The Effect of Split Ring Resonator (SRR) Metamaterials on the Bandwidth of Circular Microstrip Patch Antennas

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Abstract. A microstrip patch antenna is one type of antenna that is currently widely used in wireless communication systems. This antenna is an option because it has several advantages, such as its lightweight, small size and easy to fabricate. However, one of the disadvantages of this antenna is the narrow bandwidth. In this study, bandwidth will be increased in a single circle microstrip patch antenna. This increase in bandwidth aims to make the antenna designed to work for LTE band 3 applications with a frequency range of 1710-1880 MHz. Increasing bandwidth can be done using the Split Ring Resonator (SRR) Metamaterial. Antenna simulation and optimization were carried out using 3D electromagnetic simulator using FR-4 substrate with a thickness of 1.6 mm and a dielectric constant of 4.3. Based on the simulation results, obtained antenna bandwidth of 310 MHz with a frequency range of 1620 - 1930 MHz for return loss of less than -10 dB. The antenna gain is around 2.1-2.5 dBi with directional radiation patterns. It can be concluded that this antenna can be used for LTE band 3 applications.

1. Introduction
The need of the customers for high-speed, large-capacity data service urges Third Generation Partnership Project (3GPP) to develop Long Term Evolution (LTE) technology. LTE technology presents an increased performance with high rate data and significant capacity. This technology has the capability of providing data rate service of up to 100 Mbps on the downlink side and 50 Mbps on the uplink side. The frequency used by GSM network operators in Indonesia which support the LTE technology service using band 3 is 1800 MHz [1].

In the 3rd Generation Partnership Project, the uplink frequency ranges between 1710 Mhz and 1785 MHz, while the downlink frequency ranges between 1805 MHz and 1880 Mhz [2]. With differing uplink and downlink frequencies, an antenna with relatively large bandwidth is required to work in the uplink and downlink frequencies simultaneously.

In the wireless communication system, an antenna is an essential component for emitting and receiving electromagnetic wave [3]. In the LTE application, the antenna used must be adjusted with the working frequency range. Thus a large bandwidth is required because at the frequency of 1800 MHz has different uplink and downlink frequencies.
Microstrip antenna remains favorable for supporting wireless communication application as it has several advantages such as small size, light weight, low cost, and easy in fabrication process.

Although it is possible to use it in a wireless communication application, a microstrip antenna has some drawbacks, one of which is narrow bandwidth [4]. The limit of bandwidth increase in microstrip antenna is only around 1-3% [5]. If the bandwidth value in the microstrip antenna can be increased to more than 3%, the antenna can be used maximally for LTE band 3 application, which requires a reasonably large working frequency range.

Several methods can be employed to overcome the problem of narrow bandwidth in the microstrip antenna. According to some studies, antenna bandwidth may be increased by using metamaterial split rectangular element for a single antenna at a frequency of 1.881 GHz, which results in an increase of antenna bandwidth from 4.9 MHz to 22.5 MHz [6]. Another study used metamaterial with Electromagnetic Band Gap (EBG) structure, which can increase bandwidth from 1.9% to 39.2% [7].

In this research, a single antenna will be designed with a circular radiating element by adding a metamaterial element on the antenna ground to increase the bandwidth. The metamaterial used in this antenna design is Split Ring Resonator (SRR).

2. Microstrip Antenna
The microstrip antenna is a type of antenna with metal conductor structure attached on the ground plane. The metal conductor is part of the radiating element in one side of the substrate dielectric, which also has a ground plane on the other side. The radiating element is made of a conductor material, usually copper. The radiating component of the microstrip antenna has plenty of configurations such as square, circular, triangular, elliptical, ring, and so forth. The shapes of the radiating element can be seen in Figure 1 [3].

![Figure 1. Some shapes of microstrip patch antenna [3].](image)

One of the radiating elements frequently used in the microstrip antenna designing is a circular radiating element. Other than a rectangular radiating element, circular radiating element is commonly used due to the ease in the analysis and fabrication as well as its low radiation characteristics, especially the cross-polarization radiation. The microstrip antenna structure with a circular patch can be seen in Figure 2 [3].
3. Metamaterial
The metamaterial is an artificial material introduced by a Russian researcher, Vesalago, in 1960. As a synthetic material, the metamaterial is created to produce electromagnetic response designed in a smaller size than light wavelength [8].

