Omnidirectional MIMO Antenna with Collinear Array for LTE Applications

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ABSTRACT

To increase reception in Long Term Evolution (LTE) network inside a building, a repeater is needed. The antenna used in the repeater inside the building is usually a high gain antenna with omnidirectional radiation pattern. Meanwhile, to increase data rate in LTE, one of methods used is by using Multiple Input Multiple Output (MIMO) antenna. In this paper, the omnidirectional MIMO antenna at 1.8 GHz for LTE applications has been designed and realised. The single element of this MIMO antenna is a collinear microstrip antenna array. The design and simulation were done using 3D electromagnetic simulator software, while antenna realisation was done using FR4 microstrip with a thickness of 1.6 mm and permittivity of 4.4. The measurement results showed that this antenna has 359 MHz bandwidth in frequency range at 1.6-1.9 GHz, with a return loss less than -10 dB. The antenna gain is around 7.4 to 8.7 dBi with omnidirectional radiation pattern and mutual coupling is around -22 dB to -27 dB.

Keywords: Collinear, LTE, Microstrip Antenna, MIMO, Omnidirectional

INTRODUCTION

To increase reception in Long Term Evolution (LTE) network inside a building, a repeater is needed (Yeo, Lee, Hwang, & Kim, 2013). The function of a repeater is to receive radio signal from outside the building, strengthen the received signal, and emit it inside the desirable building (Xue, 2008). The antenna used in the repeater inside the building is usually the antenna with omnidirectional radiation pattern and high gain (Shankari & Gowtham, 2014). To increase data rate in LTE, one of methods used is by using the Multiple Input Multiple Output (MIMO) antenna (Abdullah & Yonis, 2012).

Omnidirectional antenna chosen here is monopole antenna, while to get the antenna with high gain, we make the array of the monopole antenna in collinear (Balsley & Ecklund, 1972; Wang, Yang, Li, Li, & Chen, 2011). Collinear antenna array is chosen to get antenna with high gain with omnidirectional radiation pattern. There are many types of monopole antenna and today, monopole antenna made from microstrip is being developed in vast amount. Microstrip antenna has advantages such as light, simple, and easy to be manufactured because it can be made with etching process, which is the same as the process of making PCB. Some research has been done related to collinear microstrip antenna array by several researchers (Jiao, Xueguan, Xinmi, & Huiping, 2013; Litva, Zhuang, & Liang, 1993; Peng-Fei, Li-Ming, Yong, & Xin, 2013; Polivka & Holub, 2006).

In LTE network, MIMO antenna is commonly used as a way to increase data rate. MIMO antenna suitable for indoor repeater is MIMO antenna that has omnidirectional radiation pattern (Ching-song, Hsu, Chun, Engineering, Rd, & Shiang, 2013; Fang, Sun, & Chuang, 2014; Malik, Kartikeyan, & Nagpal, 2016; Moradikordalivand, Rahman, & Khalily, 2014). Therefore, we proposed a MIMO omnidirectional antenna that has high gain, where in every antenna is microstrip monopole collinear antenna.

Mutual coupling is a critical problem in the design of MIMO antennas because it deteriorates the performance of MIMO systems, which not only affects the antenna efficiency but also influences the correlation (Li, Du, Takahashi, Saito, & Ito, 2012). Some research has been done to reduce mutual coupling in a MIMO antenna but the mutual coupling is less than -15 dB (Nguyen, Le, Le, Tran, & Yamada, 2016) and -16 dB (Ghafor, Hameed, Abdullah, Sabbagh, Al, & Bashir, 2015).

This research made use of the experimental method which consists of design and simulation using 3D Electromagnetic Simulator, fabrication of antenna, and antenna measurement. The proposed antenna is implemented using FR4 substrate, with a thickness of 1.6 mm and permittivity of 4.4. The expected specifications of the antenna are that it works at a frequency of 1.8 GHz (LTE band 3) with a frequency range from 1.7 to 1.9 GHz for return loss less than -10 dB, gain more than 5 dBi with mutual coupling less than -20 dB (Li et al., 2012) and has omnidirectional radiation pattern.

ANTENNA DESIGN

The initial step in antenna design is to determine the characteristics of the antenna that we expected. In this design, we proposed an antenna that meets the characteristics listed in Table 1 below.

Table 1
Specifications of the proposed antenna

Frequency Range	1.7 – 1.9 GHz
Gain	> 5 dBi
Bandwidth	≥ 200 MHz
Mutual Coupling	< -20 dB
Radiation Pattern	Omnidirectional
Return Loss	≤ -10dB

The first step in designing microstrip MIMO collinear antenna array is designing a single microstrip collinear antenna as shown in Figure 1. The designing process of the microstrip collinear antenna aims to increase antenna gain with omnidirectional radiation pattern. Parameters of the antenna dimensions used in the first step of collinear antenna design are given in Figure 2 and Table 2.

The second step in designing the antenna is optimisation towards the size of collinear antenna dimension so that the results of simulation will match the characteristics of the antenna to be obtained.

