Dual Band Metamaterial Inspired Antenna for Bluetooth/Wi-Max Applications

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Abstract- With the fast development of wireless communication technologies, more compact and multi-frequency antennas with a low profile, low cost and superior performances are required. At present, the simplest and widely used technique to enhance dual-band and multi-band characteristics in antennas is by using metamaterials. In this paper, a rectangular microstrip patch antenna is designed that resonates at 3.5 GHz frequency. To achieve dual band characteristics in antenna, S-shaped metamaterial structure is implemented on its ground plane. The design and simulation of an optimized S-shaped metamaterial structure for 2.4 GHz frequency is also presented. In this antenna structure, no modification in radiating patch is required. Hence, the proposed antenna has overall dimensions 36x43 mm^2 and compatible with wireless devices. Ansoft HFSS simulation software is used to obtain results of radiation parameters such as return loss, VSWR, gain, radiation pattern has satisfactory value within range. For designing of proposed antenna FR4 substrate is used. The experimental and simulated results are reported which shows a good agreement between the results.

Keywords – Microstrip Patch Antennas, Metamaterials, Dual Band Antennas

1. INTRODUCTION

In modern wireless communication system microstrip patch antenna plays a vital role owing to its favorable properties such as low cost, easily mountable, ease of fabrication, low profile and ease of integration with the circuit [1]. Additionally, these antennas can be easily mounted on missiles, satellites and even mobile phones and handheld devices.

One major revolution in field of antenna technology is the development of dual band or multiband antennas. Dual band antennas are the antennas which operate at more than one frequency band, thus supporting various wireless standards in a single antenna system. Compact dual band antenna are the useful candidate in wireless sensor networks, microwave energy harvesting, radio frequency identifiers (RFID) [2]. There are various ways to achieve dual band performance in a microstrip patch antenna, such as fractal shapes [3], variation of ground plane [4], different feeding techniques [5], different shapes of slots (C, L, U shaped slots [6-7]). But these traditional techniques usually create antenna designs which have large size, high cross polar radiation pattern and low efficiency.

The simplest and widely used technique to enhance dual-band and multi-band characteristics in antennas is by using metamaterials. Metamaterials also enhance the performance of antenna like increases the gain, bandwidth, radiation efficiency [8]. Metamaterials are defined as macroscopic composites having man-made, three dimensional, periodic cellular architecture designed to produce an optimized combination, of two or more responses to a specific excitation. They show unusual properties like negative permittivity and permeability which leads to negative refractive index that supports backward waves [9].

In this paper, an antenna is presented with dual band characteristics for Bluetooth (2.4 GHz) and WiMAX (3.5 GHz) frequency by implementing metamaterial structure on ground plane. A series of parametric analysis is investigated to find that how the characteristics of antenna depend on the position of metamaterial structure on the ground plane. The entire work is organized as follows; Section 2 describes metamaterial structure design and the parameter extraction, Section 3 describes the antenna design, synthesis and measurement. Section 4 describes result and validation and finally section 5 describes conclusion of the work. All the simulation work is carried using Ansys electromagnetic software HFSSv15.

2. METAMATERIAL STRUCTURE DESIGN AND ANALYSIS

Earlier, realization of left-handed metamaterials consists of a bulky combination of metal wires that has a negative permittivity and split ring resonators (SRR) that has a negative permeability (which is known as resonant approach) [10]. But, in microwave engineering applications, the resonant approach is not practical as the structures are bulky, lossy and have narrow band due to requirement of operation near SRR resonance.

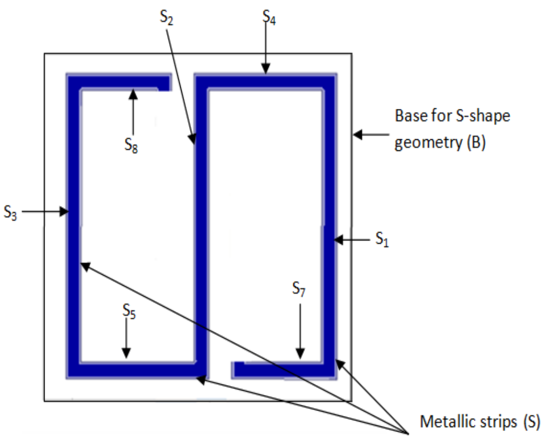
The metamaterial geometries like omega-shaped, S-shaped, I-shaped etc structures have been examined to be useful in constructing innovative design for miniature and broadband/multiband antennas and these structures also overcome the problems faced in resonant approach [11-12]. A dual antenna system is proposed in [13] which is very small in size and antenna structure consists of patch antenna with slotted ground plane along with metamaterial structures near the feed line.