Metamaterial may have negative permittivity and permeability, which indicates how a material interacts with electromagnetic radiation, including microwave, radio wave, x-rays and other electromagnetic waves [9].

4. Antenna Parameters
To figure out the performance of an antenna, some parameters are used, such as bandwidth, radiation pattern, and gain. The bandwidth of an antenna is defined as the frequency range where the antenna performance is related to some characteristics such as VSWR and return loss. VSWR is a comparison between the maximum and minimum amplitudes of a standing wave. Return loss is a ratio between the magnitude of a wave reflected to the magnitude of the wave sent. Return loss may occur due to the discontinuity between the transmission channel and load input impedance (antenna). The radiation pattern is a mathematical function or a graphical representation of the antenna radiation characteristic as a spatial function. Gain demonstrates how efficient an antenna is in transforming the power in the input terminal into power radiated to a given direction [3].

5. Antenna Design
The initial stage of antenna designing was determining the desirable characteristics or parameters of the antenna. In the initial designing, it was expected that the antenna produces the attributes as shown in Table 1.

| Parameter           | Value         |
|---------------------|---------------|
| Frequency Range     | 1.71-1.88 GHz |
| Return Loss         | \( \leq -10 \text{ dB} \) |
| Radiation Pattern   | Directional   |
| Gain                | > 2 dBi       |

The first designing was done by creating a circular microstrip patch antenna as seen in Figure 3. Based on the results of calculation using equations 8 and 9, the substrate size is 77.95 x 59.704 mm², while the patch radius is 23.5 mm², which was obtained from equation 3. The antenna simulation was conducted by using software 3D electromagnetic simulator.
Figure 3. The dimension of the circular patch microstrip antenna.

Equation 1 may be used to design the patch radius [3].

\[ a = \frac{F}{\sqrt{1 + \frac{2h}{\pi \varepsilon F} \left[ \ln \left( \frac{\pi F}{2h} \right) + 1.7726 \right]}} \]  

\[ (1) \]

Beforehand, the F value can be obtained by using equation 2 [3].

\[ F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}} \]  

\[ (2) \]

Thus,

\[ F = \frac{8.791 \times 10^9}{1.8 \times 10^9 \sqrt{4.3}} = 2.35 \]

The antenna radius obtained by equation 1 is 10.55 mm. For the circular microstrip patch antenna, a correction factor in the form of effective radius \((a_e)\) was introduced due to the existence of the fringing effect. The \((a_e)\) value is formulated in equation 3 [3].

\[ (a_e) = a \left\{ 1 + \frac{2h}{\pi \varepsilon F} \left[ \ln \left( \frac{\pi F}{2h} \right) + 1.7726 \right] \right\} \]  

\[ (3) \]

Thus,

\[ (a_e) = 10.55 \left\{ 1 + \frac{2(0.16)}{\pi(4.3)(2.355)} \left[ \ln \left( \frac{\pi(2.355)}{2(0.16)} \right) + 1.7726 \right] \right\} \]

\[ = 10.55(2.227) = 23.5 \text{ mm} \]

With \(Z_0 = 50 \, \Omega\), \(\varepsilon_r = 4.3\) and \(h = 1.6\) m, the width and length of the microstrip feeder may use equation 4 to find the B value first [3].
\[ B = \frac{60\pi^2}{Z_0 \sqrt{\varepsilon_r}} \]  

(4)

By using equation 4, the B value was obtained at 5.7.

