A Metamaterial based reflector for the wide-band regime design, fabrication and characterization

A project Report
submitted by

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for the award of the degree of

Master of Technology

Under the guidance of

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Thesis Certificate

This is to certify that the thesis titled **A metamaterial based reflector for the wide-band regime design, fabrication and characterization**, submitted by **K Devidas**, to the Indian Institute of Technology, Madras, for the award of the degree of **Master of Technology**, is a bona fide record of the research work done by him under our supervision. The contents of this thesis, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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It is a privilege to be a student in IIT Madras. I express special thanks to all my teachers for all the academic insight obtained from them. I also acknowledge the excellent facilities provided by the institute to the students. I would like to thank all my college friends who made this stay at IIT Madras a pleasant and memorable one.

Abstract

The extensive development of Electronic systems and telecommunications had lead to major concerns regarding Electromagnetic Radiation. Motivated by environmental questions and by a wide variety of applications, the quest for materials with high efficiency to migrate Electromagnetic Interferences (EMI) Radiation has become a mainstream field of research. In the past, many EMI shields have been proposed and implemented using conductive metal to reduce EMI by Reflection. The shields implemented by using metals are relatively rigid, bulky and heavy. In this project an attempt has been made to design and implement Metamaterial based Electromagnetic shield which resolves the disadvantages of metals based EMI shield.

It explores the configuration of EMI shield in which a dielectric substrate is sandwiched between two patterns of copper metal layers. The structure is simulated in CST microwave studio and displays a Reflection rate at 99.25% at 6.02 GHz resonant frequency. The verified optimal design is also fabricated and the experiment was performed to confirm with the simulation results.

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Abbreviations

A	Absorptivity
BC	Boundary Condition
CST	Computer Simulation Technology
dB	Decibel
EM	ElectoMagnetic
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
GHz	Giga Hertz
MM	Meta Material
MWS	Microwave Studio
NRI	Negative Refractive Index
PEC	Perfect Electric Conductor
PMC	Perfect Magnetic Conductor
R	Reflectivity
T	Transmitivity
VNA	Vector Network Analyzer

Notations

E	Electric Field
H	Magnetic Field
d	Thickness of dielectric
λ	Wavelength
ε	Electrical Permittivity
μ	Magnetic Permittivity
Z	Impedance
n	Refractive Index
ω	Angular frequency
k	Wave vector
η_s	Intrinsic impedance of medium
η_0	Intrinsic impedance of free space
EI	Incident electric field
ER	Reflected electric field
ET	Transmitted electric field
HI	Incident magnetic field
HR	Reflected magnetic field
HT	Transmitted electric field
ρ	Average size of unit cell
PI	Incident power
PT	Transmitted power

Chapter 1

Introduction

The experimental growth of wireless communication, portable communication devices are common sights in our daily life. Also, with the heavy reliance on wireless communications, an increasing number of base stations are expected to ensure good wireless coverage. Such a trend has posed potential electromagnetic interference (EMI) risk or radiation hazards for some buildings. The effect of rapid growth of Electronic industries and widespread of electronic equipment's in communication, computers, automotive, bio-medical, space and other purpose has led to exponential increase in Electromagnetic Interference (EMI).

Today's one of the most common application is the indoor wireless systems. With the increasingly popularity and deployment, the electromagnetic signals interfere between devices. Thus, there is strict demand for effective and practical shielding solutions. Unless the electronic equipment's are properly shielded in the design phase, the threat from EMI is going to be very severe. Electromagnetic interference (EMI) shielding refers to the reflection and/or absorption of electromagnetic radiation by a material, which thereby acts as a shield against the penetration of the radiation through the shield.

Metamaterials are widely used in microwave devices to improve their performance, They are used in amplifiers filters and power dividers. most of the metamaterials are widely used in the design of antennas. Since they can provide bandgaps, they are used to enhance the isolation between closely packed MIMO antenna systems. They are also used in antenna miniaturization and to modify the characteristics of antennas[2].

