# A Miniaturized Metamaterial Inspired Hexaband Antenna for GSM, GPS-L1, WLAN and WiMAX Applications

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**Abstract**— This paper illustrates the application of metamaterial inspired unit cells in the patch as well as the ground plane to obtain a compact hexaband antenna. Distinct bands were obtained at various frequencies for GPS-L1 (1.575 GHz), GSM (1800/1900 GHz), UMTS (B2/B1), WLAN (2.4 and 5.5 GHz) and WiMAX (2.5 and 3.5 GHz). This was achieved while keeping the antenna dimensions limited to $30 \times 30 \times 1.6\,\text{mm}^3$ resulting in a miniaturized antenna. The proposed antenna has a size of $0.1575\lambda_0$. The antenna was fabricated and tested to verify the simulated results.

## 1. INTRODUCTION

In recent years, most devices such as smart phones, tablets and portable communication systems require services from various sources that operate in distinct frequency bands. The use of antennas that are responsive to a single band of frequency is inefficient as it requires several antennas for different purposes.

Multiband antennas resonate at multiple frequencies. This reduces the amount of VLSI real estate required to set up the communication device as a single antenna can replace multiple antennas resonating at distinct frequencies. However, one of the most significant drawbacks of a multiband antenna is its considerably larger size when compared to a single band antenna. This is counterproductive when the aim is to reduce the size of the device.

In [1], the authors have presented an antenna with dimensions $30\,\text{mm} \times 43\,\text{mm}$ for WiMAX, UMTS and WLAN applications. In [2], the paper presents a compact antenna with an overall dimension of $65\,\text{mm} \times 40\,\text{mm}$ for WLAN. In [3] the authors have presented an antenna that has a compact dimension of $40 \times 5\,\text{mm}^2$ mounted on a substrate of size $40 \times 65\,\text{mm}^2$. This antenna resonates at four bands.

In the design presented, metamaterial split ring resonators and other structures such as the spiral in the ground plane are implemented to obtain a hexa-band antenna. Furthermore, the size of the patch is reduced to $20 \times 20\,\text{mm}$ square which accounts for over 50% reduction in size. Hence a miniaturized hexa-band antenna has been obtained.

One major aspect of any multiband antenna is that several other parameters are compensated for getting multiple bands. These include gain, directivity and size of the antenna. To overcome this drawback various techniques have been devised. One prominent method is the application of metamaterial structures such as the split ring resonators to decrease the size. In the design presented, several metamaterial structures like the split ring resonators have been used to increase the number of bands and to miniaturize the design.

In this paper, the discussion is divided into five sections. The first section gives an introduction into the basic concepts that are discussed in the paper. The second section covers a brief theory of antenna's and metamaterials. This is followed by the description of the proposed antenna in the third section. The fourth section discusses the graphs and the results obtained. Finally, the paper is concluded with a review of the results obtained and its significance.

## 2. THEORY

DNG (double negative metamaterials) are extraordinary materials that simultaneously possess negative permittivity ($\varepsilon$) and permeability ($\mu$). In 1967, Victor Veselago did extensive research on these materials and had analytically determined that refraction of light occurs in the reverse direction (negative refractive index) at the interface between a material with negative refractive index and a material exhibiting the usual refractive index (positive) [4].

Metamaterials are composite materials artificially engineered to obtain specific properties that do not occur naturally. Properties like negative permittivity and permeability are very useful in several fields like optics (for cloaking applications) and electromagnetic radiation (antennas) but are not found in nature. Metamaterials is a good alternative in such cases [5]. These special properties are not controlled by changing the chemical composition of the material but rather by changing its physical structure. This allows large amount of flexibility in realizing different properties.

In antennas, the utilization of microwave metamaterial structures help in shrinking the size of the antenna. One common microwave metamaterial structure is the split ring resonator (SRR). Such SRR's, which have suitable inductive and capacitive characteristics, are integrated in designing antennas that are small and compact.

One of the most common DNG structure is the split ring resonator. The splits in the rings helps in the process of making the SRR unit cell resonant at radiated wavelengths which are to a great extent larger than the diameter of the rings. Therefore, the utilization of such SRR's reduce the size of the antenna.

## 3. PROPOSED DESIGN

### 3.1. Unit Cell

The patch design consists of square split rings, which serves as the metamaterial structures for obtaining the desired operating frequencies[6]. There are three split rings each of thickness 0.5 mm. The spacing between these rings are also 0.5mm. The largest ring has a dimension of $20 \times 20\,\text{mm}^2$. The centre of the patch consists of a circular patch of radius 6.2 mm with an interlocking pattern at the middle[9]. The patch is positioned on the substrate whose dimensions are $30 \times 30 \times 1.6\,\text{mm}^3$. The antenna is excited using a line feed of length 5 mm [10]. The antenna patch design is shown in Fig. 1.

### 3.2. Ground Plane

The FR4 Epoxy substrate ($\varepsilon_r = 4.4$) is 1.6 mm thick. The Ground plane is in the shape of a spiral which is also a meta-material structure as shown in Fig. 1. The spiral is formed by etching out copper from the ground plane. The thickness of the etched region is 0.2 mm. The spiral structure in the ground adds extra resonating bands in the antenna. The dimensions of the ground plane is $30 \times 30\,\text{mm}^2$.