Equation 5 is used to determine the width of the microstrip feeder [3].

\[
\frac{W_f}{h} = \frac{2}{\pi} \left[ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2 \varepsilon_r} \left( \ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right) \right]
\]  

(5)

The following was obtained

\[
\frac{W_f}{h} = 1.94 \quad W_f = 1.94(1.6) = 3.104 \text{ mm}
\]

Equation 6 was used to obtain the length of the microstrip feeder [3].

\[
L_f = \frac{c}{4f_r \sqrt{\varepsilon_{\text{eff}}}}
\]  

(6)

With \( c = 3 \times 10^8 \text{ m/s} \), and \( f_r = 1.8 \times 10^9 \text{ GHz} \), \( \varepsilon_{\text{eff}} \) can be calculated based on equation 7 [3].

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( \frac{1}{\sqrt{1 + \frac{12h}{W_f}}} \right)
\]  

(7)

The following was obtained

\( \varepsilon_{\text{eff}} = 3.80665 \)

Thus,

\[
L_f = \frac{3 \times 10^8}{4(1.8 \times 10^9)(\sqrt{3.80665})} = 0.02135 \text{ m} = 21.35 \text{ mm}
\]

Equation 8 was used to determine the width of the substrate. Meanwhile, the width of the substrate was obtained using equation 9.

\[
W_g = 6h + W_f + D_{\text{patch}}
\]  

(8)

The following was obtained

\( W_g = 59.704 \text{ mm} \)

\[
L_g = 6h + L_f + D_{\text{patch}}
\]  

(9)

Thus,

\( L_g = 77.95 \text{ mm} \)

After the circular microstrip patch antenna was designed, simulation and optimization are carried out to obtain a working frequency of approximately 1800 MHz. Then, to increase the bandwidth, SRR metamaterial is added on the antenna ground as shown in Figure 4.
6. Results and Discussion

6.1. Initial Simulation
In this stage, an initial simulation of the microstrip antenna using the dimensions obtained from the calculation was conducted. The parameters of the antenna dimension without metamaterial can be seen in Table 2.

| Antenna parameters            | Dimensions (mm) |
|-------------------------------|-----------------|
| $a_e$ (radiating element radius) | 23.5            |
| $W_g$ (width of substrate and ground plane) | 59.704          |
| $L_g$ (length of substrate and ground plane) | 77.95           |
| $L_f$ (length of feeder)       | 21.35           |
| $W_f$ (width of feeder)        | 3.104           |
| $W_i$ (width of inset)         | 1               |
| $L_i$ (length of inset)        | 10              |

Figure 4. The SSR metamaterial design.

Figure 5. The dimension of the circular patch microstrip antenna.
According to the results of the initial simulation, the return loss value at the frequency of 1800 MHz was still above -10 dB. However, resonating frequency has occurred at this frequency. Figure 5 and 6 show the initial design of the circular microstrip patch antenna and the results of the return loss simulation.

![Figure 6. The simulation result of the return loss of the initial design.](image)

As the results of the initial simulation had not met the expected specification, optimization was conducted by changing some parameters such as lowering the patch radius, dimension of substrate and ground plane, length of the feeder as well as the length and width of the inset. The optimized parameters of the antenna can be seen in Table 3.

| Antenna parameters                              | Initial simulation (mm) | Simulation after optimization (mm) |
|-------------------------------------------------|-------------------------|-----------------------------------|
| $a_r$ (radiating element radius)                 | 23.5                    | 22.3                              |
| $W_g$ (width of substrate and ground plane)      | 59.704                  | 46                                |
| $L_g$ (length of substrate and ground plane)     | 77.95                   | 62                                |
| $L_f$ (length of feeder)                         | 21.35                   | 11                                |
| $W_f$ (width of feeder)                          | 3.104                   | 3.137                             |
| $W_i$ (width of inset)                           | 10                      | 34.5                              |
| $L_i$ (length of inset)                          |                         |                                   |

The return loss results of the simulation of the antenna after optimization can be seen in Figures 7.

![Figure 7. Return loss results of the simulation of the antenna after optimization.](image)
6.2. Antenna Design Using SRR Metamaterial
The next stage was designing the antenna by adding SRR metamaterial in the ground plane. In the initial designing simulation of the antenna using metamaterial, the desired specification had not been met as the bandwidth was still narrow, which required optimization. The return loss result of the simulation of the antenna using one SRR can be seen in Figure 8.

