Low-Cost Metamaterial Loaded Microstrip Antenna for Defense Applications

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Abstract

We have designed a Metamaterial unit-cell for 9 GHz frequency. Periodic structure was used at 4.25×4.25 mm with a thickness of 0.35 mm and giving us the 99.99% of absorbance at 9 GHz in simulated results. We have implemented a rectangular microstrip antenna and loaded it with Metamaterial unit-cells which provided improved results. There were results available for reflection coefficient (s11 parameter) at 9 GHz and also helping for the reduction of the Radar Cross Section of an antenna, which reduced more than 20 dB and not affected its directivity and gain.

Keywords

Microstrip Antenna (MSA), Metamaterial Absorber (MMA),
Single Band MMA, Radar Cross Section (RCS), X-Band

1. Introduction

Nowadays, as researchers are trying to achieve electromagnetically different characteristics than the conventional materials and so the material entered and it's a Metamaterials. It has been proved to be very effective here. Metamaterial is basically periodic structures which show change in characteristics than normal material while resonating at certain frequencies [1]. Which provides us a whole new area of research to understand the characteristics of materials. So, with help of these new properties of material we can achieve number of goals like, to reduce the Radar cross section for stealth technologies and to make clocking devices and many more advance technologies. The reduced RCS of an antenna will help to achieve secrecy of an antenna to be less detectable in enemy radar section.

MMA's properties offer's us magnificent features, that includes near-unity

absorbance, extremely-thin thickness with wide-range angles of incidence and polarization insensitivity, felicitous for antennas designs, for the reduction of radar cross section (RCS) in stealth technology by enhancing absorption to improve the performance and also useful in wireless communication technologies [2].

Metamaterials are widely used in with the antenna designs are having the negative refractive index. Negative refractive index is one of the most significant characteristics of the metamaterial. The phase of signal advances as its moves away from the source and fleeting waves increase as they get further away from the source, which shows us the difference between conventional material and metamaterial properties. In normal or conventional material E-field and H-fields creates a right-handed triplet with the direction of phase propagation. In negative refracted material has negative μ and negative ε, they create a left hand triplites and also known as left-handed materials [3], which are not been found in nature but can be able to produce artificially [4]. Wide research is going on in this field, researchers and engineers are getting more capable to design or create these types of material as never before.

2. Microstrip Antenna without Metamaterial

We are using very simple MSA configuration consisting of radiating patch on the top of dielectric substrate and ground plane at bottom. Also, it is more suitable for these types of metamaterial loaded antennas because of intelligible structure, linearly polarized, conformable to planar and non-planar structures, less expanses, can easily implementable and reconcilable with the PCB technology [5]. All the parameter of a rectangular microstrip patch antenna is calculated with the help of standard equations, based on studies of Balanis. We Obtained parameters as an optimized design of patch's length and width of 6.96 mm and 7.23 mm, respectively. Thickness of patch is 0.035 mm. A dielectric substrate is having a thickness of h_1 = 1.35 mm in centre and in other area thickness h_2 = 0.35 mm for the better performance while loaded it with metamaterial and used FR-4 epoxy (ε_y = 4.4, $\tan\delta$ = 0.02) as a dielectric material. The top view and a side view have been given in Figure 1.

All parameters calculated at 9 GHz are given in Table 1.

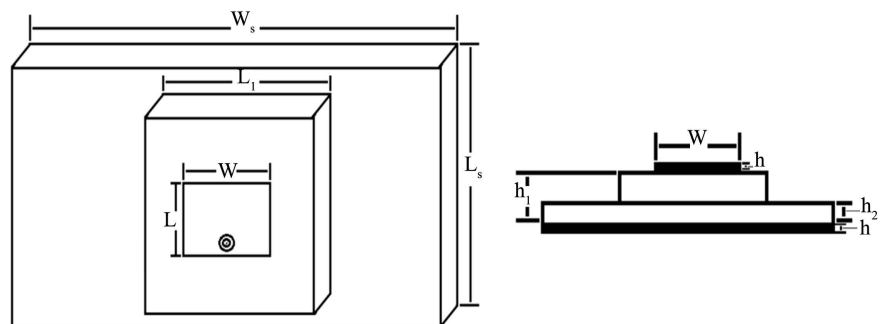**Figure 1.** Top view and side view of MSA.

Table 1. Description of all dimensions.