In this paper, the S-shaped metamaterial structure that resonates at 2.4GHz frequency with optimized parameters of negative index behavior in which both negative permittivity and negative permeability co-exist simultaneously in the required frequency region is designed. The desired 2.4GHz frequency can be controlled by proper selection of metallic strips dimensions for designing of metamaterial structure which is simulated by HFSS. The material for base structure used is non-magnetic FR4-Epoxy with a relative permittivity of 4.4, the thickness of 1.6mm and a loss tangent of 0.02. The optimized metamaterial structure is designed as shown in fig.1.The formulae used for calculating the resonating frequency of metamaterial structure is given in below [9]

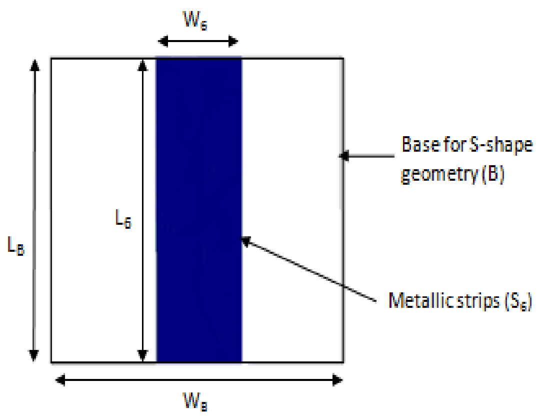
$$\mathbf{f_r = C/2\, L_{eq} \sqrt{\epsilon_{re}}}$$

Where C is speed of light, f_r is resonant frequency, ϵ_{re} is effective dielectric constant

Now, the Region is needed to confine the radiation of the designed geometry of metamaterial structure, so that we get desired value of S parameters. The two floquet ports will be used as shown in fig.2 and fig.3, for which the simulation results are shown in fig.4. The Floquet port is closely related to a wave port in that a set of modes (Floquet modes) represents the fields on the port boundary. Two Floquet ports will be used for incident wave excitation and termination of transmitted and reflected fields. The Floquet ports works in conjunction with the Master/Slave boundaries to enforce the surface's periodicity [14, 15]. For Floquet port 1 - The assigning of Floquet port 1 is shown in fig.2.



(a) Front View



(b)Back View

Figure1. S-Shaped Metamaterial Structure

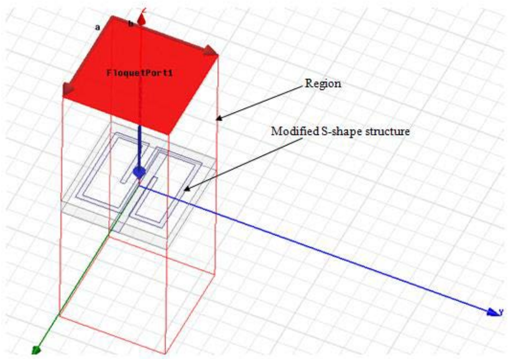


Figure .2. Assigning Floquet port1

For Floquet port 2 - The assigning of Floquet port 2 is shown in fig. 3.

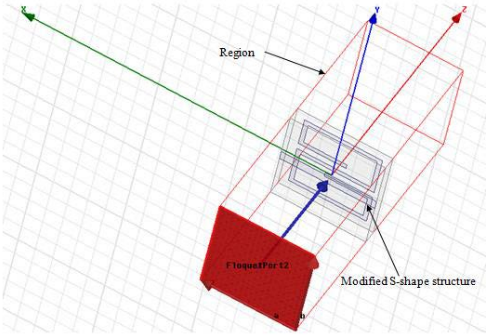


Figure 3 : Assigning Floquet port2

To analyze the characteristics of the proposed metamaterial structure for embedding in the antenna structure, reflection (S_{11}) and transmission (S_{21}) coefficients are extracted as shown in fig.4. From fig.4, we conclude that at frequency of 2.4 GHz, the value of S_{11} (dB) is -18 dB and S_{21} (dB) is -15dB. By using the value of (S_{11}) and (S_{21}) ,we will calculate the value of effective permittivity (ε_r), permeability (μ_r), and refractive index (n_r) by using NRW approach which are expressed as follows [16]

