Investigation of Left Handed Metamaterial In Microstrip Antenna Application

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Abstract - The speculation and invention of Left-Handed Meta Material (LH MTM) had sparked the interest of many researchers globally and was said to help increase the gain and directivity of the microstrip antenna. Therefore, the scope of this project was to design, simulate a LH MTM structure in order to proof the claims. The combination of the Square Rectangular Split Ring and the Thin Wire Structure was used to obtain the negative value of permeability, μ and the negative permittivity, ε. From the simulation done, the gain of the antenna has been increased to 1 dB. This had proven that the focusing effect of the LH MTM really enhance the gain of the antenna.

Keywords:Left Handed Metamaterial; Microstrip Antenna; Metal Wire; Square Rectangular Split Ring

1. INTRODUCTION

Recently, several papers have exposed the usefulness of metamaterials that produce negative indexes of refraction. It's all started in year 1967 when Victor Vesalago, a Russian Physicist made a theoretical speculation on the existence of substances with simultaneously negative permittivity and permeability. The Veselago's intuition remained silent for 29 years until year 1996 when Prof J.B Pendry proposed his design of Thin-Wire (TW) structure that exhibits the negative value of permittivity, ε [1] and the Split Ring Resonator (SRR) with a negative permeability, μ value. Following this interesting discovery, Dr. Smith combined the two structures which represented the first experiment LH MTM prototype.

In the last few years, the interests on focusing devices have been spurred by the use of media having simultaneously negative permittivity and permeability values, which are referred to as left-handed media or double negative media (DNG). In normal material, when both permittivity and permeability are positive the sign of n is also positive, in the case of double negative, left handed metamaterial when both permittivity and permeability are negative n is also negative, in the cases when one of the permittivity or permeability is positive, the other negative (off- diagonal terms in the table) the value of n is imaginary, so there is no wave propagation [2].

On the other hand, many researches were done to improve the response of microstrip antennas in particular since this type of antenna is desired for its low cost properties but with the compromise in the gain and directivity. According to some studies done [3]-[4], the LH MTM could actually increase the directivity of the microstrip antennas by locating a LH MTM cover in front of the propagating face of the antenna.

The objective of this paper is to show that the performances of a patch antenna can be considerably increased by making use of a LHM MTM without using any array of several types of antennas. A rectangular patch antenna was designed at a frequency where both values of permittivity and permeability of the LHM MTM were negative. Then, the LHM MTM is placed above the patch antenna in order to study its influence and the results are compared with those of the antenna alone.

2. LH MTM THEORY

2.1 Metal Thin Wire (TW)

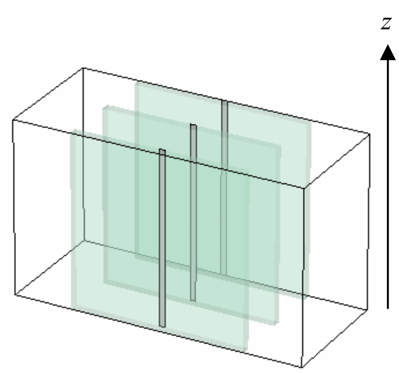

Fig. 1 Metal thin wire

If the excitation of the electric field **E** is parallel to the *z*-axis of the figure 1, so as to induce a current along them and generate equivalent electric dipole moment. This MTM exhibits a plasmonic type permittivity frequency function of the form [8]:

$$\varepsilon_r(\omega) = 1 - \frac{\omega_{pe}{}^2}{\left(\omega^2 + \zeta^2\right)} + j\frac{\xi\omega_{pe}{}^2}{\omega(\omega^2 + \zeta^2)} \quad (3)$$

Where ω_{pe} = electric plasma frequency, makes Re $(\varepsilon_r) < 0$ for $\omega^2 < (\omega_{pe}{}^2 - \zeta^2)$ which reduces if $\zeta = 0$ to $\varepsilon_r < 0$ for $\omega < \omega_{pe}$

2.2 Square Rectangular Split Ring (SRR)

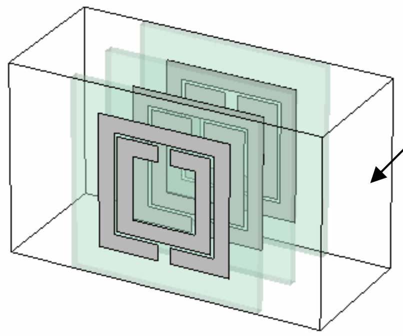

Fig. 2 Split ring resonator

If the excitation magnetic field **H** is perpendicular to the *y*-plane of the figure 2, so as to induce resonating currents in the loop and generate equivalent magnetic dipole moment. This MTM exhibits a plasmonic type permeability frequency function of form [5]:

$$\mu_r = 1 - F\omega^2\frac{(\omega^2 - \omega_{0m}{}^2)}{(\omega^2 - \omega_{0m}{}^2)^2 + (\omega\zeta)^2} + j\frac{F\omega^2\zeta}{(\omega^2 - \omega_{0m}{}^2)^2 + (\omega\zeta)^2} \quad (4)$$

Where ω_{0m} = magnetic resonance frequency, makes $\mu_r < 0$, for $\omega_{0m} < \omega < \omega_{0m} / \sqrt{(1-F)} = \omega_{pm}$ (magnetic plasma frequency).