Description	Dimensions (mm)	Parameter
L_s/w_s	29.75/67.5	Periodicity of the structure
L_1	12.5	Central substrate length
h_1	1.35	Height of central substrate
h_2	0.35	Height of substrate
L	6.96	Length of patch
W	7.23	Width of patch
H	0.035	Height of patch

At the bottom copper ground is given with the thickness of 0.035 mm. Coaxial cable is used to feed the antenna at a point where it is giving better matching impedance around 50 Ω. This structure has been made with commercial software HFSS V 19. Simulated results of simple microstrip antenna the scattering coefficient (s_{11}) without loading metamaterial is achieved to be −36.33 dB at 9 GHz. Metamaterial are basically artificially designed periodic structures which shows different electro-magnetic properties than the conventional material. Metamaterials have a negative refractive index which is not found in natural material, which is first postulated by Veselago in 1968 [6] demonstrated in Figure 2.

These designed periodic structures are resonating at certain frequencies and able to absorb the electromagnetic radiation in the form of light. The theoretical background based on the negative refractive index of values of ε (permittivity) and μ (permeability).

Which is given as:

$$\eta = -\sqrt{\mu_r \varepsilon_r} \ .$$

And Pendry introduced the idea of artificial magnetism [7], that opened up the possibility of creating negative index material [8] and after that number of researches came out to support this concept and new era of metamaterial begun. In 2008, Landy [9] *et al.* proposed the first-ever perfect metamaterial absorber (MMA). By designing electric resonator on the top plane and cut wire on the bottom plane of the substrate, the absorber was able to get absorption closely 99% at a single band frequency. After that, the research on absorbers has obtained prodigious amount of development, such as single-band [10], dual-band [11] [12], triple band [13], multi-band [14] [15], broadband [16] and tunable absorption [17]. Typically, metamaterial components are fashioned from the highly conductive materials like, gold, silver, copper and formed into the periodic structure to get desired characterization of EM properties.

Different types of periodic structures are designed at different frequencies to achieve good absorption and the rate of absorption can be achieved up to 100% with necessary height of substrate and structure of material designed [18]. And can be combined with the rectangular patch antenna to improve the performances. MMA loaded antenna can give more improved gain and directivity or keep them as it is [19]. Metamaterial absorber are widely used to reduce the radar cross section (RCS).
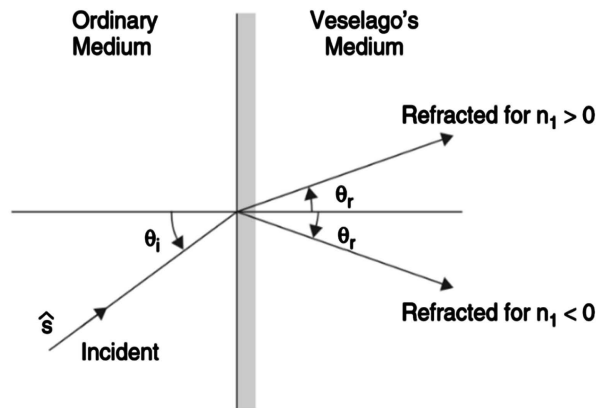
Figure 2. Presentation of Negative refractive index.

3. Proposed Antenna Design with Metamaterial

In proposed unit cell design, we have taken a unit cell of 4.25 × 4.25 mm, which is very compact in size. FR-4 epoxy is used as dielectric having ε_γ = 4.4, $\tan\delta$ = 0.02 and the height of 0.35 mm with the copper as a metallic part. The gap between two-unit cell is 0.15 mm. The unit cell is shown in Figure 3. The unit cell structure is consisting of rectangular rings and triangle, which looks like a charismas tree. The back surface of the given unit cell structure is made of metal, to ensure the zero transmission on the other side of structure [18] [19]. Back radiation or transmission is terminated the transmission coefficient $s_{21}(\omega) = 0$. And the reflection from the structure needs to be decrease [20].

The proposed structure is simulated in HFSS V 19 software as it provides nice performance for similar structure [21]. The Floquet port and master-slave boundary conditions are utilized to simulate this finite array structure of Metamaterial. As shown in Figure 3. The absorption is taking place at a 9 GHz frequency and absorption obtained through simulation is 99.99% as shown in the figure. Here, we have taken arrays of 7 by 7 for analysis [22].

