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LEFT-HANDED METAMATERIAL (LHM) STRUCTURE STACKED ON A TWO-ELEMENT MICROSTRIP ANTENNA ARRAY

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ABSTRACT

Antenna can be one of the largest components in a wireless device; therefore antenna miniaturization can reduce the overall size of wireless devices. One method used to reduce the element size of an antenna is by using metamaterial structures. This paper discusses a Left-Handed Metamaterial (LHM) structure stacked on a two-element microstrip antennas array for miniaturization and gain enhancement at a frequency of 2.35 GHz. To observe the impact of the LHM structure on the antenna, first this paper discuss the design of a conventional rectangular shape microstrip antenna without a LHM structure, then a design of the LHM structure which shows both negative permittivity and negative permeability. This LHM structure is then implemented on a conventional single element microstrip antenna and on a two-element microstrip antennas array. Results and discussion of implementation of the LHM structure on the conventional microstrip antenna is provided in this paper. The results show that good agreement between simulated and measured results has been achieved. The simulation results show that the antenna works at a frequency of 2.29–2.42 GHz with a bandwidth of 128 MHz (5.4%) and a gain of 8.2 dBi, while the measurements show that the antenna works at a frequency of 2.26–2.41 GHz with a bandwidth of 146 MHz (6.21%) and a gain of 8.97 dBi. In addition, by comparing the substrate dimension for the two element array antennas, with and without the LHM structure, shows a 39% reduction is achieved.

Keywords: Array antenna; Metamaterial structure; Microstrip antenna; Split ring resonator

1. INTRODUCTION

Currently, the high demand for communication technology shows the need for a wireless technology system to be integrated into a single chip. Miniaturization of antenna, that is one of the largest components in the devices, play an important role in improving the performance and reducing the overall size of wireless devices. Meanwhile, during the last decade, many papers investigated and analyzed artificial metamaterials due to their unique characteristics, such as backward wave propagation and negative permittivity and/or negative permeability (Smith et al., 2000; Erentok et al., 2005). Metamaterials also have been used for antenna miniaturization (Singh, 2010; Rahardjo et al., 2012). Several methods have been used to miniaturize antennas, which include the Composite Right/Left-Handed Transmission Line (CRLH-TL) antenna structure (Selvanayagam, 2010) and the Complementary Split Ring Resonator (CSRR).

Various methods are implemented by etching the ground plane (Lai et al., 2007), by using the

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Composite Right/Left-Handed (CRLH) metamaterial mushroom type structure (Notris et al., 2004), with the use of many gaps at the edges of the patch (Sarabandi & George, 2006), and by using a highly reactive impedance surface (Ziolkowski, 2003).

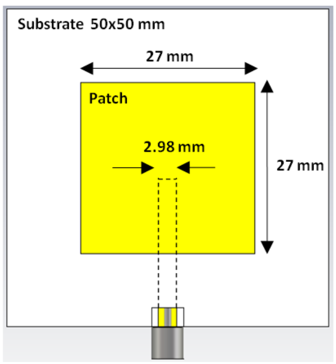
The miniaturization technique proposed in this paper is a modified Split Ring Resonator (SRR) structure to excite metamaterial characteristics, such as negative permittivity and negative permeability which is then identified as Left-Handed Metamaterial (LHM). The selection of the SRR-based LHM is due to its small size, free of via, easy fabrication and easy antenna implementation. It is not necessary to enlarge the dimensions of the antenna because it can be made as slots in the ground plane. Consequently, the SRR-based LHM is quite suitable for the miniaturization process.