Changes of antenna dimension after optimisation include parameters a, c and d. After optimising those parameters, the size of antenna is obtained, followed by obtaining the characteristics of the antenna. These parameters are also shown in Table 2.
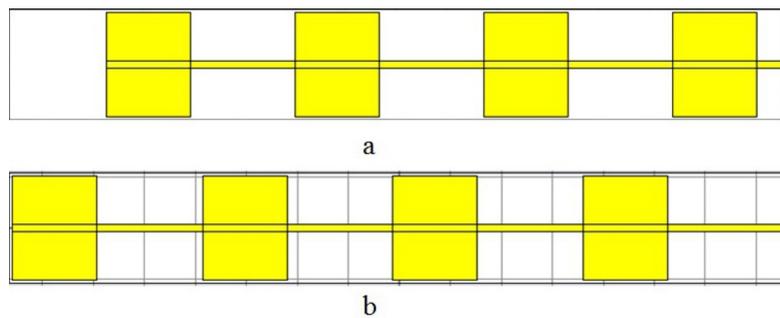
Figure 1. (a) Layout of collinear antenna, top view (b) Layout of collinear antenna, bottom view
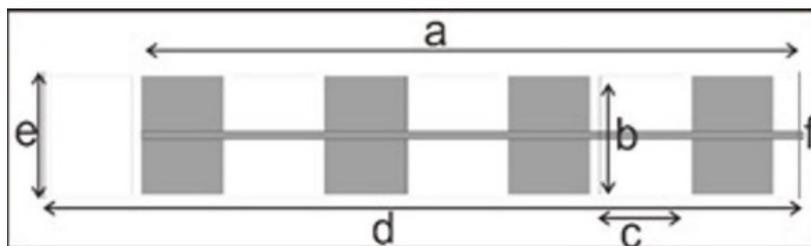
Figure 2. Initial parameters of collinear antenna array

Table 2
Parameters of the collinear antenna array before and after optimisation

Antenna Parameters	Dimension (mm)	
	Before Optimisation	After Optimisation
Length of Feeder (a)	266.87	265.5
Length of Patch (b)	46	46
Width of Patch (c)	30	33
Length of Substrat (d)	294	305
Width of Substrat (e)	49	49
Width of Feeder (f)	3.065	3.065

MIMO ANTENNA DESIGN

The third step of antenna design is designing MIMO antenna from the collinear antenna that has been made before. The design of the antenna is shown in Figure 3. To get the characteristics of MIMO antenna that we expected, the modification of antenna dimension should be done. Therefore, optimisation process, the same process with the optimisation of single collinear antenna, should be done. In this optimisation, there are a few parameters that will be adapted towards antenna dimension so that the characteristics of the antenna produced match the characteristics of the antenna that we expected. Dimension and distance parameters of the MIMO antenna, before and after the optimisation, are shown in Table 3. Based on data in Table 3, all the parameters have changed except for patch width and feeder width.
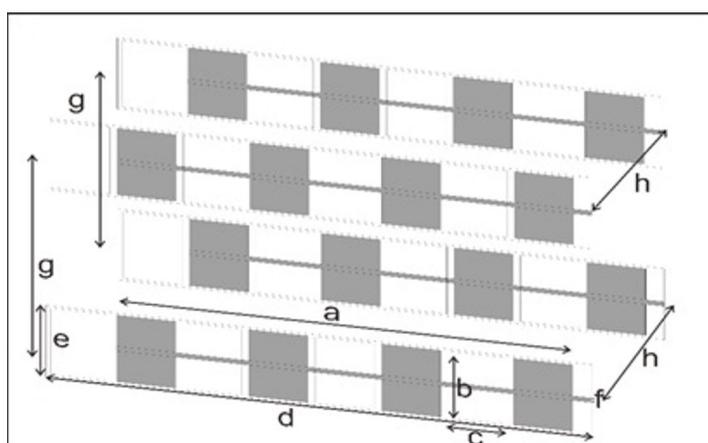
Figure 3. The Antenna MIMO design

Table 3
Dimension and distance parameters of the MIMO antenna before and after the optimisation

Antenna Parameters	Dimension (mm)	
	Before Optimisation	After Optimisation
Length of Feeder (a)	265.5	267.6
Length of Patch (b)	46	41
Width of Patch (c)	33	33
Length of Substrat (d)	305	306
Width of Substrat (e)	49	43.25
Width of Feeder (f)	3.065	3.065
Antenna Distance (g)	170	160
Antenna Distance (h)	170	160

