Left-Handed Metamaterial Incorporated with Microstrip Antenna at 6 GHz

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1. Introduction

Left-handed metamaterial (LHM) is an interesting material to be investigated where this artificial material has several unique properties such as the backward wave and the focusing effect inside it slab. Thirty four years later, on 2001, Smith made the first prototype structures of LHM [1]. The LHM is a combination of Split Ring Resonator (SRR) and thin wire (TW). Since the introduction of LHM twelve years ago, a lot of researcher interested in investigating this artificial material and several of them was using LHM to improve the properties of the microwave devices such as antenna and filter [2]. Many papers have been published about the LHM integrated with antennas and their properties have been analyzed. The focusing affect of LHM made a low gain antenna becomes directive and have an increment of gain [3 and 4]. The history of LHM was started from Veselago when he made a theoretical speculation of this artificial material that exhibit negative permittivity and negative permeability.

This paper discussed and analyzed the properties of the antenna with and without the LHM structure. The designed LHM is a combination of a modified SRR and capacitance loaded strip (CLS). The LHM and antenna were designed to operate at 6.2 GHz. The negative permittivity and negative permeability of the simulated LHM structures were presented. The gain of the antenna increased and validated through measurement.

2. Design of LHM

Figure 1 illustrates the LHM structure where it is a combination of a modified (SRR) and two (CLS). The modified SRR will produce magnetic material-like responses and exhibit the negative permittivity and the CLS will produce strong dielectric-like responses and exhibit the negative permeability [5 and 6].

3. Simulation of LHM

The simulation of LHM was done using Computer Simulation Technology (CST) software. Figure 2 shows the 3 cell of the LHM simulated using the software. Perfect magnetic conductor (PMC) boundary condition was set on the front and back faces of the block and perfect electric conductor (PEC) boundary condition was set on the top and bottom of the block. The E- field of the incident
wave is polarized along $y$-axis while the $H$-field of the incident wave is polarized along $z$-axis. The LHM structures are patterned on a FR4 board with a thickness of 1.6 mm. The relative permittivity of the FR4 board is 4.7 and its tangential loss is 0.019.

Figure 2:  Simulation of LHM using CST software

The S-parameters that was obtained from the simulation were then exported to the MathCAD. Nicholson, Ross and Wier (NRW) approach [5] was used to determine the permittivity and permeability of the LHM structure and the results is shown in figure 3 below. The equations used to determine the $\varepsilon$ and $\mu$ are [5]:

$$\varepsilon_r := \frac{2c \cdot (1 - v_1)}{w \cdot d \cdot i \cdot (1 + v_2)}$$  

$$\mu_r := \frac{2(1 - v_2) - c}{w \cdot d \cdot i (1 + v_2)}$$  

Where; $w =$ radian frequency  
$d =$ thickness of slab  
$v_1 := s_{21} + s_{11}$  
$v_2 := s_{21} - s_{11}$

Figure 3:  Negative permittivity and negative permeability value

From Figure 3, the range of the negative permittivity and negative permeability (-$\varepsilon$ and -$\mu$) starts from 5.17 GHz to 6.0 GHz. A single patch microstrip antenna was then designed to operate at the frequencies where the value of negative permittivity and negative permeability are almost the same. The centre frequency of 5.64 GHz was chosen as the operating frequency of the microstrip antenna. The same material of LHM was used for the microstrip antenna and a coaxial feed was used to feed
the patch of microstrip antenna. The LHM structure was placed in front of the microstrip antenna with a distance of 11.6 mm as shown in Figure 4. The simulated return loss ($s_{11}$) of the antenna with and without the LHM structure is shown in Figure 5. The simulated radiation pattern of the antenna is shown in Figure 6 and the radiation pattern of the antenna integrated with LHM structures is shown in Figure 7.

3. Fabrication of LHM

The fabrication was done using the same board properties (FR4 board) as in the simulation. Figure 8 shows the fabricated microstrip antenna and LHM structure. The measured return loss was shifted to a higher frequency due to the inconsistency of the dielectric constant of the FR4 board. Both the microstrip antenna and LHM structure were measured and operating at 6.18 GHz. The measured return loss shows a good agreement between the microstrip antenna with and without integration of LHM structure where both are below -10dB. The measured radiation patterns of the microstrip antenna with and without the LHM structure are shown in Figure 9 and Figure 10.
4. Discussion

From observation, the radiation pattern of microstrip antenna integrated with LHM structure has an improved gain compared to the gain of the microstrip antenna without LHM structure. An improvement of the gain by 3dB in simulation and measurement is obtained when LHM is placed in front of the microstrip antenna. The half-power beamwidth (HPBW) of the single patch microstrip antenna with LHM structure is narrower than the HPBW of the single patch microstrip antenna. This shows that LHM can be a focusing device where the beam become narrow and the gain increased. However, despite increasing of gain, the side and back lobe was also increased. If the side and back lobe can be reduce, the gain of the microstrip antenna with LHM structure can be further improved.

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References

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