2. RESEARCH METHODOLOGY

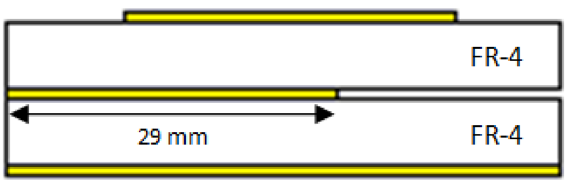
This paper discusses a LHM antenna structure made to miniaturize a two-element microstrip antenna array dimensions but still maintain the performance of the antenna, such as gain and bandwidth. The two-element microstrip antenna array (MSA) is designed to work at a frequency of 2.3–2.4 GHz, which is for broadband wireless access application. The methodology to achieve this application follows several steps. In the first step, the design of a conventional microstrip antenna is discussed, next the design of the left-handed metamaterial structure and at last the implementation of the LHM structure on the conventional microstrip antenna. Comparisons between the conventional and LHM structure antenna is discussed with simulation and measurement results. Simulation results were obtained using Computer Simulation Technology (CST) Microwave Studio software, while measurement results were taken in anechoic chamber in the Department of Electrical Engineering, Faculty of Engineering, Universitas Indonesia. All designs used a FR-4 substrate with a dielectric constant of 4.6 and a loss factor of 0.025.

2.1. Conventional Microstrip Antenna Design

The conventional microstrip antenna (MSA) is designed to work at a frequency of 2.3–2.4 GHz. To achieve this design, first the dimensions of the square patch are obtained using the well-known (Balanis, 2005) formula for a square patch microstrip antenna. Then by using the software, characterization is conducted and the antenna substrate dimensions achieved are 50×50 mm. The length/width dimension of the antenna patch is 29.6×29.6 mm and the thickness is 3.2 mm (2×1.6 mm). The feeding technique used here is proximity-coupled in order to obtain a wide bandwidth. The width of the line feeding is 2.98 mm. The geometry of the antenna design is shown in Figure 1.



(a)



(b)

Figure 1 Geometry of conventional antenna design (a) Top view (b) Side view

2.2. Design of Left-Handed Metamaterial

The design of the Split Ring Resonator (SRR) structure as the LHM is shown in Figure 2. The two strips in the left and right edge of LHM have been added to shift the resonant frequency lower. Therefore, more dimensional miniaturization can be achieved.

The parameters G, L, and W, in the Figure 1 denote gap, length, and width, respectively. The dimensions are: G_1 = 1 mm, G_2 = 0.5 mm, and G_3 = 2 mm, L_1 = 13 mm, L_2= 6 mm, L_3 = 5 mm, L_4 = 15 mm, L_5 = 9 mm, L_6 = 7 mm, W_1 = 1 mm, W_2 = 1 mm, W_3 = 0.5 mm.

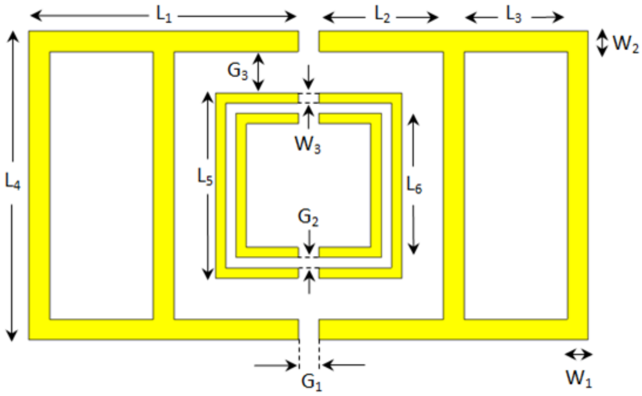


Figure 2 Proposed LHM structure

The LHM unit cell is simulated with a Perfect Magnetic Conductor (PMC) and a Perfect Electric Conductor (PEC) as the boundary conditions show in Figure 3. The incident wave propagates in the *z*-axis direction, while the *E*-field and *H*-field of the incident wave is polarized along the *y*-axis and *x*-axis, respectively. Figure 4 shows the S_{11} and S_{21} parameters of the LHM. Given a certain power from source signal, the S_{11} parameter is the reflection coefficient from the LHM structure, while the S_{21} parameter is the insertion loss from the transmission. These parameters are then extracted with the Nicholson, Ross, and Weir (NRW) approach to determine the permittivity and permeability of the LHM structure.