RESULTS AND DISCUSSION

Early Simulation

In this step, early simulation of microstrip collinear antenna is done with dimension from the literature review. Feeding technique used is the feeding with microstrip transmission line. The return loss of the early simulation does not match with the expected frequency range. Figure 4 shows the former design of microstrip collinear antenna with the parameter from Table 2, while Figure 5 shows the return loss value of the antenna and Figure 6 shows gain and radiation pattern of the antenna at 1.8 GHz.
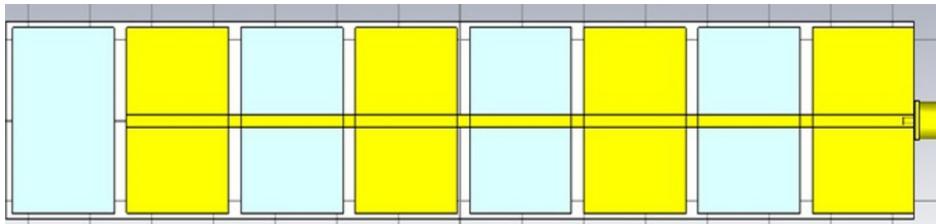
Figure 4. Former design of the microstrip collinear antenna
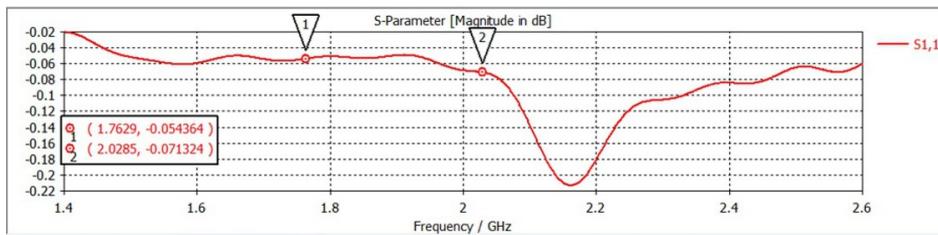
Figure 5. Return loss of the antenna in the early design
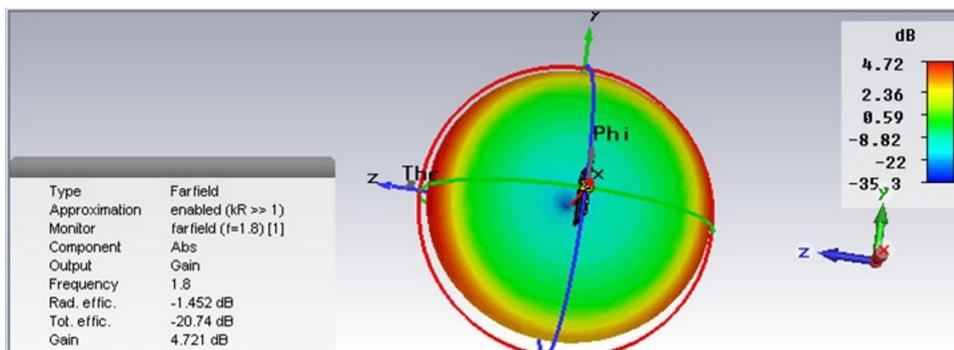
Figure 6. Gain and radiation pattern of the antenna at 1.8 GHz

Result of design simulation of early microstrip collinear antenna shows that the characteristics of the antenna in Figure 5 do not match with the characteristics of the expected antenna. Therefore, the optimisation towards antenna dimension should be done. Dimensional change is done by changing parameter c or patch width from 30-36 mm using 5 samples. The result of return loss simulation is presented in Figure 7.

Based on the data in Figure 7, we can see that when the patch width is 33 mm, the resonant frequency of the antenna is around 1.8 GHz, while the dimension is close to the characteristics of the expected antenna when the patch width is 33 mm. If we extend the patch width of antenna, the resonant frequency shifts to the lower frequency. The resonant frequency of the antenna shifts to the upper frequency if we shrink the patch width of the antenna. Antenna dimension is proportional with the wavelength or inversely proportional with the frequency (Balanis, 2005; Kraus, Marhefka, & Khan, 2010).

