Simulation Study of Metamaterial Effect towards Ultra Wide Band Antenna

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Abstract. In this paper, the design of a metamaterial ultra-wideband (UWB) antenna with a goal towards application in microwave imaging systems for detecting unwanted cells in human tissue, such as in cases of breast cancer, heart failure and brain stroke detection is proposed. The metamaterial unit cell is constructed using circular split ring resonator (CSRR) technique and wire, to attain a design layout that simultaneously exhibits both a negative magnetic permeability and a negative electrical permittivity and attached as superstrate in front of the UWB antenna. This design results in an astonishing negative refractive index that enables amplification of the radiated power of this reported antenna, and therefore, high antenna performance. A Rogers (RT5880) substrate material is used to design and print this reported antenna, and has the following characteristics: thickness of 0.51 mm, relative permeability of one, relative permittivity of 2.70 and loss tangent of 0.02. The metamaterial antenna is design to be operated at frequency between 300MHz to 30GHz which is suitable for biomedical application such as Microwave Imaging. The overall metamaterial antenna size is 90 mm × 50 mm × 0.51 mm. The design and simulation has been carried out using Computer Simulation Technology Microwave Studio (CST MWS).

1. Introduction

Nowadays, Metamaterial has been a popular research topic for almost two decades. Most of the researcher agree on certain the basic metamaterial definition characteristics although it has different definitions. Metamaterials are materials not generally found in nature and having negative permittivity and permeability but are instead artificially medium with a negative index of refractive and structures that have properties that are either not or seldom found in natural material [1-3].

In 1968, Veselago reported the theoretical prediction of an engineered material showing negative permittivity and negative permeability simultaneously [4]. In 1999, Pendry demonstrated metamaterials based on the split ring resonator (SRR) [5] and ultimately, in 2000, Smith effectively demonstrated and validated the metamaterial (negative µ and ε) concept [6]. Various metamaterials (left-handed) have been described using different shapes, such as split ring resonator (SRRs) [1] multiple SRRs [2], fishnet structures [3], spiral SRRs [4], double-sided SRRs [5] lay-outs of transmission line [6], H-shaped pairs periodic arrays [7], double-bowknot shaped resonators [7]. The area of metamaterials research is able to enhance a variety of technologies. However, due to the limited frequency band, the range and spectrum of their applications are restricted. It is difficult to fabricate and use these materials in antenna design. Therefore, the fields of metamaterial application research is broadening to overcome these difficulties.
A split-ring resonator (SRR) is a component part of a negative index metamaterial (NIM), also known as double negative metamaterials (DNG). They are also component parts of other types of metamaterial such as Single Negative metamaterial (SNG)[8]. SRR is a novel design consisting of two concentric rings with a split on each ring. The structure is called resonator since it exhibits a certain magnetic resonance at a certain frequency. Split ring resonators can result in an effective negative permeability over a particular frequency region. The SRR structure is formed by two concentric metallic rings with a split on opposite sides.[8-10]

The field of electromagnetic waves and antennas has attracted increasing interest for the medical application of microwave systems. Microwave imaging is an example of using such a system for detecting breast cancer [11,12]. A microwave imaging sensor is used to identify the contrast between the electrical properties of human tissues. Power is radiated through an antenna in a microwave imaging system and one or more antennas receive the scattered power. To detect unwanted cells (targets), the scattered signals are then resolved. The ultra-wideband (UWB) pulse provides stable penetration and resolution characteristics. These typical microwave imaging systems have been suggested for detecting hidden breast cells [13-16]. Ultrawideband (UWB) (300 MHz- 30 GHz) microwave imaging is a promising method for biomedical applications such as tumor detection because of their good penetration, resolution characteristics, and has the ability to send and receive very short pulses in a distortionless manner. Microwave imaging are major components of these telemetry systems of telemetry systems linked to biomedical applications [12].

This paper introduces a microwave imaging sensor based on a novel metamaterial antenna. Metamaterial unit cells (a combination of a modified SRR and wire simultaneously show both negative permittivity and negative permeability. A combination of theory and experimental techniques such as modified SRR, and wire applied in this paper, which bears the novelty of the proposed metamaterial antenna as microwave imaging sensor. This proposed metamaterial antenna is very much suitable for medical instrumentation industry.