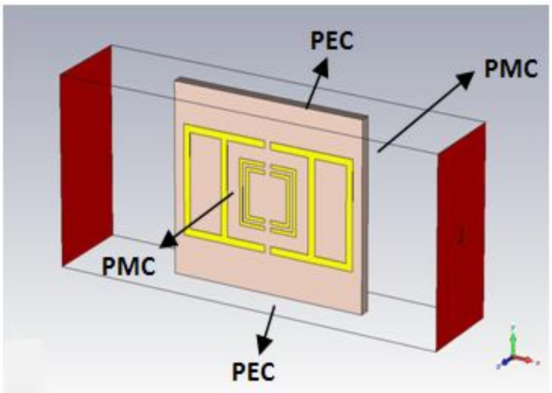


Figure 3 The LHM simulation setup

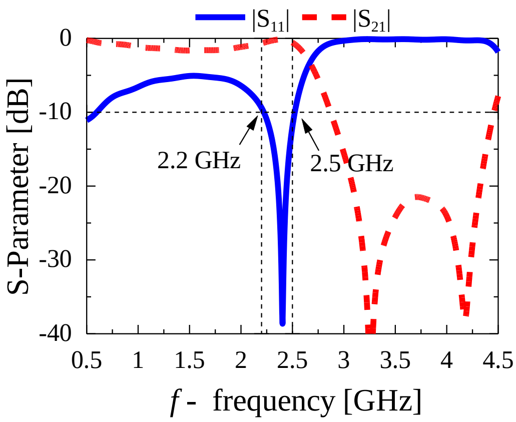


Figure 4 Value of S_{11} and S_{21}

The basic equations to determine ε_r and μ_r are shown below in Equations 1 and 2 (Ziolkowski, 2003):

$$\varepsilon_r \approx \frac{2}{jk_0 d}\frac{1-\nu_1}{1+\nu_1} \tag{1}$$

$$\mu_r \approx \frac{2}{jk_0 d}\frac{1-\nu_2}{1+\nu_2} \tag{2}$$

where:
$v_1 = S_{21} + S_{11}$, $v_2 = S_{21} - S_{11}$, $k_o = \omega/c$, ω is the radian frequency, d is the slab thickness, and c is the speed of light.

The results from simulation and the NRW formulae show the permittivity and permeability of the LHM structure. Figure 5 shows that the LHM structure has negative permittivity (Figure 5a) and negative permeability (Figure 5b) at the range of 2.057 – 2.7725 GHz, so the material can be classified as double negative material (DNG).

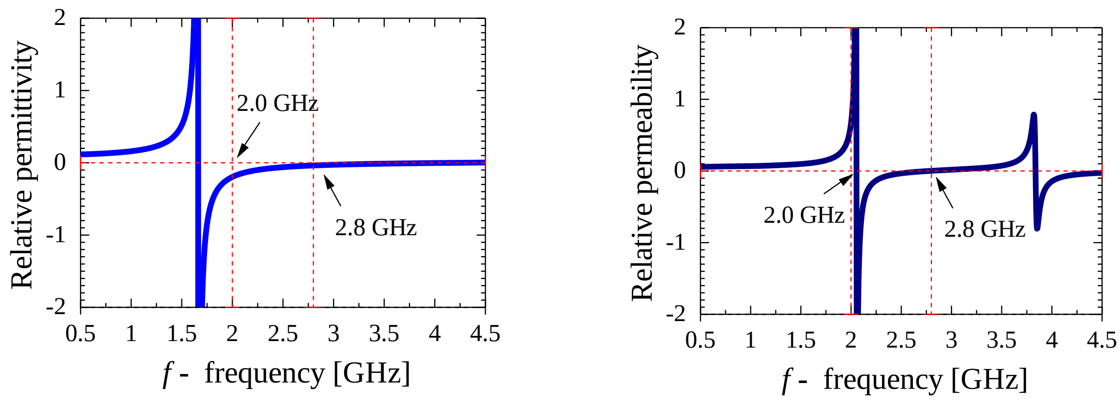
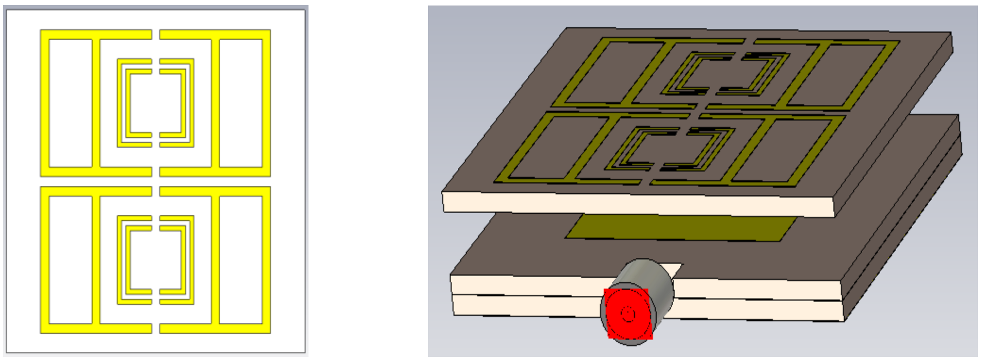