This work designs a meta-material based Reflector which consists of a bi-layer unit separated by a dielectric substrate structure for shielding based application. The design is verified using CST Microwave Studio and then the results are obtained post fabrication of the optimized design. The MM perfect reflection between two frequency range with 99.25% at 6.02GHz.. The Reflector has a polarization in sensitive feature owing to its symmetric structure. These meta-material based on Reflector/absorbers are promising candidates for thermally based imaging due to the relatively low volume, low density and narrow band response.

Chapter 2

Meta-material

2.1 What are metamaterials

Before researching the technical aspects of metamaterials, we shall first define the meaning and scope of the word. The prefix meta comes from Greek and means after or beyond. In English it is used to either denote that something has occurred later, derived from a transformation, is a more highly organized or specialized form of, or transcends something else [3]. Thus with that in mind, a Metamaterial is expected to display one or more properties rather qualitatively different - some investigators claim extraordinary than those of its ordinary constituents.

Metamaterials, artificial composite structures with exotic material properties, have emerged as a new frontier of science involving physics, material science, engineering and chemistry. In general, metamaterial is a metallic or semiconductor substance whose properties depend on its inter-atomic structure rather than on the composition of the atoms themselves. The property of a classical bulk material is essentially determined by the chemical elements and bonds in the material. Existing materials only exhibit a small subset of electromagnetic properties theoretically available but metamaterials can have their electromagnetic properties altered to something beyond what can be found in nature such as negative index of refraction, zero index of refraction, magnetism at optical frequencies etc.

Metamaterials are composite materials the electromagnetic properties of which not only depend on their mate rial composition, but also on the inclusion of macroscopic structures that are specially designed to obtain a specific response. The properties of a material can hence be modified by introducing different structures within it. This behaviour of metamaterials has made them very desirable for applications in a wide variety of frequency ranges, ranging from micro waves to optics [2].

Leading authors in the field of metamaterials have suggested adding another constraint in order to differentiate Electro Magnetic Metamaterials (EM-MTM) from other closely related optical devices such as photonic crystals[4]. The average size p of a unit cell also known as meta-atom in an EM-MTM should be much smaller than the driving wavelength of light ($\rho << \lambda$). Some authors go further as to propose a rule of thumb to clearly discriminate EM-MTM devices via an effective homogeneity condition ($\rho < \lambda$). The rationale behind that distinction is that EM-MTM is effectively homogeneous media for incident radiation. While classical diffractive components like photonic crystals, whose cellular dimensions are typically integer multiples of a half-wavelength ($\rho \approx n\lambda/2$), cannot be considered as homogeneous. Hence cannot be characterized by a single value of the refractive index. In the case of photonic crystals, the waves scatter at each layers of the photonic crystal and interfere constructively in the Bragg regime [4]. At the early stage most research focused on metamaterials in the microwave region to implement artificial magnetism, artificial dielectrics, negative refractive index, and super lens [5]. Within past few years, metamaterials have rapidly advanced to terahertz and optical frequencies.

2.2 Reflection Theory

The Reflection coefficient is a parameter that describes how much of an electromagnetic wave is reflected by an impedance discontinuity in the transmission medium. It is equal to the ratio of the amplitude of the reflected wave to the incident wave, with each expressed as phasors [6]. In particular, at a discontinuity in a transmission line, it is the complex ratio of the electric field strength of the reflected wave (E^-) to that of the incident wave (E^+). This is typically represented with a and can be written as:

$$\Gamma = \left(\frac{E^-}{E^+}\right) \tag{2.1}$$

The reflection coefficient of a load is determined by its impedance Z_S and the impedance toward the source Z_L.

