Miniaturisation of WLAN Feeler Using Media with a Negative Refractive Index

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Abstract - It presents a rectangular microstrip patch antenna integrated with combination of pentagonal and hexagonal shaped structure etched at the height of 3.276 mm from the ground plane. It is demonstrated that the application of the media with a negative refractive index or metamaterial eliminates the spurious harmonics (these are those unwanted dips which shows in the S11 graph) associated with the original structure. Furthermore the return loss is improved by the inclusion of the metamaterial structure reaching -27.1919 dB compared with -10.1286 dB achieved by the original patch antenna structure alone. Main focus in this design process is not to reduce the return loss but reduce the size of the antenna and this target has been achieved by reducing the size of antenna up to 65%. Numerical simulation results show that this proposed design possesses several desirable characteristics, for instance, high bandwidth, low loss and improved directivity compared to the alone RMPA. The CST-MWS software is used for designing and simulation, and MS-Excel for metamaterial proving.

Index Terms - Media with negative refractive index (metamaterial), rectangular microstrip patch antenna (RMPA), permittivity, permeability, NRW approach, Return Loss.

1. INTRODUCTION

In last decade the peremptory of Wireless communications systems have grown drastically. To fulfil this requirement, multifunction antennas have been designed for multipurpose operation over different wireless services. Recent improvement in communication technology and extensive growth in the wireless communication market and user demands exhibits the need for compact, reliable and efficient, wireless systems. Integrating whole transmitter and receiver system on a single chip [1], [3] is the imagination for future wireless systems. This particular idea has the benefit of cost reduction and enhancing system reliability. Antennas have always been considered as the largest components of integrated wireless systems, consequently antenna miniaturization became a necessary piece of work in achieving a favourable design for integrated wireless systems. Moreover, compactness is important aspect in wireless communication, addition with the other parameters improvement like directivity, return loss, bandwidth [2]. These characteristics can be achieved by covering of microstrip patch antennas with metamaterial structures [4], [5].

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Several researchers have been trying from years to reduce the size of the antenna. It has been attempted in many ways and different concepts were proposed. Recently, metamaterial based structure, originally proposed by Pendry, has opened the door to new design strategies, where miniaturization and compatibility in planar circuit technology are key aspects. In 21st century split rings resonators (SRRs), originally proposed by Pendry [6], [7], have attracted a great interest for the design of negative permeability, negative permittivity and left-handed (LH) effective media [5].

In late sixties (1967) Victor Georgievich Veselago [5], a Russian physicist was the first researcher who presented the theory of metamaterial, which exhibit negative permittivity ε, and permeability μ [16] also known as media with a negative refractive index or left handed material [11], [13]. In such a material, he showed that the phase velocity would be anti-parallel to the direction of Poynting vector. This is contrary to wave propagation in natural occurring materials. In the beginning of 21st century, papers were published about the first demonstrations of an artificial material that produced a negative index of refraction (that was discussed in last paragraph). By 2007, research experiments which involved negative refractive index or metamaterial properties had been conducted by many groups.

2. DESIGN METHODOLOGY

All the design work and simulation work has been done on the computer simulation technology microwave studio (CST-MWS). And the proving of the metamaterial which used to enhance the property of RMPA, Microsoft excel software is used. Initially dimensions were calculated for the operating resonant frequency i.e. 2.05GHz by using formulas shown below.For calculation of width and length of the patch antenna:

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r+1}} = \frac{c}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (1)$$

$$L = Leff - 2\Delta L \quad (2)$$

Where,

$$Leff = \frac{c}{2f_r\sqrt{\varepsilon_{eff}}} \quad (3)$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad (4)$$

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(\frac{1}{\sqrt{1+\frac{12h}{w}}}\right) \quad (5)$$

In above used formulas the symbols have their usual meanings.

e.g.

c = Velocity of light in free space,

ε_r = Substrate's Dielectric constant,

ε_{eff} = Effective dielectric constant,

L_{eff} = Effective length.

After dimension calculation design work has been done. Perfect electric conductor was used to make the patch antenna over the ground which also having the same material with substrate between patch and ground. RMPA at 2.05GHz frequency is shown in figure 1.

