Multi Band Metamaterial Based Bowtie Antenna for Wireless Applications

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Abstract— A new meta-material based bowtie antenna is proposed in this paper. Multi band response is observed in the simulated result of return loss for different frequencies (i.e., 1–12 GHz). Apart from this it is seen that the return loss is improved in the case of metamaterial antenna in comparison to the conventional antenna. Simulated results of ξ and μ versus frequency are shown and it is observed that negative ξ and negative μ are obtained in different frequency bands respectively.

1. INTRODUCTION

Next generation wireless communication systems demand an antenna to exhibit multiple bands that are not harmonically related. A bowtie antenna is made from a bi-triangular sheet of metal with the feed at its vertex and is used due to its light weight and broadband properties. Many methods have been employed to increase the bandwidth of the planar bowtie antenna such as use of tapered slot, bowtie arms, double side and different feed structures [1]. In order to increase bandwidth Meta-materials can also be incorporated as substrates. They are worth candidates as antenna substrates for miniaturizations, bandwidth enhancement and for controlling direction of radiation [2]. Metamaterial substrates can be designed to act as a very high dielectric constant substrate at a particular frequency and as a result it can be used to miniaturize the antenna size. The property of exhibiting negative permittivity and permeability (hence negative refractive index) by the metamaterial is often used by the antenna designer to achieve desired results as they are artificial engineered materials. The negative refractive index supports the backward waves [3, 4].

In this paper, a bowtie antenna is simulated on the metamaterial substrate which results in multi band resonating frequencies. The band obtained shows that the simulated antenna can be used for wireless applications. The results are simulated using Ansoft HFSS software.

The paper is organized as follows. In Section 2 the antenna specifications and design issues are discussed. In Section 3 the equivalent circuit of unit cell is presented. The results are presented in Section 4 and their features are analyzed and discussed. The conclusion is made in the Section 5.

2. ANTENNA DESIGN

Figure 1 shows the basic bowtie antenna which is a complimentary antenna. The dimensions of the substrate are $x = 45\,\text{mm}$, $y = 69\,\text{mm}$. The thickness of the substrate is $h = 1.6\,\text{mm}$. FR4 is taken as substrate having permittivity of 4.4. The ground plane consists of 77 unit cells with 7 cells in rows and 11 cells in column. The dimension of each unit cells is $3 \times 3\,\text{mm}^2$. The unit cells are made periodic by keeping a uniform distance in x-axis as well as y-axis as 3 mm. The lumped port feed is provided to the bowtie antenna. These parameters are optimized so that the return loss of the basic bowtie antenna is less than $-10\,\text{dB}$.

Figure 2 shows the metamaterial ground which is placed below the bowtie antenna. Figure 3 represents the metamaterial unit cell. Figure 4 represents the negative permittivity, negative permeability and negative refractive index. The electromagnetic properties such as complex permeability and permittivity can be evaluated either by Drude-Lorentz method or by retrieval of S-parameters methods. The S-parameters have been extracted from HFSS, which is commercially available Finite-Element Method (FEM)-based Full wave simulator [5].

The real part of refractive index [3] is given by $re(n) = \frac{1}{kd}\cos^{-1}[\frac{1}{2S_{21}}(1 - S_{11}^2 + S_{21}^2)]$ and the wave impedance is $z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}}$. Further n and z are related to μ and ξ [4] by the relations $\xi = \frac{n}{z}$. and $\mu = nz$.

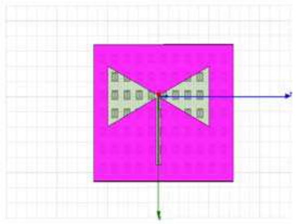

Figure 1: Bowtie antenna.

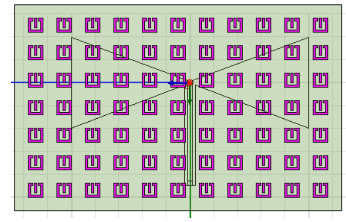

Figure 2: Meta-material ground.

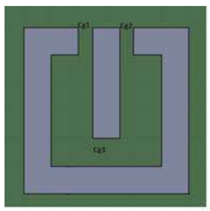

Figure 3: Meta-material unit cell.

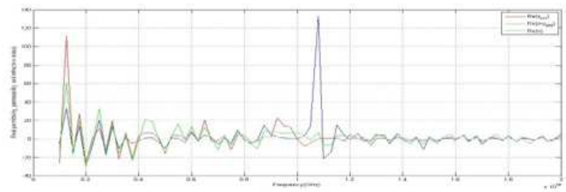

Figure 4: Real part of permittivity, permeability and refractive index.

3. EQUIVALENT CIRCUIT OF META-MATERIAL UNIT STRUCTURE

The equivalent circuit of the meta-material unit structure is shown in the Figure 5. The resonant frequency of the metamaterial unit structure is given by [6]

$$f_{res} = \frac{1}{2\pi\sqrt{L_T C_T}} \tag{1}$$

The gap capacitance is given by [7]

$$C_g = \frac{\varepsilon_r \varepsilon_o A t w}{g} \tag{2}$$

where A is modification factor ($A = 60$), t is thickness of metal (copper) strip, ε_r is the relative permittivity of the substrate. The self inductance produced by sheet is given by [8]

$$L_D = \frac{\mu_0 n^2 \left[\ln\frac{2}{\rho} + 0.5 + 0.178\rho + 0.146\rho^2 + \frac{0.5(n-1)S^2}{(\rho n)^2} + 0.178\frac{(n-1)S}{n}\frac{1}{n}\ln\frac{(w+t)}{w}\right]}{2\pi} \tag{3}$$

where, $\rho = \frac{nw+(n-1)S}{L}$ and n, w, L & S are the numbers of turns, metal width, length of the ring & the space between inner and outer rings respectively.