Figure 5 Single cell LHM: (a) negative permittivity; (b) negative permeability



(a) (b)

Figure 6 (a) Design of LHM structure for gain enhancement; (b) Exploded view of single element antenna with LHM structure on top

3. RESULT AND DISCUSSIONS

After the design of the single element conventional microstrip antenna and the single unit LHM structure was conducted, then these design are combined together. The implementation is discussed in the following subsections.

3.1. Implementation of LHM on a Conventional Single Element Microstrip Antenna

Implementation of LHM structure on a conventional microstrip antenna is depicted in Figure 6. By placing the LHM structure on top of the conventional single element microstrip antenna, the resonant frequency of the antenna is shifted to a lower frequency. Therefore, to obtain the resonant frequency at 2.35 GHz, we have to redesign the conventional microstrip antenna by reducing the size of the antenna patch and the antenna substrate. After characterization, the dimension of the antenna patch is 19.3×19.3 mm, the feed line length is 15 mm, and the substrate dimension can be reduced to 35×35 mm.

Table 1 shows the size comparison between microstrip antenna with and without LHM. A size reduction of antenna substrate is up to 51%.

Table 1 Dimension comparison between microstrip antenna with and without LHM

	Without LHM	With LHM	% Miniaturization
Patch dimension	27×27 mm	19.3×19.3 mm	48.9%
Substrate dimension	50×50 mm	35×35 mm	51.0%

Figure 7 shows the simulation result of the reflection coefficient from the conventional antenna (without LHM structure) and compared with the antenna with LHM structure. The result shows similarity, therefore this antenna with LHM structure works at the same frequency as the conventional one.

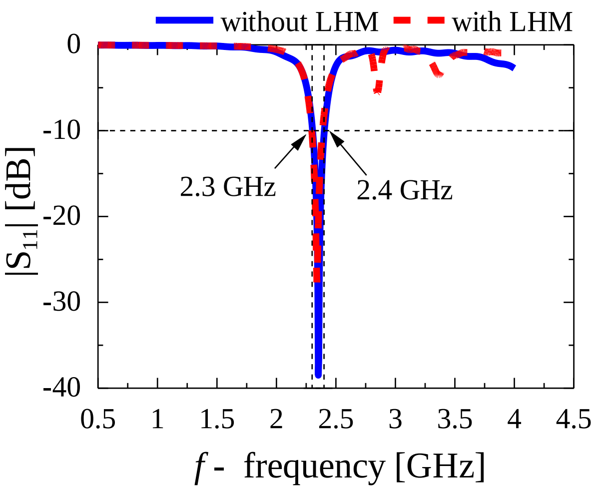


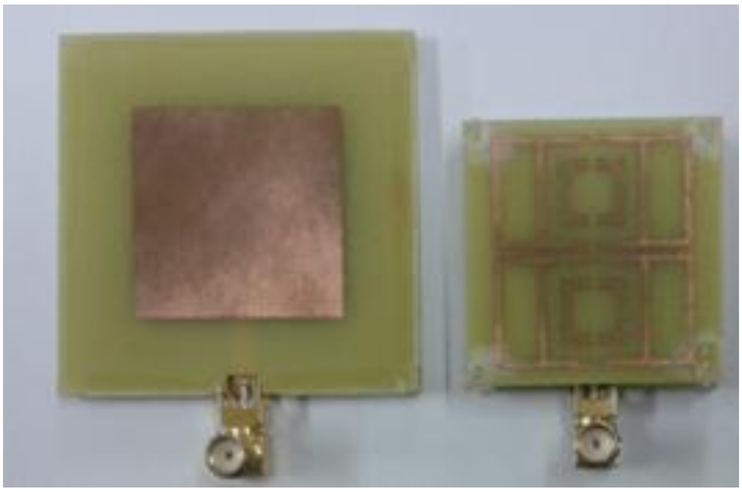
Figure 7 Simulation result of reflection coefficient antenna with and without LHM structure

Table 2 shows the comparison of antenna parameters between the microstrip antenna with and without LHM. Although there has been a size reduction of 51%, the antenna gain has not been reduced and is maintained at 4.52 dBi. This antenna is then fabricated and measured. The results will be compared between simulation and measurement of the antenna.