$$\Gamma = \frac{z_L - z_S}{z_L + z_S} \tag{2.2}$$

A wave experiences partial transmittance and partial reflectance when the medium

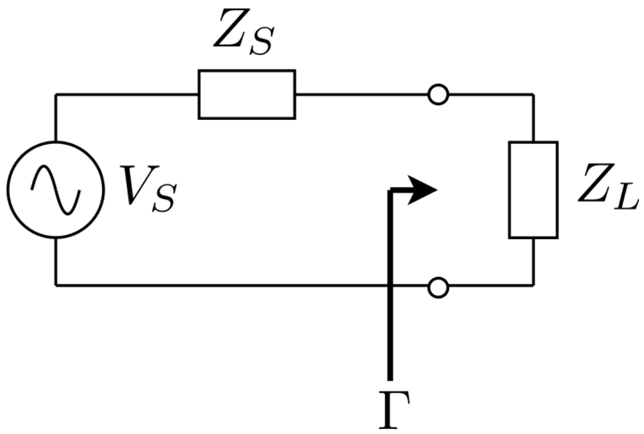


Figure 2.1: Simple circuit configuration showing measurement location of Reflection coefficient

through which it travels suddenly changes. The reflection coefficient determines the ratio of the reflected wave amplitude to the incident wave amplitude.

2.3 Why MM for Reflection application?

In electromagnetic, the permittivity, permeability, and conductivity define the material's characteristics. The extraction of these values for different frequencies defines the propagation profile of the material at that frequency. In the extraction method used in this work, the refractive index and impedance of the material are used to extract the permittivity and permeability of the material under test [2].

1. Design demonstrated in a particular band of electro magnetic spectrum can be made to operate in some other band by optimizing the geometry of the metamaterial structure.

2. Since the mechanism of reflection/absorption can be achieved through impedance matching and the loss. Metamaterials based reflector permit construction of complex materials by activity of the electromagnetic parameters like electric permittivity (ε) and magnetic permeability (μ) [5].

3. Comparatively broad Bandwidth (BW) can be realized by creating unit cells with matched impedance at multiple frequencies that are close enough to create a broadband single peak or by introducing lumped elements such as resistances

and capacitances in the MM structures. Dynamic/Tuneable Reflectance or absorbance can be achieved by integrating microwave diodes into the metamaterial array and biasing the Varactor Diodes at different levels

4. In contrast to conventional Reflector that require a thickness of at least 0/4, metamaterial Reflector can be relatively very thin even up to the order of 0/75. In certain applications it provides the ability of the metamaterial reflector to be highly flexible.

5. Availability of many commercial simulation programs like CST Microwave Studio, HFSS and Console which yield good match between simulated and experimental results. Above all, the metamaterial offers low volume, low density, low weight and low cost.

2.4 Electromagnetic Shielding

In this project I considered the radiation emission alone. Radiated emission can be controlled by containing the emission or by exclusion of radiated emission as shown in fig. 2.2 and 2.3 respectively. The most popular means to reduce the effect of EMI is by employing electromagnetic shield. An electromagnetic shield can be defined as housing, screen, or other object, usually conducting, that substantially reduces the effect of electric or magnetic fields between the source and the victim. The main purpose of the EMI shield is reduction of the electromagnetic field in a prescribed region of interest.