The result of return loss simulation from antenna with desirable dimension obtained from optimisation (Table 2) is depicted in Figure 8. The resonant frequency is around 1.8 GHz with the frequency range of 1.6 GHz to 1.9 GHz and return loss less than -10 dB. Gain and radiation pattern of the single microstrip collinear antenna are shown in Figure 9. From Figure 9, we can see that the gain of single microstrip collinear antenna is 5.459 dBi with omnidirectional radiation pattern.
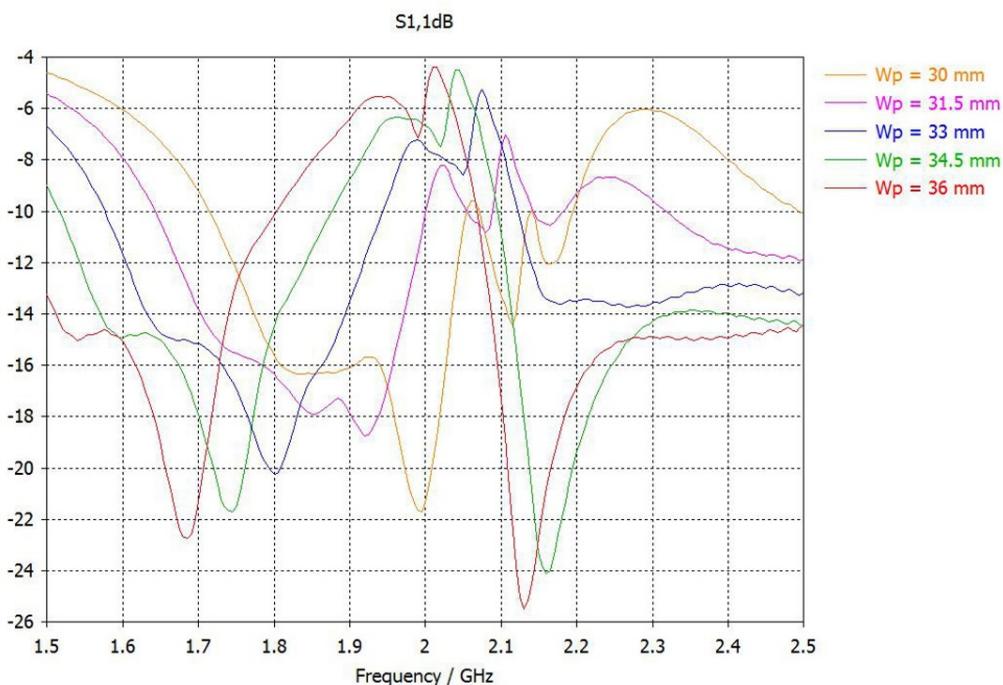
Figure 7. The simulation result of return loss for five different patch width values
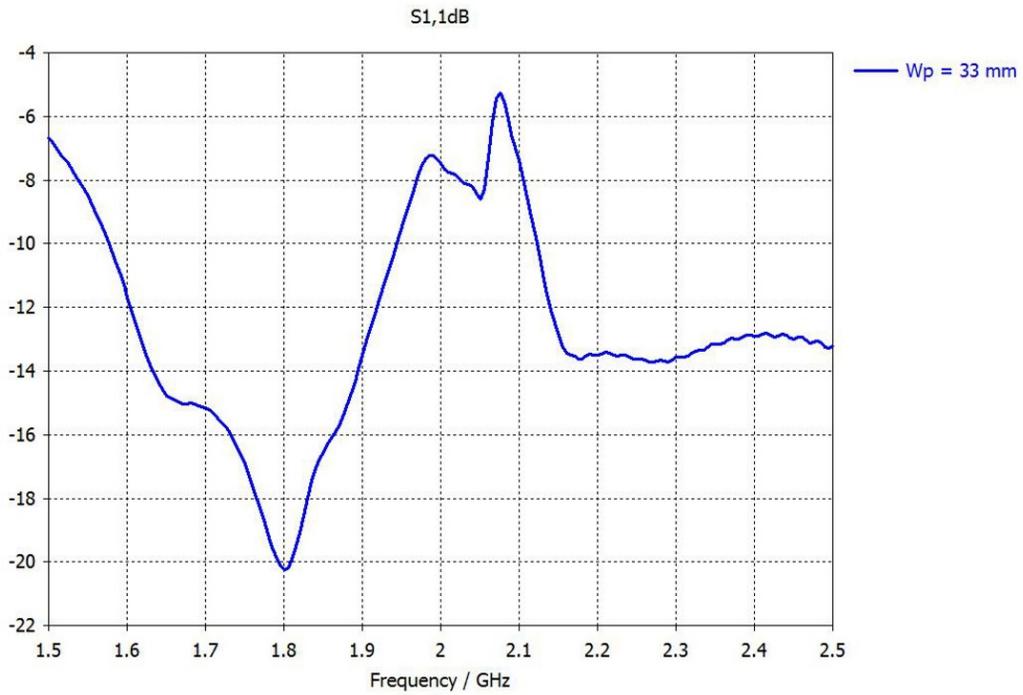
Figure 8. The simulation result of antenna return loss with optimal dimension obtained from optimisation

Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.8) [1]
Component	Abs
Output	Gain
Frequency	1.8
Rad. effic.	-0.3513 dB
Tot. effic.	-0.3926 dB
Gain	5.459 dB
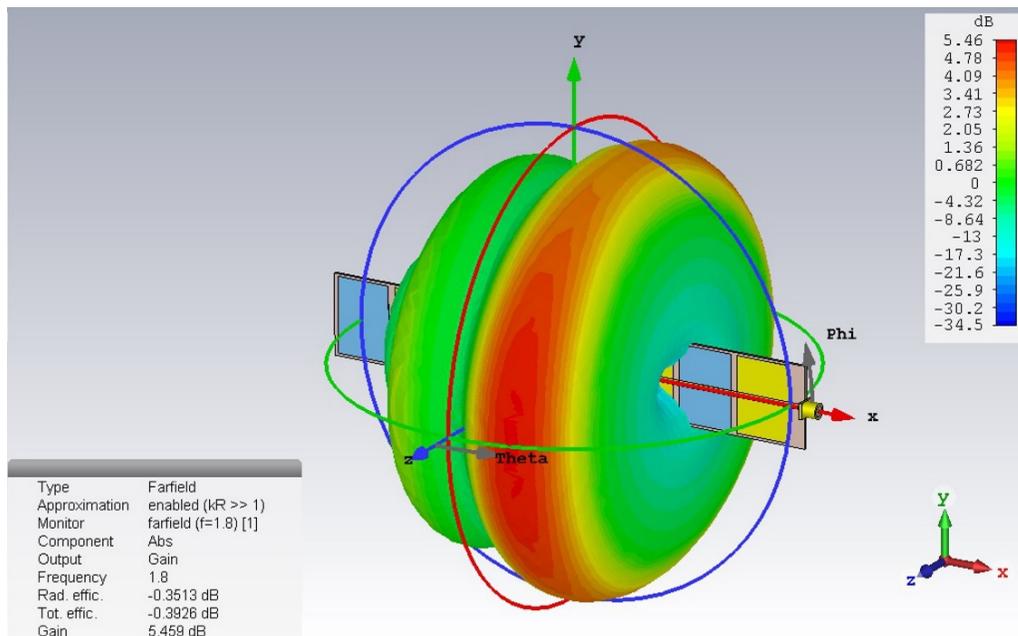
Figure 9. Gain and radiation pattern of the single microstrip collinear antenna

Results of the MIMO Antenna Simulation

The proposed MIMO antenna consists of four microstrip collinear antenna with specific distance. To get the final specification expected, optimisation toward the distance between antennas is done. The distance expected is as close as possible so that the total dimension is not too big but with mutual coupling value less than -20 dB in the expected frequency range.