2. Unit Cell Design Architecture
A metamaterial unit cell is used to initiate the proposed antenna design architecture. The goal is to attain a unit cell design having a resonance characteristic in the frequency range of 3.1 GHz to 10.6 GHz. Various reputed methods are used for metamaterial structure design, such as SRRs [17-19]. In this research, the initial unit cell is based on an SRR structure. The SRR is made of four loops: i.e., a smaller loop within a bigger one, with slots incorporated onto each loop at opposite ends [5,18]. A perpendicular magnetic field reacts with a magnetically resonant structure such as an SRR, which can be used to create negative permeability. Gaps (splits) added to the ring, introduce capacitance, which allows for the control of the resonant characteristic of the structure. The first unit cell is the modified wit rectangular and SRR shown in Figure 1. The modification is the closing of the loop on the outer ring, which reduces the series capacitance of the SRR. Furthermore, closing the outer ring enhances the coupling between the outer and inner rings, which enables a wide backward-wave passband [18]. The unit cell is printed onto a Rogers (RT 5880) substrate with a dielectric constant of 2.7, and a thickness of 0.51 mm. The unit cell design specifications are summarized in Table 1.
Figure 1. (a) The front side of the unit cell, (b) The back side of the unit cell and (c) the simulation geometry.

Table 1. The design parameters for the unit cell.

| Parameter | Dimension (mm) | Parameter | Dimension (mm) |
|-----------|----------------|-----------|----------------|
| a         | 13             | w         | 0.5            |
| b         | 13             | R1        | 1.75           |
| Wr1       | 6.0            | R2        | 2.675          |
| Lr1       | 6.0            | R3        | 3.6            |
| Wr2       | 5.4            | R4        | 4.525          |
| Lr2       | 5.4            | c         | 0.08           |

The metamaterial (MTM) unit cell was simulated using Computer Simulation Technology (CST) software based on the finite-difference time domain (FDTD) approach for attaining the S-parameters. The unit cell simulation geometry is shown in Figure 1b. The structure used for testing was located between two waveguide ports situated on each side of the x-axis. An electromagnetic wave was excited along the x-axis. A perfectly-conducting electrical boundary condition was applied along the walls perpendicular to the y axis, and a perfectly-conducting magnetic boundary was applied at the walls perpendicular to z-axis. A frequency domain solver is applied to simulate this metamaterial structure. The normalized impedance is matched to 50 Ω. This simulation is executed over the 3–15 GHz frequency range. To extract the constitutive effective parameters from S21 and S11, including the refractive index n_r, the relative effective permittivity ε_r, and the permeability μ_r. By using the CST Simulation.[6]
The effective parameters are retrieved using CST Simulation. The refractive index, the permeability, and the permittivity of the unit cell are plotted in Figure 3. The negative frequency regions are listed in Table 2. From Table 2, the MTM unit cell is found to belong to a different resonant property in the frequency zone of negative value. The parameters of the proposed MTM design are significantly improved compared with those of previously reported MTMs that also possess negative values over a broad band.

Figure 2. (a) The magnitude of the S-Parameter (S11 and S21) (b) The phase of the S-Parameter (S11 and S21)
Figure 3. The proposed unit cell (a) permeability, (b) permittivity, (c) refractive index, (d) wave impedance.

Table 2. The permeability, permittivity and refractive index in the negative frequency zone.

| Parameter               | Negative Frequency Zone (GHz) |
|-------------------------|------------------------------|
| Permittivity, $\varepsilon_r$ | 0.20-2.78                   |
| Permeability, $\mu_r$     | 2.67-2.70                    |
| Refractive index, $n_r$   | 0.00-0.70, 2.63-2.75         |
| Permittivity, $\varepsilon_r$ | 0.20-2.78                   |
| Permeability, $\mu_r$     | 2.67-2.70                    |
| Refractive index, $n_r$   | 0.00-0.70, 2.63-2.75         |