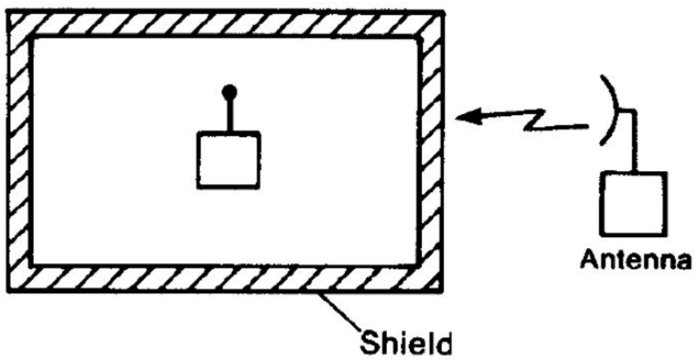


Figure 2.2: Shielded enclosure to contain radiated emissions

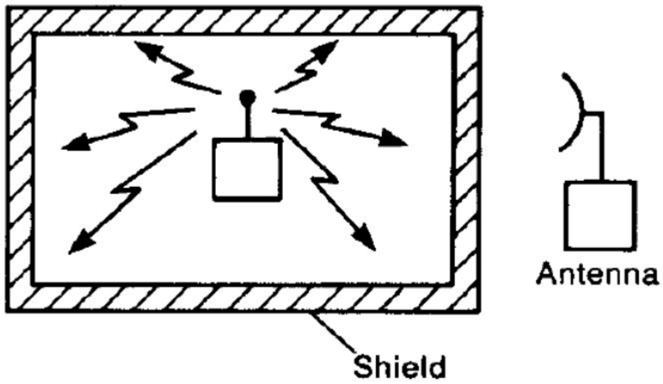


Figure 2.3: Shielded enclosure to exclude radiated emissions

2.5 Theory of EMI shielding

When an electromagnetic plane wave (E_I) is incident on a shielding material having different intrinsic impedance than the medium in which the EM plane wave was propagating, it undergoes reflection and transmission at the interface (x=0) thus creating a reflected wave (E_R) and a transmitted wave ($E_(I-R)$), at the external surface [7]. The amplitude of the E_R and $E_(I-R)$ waves depend on the intrinsic impedance of the shielding material (η_s) and the EM incident wave propagating medium (η_0).

The transmitted wave ($E_(I-R)$) then travels into the internal shield, the amplitude of the wave decreases exponentially due to absorption. When the wave encounters the second interface at x=d, the part of wave incident will be transmitted out of the shield and a portion will be reflected in a shield. If the shield is thicker than the skin depth, the reflected wave from the internal surface will be Reflected by the conductive material, and thus multiple-reflection can be . However, if the shield is thinner than the skin depth, the influence of multiple-reflection will be significant in decreasing overall EMI shielding.

2.6 Shielding Efficiency (SE)

A shield is, conceptually, a barrier to the transmission of electromagnetic fields. We may view the effectiveness of a shield as being the ratio of the magnitude of the electric (magnetic) field that is incident on the barrier to the magnitude of the electric (magnetic) field that is transmitted through the barrier. Alternatively, we may view

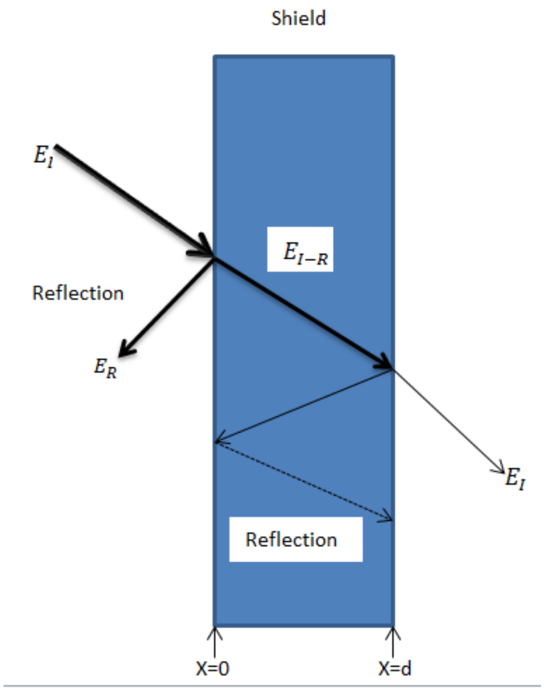


Figure 2.4: Components of EMI shielding

this as the ratio of the electric (magnetic) field incident on the products electronics with the shield removed to that with the shield in place. Thus shield prevents coupling of undesired radiated electromagnetic energy into equipment otherwise susceptible to it.

SE defined for electric field in $dB = 20\log_{10}\left(\frac{E_I}{E_T}\right)$

SE defined for magnetic field in $dB = 20\log_{10}\left(\frac{H_I}{H_T}\right)$

Also, EMI SE (in terms of power) is the logarithm of ratio of the transmitted power when there is no shield (P_I) to the power when there is a shield (P_T).

$$dB = 20\log_{10}\left(\frac{P_I}{P_T}\right)$$

For a single layer shield, the total SE has three components due to contributions from reflection (SE_R), absorption (SE_A) and multiple reflections (SE_M) [3]. The additional effects of multiple reflections inside shielding barrier need not be considered when $SE_A > 15dB$.