Distance optimisation between MIMO antennas is done by changing parameter g and h (Ja) with a distance of 140-170 mm to get the expected simulation result. The result of return loss simulation with antenna distance 140-170 mm is given in Figure 10.
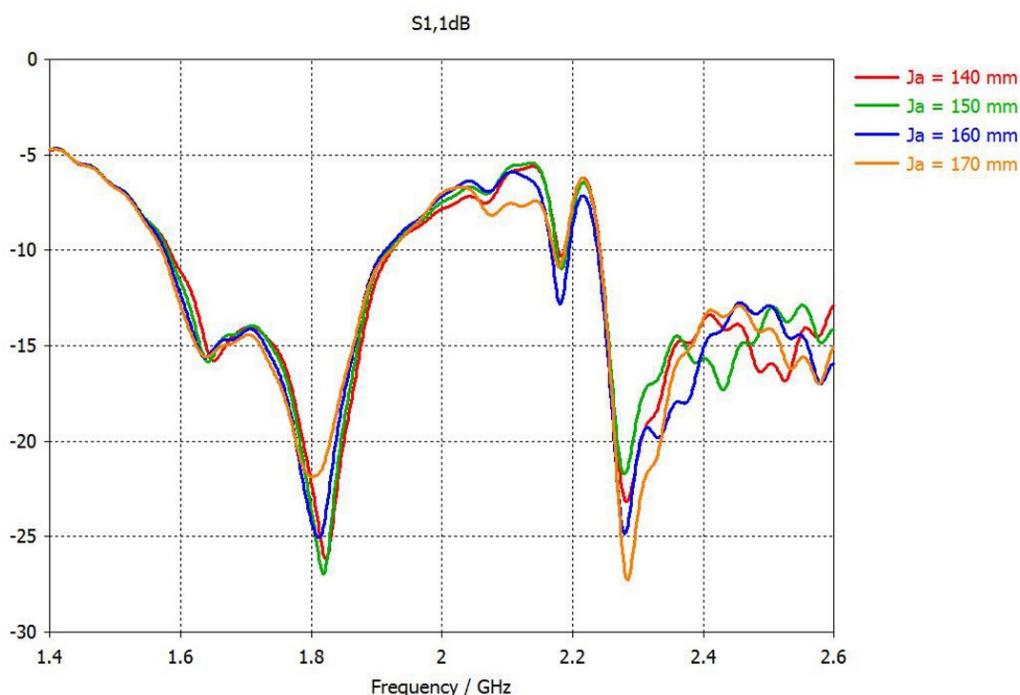
Figure 10. The simulation result of return loss with the antenna distance of 140-170 mm

The simulation result of return loss in Figure 10 shows that the variation in the antenna distance from 140 mm to 170 mm does not have any significant difference. From Figure 11, however, we can see that the ideal antenna distance or the closest distance is 160 mm. If we shrink the antenna distance, the total dimension of MIMO antenna will become smaller but the mutual coupling will increase. Meanwhile, if we extend the antenna distance, the mutual coupling will decrease but the total size of MIMO antenna will be larger. Thus, the ideal antenna distance in this case is 160 mm. This value is close to 1 wavelength (1λ) where the λ at frequency 1.8 GHz is 166.67 mm. Linnartz (2008) said that mutual coupling would add extra degradation to the outage capacity of the MIMO system. Therefore, to guarantee minimal loss in capacity, the antennas should be spaced about 1 wavelength apart. The final result of the return loss simulation of MIMO antenna is presented in Figure 12.

The final result of the return loss simulation of MIMO antenna in Figure 12 shows that the specifications already match with the specification set at the beginning, i.e. 1.8 GHz with bandwidth 359 MHz (1.576-1.935 GHz). The mutual coupling value from the final simulation is shown in Figure 13.