3. Metamaterial Design and Simulation

A research on LH MTM was carried out to understand the fundamentals of the newly discovered substance. Then, the CST Microwave Studio was chosen to simulate the structure showed in Figure 3 as this software is desirable for a 3D platform in simulating a full wave simulation. This structure was obtained from [6] and the boundary conditions were set similar to a waveguide setup explained in [7].

The S-parameters that was obtain from simulation then, were exported to the MathCAD to calculate the effective values of permittivity and permeability. Nicolson-Ross-Weir (NRW) Approach [8] was used in the calculation effective values of permittivity and permeability and the results obtained are shown in figure 4. The equations used in this paper were:

$$S_{11} \approx \frac{2jkd(\eta^2 - 1)}{(\eta+1)^2 - (\eta-1)^2} = \frac{2jkd(\eta^2 - 1)}{4\eta} \quad (1)$$

$$\varepsilon_r = \mu_r + j\frac{2S_{11}d}{k_0} \quad (2)$$

From the figure 5 extracted, we can notice that the most interesting part of the LHM lies in the 2.08–2.20 GHz range where the losses are very low. It is noted that at around 2.1 GHz, the real parts of both and are almost the same.

A microstrip antenna was then designed to operate at the Left Handed frequency range where the losses are very low and both values of permittivity and permeability were negative. In this paper, the frequency of 2.12 GHz was chosen for the microstrip antenna's operating frequency and the antenna's specifications are shown in Table 1. The antenna was simulated and the desired result as in table 4 was obtained, LH MTM and the microstrip antenna was combined and simulated using the CST Microwave Studio. Figure 7 illustrates the set up of the antenna with the LH MTM. Then, the distance between the LH MTM and the antenna was altered to obtain the optimum distance in achieving the perfect matching for the antenna. From the simulated results, the distance of 42 mm proved to present the best matching results where the return loss of the microstrip antenna is below -10 dB.

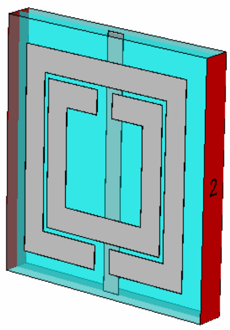

Fig. 3 3D perspective view of the proposed structure

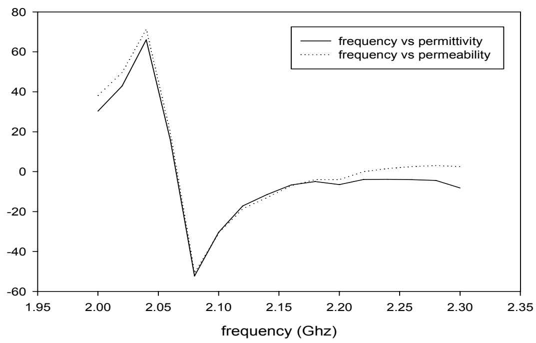

Fig. 4 Graph of the negative parameters obtained from MathCAD

TABLE I: MICROSTRIP ANTENNA SPECIFICATIONS

	Magnitude	Unit
Operating Frequency	2.12	GHz
Length (L)	31	mm
Width (W)	42	mm
Feed	Coaxial	-
Feed Location	X=21, Y=9	mm