The absorption of the unit cell is given by the equation:

$$A(\omega) = 1 - R(\omega)^2 - T(\omega)^2,$$

where, $A(\omega)$ = Absorption.

$R(\omega)$ = Reflected power.

$T(\omega)$ = Transmitted power.

Now MSA with loaded MMA have been explained. Loading the microstrip antenna with metamaterial cells which is shown in Figure 4. The Metamaterial cells are loaded on the substrate having a height of 0.35 mm [23]. The length and width of the lower substrate is 29.75 mm for 7 by 7, shown in Figure 4.

The absorption plot after loading the MSA with MMA is as given in Figure 5.

We can see that after loading the MSA with MMA it doesn't affect the gain and directivity as they are very similar to MSA results, as scattering parameter, Gain and Directivity comparison is given in Figure 6 with and without MMA loaded MSA [24] [25].
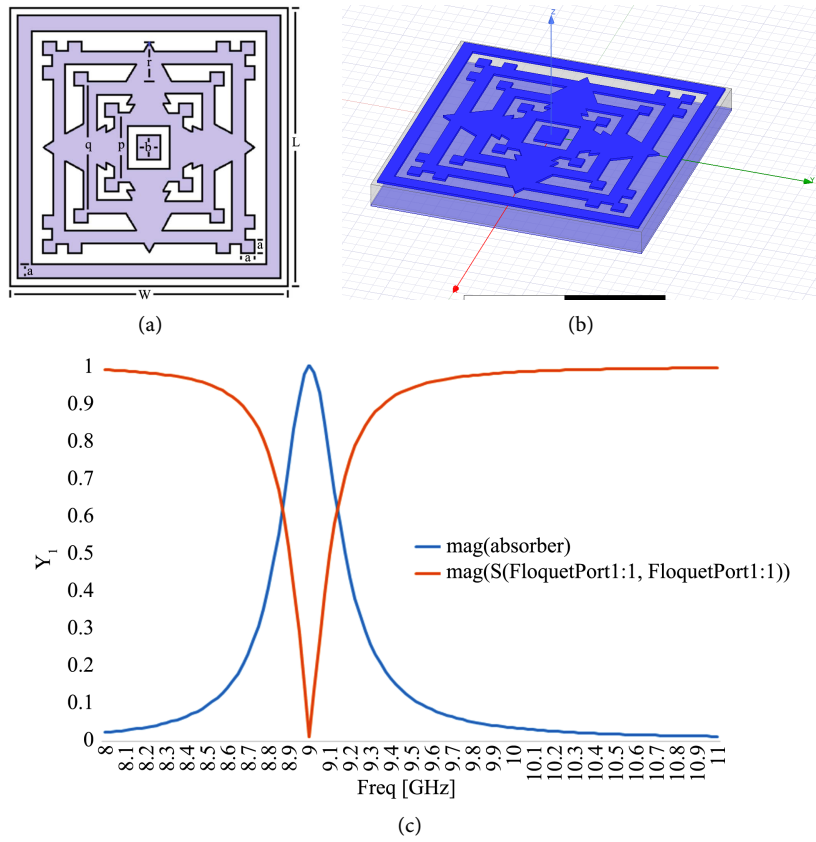
(a)

(b)

(c)

Figure 3. (a) Unit cell top view; (b) Trimetric view of unit cell; (c) Absorption plot of MMA.
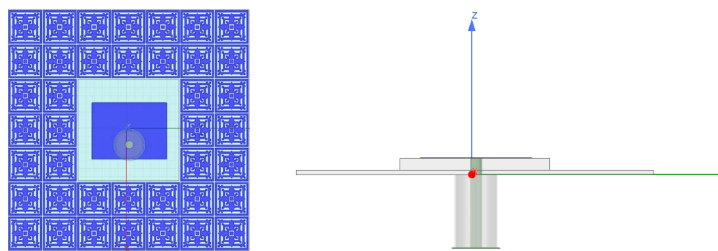