The average mutual coupling value in Figure 13 is under -20 dB in frequency range 1.6-1.9 GHz. So, mutual coupling value is match with the value in the beginning. While antenna gain 1 to 4 from final simulation is shown in Figure 14.
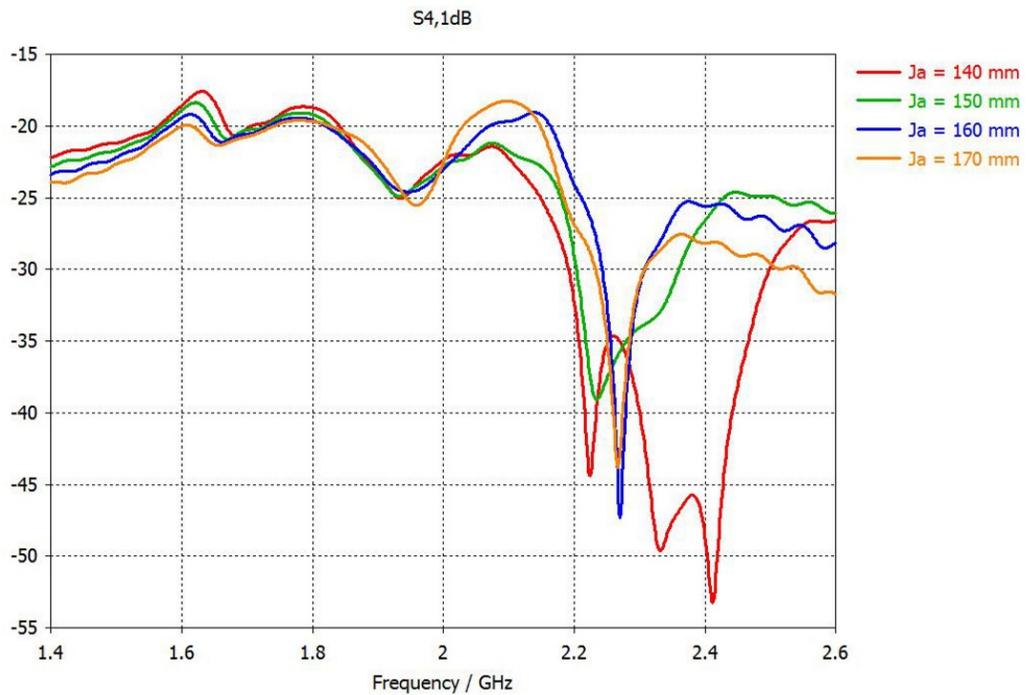
Figure 11. Mutual coupling from antenna distance optimisation from 140 mm to 170 mm
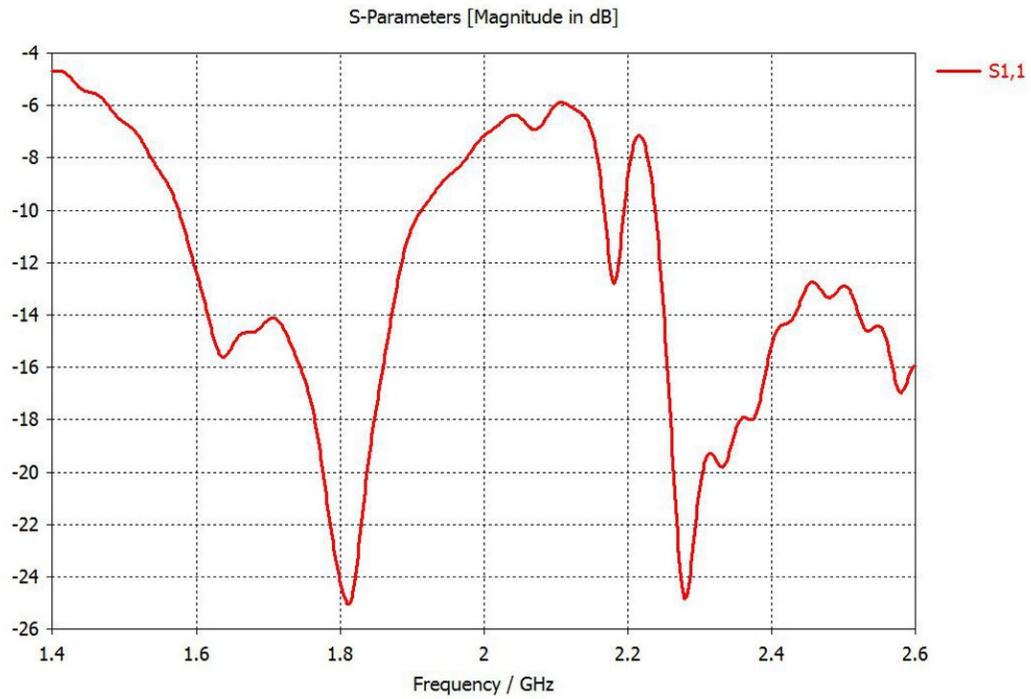
Figure 12. The final result of the return loss simulation of MIMO antenna
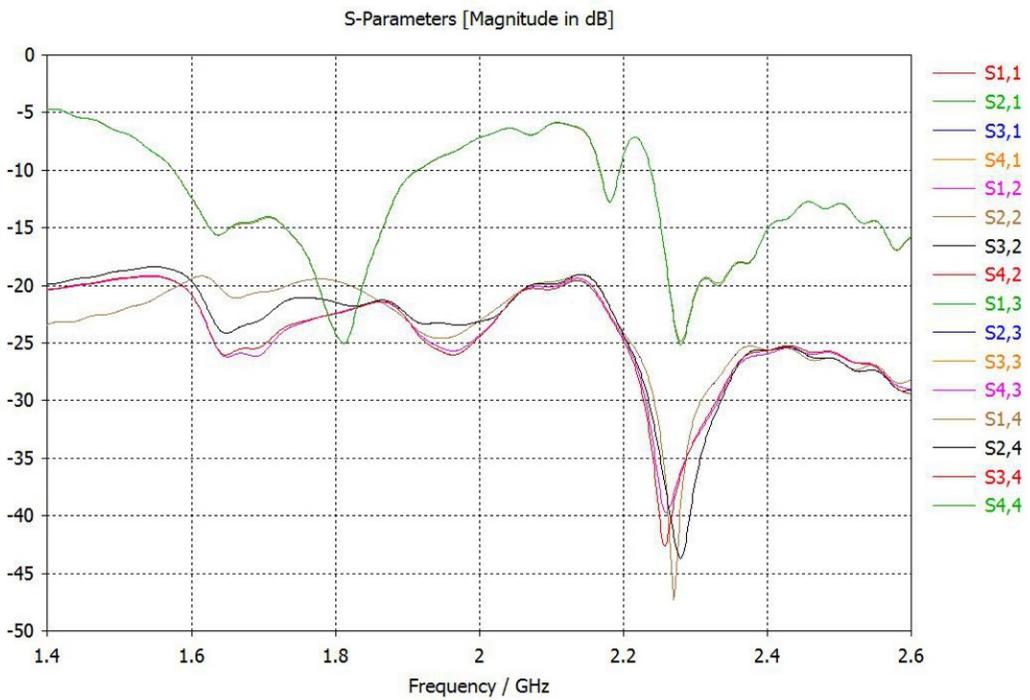
Figure 13. Mutual coupling of the MIMO antenna from the final simulation
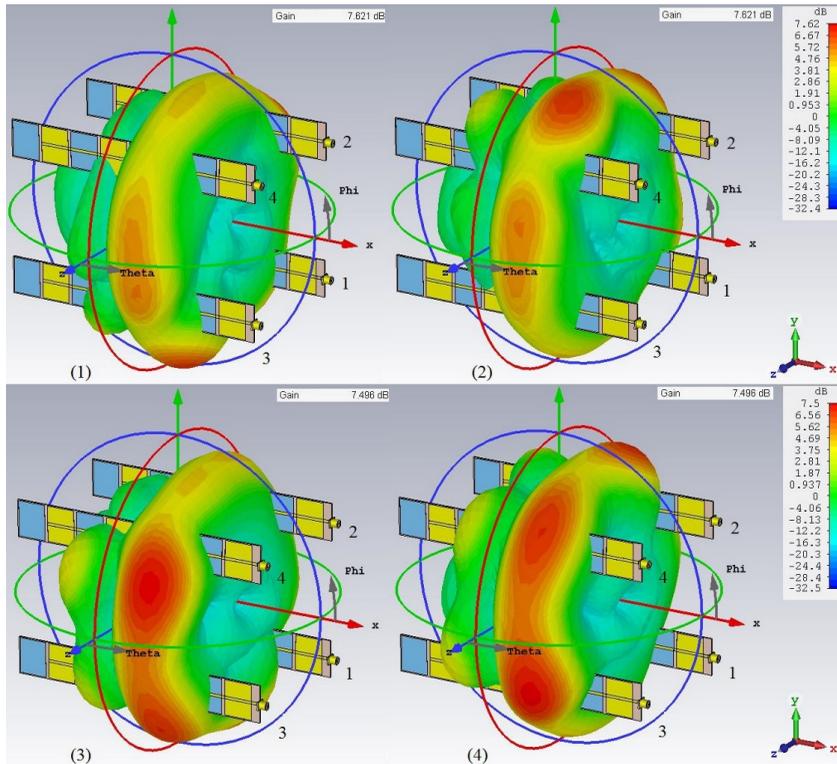
Figure 14. Simulation result of the MIMO antenna gain: (a) gain of antennas 1 and 2 (7.621 dBi), and (b) gain of antennas 3 and 4 (7.496 dBi)