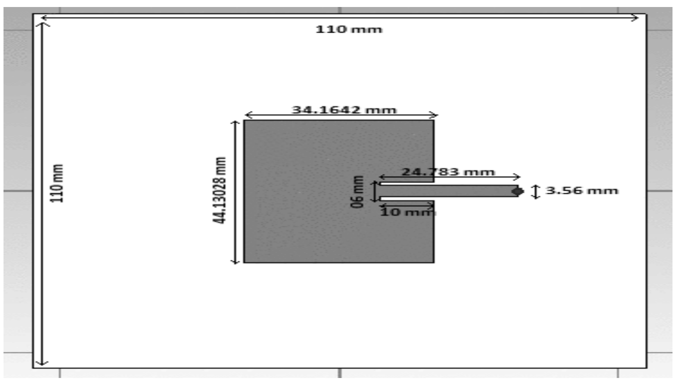

Figure 1: RMPA at height of 1.6mm from ground of 2.05GHz.

The simulation result of the patch shown in figure 1 is in graphical form shown in figure 2, with the return loss and bandwidth of -10.1286dB and 7.7MHz respectively.

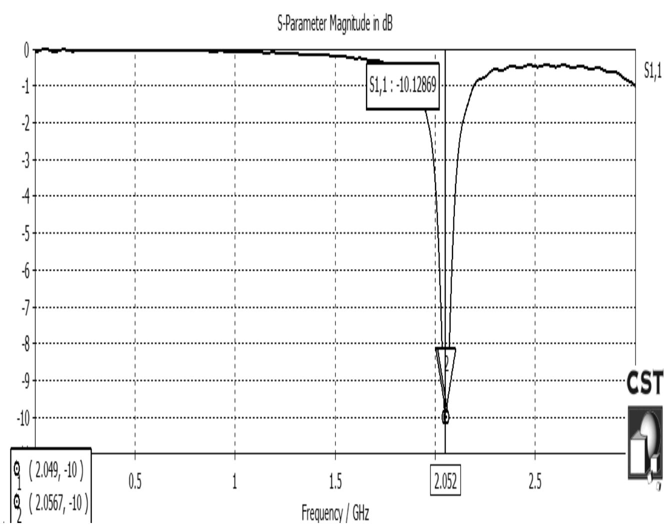

Figure 2: Simulation result of the RMPA with return loss of -10.12dB and bandwidth of 7.7MHz at 2.05GHz.

After the RMPA simulation the metamaterial cover is implemented over the patch antenna at the height of 3.2mm from the ground. The proposed metamaterial structure implemented as the cover of antenna with its dimension used in the proposed design is shown in figure 3.

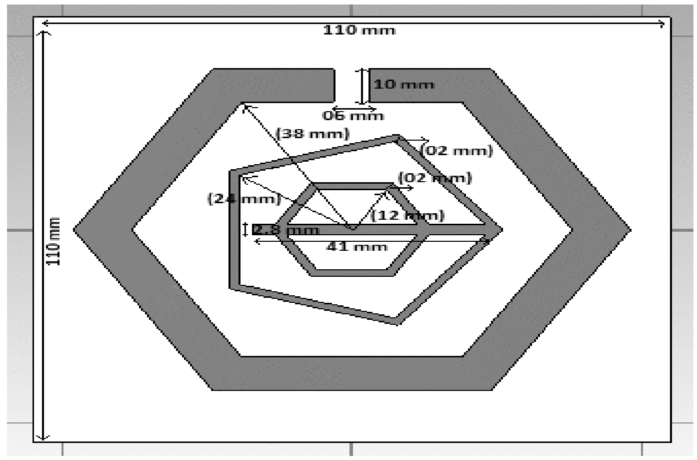

Figure 3: Proposed metamaterial structure at the height of 3.2mm from ground.

The simulation result after the implementation of the metamaterial over the rectangular microstrip patch antenna at the height of 3.2mm from the ground enhance the property of the RMPA alone and reduces the size of the antenna by shifting the lowest dip to a frequency other than the operative frequency i.e. at 0.651GHz. The size is being reduced to 65%. The simulation result with the metamaterial is shown in figure 4.