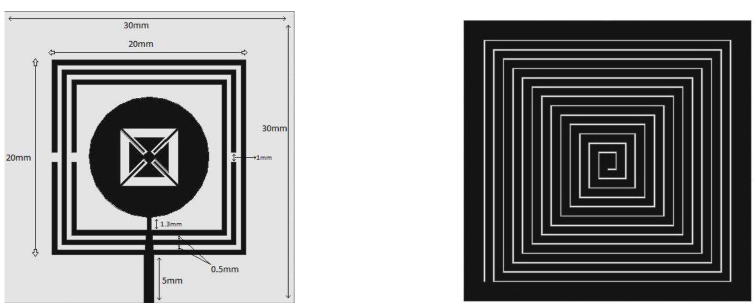


Figure 1: Antenna patch and ground plane.

The inclusion of these meta-material structures in the antenna design has facilitated good S11 characteristics as well as miniaturization of the design [6].

## 4. RESULTS AND DISCUSSION

The $S_{11}$ characteristics have shown resonating frequencies at several commercially used frequency bands such as GPS-L1 (1.575 GHz), GSM (1800/1900 GHz), UMTS (B11/B1), WLAN(2.4 and 5.5 GHz). The overall size of the antenna is 30 mm along both length and breadth; with the largest SRR having a maximum size of 20 mm along the length and breadth.

The graph below shows the $S_{11}$ characteristics (simulated) for the following cases:

- $S_{11}$ without the spiral in the ground plane (dashed graph)
- $S_{11}$ without the central circular pattern (dotted graph)
- $S_{11}$ of the proposed antenna (solid graph)

It is observed that the presence of the spiral in the ground plane increases the number of resonating bands. In addition, we also see that the resonating frequencies have shifted towards the lower frequency region.

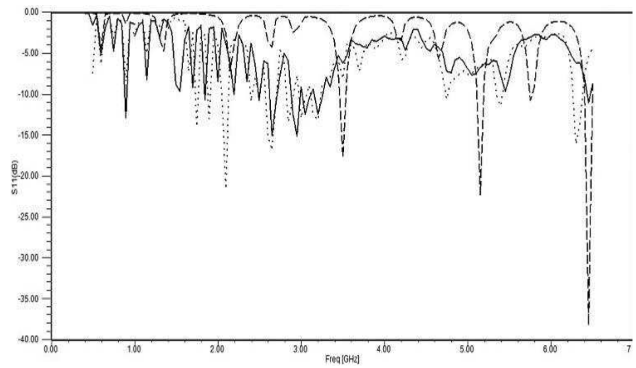


Figure 2: $S_{11}$ graphs under different parameters.

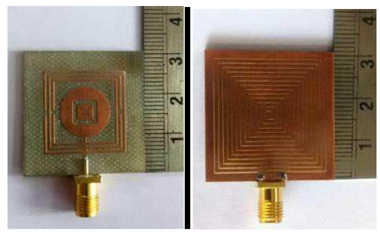

Figure 3: The fabricated antenna.

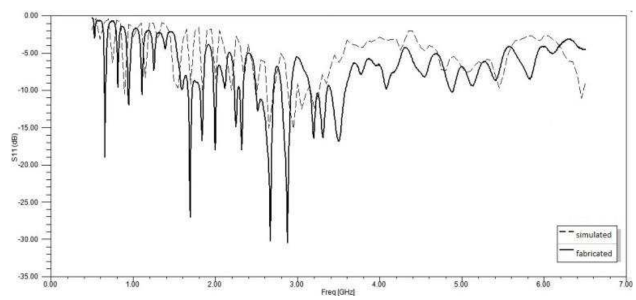


Figure 4: $S_{11}$ graph of the proposed antenna.

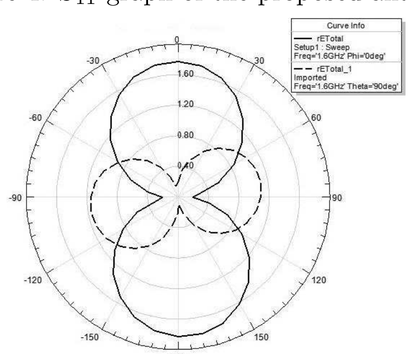


Figure 5: Radiation pattern: $E$&$H$-plane 1.6 GHz (GPS-L1).

The antenna was fabricated with the MITS machine and the $S_{11}$ was determined and plotted in a graph.

The $S_{11}$ graph for the proposed antenna was simulated and observed as shown by the dashed line. The fabricated antenna had an $S_{11}$ as shown by the solid line in the figure below:

From the graph it is inferred that the antenna resonates at several frequency bands from 900MHz to 6.5 GHz. Among these, the useful bands are obtained at GSM, GPS-L1, WLAN and WiMAX ranges.