Table 2 Parameter comparison between microstrip antenna with and without LHM

Parameter	Without LHM	With LHM
Frequency (return loss $\leq$ -10 dB)	2.31–2.40 GHz	2.30–2.39 GHz
Center frequency	2.35 GHz	2.34 GHz
Return loss at center frequency	-38.49 dB	-27.44 dB
Bandwidth	98.9 MHz (4.2%)	90 MHz (3.8%)
VSWR at center frequency	1.02	1.09
Gain	4.66 dBi	4.52 dBi
Beamwidth	94.7^o	111.2^o

Figure 8 shows the fabricated antenna comparison between the microstrip antenna without (Figure 8a) and with LHM structure (Figure 8b). The results are compared and shown in Table 3.



(a) (b)

Figure 8 Photograph of microstrip antenna: (a) without LHM; and (b) with LHM structure

Table 3 Comparison between simulated and measured single element LHM antenna

Parameters	Simulation	Measurement
Frequency	2.30–2.39 GHz	2.27–2.38 GHz
Center frequency	2.34 GHz	2.33 GHz
Return loss	-27.44 dB	-21.531 dB
Bandwidth	90 MHz (3.8%)	114 MHz (4.89%)
VSWR minimum	1.089	1.1824
Gain	4.52 dBi	4.62 dBi

The comparison between measured and simulated results shows good agreement. The slightly different results occur due to the tolerances of dielectric constant of the materials used and imperfections during the fabrication process.

3.2. LHM Implementation on Conventional Two-Element Microstrip Antenna Array

Before implementing the LHM structure, a conventional two-element microstrip antenna array was designed. This design was conducted to increase the antenna gain. The single element antenna shows a gain of 4.5 dBi; therefore, by designing a two-element microstrip antenna array, an increase in antenna gain can be achieved.

The two square antenna patch is placed with a distance of d = 60 mm. The length and width of the antenna patch is 29.6×29.6 mm, while the total ground plane has a dimension of 160×60 mm. The feeding technique used here is the same as the single element antenna which is proximity-coupled.

Implementation of LHM structure on the conventional two-element microstrip antenna array is depicted in Figure 9. By placing the LHM structure on the top and bottom of the conventional two-element microstrip antennas array, the resonant frequency of the antenna is shifted to a lower frequency. Therefore, to obtain the resonant frequency at 2.35 GHz, a slight redesign to the conventional microstrip antenna is conducted by reducing the size of the antenna patch and the antenna substrate. After characterization, the optimum dimension of the antenna patch is

19.3×19.3 mm, the feed line length is 15 mm and the substrate dimension can be reduced and it has a dimension of 130×45 mm.