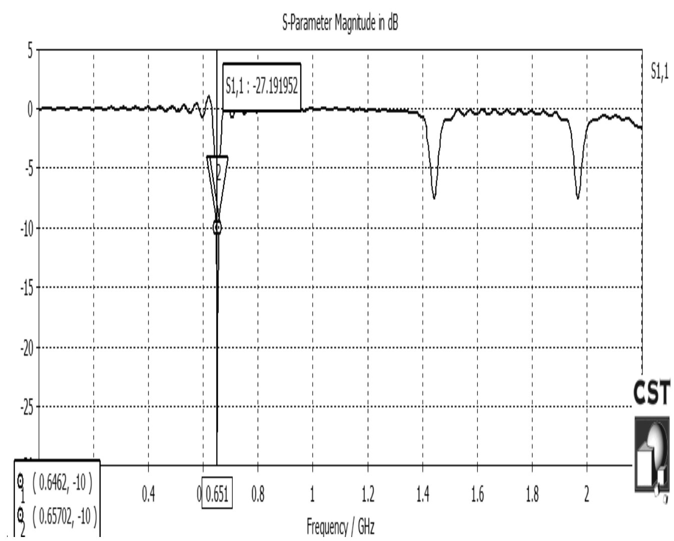

Figure 4: This simulated result is showing the return loss of -27.19dB and bandwidth of 10.82MHz at 0.651GHz.

Comparison of dimensions between reduced patch antenna using media with negative refractive index at operating frequency 2.05GHz and RMPA alone at 0.651GHz is in tabular form below.

	Dimensions of RMPA alone at 0.651GHz	Dimensions of RMPA using metamaterial works at 0.651GHz	Unit
Length	110.9574	34.1642	mm
Width	141.5426	44.1302	mm
Cut width	20	6	mm
Cut length	35	10	mm
length of feed	85.2926	24.7830	mm
Width of feed	14	3.56	mm

Table 1: Comparison of Dimensions

After comparing it is necessary to prove that the material here used to reduce the size of RMPA is Meta, NRW (Nicolson Ross Weir) approach [14] is used to prove it. The following formulas belong to NRW approach:

$$\mu_r = \frac{2.c(1-v2)}{\omega.d.i(1+v2)} \quad (6)$$

$$\varepsilon_r = \mu_r + \frac{2.S11.c.i}{\omega.d} \quad (7)$$

Where,

V_2 = S21 - S11 or Voltage Minima,

ω = Frequency in Radian,

d = Thickness of the Substrate,

c = Speed of Light,

μ_r = Relative permeability,

ε_r = Relative permittivity.

In NRW approach, proposed design of patch antenna having metamaterial structure placed between two waveguide ports on both sides of antenna on X-axis to calculate S11 and S21 parameters. Y and Z planes are defined as the perfect electric and magnetic boundary respectively. Following that, the wave was excited toward the port 2 from port 1 or left to right.

Later on, after the simulation in CST-MWS software the S11 and S21 parameters were exported to MS Excel software for further calculation. In MS Excel equation number (6) & (7) were used for proving of structure that it is metamaterial. The result obtained using NRW approach are showing negative permeability and permittivity in figure 6 & 7 respectively.

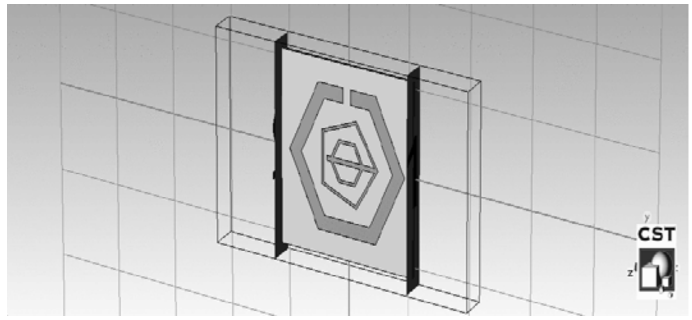

Figure 5: Proposed metamaterial structure between waveguide ports.

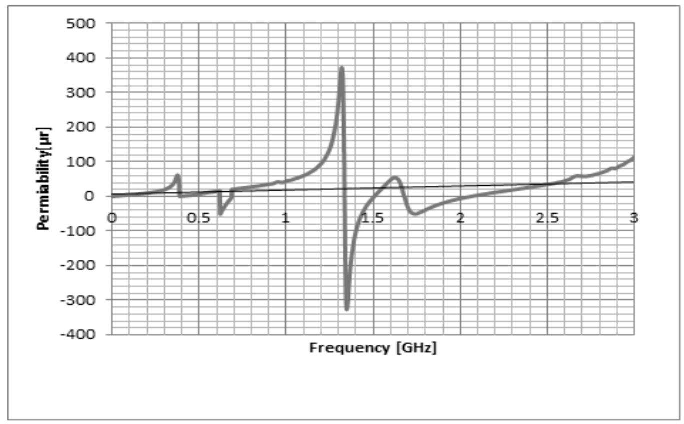

Figure 6: Permeability versus frequency graph obtained from Excel software.