![Figure 8. The simulation results of the return loss of the antenna with SRR metamaterial.](image)

6.3. Result of The Final Simulation of The Antenna with SRR Metamaterial
Some optimization was carried out again to obtain the final simulation results, including optimizing the number of SRR metamaterial in the ground plane, where the final antenna design was obtained by adding four SRR metamaterials. The dimension parameters of the antenna with four SRR metamaterials can be seen in Table 4. The final design of the antenna with four metamaterials is shown in Figure 9 and 10, and the return loss result of the simulation can be seen in Figure 11.

| Table 4. Parameters of the antenna with four SRR metamaterials |
|---------------------------------------------------------------|
| Antenna parameters   | Value (mm) |
|----------------------|------------|
| $a_r$ (radiating element radius) | 19.68      |
| $W_g$ (width of substrate and ground plane) | 42         |
| $L_g$ (length of substrate and ground plane)  | 57         |
| $L_f$ (length of feeder)  | 9.35       |
| $W_f$ (width of feeder)  | 3.137      |
| $W_i$ (width of inset)   | 1.315      |
| $L_i$ (length of inset)  | 10.4       |

![Figure 9. Front view of antenna design with four SRR metamaterials.](image)

![Figure 10. Back view of antenna design with four SRR metamaterials.](image)
In Figure 11, it can be seen that the frequency range has met the initial specification, which covered the frequency of 1710 – 1880 MHz for return loss lower than -10 dB. From Figure 11, it can also be seen that the antenna bandwidth was around 310 MHz (1620 – 1930 MHz) for return loss less than -10 dB.

3D radiation pattern and gain from the simulation of the antenna are shown in Figure 12. From Figure 14, it can be seen that antenna with four SRR metamaterials has a gain of 2.581 dBi. Meanwhile, the antenna radiation pattern on the azimuth and elevation with four SRR metamaterials from the simulation can be seen in Figure 13 and 14.
The radiation pattern of the antenna with SRR metamaterial from the simulation appeared to be directional radiation pattern. Therefore, the radiation pattern resulted from the simulation has met the initial specification desired, which is directional.

7. Conclusions
1. According to the simulation results, the antenna bandwidth is 310 MHz, with a working frequency range of 1.62 – 1.93 GHz. Therefore, the addition of metamaterial SRR in the antenna designed may increase the bandwidth.
2. The gain of a circular patch microstrip antenna with four metamaterial SRR is 2.581 dBi.
3. The radiation pattern of a circular patch microstrip antenna with four metamaterial SRR is directional.

8. References
[1] Rumney, M. (2013). LTE and the Evolution to 4G Wireless. Singapore: John Wiley & Sons, Ltd.
[2] ETSI. (2009). LTE Evolved Universal Terrestrial Radio Access (E-UTRA) Radio Frequency (RF) system scenarios (3GPP TR 36.942 version 8.2.0 Release 8). France.
[3] Balanis, C. A. (2005). Antenna Theory Analysis and Design Third Edition. New Jersey: John Wiley & Sons, Inc.
[4] Garg, R. (2001). Microstrip Antenna Design Handbook. London: Artech House, Inc.
[5] Raja Abdullah, D. Y. (2008). Bandwidth Enhancement for Microstrip Antenna. Modern Applied Science, 179-187.
[6] Sapana Yadav, D. R. (2012). At 1.881 GHz, Rectangular Microstrip Patch Antenna Using Split Rectangular Shape of Metamaterial Structure for Bandwidth Improvement. International Journal of Advanced Technology & Engineering Research (IJATER), 72-78.
[7] Ananya Parameswaran, S.(2013). Bandwidth Enhancement of Microstrip Patch Antenna Using. IOSR Journal of Electronics and Communication Engineering (IOSR-JECE), 5-10.
[8] Engheta, N. (2006). METAMATERIALS Physics and Engineering Explorations. Canada: John Wiley&Sons, Inc
[9] Caloz, Christopher. (2006). Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications. Canada: John Wiley & Sons, Inc.