3. Metamaterial Antenna Design
The proposed metamaterial antenna design architecture shown in Figure 4. The metamaterial unit cell is constructed as superstrate in front of the antenna. The antenna is printed on Rogers (RT 5880) material with a dielectric constant of 2.1 and 0.51 mm thickness. The overall antenna dimensions are 90 mm × 50 mm × 0.51 mm, where at the lower frequency band of 2.67 GHz. The MTM unit cells are homogeneous to each other. A Sub Miniature Version A connector is attached to the port that delivers a 50 $\Omega$ impedance. The optimal design parameters are summarized in Table 3.
Table 3. The antenna design parameters according to Figure 4 (a)

| Parameter | Dimension (mm) |
|-----------|----------------|
| Rp        | 7.50           |
| Wpe       | 8.00           |
| Lpe       | 32.4           |

Figure 5 illustrates the S-Parameter of metamaterial antenna with and without unit cell. The metamaterial antenna achieves at frequency range of 2-10 GHz. Apparently, the proposed antenna design with full structure of unit cells provides the optimal computed results regarding gain and directivity while covering the standard UWB frequency range (3.1–10.6 GHz).
Return loss is the measurement of the effectiveness of power delivery from transmission line to the load of antenna. The good performance of antenna is when the return loss is below than -10dB. The return loss -10dB means 90% of energy is radiate and 10% of energy is reflected.

The result shows, return loss of Metamaterial antenna cover the frequency from 2 GHz until 10 GHz. This Metamaterial antenna frequency that choose that suitable with Biomedical Application which is covers 0.5 – 3 GHz. This antenna without and with metamaterial unit cell have a performance at frequency 2.67 GHz with the return loss is -24.82dB and -22.93 dB.

Gain is one of the important parameters to determine the performance of the Metamaterial antenna. Table 4 and 5 illustrates the gain and directivity of antenna without unit cell and with unit cell.
Table 4 shows the variation of frequencies versus the gain and directivity of antenna without unit cell. The lowest gain is 2.613 dB which at 2 GHz while the largest gain is 12.21 dB at 10 GHz.

**Table 4.** The effects of the gain, and directivity of metamaterial antenna with no unit cell.

| Frequency (GHz) | Gain (dB) | Directivity (dBi) |
|----------------|-----------|------------------|
| 2              | 2.613     | 2.671            |
| 2.67           | 2.726     | 2.761            |
| 3              | 3.311     | 3.351            |
| 4              | 5.952     | 5.981            |
| 5              | 5.952     | 7.516            |
| 6              | 6.298     | 6.339            |
| 7              | 7.916     | 7.903            |
| 8              | 9.028     | 8.994            |
| 9              | 10.48     | 10.43            |
| 10             | 12.21     | 12.15            |

Table 5 shows the variation of frequencies versus the gain and directivity antenna with unit cell. The lowest gain is 2.745 dB which at 2 GHz while the largest gain is 11.94 dB at 10 GHz.

**Table 5.** The effects of the gain, and directivity of metamaterial antenna with one unit cell.

| Frequency (GHz) | Gain (dB) | Directivity (dBi) |
|----------------|-----------|------------------|
| 2              | 2.745     | 2.808            |
| 2.67           | 2.672     | 2.708            |
| 3              | 3.329     | 3.370            |
| 4              | 5.920     | 5.949            |
| 5              | 7.706     | 7.752            |
| 6              | 5.505     | 5.547            |
| 7              | 7.863     | 7.882            |
| 8              | 9.421     | 9.420            |
| 9              | 10.45     | 10.44            |
| 10             | 11.94     | 11.90            |
4. Conclusion

In this paper, metamaterial antenna has been presented as a microwave imaging. This microwave antenna sensor consists of unit cells along one axis and each unit cell disclose negative permittivity, negative permeability, and negative refractive index simultaneously. The overall antenna size is 90 mm × 50 mm × 1.635 mm where covering the working frequency range 2–10 GHz. The performance of the proposed metamaterial antenna was design and simulate by using Computer Simulation Technology Microwave Studio (CST MWS).

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