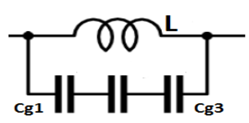

Figure 5: Equivalent circuit of the meta-material unit structure.

4. RESULTS AND DISCUSSION

Figure 6 shows that the return loss of -10dB or better is achieved within the band of 6.2 GHz–7 GHz and 9.8 GHz–10.9 GHz which has relative bandwidth of 0.9057 GHz and 1.1434 GHz. It is seen that when the antenna is used without the metamaterial unit cell, only two resonant frequencies are present specifically at 6.6 GHz and 10.3 GHz.

Figure 7 shows the return loss of -10 dB or better that is achieved in the band approximately from 3.6 GHz–4.4 GHz, 5.5 GHz–6.1 GHz, 7.3 GHz–8.0 GHz, 8.9 GHz–9.7 GHz and 11.4 GHz–11.7 GHz which has relative bandwidth of 0.8378 GHz, 0.6 GHz, 0.7699 GHz, 0.8181 GHz and 0.2943

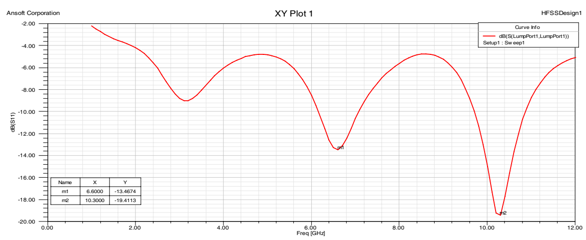

Figure 6: Return loss vs frequency without metamaterial unit cell.

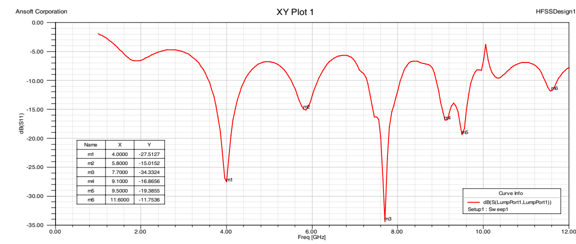

Figure 7: Return loss vs frequency with metamaterial unit cell.

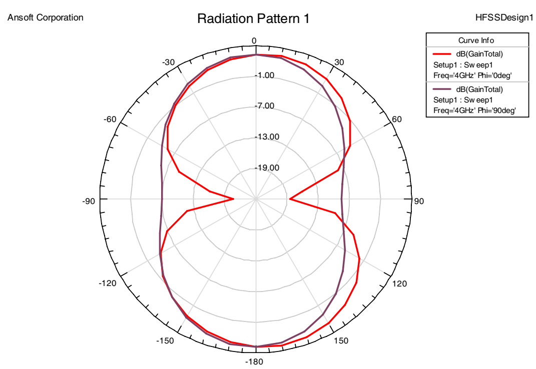

Figure 8: Radiation pattern at 4.0 GHz.

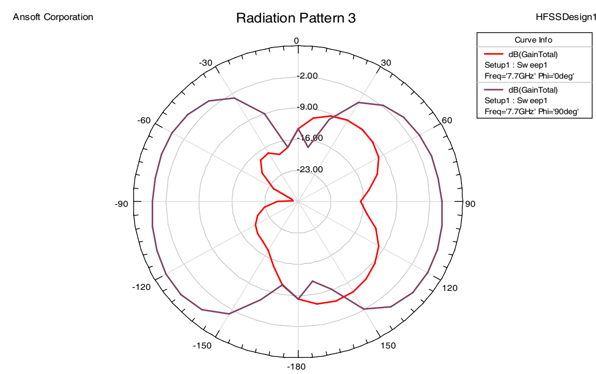

Figure 9: Radiation pattern at 7.7 GHz.

GHz respectively. It is seen that with the metamaterial substrate, the bowtie antenna has shown more numbers of resonant frequencies. In this case 6 distinct resonating frequencies have been obtained such as 4.0 GHz, 5.8 GHz, 7.7 GHz, 9.1 GHz, 9.5 GHz and 11.6 GHz. This shows the multi-band behavior of the metamaterial based bowtie antenna.

Figure 8 shows the radiation pattern at resonating frequency of 4.0 GHz. The shape of the radiation pattern seems like number "8" which is a property of a bowtie antenna. However figure 9 represents the radiation pattern at resonating frequency of 7.7 GHz which shows inverted pattern with respect to the 4.0 GHz frequency.

5. CONCLUSION

A new multiband metamaterial based bowtie antenna is demonstrated in this paper which overcomes the disadvantages of a basic bowtie antenna (which has poor bandwidth property) and displays multi-band characteristics. This can be used for different wireless applications. Radiation pattern shows the characteristics nearer to the Omni-directional antenna. The results show that the proposed antenna can be used as a compact multi-frequency antenna in microwave band (C-band, X-band).

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