The fabricated antenna displays better $S_{11}$ characteristics at several frequencies in comparison to the simulated results. Apart from this, the frequencies of resonance are comparably similar to the simulated antenna. Some of the bands in this antenna satisfies the $-6$ dB $S_{11}$ which is good enough for compact portable wireless communication devices [7].

The graphs in the following figures show a fairly omni-directional radiation pattern at most frequencies, which is useful in most wireless communication devices. Besides, the radiation patterns exhibit wide beam widths which is valuable in GSM communication. The radiation pattern for 5.5 GHz shows a deviation from the other ones. The pattern for this band shows a narrower beam width and increased directivity.

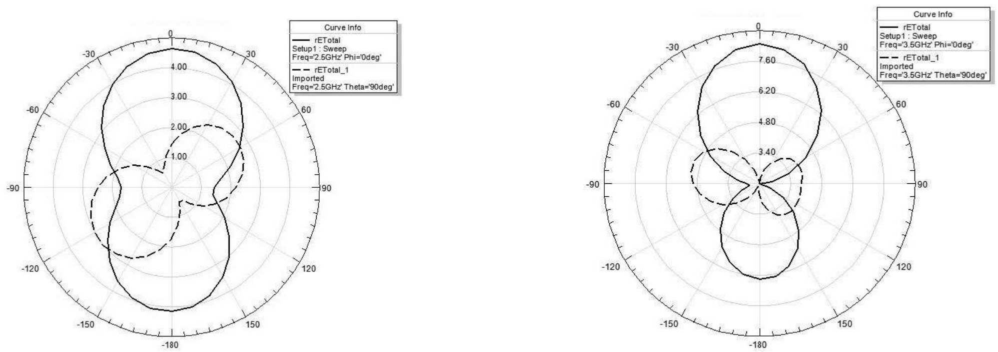


Figure 6: Radiation pattern: $E$&$H$-plane 2.5 GHz (WiMAX) and 3.5 GHz (WiMAX).

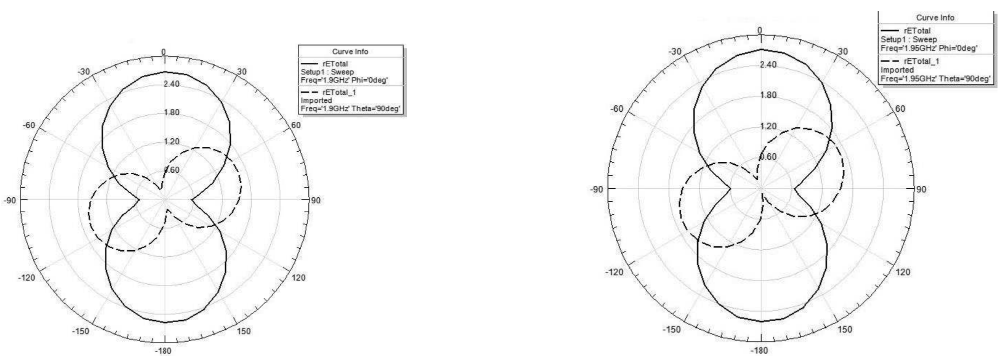


Figure 7: Radiation pattern: $E$&$H$-plane 1.9 GHz (GSM) and 1.95 GHz (GSM).

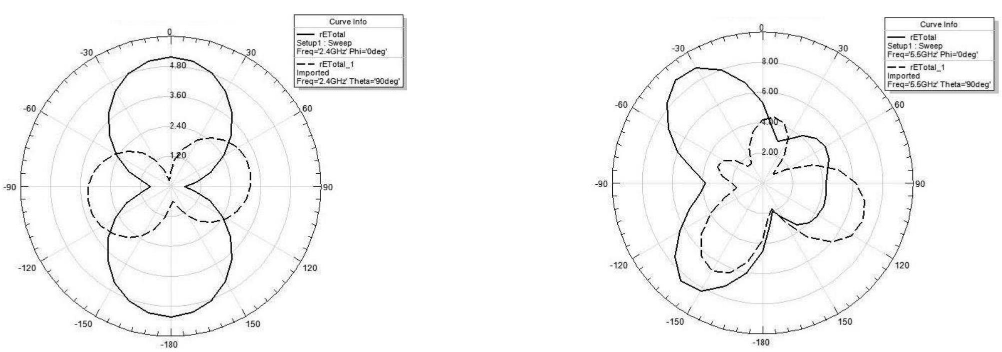


Figure 8: Radiation pattern: $E$&$H$-plane 2.4 GHz (WLAN) and 5.5 GHz (WLAN).

## 5. CONCLUSION

We have designed, fabricated and tested a miniaturized multiband meta-material Antenna with an overall dimension of $30 \times 30\,\text{mm}^2$ and resonating frequencies at GPS-L1 (1.575 GHz), GSM (1800/1900 GHz), UMTS (B2/B1), WLAN (2.4 and 5.5 GHz). This design, in addition to the common SRR, uses two other meta-material structures which has been implemented at the center of the patch and in the ground plane. These structures have shifted the resonating frequencies towards the lower frequency region, and increased the number of bands obtained for the specified size of the antenna.

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