei E5372s Bolt modem. The test scheme can be seen in Figure 10.

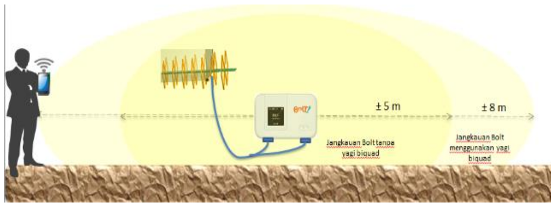

Fig. 10. Scheme of Yagi Biquad Antenna Testing.

Figure 10 shows a range increase of ± 3 m, this method is taken by making the handset or laptop as a medium to know the quality of Wi-Fi on the modem by using the application speed test and shift the place until the handset or laptop device does not get Wi-Fi signal from the modem. In Figure 11 shows the difference in the quality of data rates between modems that do not use yagi biquad antennas and those using yagi biquad antennas.

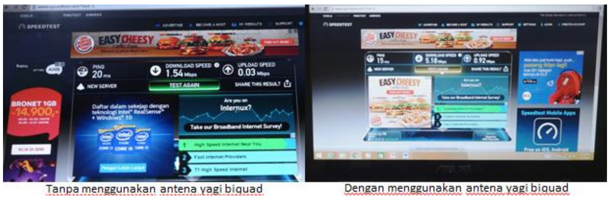

Fig. 11. Comparison of Data Quality Speed.

The result of range and data quality increase is not very significant because the antenna is working at 2364 MHz – 2464 MHz, while the working frequency of the modem tested is at 2300 MHz frequency with 15 MHz bandwidth.

4 Conclusion and Suggestion

4.1 Conclusion

From the whole process of planning, simulating, making and measuring yagi biquad antenna by using copper wire, hence it can be concluded as follows:

1. Simulation results for working frequency 2100 MHz – 2400 MHz slightly differ from actual measurement result that is 2364 MHz – 2464 MHz. This is because the fabrication is done manually, so the installation distance of Biquad wire on the antenna boom is not soldered in neat and cleanly.

2. Return loss obtained is at 2400 MHz frequency of -26.44 dB with VSWR 1.27 and gain 9.23 dB which the measurement results are better than the standard reflection factor <-10 dB and VSWR <1.5.

3. Installation of yagi biquad antenna as external antenna on portable modem can increase signal range ± 3m with speed improvement data quality download at 3.64 Mbps and

upload at 0.89 Mbps. The result of range and data quality increase is not very significant because the antenna is working at 2364 MHz – 2464 MHz, while the working frequency of the modem tested works at 2300 MHz frequency with 15 MHz bandwidth.

4.2 Suggestion

To get a good enough antenna performance, there are some things that can be used as a suggestion for future development: Conducting fabrication by using the qualified services to obtain maximum results in which accordance with the simulation. The antenna testing can be done in the anechoic chamber in order to get better results.

References

[1]M. E. Azira and S. Omar, “An Acceptance of 4G (Fourth Generation) Mobile Network in Malaysia,” Int. J. Inf., vol. 3, no. 8, pp. 232–237, 2013.
[2]R. Reshma and B. E. Caroline, “Design and Simulation of Crescent Monopole Antenna for 4G LTE Application,” vol. 1, no. 3, pp. 216–220, 2017.
[3]A. Yasin and C. Paul, “Performance Analysis Of Adaptive Antenna System In Lte (4g) Using Ofdm Technique,” Int. J. Adv. Eng. Technol., vol. 5, no. 2, pp. 93–99, 2013.
[4]A. K. Verma, S. Maheshwari, and N. Goel, “Design and Parametric Analysis of Compact Internal Antenna for 4G LTE Application,” vol. 7, no. 1, pp. 43–46, 2017.
[5]J. Hallas, “Basic Antennas,” 2009.
[6]Nurhadi, Perekayasaan Sistem Antena. 2013.