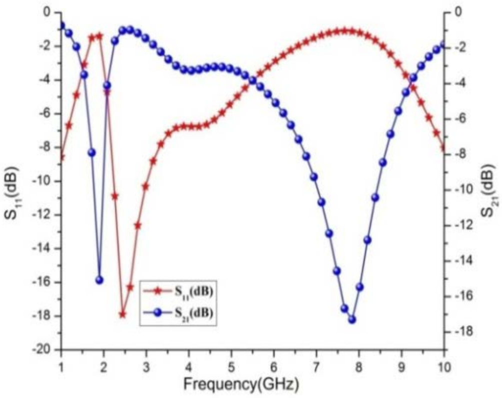


Figure 4.Reflection coefficient and transmission coefficient v/s frequency

In Nicolson-Ross-Weir (NRW) algorithm, the reflection coefficient is

$$\Gamma = \chi \pm \sqrt{\chi^2 - 1} \quad \text{........... (1.1)}$$

Where

$$\chi = \frac{s_{11}^2 - s_{21}^2 + 1}{2s_{11}} \quad \text{........... (1.2)}$$

As a step to acquire the correct root, X is must be in the form of S-parameter, the magnitude of the reflection coefficient must be less than one. The following stage is to calculate the transmission coefficient of metamaterial structure.

$$T = \frac{S_{11} + S_{21} - \Gamma}{1 - (S_{11} + S_{21})\Gamma} \quad \text{........... (1.3)}$$

$$\ln\left(\frac{1}{T}\right) = \ln\left(\frac{1}{T}\right) + j(\theta_T + 2\pi n) \quad \text{........ (1.4)}$$

Where

$$n = \frac{L}{\lambda_g} \quad \text{........... (1.5)}$$

n = *number of root*, L=*material length in cm* λg=*wavelength in cm*, θ_T=phase *of transmision coefficient in radian*

We define:

$$\frac{1}{\Lambda^2} = -\left[\frac{1}{2\pi L}\ln\left(\frac{1}{T}\right)\right]^2 \quad \text{.......... (1.6)}$$

Then we can solve the permeability using

$$\mu_r = \frac{1+\Gamma}{(1-\Gamma)\Lambda\sqrt{\frac{1}{\lambda_0^2} - \frac{1}{\lambda_c^2}}} \quad \text{......... (1.7)}$$

Where λ_0 is the free space wavelength and λc is the cutoff wavelength.

The permittivity is given by

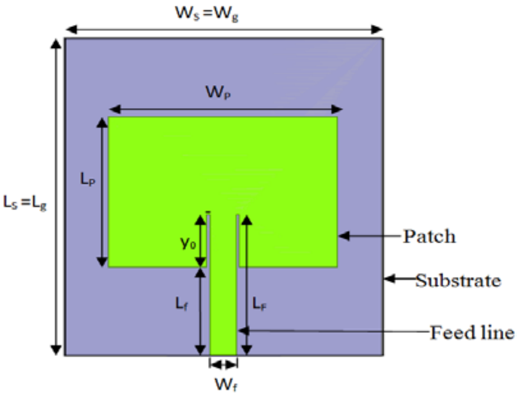
$$\varepsilon_r = \frac{\lambda_0^2}{\mu_r}\left[\frac{1}{\lambda_c^2} - \left[\frac{1}{2\pi L}\ln\left(\frac{1}{\mathrm{T}}\right)\right]^2\right] \quad \text{....... (1.8)}$$

When we simplified the above equations (1.1 to 1.8) by putting the values of reflection coefficient and transmission coefficient which is derived from the graph as shown in fig.4, we conclude that value of permittivity and permeability is below zero (negative) at the resonating frequency of 2.4 GHz. Hence, the proposed S-shaped structure exhibits metamaterial characteristics which include simultaneously negative permittivity and permeability that further leads to a negative refractive index which supports backward waves.

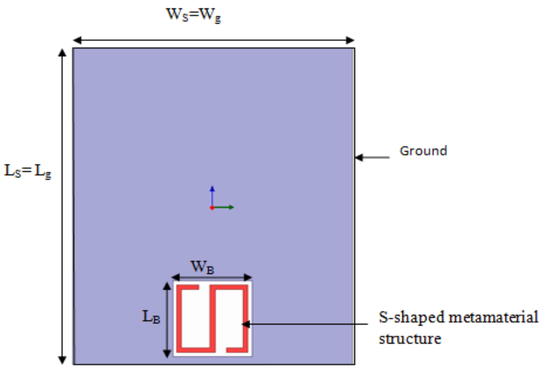
3. ANTENNA DESIGN AND ANALYSIS

While designing a microstrip antenna, usually FR4 substrate is used as it has higher dielectric constant which results to a smaller patch size, lower gain and higher tangent loss. Standard formulas are used to calculate the dimensions of antenna structure [1].