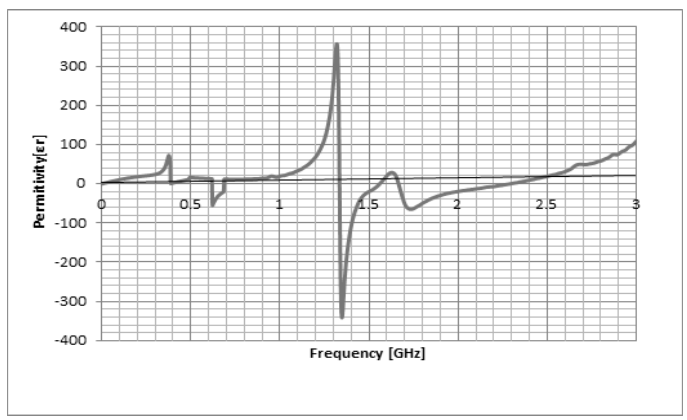

Figure. 7: permittivity versus frequency graph obtained from Microsoft Excel software.

The Table's generated for permittivity and permeability by using MS-Excel Software was too large, therefore the Table 2 & Table 3 shows the negative value of permittivity and permeability only in the frequency range 0.6419-0.6539GHz.

Frequency [GHz]	Permeability[μr]	Re[μr]
0.6419999	-31.9316370277838-14.5648307462409i	-31.93163703
0.64499998	-29.5759201229285-14.3467942395896i	-29.57592012
0.648	-27.3064654388456-14.1729215593206i	-27.30646544
0.6509999	-25.1190003040519-14.0363460044533i	-25.1190003
0.65399998	-23.0080937796368-13.9305290718914i	-23.00809378

Table 2: Sampled Values of Permeability at 0.651GHz Calculated on MS Excel Software.

Frequency [GHz]	Permittivity[εr]	Re[εr]
0.6419999	-37.1552405011718-24.6492429073745i	-37.1552405
0.64499998	-35.314195613912-25.2329994815107i	-35.31419561
0.648	-33.6325777383075-25.8021819587365i	-33.63257774
0.6509999	-32.0899516273428-26.3433936840906i	-32.08995163
0.65399998	-30.665474813861-26.8496952334226i	-30.66547481

Table 3: Sampled Values of Permittivity at 0.651GHz Calculated on MS Excel Software.

After proving of metamaterial it has been defined that the proposed structure to miniaturize the antenna was metamaterial. Post proving, hardware of the proposed design was constructed and analyzed using spectrum analyzer and the results of RMPA alone and incorporated feeler were compared. Figures are shown below.

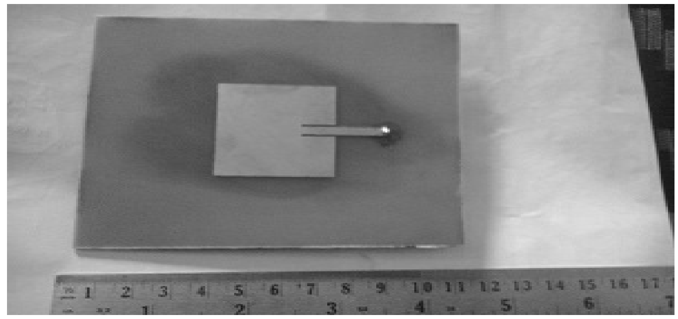

Figure 8: Hardware of RMPA alone at 2.05 GHz.