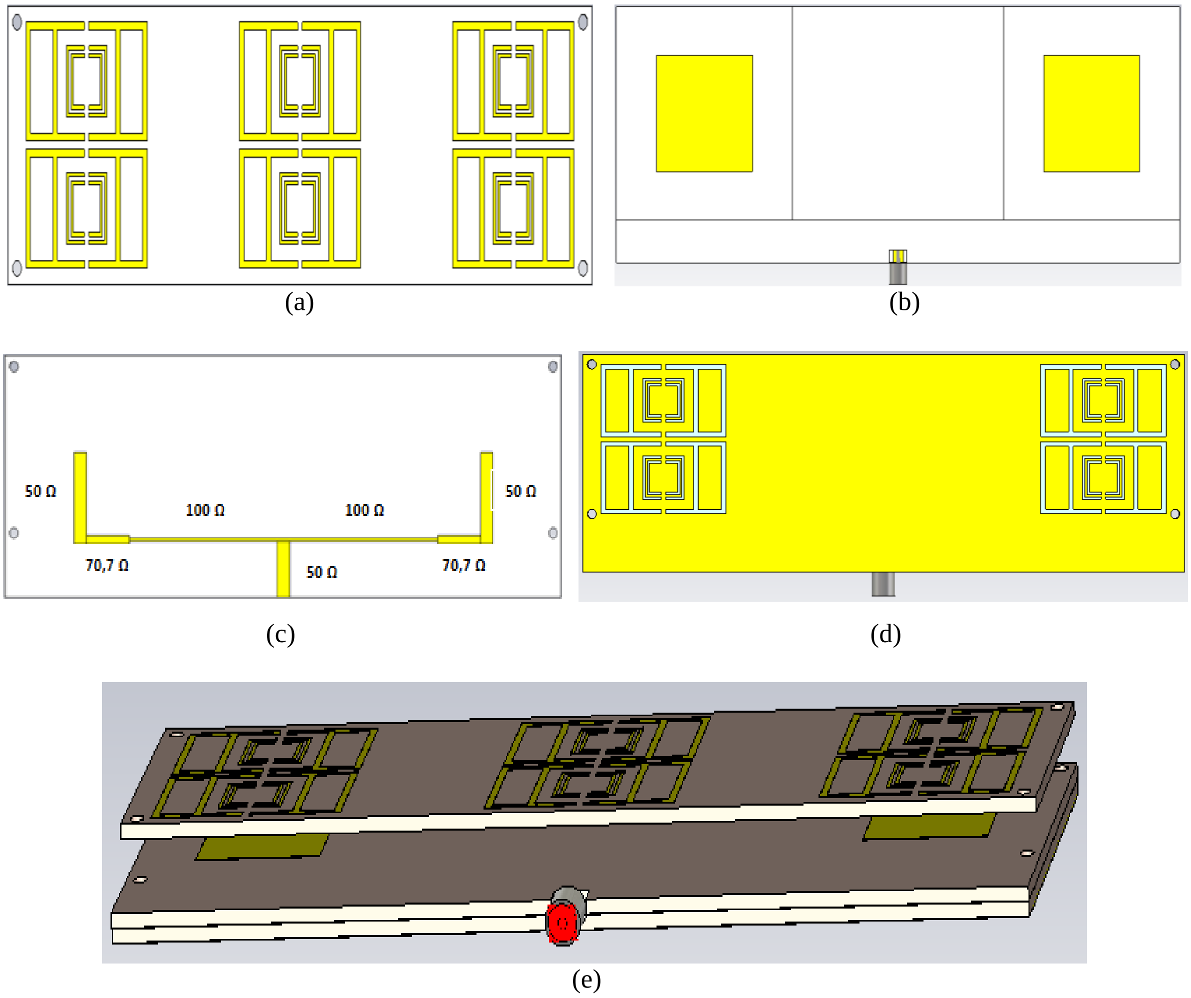


Figure 9 Design of two element array LHM antenna: (a) Gain enhancement element; (b) two element patch antenna; (c) Power divider; (d) bottom view of antenna; (e) exploded view of antenna

The size comparison between the microstrip antenna with and without LHM shows a size reduction of antenna substrate up to 39%. This antenna is then fabricated and measured. Figure 10 shows the fabricated antenna with the LHM structure. The results are compared and shown in Table 4. The comparison between measured and simulated results shows good agreement. The slightly different results occur due to the tolerances of the dielectric constant of the material used and imperfections during fabrication process.

Figure 10 Photo of two-element microstrip antennas array with LHM

Table 4 Comparison between simulated and measured two element antenna with LHM

Parameters	Simulation	Measurement
Frequency	2.28 – 2.41 GHz	2.26 – 2.41 GHz
Bandwidth	128 MHz (5.4 %)	146 MHz (6.21 %)
Gain	8.19 dBi	8.97 dBi

4. CONCLUSION

A LHM structure has been designed and implemented on the two-element microstrip antenna array to work at a frequency of 2.3–2.4 GHz. By using this LHM structure, the antenna dimension can be effectively reduced up to 39% and the measured antenna gain is 8.97 dBi; therefore, the LHM structure can be used for miniaturization and gain enhancement of an antenna.

5. ACKNOWLEDGEMENT

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