To obtain dual band antenna, various cases are investigated to implement metamaterial structure at different positions of antenna [17]. For validation various simulations have been performed to find the optimum condition for implementing metamaterial structures on antenna geometry. Hence, the optimum condition obtained to achieve dual band characteristics in antenna is by implementing metamaterial structure at a distance of 1 mm from the lower boundary of ground plane. Fig.5 shows the front and back view of proposed antenna geometry whose overall dimension is $36 \times 43 \times 1.6 mm^3$.

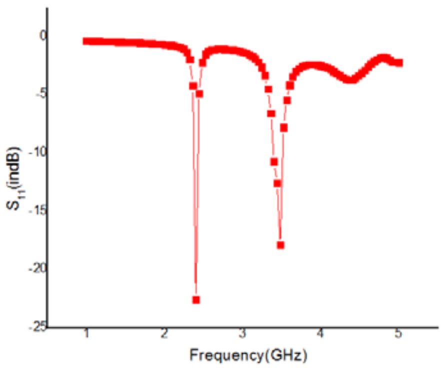


(a) Front View

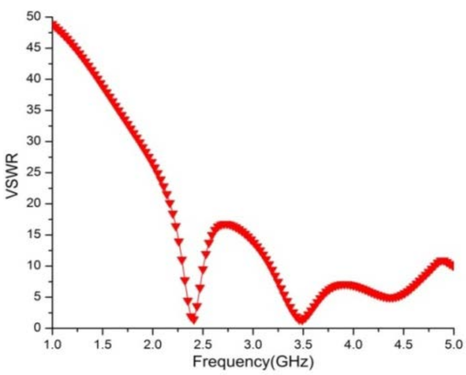


(b) Back View

Figure 5: Geometry of Proposed Antenna



(a) Reflection Coefficient (S_{11}) v/s frequency

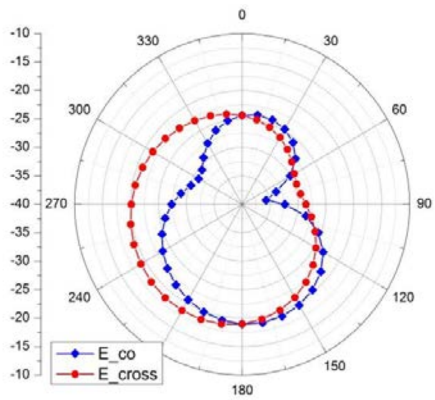


(b) VSWR v/s frequency

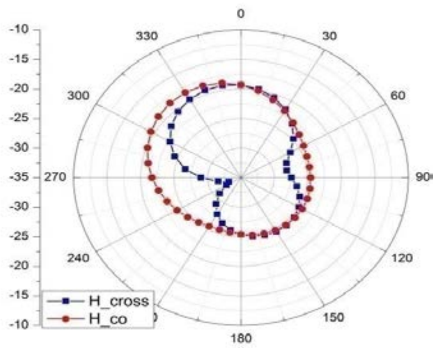
Figure 6 : Simulated Result of proposed antenna

From fig.6 (a) , we conclude at frequency of 3.5 GHz, the value of S11 (dB) is -23dB and at frequency of 2.4GHz, the value of S11 (dB) is -33dB.The proposed metamaterial inspired antenna shows successful dual band characteristics with VSWR < 2 as shown in fig.6 (b).

The radiation pattern for proposed antenna geometry at WiMAX and Bluetooth frequencies are shown in fig.7 and fig.8. The E-plane characteristic exhibits figure of 8 patterns in co-polarization while omni-directional pattern in cross-polarization as shown in fig.7(a). While the H-plane characteristic exhibits good omni-directional pattern in co-polarization and dumble shape pattern in cross-polarization as shown in fig.7(b). The overall gain of antenna is less than 2dBi for resonating frequencies.