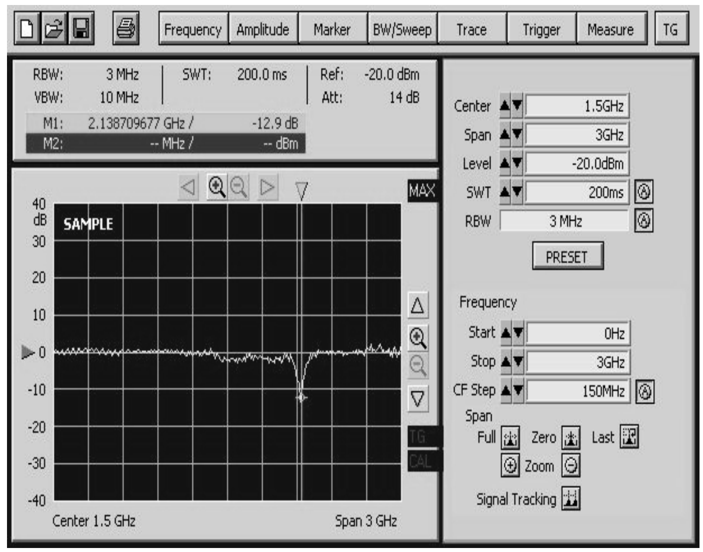

Figure 9: Analyzed result of patch showing return loss of -12.9 dB at 2.13 GHz.

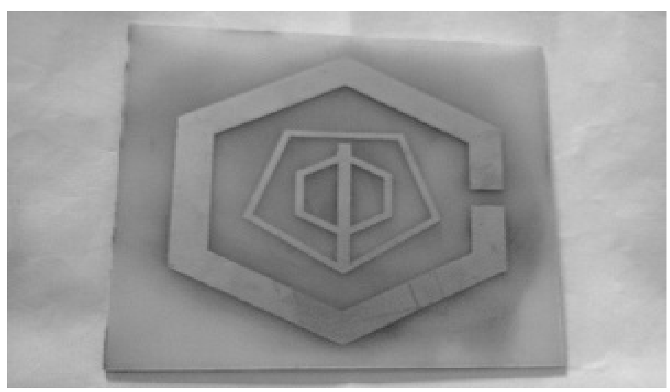

Figure 10: Incorporated metamaterial structure over patch surface.

3. CONCLUSION AND FUTURE SCOPE

By emphasizing RMPA with the Metamaterial structure the frequency on which it shows its maximum power output or lowest return loss is 0.651GHz. Table 1 shows the comparison of patch antenna designed at the frequency of 0.651GHz and at 2.05GHz with metamaterial. RMPA at 0.651GHz consumes a large area instead of RMPA at 2.05GHz. By using metamaterial it became possible that the antenna at 2.05GHz operating frequency be able to work at 0.651GHz frequency with 65% less area and more accurate results [9][10]. Figure 2 & 4 shows the comparison of return loss & bandwidth of the RMPA alone and with the metamaterial. It has been found that the return loss is reduced by 17dB & the bandwidth is increased by 3MHz of the proposed structure. The Figure 6 & 7 shows the negative value of permittivity & permeability at the operating frequency of 0.651GHz. This proves that the proposed Design of media with a negative refractive index is a Metamaterial Structure.

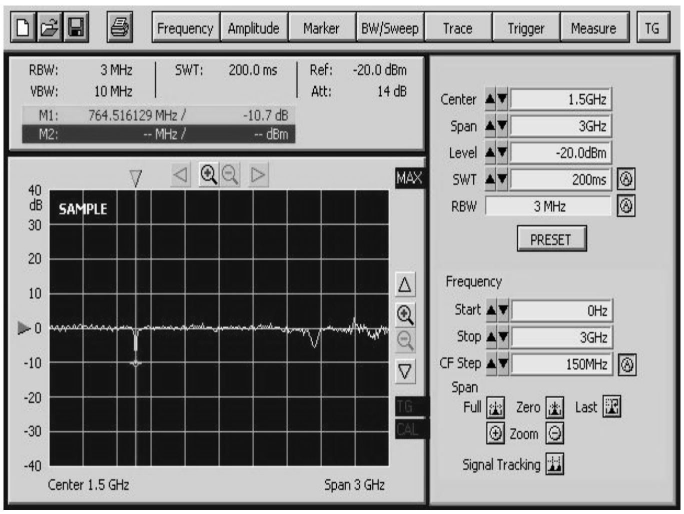

Figure 11: Analyzed result after negative media incorporation showing return loss at 0.76 GHz.

Authors presented a new design methodology in this letter for creating highly miniaturized patch antennas, by adding a single layer that contains a combination of hexagonal and pentagonal like structure at a height of 3.276 on RMPA. The size of the antenna can be reduced significantly without affecting bandwidth with little effort at low cost. The purpose of this work is to produce a small, low cost Antenna that can be used for L band (1-2GHz) applications. An even smaller antenna is possible by this proposed design, but with further miniaturisation comes lacking in radiation efficiency and bandwidth that may prove undesirable.

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