The results for the MIMO antenna radiation pattern for azimuth and elevation plane are given in Figure 15. The radiation pattern of microstrip MIMO antenna from the simulation shows that the antenna has omnidirectional radiation pattern. Hence, the radiation pattern matches the expected radiation pattern.
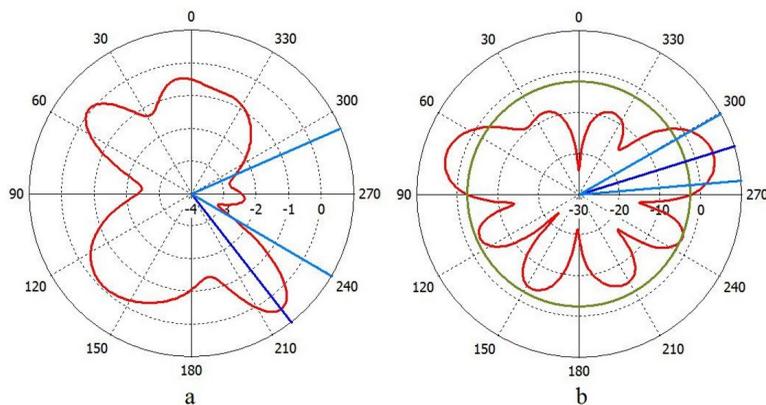
Figure 15. Radiation pattern of the antenna: (a) Azimuth plane, and (b) Elevation plane

Fabrication of Antenna

Based on the final simulations of MIMO antenna, the antenna is manufactured. Figure 16 shows the result of antenna fabrication. Antenna substrate used is FR4 with dielectric constant 4.4 and 1.6 mm of thickness, while the antenna mounting is using acrylic.
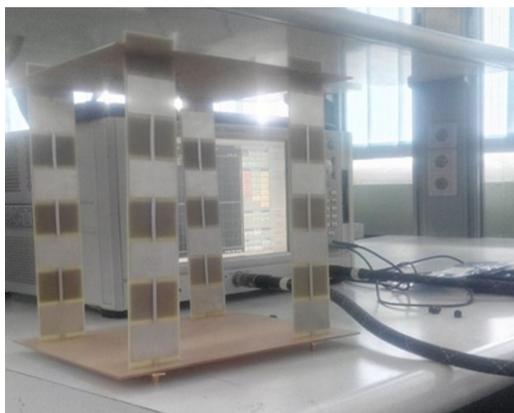
Figure 16. Results of the MIMO antenna manufacturing