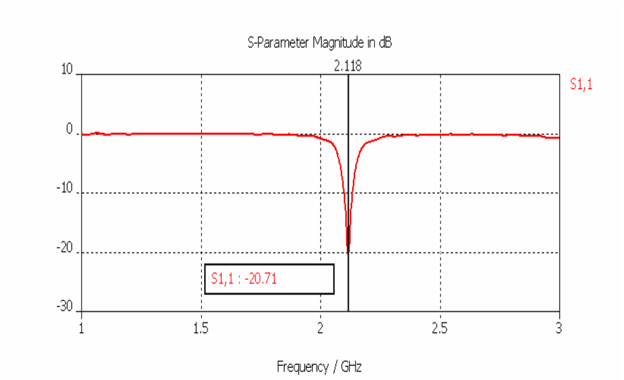

Fig. 6 Simulation result of the Return Loss (S_{11}) of the microstrip antenna

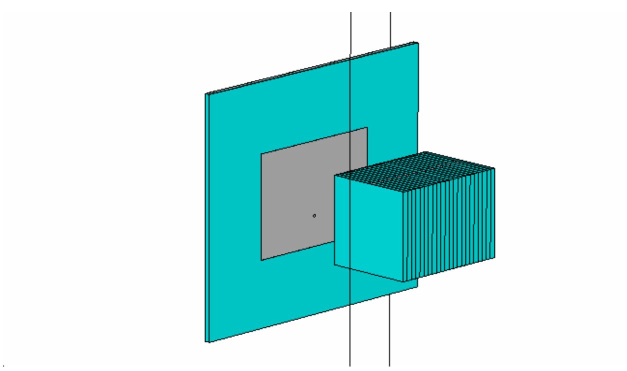

Fig. 7 3D view of the integration of LH MTM and microstrip antenna

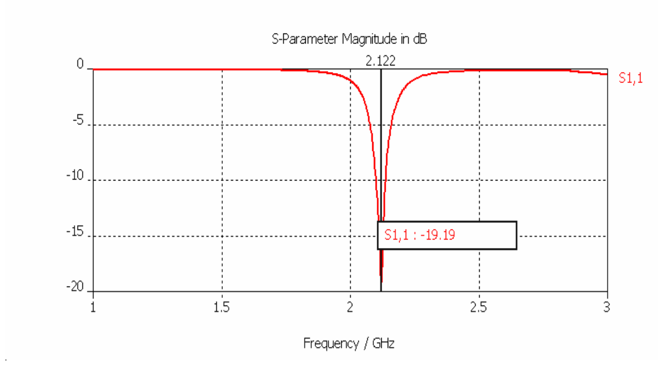

Fig. 8 Simulation result of the Return Loss (S_{11}) of the microstrip antenna

Finally, the 3D radiation patterns of the microstrip antenna with and without the integration of the LH MTM were also simulated and shown in Figure 9 and 10. The return loss of the integaration of LH MTM and microstrip antenna is also below -10 dB. In order to illustrate the difference between the response of the microstrip in the presence of the LH MTM or instead, Table II has been constructed. In that particular table, it was obvious that the S_{11}, Gain and Directivity had soared and produced encouraging results.

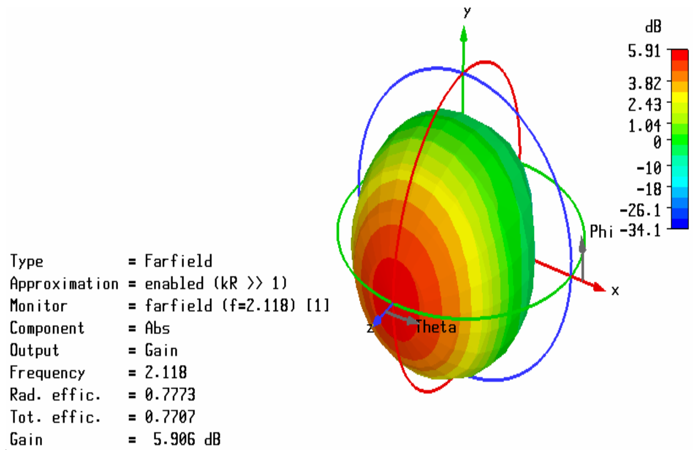

Fig. 9 Radiation pattern of the microstrip antenna without the LH MTM

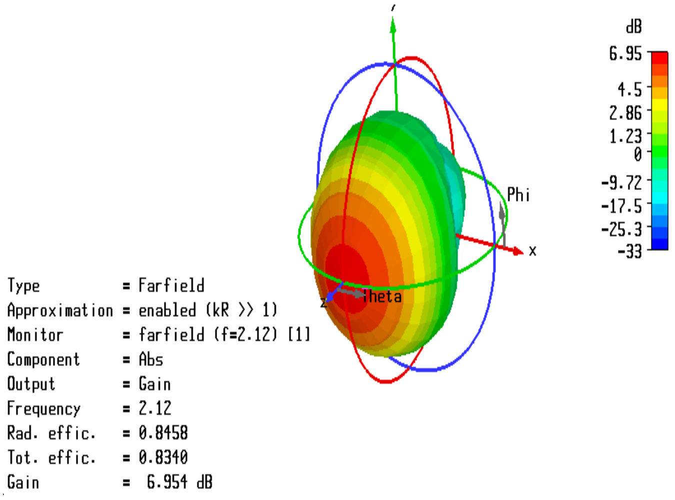

Fig. 10 Radiation Pattern of the microstrip antenna with the LH MTM

TABLE II: SIMULATION RESULTS COMPARISON

	Parameters	Without LH MTM (2.12GHz)	With LH MTM (2.12 GHz)
1	Return Loss (S_{11})	< -10 dB	< -10 dB
2	Gain	5.986 dB	6.954 dB
3	Directivity	6.923 dBi	7.686 dBi

4. CONCLUSIONS

The design and simulation of the LH MTM were successfully done and all the objectives within the scope of the project were met. All simulation work was done in the Wireless Communication Centre (WCC), UTM.

This study on the patch antenna shows that the enhancement of its performances is possible even without the use of an array of several elements. In addition, the presence of LH MTM could improve the gain and directivity of a microstrip antenna as well as reducing the Return Loss of the antenna. An improvement of the gain by 1 dB is achieved and a more directional antenna is obtained when the LHM is placed above the patch. This was proven true by the simulation results. Besides, the modified NRW Approach was proven to yield reliable results from the outcome of the whole project.

5. ACKNOWLEDGEMENT

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