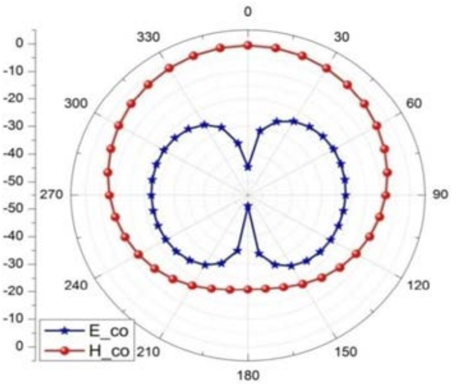
(a) E-plane characteristics



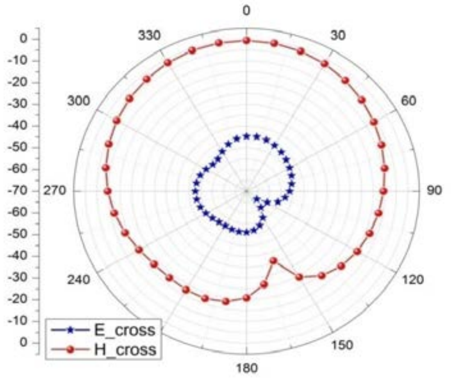
(b) H-plane characteristics

Figure 7 : Radiation Pattern of proposed antenna at 2.4 GHz frequency

From fig. 8(a), we conclude that the designed antenna has omni-directional radiation pattern in the co-polarization H-plane, while in the co-polarization E-plane the radiation exhibits typical figure-of-eight pattern. From fig.8(b), we conclude that the designed antenna has low cross-polarization E-plane and H-plane.



(a) Co-polarization radiation pattern

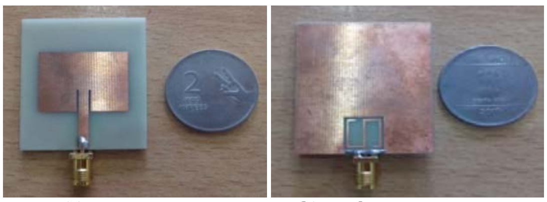


(b) Cross-polarization radiation pattern

Figure 8: Radiation Pattern of proposed antenna at 3.5 GHz frequency

4. RESULT AND DISCUSSION

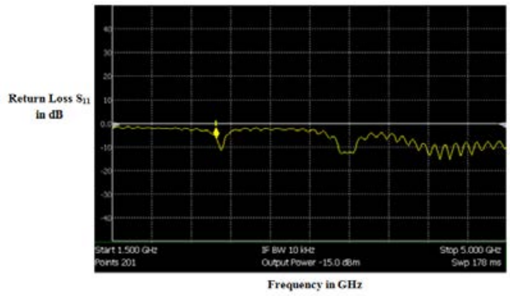
The fabricated antenna design is shown in fig. 9. The model number N9981A of vector network analyzer (VNA) is used on which measured results are obtained. The measured return loss (S_{11}) VSWR result of dual band metamaterial inspired antenna has been shown in fig.10 (a) and (b), respectively.



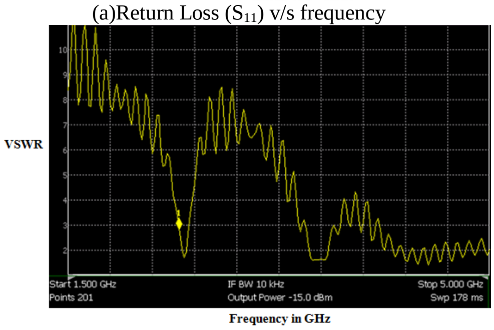
(a) Front View (b) Back View

Figure 9: Photograph of Fabricated Antenna

Table 1 shows the return loss and VSWR comparison between simulated and measured results of the optimized metamaterial inspired antenna. There seems to be a difference between measured and simulated results, which could be due to the effect of SMA connector and imperfection in fabrication.



(a)Return Loss (S_{11}) v/s frequency



(b)Figure 10.VSWR (S_{11}) v/s frequency

Figure 10 :.Measured result of proposed antenna

Table 1: Return Loss and VSWR of Proposed Antenna

	Return Loss		VSWR	
Frequency in GHz	Simulated	Measured	Simulated	Measured
2.4 GHz	-24 dB	-12.71dB	1.6	1.8
3.5 GHz	-18 dB	-12.90 dB	1.5	1.6

5. CONCLUSION

The Proposed metamaterial inspired antenna covers dual band at 2.5 GHz and 3.5 GHz frequency for Bluetooth and WiMAX applications. The proposed antenna has a simple structure and overall size of 36x43x1.6mm3. Results of this antenna shows that proposed antenna can be a good applicant for the wireless applications. In future, the proposed antenna can be extended for triple/multiband characteristics in antenna by increasing the number of metamaterial structure on antenna geometry. Also, the antenna with different sizes and shapes of metamaterial structure can be design for further improvements such as increase in bandwidth and gain.

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