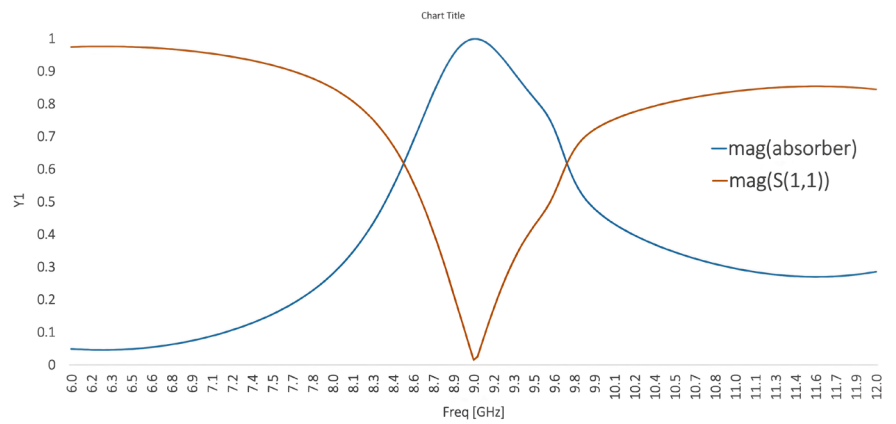**Figure 4.** MSA loaded with MMA and side view of MMA loaded MSA.

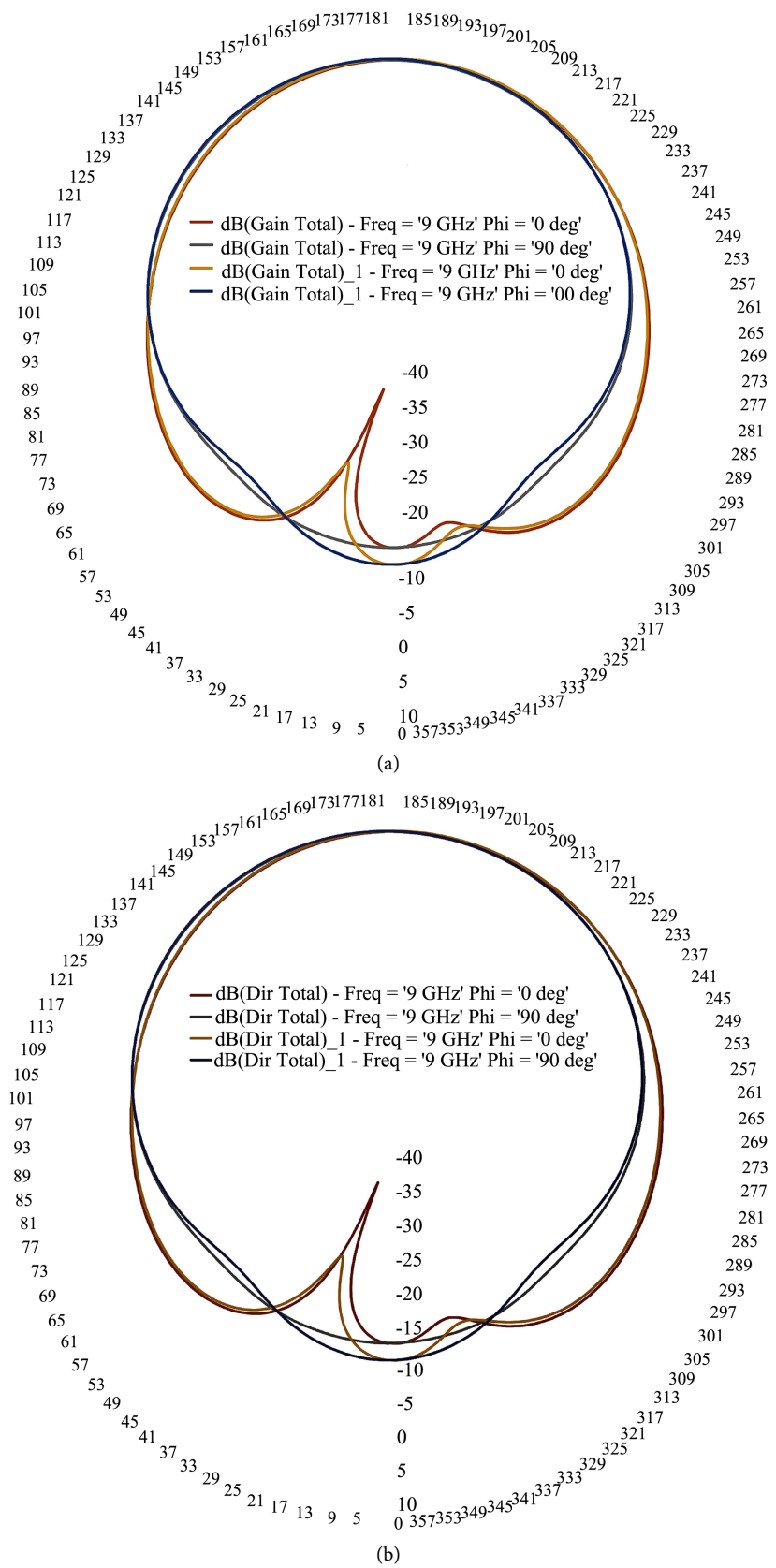**Figure 5.** Absorption plot of MSA loaded with MMA.