The Result of Antenna Measurement

Antenna return loss measurement. Results for measuring return loss of MIMO antenna are presented in Figure 17. From this figure, we can see that the expected return loss value matches with the results of the return loss measurement, which is less than -10 dB in the frequency range of 1.6-1.9 GHz.
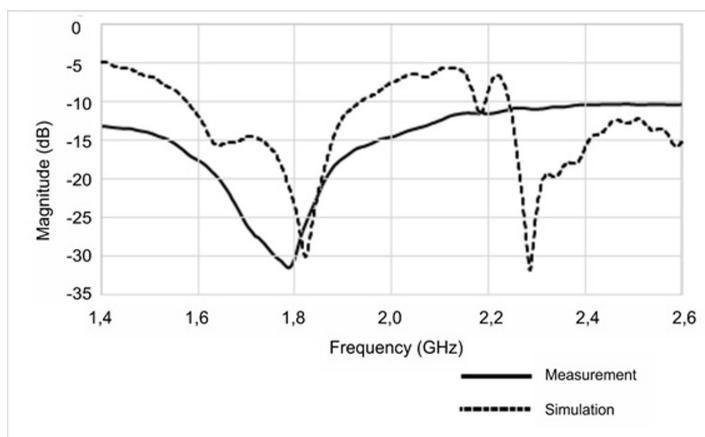
Figure 17. Result of measuring return loss

Mutual coupling measurement. Mutual coupling of MIMO antenna is shown in Table 4. It shows that mutual coupling at 1.8 GHz is around -22 dB to -27 dB. Hence, the mutual coupling of this MIMO antenna matches the specification that is less than -20 dB.

Table 4
Mutual coupling of MIMO antenna at 1.8 GHz

	Parameters					
	S12/S21	S13/S31	S14/S41	S23/S32	S24/S42	S34/S43
Mutua Cloupling (dB)	-26.4	-22.7	-23.6	-23.6	-22.7	-27.5

Results of Radiation Pattern Measurement

The result of measuring radiation pattern is given in Figure 18. In Figure 18, we can see that the result of radiation pattern measurement has a shape that is almost similar with the simulation result of radiation pattern. From Figure 18, we also can see that the radiation pattern azimuth base is omnidirectional. Hence, the radiation pattern of the MIMO antenna matches the specification, i.e. omni directional.
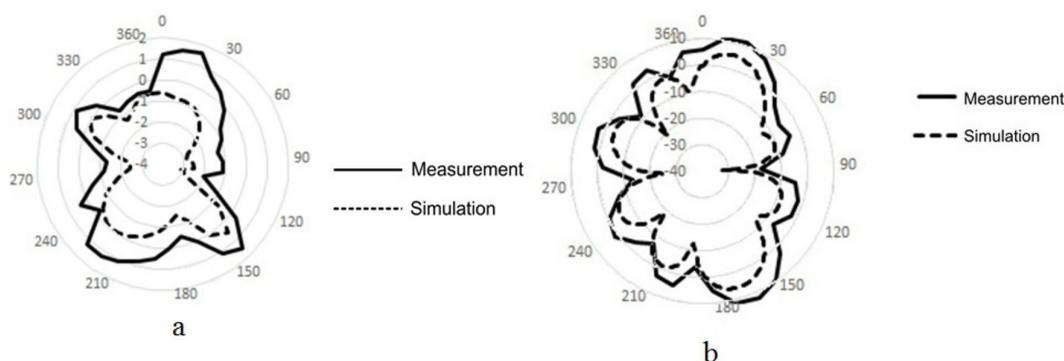
Figure 18. The result of measuring radiation pattern: (a) Azimuth plane (b) Elevation plane

The Results of Gain Measurement

The measuring of gain is done using two similar antenna methods. We can see the differences in Table 5. From Table 5, we can see that MIMO antenna gain is between 7.44-8.77 dBi. The gain is obtained from measurement using two similar antenna methods. The result matches with the expected value that is more than 5 dBi. Although the MIMO antenna uses monopole antenna, the gain obtained is higher compared to when common monopole antenna is used. This happened because we used collinear antenna that consists of monopole antenna arranged in a line order for every element of the MIMO antenna, so that the gain obtained is higher than that of the common monopole.

Table 5
The result of antenna gain measurement

Frequency (GHz)	Gain (dBi)			
	Antenna 1	Antenna 2	Antenna 3	Antenna 4
1.7	8.1	7.9	8.2	8.38
1.75	8.29	8.11	7.98	7.89
1.8	8.29	7.71	7.44	7.97
1.85	8.67	8.5	7.96	8.21
1.9	7.91	8.13	8.7	8.77

CONCLUSION

In this research, we have done the designing, arrangement and measurement processes of the Microstrip MIMO antenna. The arrangement of the microstrip MIMO antenna can work in 1,6-1,9 GHz frequency with return loss less than -10 dB. Antenna gain obtained from the measurement is about 7435-8765 dBi, which matches the expected specifications. The mutual coupling value of micro-strip MIMO antenna array is less than -20 dB, which also matches the specification. Based on the results of the measurement of radiation pattern, the arrangement of the microstrip MIMO antenna is already omnidirectional. Therefore, the proposed antenna can be used for the LTE application.

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