(a)

(b)

Figure 6. (a) Gain comparison of with and without MMA loaded MSA; (b) Comparison of directivity with and without MMA loaded MSA.

The monostatic Radar Cross Section (RCS) is an important design parameter for many applications but accurate RCS prediction of an electrically large structure continues to be a challenging task in Monostatic Radar both Tx and Rx antennas are placed close to each other at the same location Now, Monostatic RCS Analyses with and without MMA loaded MSA and its comparisons are explained. RCS is also an importance aspect of designing this Microstrip antenna with Metamaterial absorber structure as it helps to reduce the radar cross section very effectively for a given resonant frequency.

Here, we have measured Monostatic RCS for loaded arrays of MMA on MSA for x-polarization and y-polarization. It has been found that the values of monostatic RCS have been reduced efficiently. The value of RCS at the exact 9 GHz is found to be −37.71 dB for Phi = 0 degree and Theta = 0 degree (x-polarization) and −38.21 dB for Phi = 90 degree and Theta = 0 degree (y-polarization). The analyses have been given for the loaded MSA with MMA, as it given in **Figure 7**. Which are efficiently good values but one can reduce the values of RCS by considering a greater number of arrays as mentioned in **Table 2**.

Table 2. Dimensions of parameter of unit-cell.

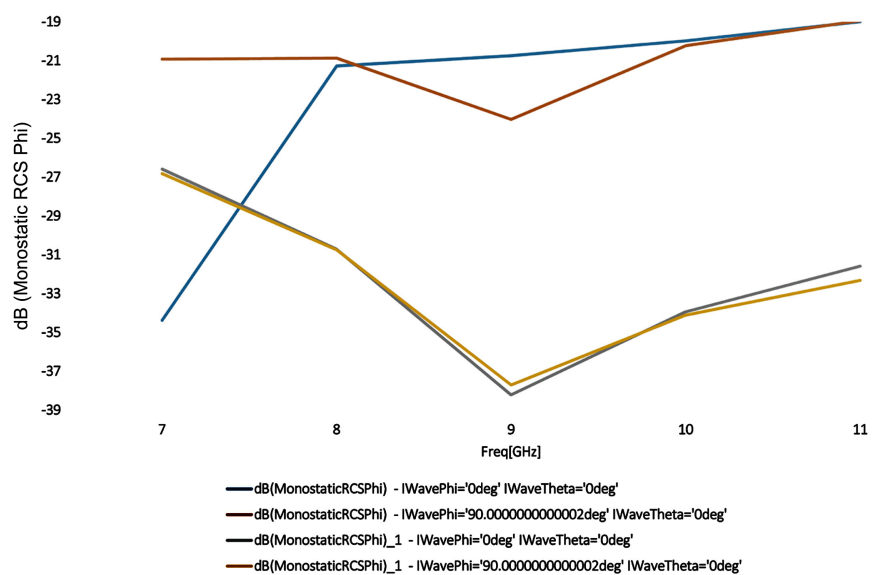| Parameter	Dimensions (mm)
W	4.25
L	4.25
a	0.2
b	0.4
p	1.1
q	2.1
r	0.7

Figure 7. Comparison of with and without MMA loaded MSA monostatic RCS.

4. Conclusion

In this research project work, we have proposed the metamaterial absorber structure operating at 9 GHz of an x-band. An analysis has been given for results of simple microstrip antenna and Metamaterial loaded antenna. Metamaterial unit cell is designed to give absorption at exact 9 GHz and it's nearly 100%. Monostatic RCS had been considered to check the values of RCS and its analytical result of MMA loaded MSA had been given. The values are effectively reducing for RCS. This structure finds its applications in stealth technology for defense applications like, military planes, space aircraft, missiles, ships, and other sensitive vehicles for long distance wireless communication to reduce RCS.

Acknowledgements

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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