$$SE_{dB} = SE_R + SE_A + SE_M$$

$$\text{SE by reflection} SE_R = 20\log_{10}\left(\frac{\eta_0}{4\eta_s}\right)$$

$$\text{SE by absorption} SE_A = 20\log\left(e^{\frac{d}{s}}\right)$$

$$\text{SE by multiple reflection} SE_M = 20\log\left|1 - e^{\frac{-2d}{s}}\right|$$

The S_{11} and S_{12} are the scattering parameters (S-parameters) of the two-port vector network analyzer (VNA) system representing the reflection and transmission coefficients, respectively. The transmittance (T), reflectance (R), and absorbance (A) through the shielding material are related to the S parameters as follows:

$$R = |S_{11}|^2$$

$$T = |S_{21}|^2$$

$$A = 1 - (R + T)$$

The SE_M is a correction term whose value may be positive, negative or zero. The effect of multiple reflections between both interfaces of the material is negligible when $SE_A > 10dB$.. Therefore, the relative intensity of the effectively incident EM wave inside the materials after reflection is based on (1R). Therefore, the effective absorbance (A_{eff}) can be described as $A_{eff} = 1 - (R + T)(1 - R)$ with respect to the power of the effectively incident EM wave inside the shielding material.

$$SE_R = 10\log_{10}(1 - R)\,\text{indB}$$

$$\text{SE}_A = 10\log_{10}(1 - A_{eff})\,\text{indB} = 10\log_{10}\left(\frac{T}{1 - R}\right)$$

Chapter 3

Designs and Simulation

3.1 Design Consideration

Various configurations have been proposed for metamaterial based configuration of the metal and the dielectric layers are employed. A configuration with two copper layers separated by a dielectric substrate is the most popular of the available design with complimentary. In many cases the bottom layer is completely copper laminated called ground plane while the top layer has periodic arrangement of patterns [9]. Many patterns like cross, split wire, rhombus, circular or square rings, triangle have been reported [10]. Few cases of the MM based reflector have reported periodic pattern of FR4 and copper patterns on front and back layers [11].

The selection and design of a metamaterial depends on the application and available resources. Metamaterials can be accurately designed using full-wave analysis, but it is a time-consuming task. On the other hand, a priori knowledge of the electromagnetic properties of the material will accelerate the design procedure. The electromagnetic properties, such as the complex permeability (μ) and the permittivity (ε) [2].

The wave vector is perpendicular to the top and bottom plane containing the metal pattern in the Z direction. The electric component of EM wave is parallel with the X-axis and the magnetic component is parallel with the Y-axis. In rhombus with SRR(Split Ring Resonator),CSRR(Complimentary SRR) of symmetry about the propagation axis and hence polarisation insensitive whiles the front and back structure consist of Electric LC Resonator. The ELC Resonator responses strongly electric field for incident EM wave with electric polarized along the Rhombus wire of the ELC Resonator.similarly the magnetic field of incident EM wave passes through dielectric substrate and the top ELC resonator and bottom conductor plane make anti-parallel surface current structure leading to magnetic coupling. Therefore, the characteristic impedance of the metamaterial is matched to free space by modifying the scale of ELC resonator's component and substrate thickness. In either of the MM reflector configurations, when EM wave is incident on the structure, the electric field is coupled with the top periodic resonator structure which controls the value of electrical permittivity (ε) and the anti-parallel current between the top and bottom layer can be coupled with the magnetic field which controls the magnetic permeability (μ). The electric and the magnetic fields can be highly coupled by optimally adjusting the physical parameters of the top and bottom layer along with fine tuning of the dielectric substrate thickness. The above tuning can be achieved in a particular frequency range where the surface impedance (η_s) can be matched with free space impedance (η_0). The absorption can be maximized by minimizing both reflected power and transmitted power. For materials with complex permittivity (ε) and magnetic permeability (μ), the total loss depends on the imaginary part of both refractive index and surface impedance.

$$Z(W) = \sqrt{\frac{\mu_r \mu_0}{\in_r \in_0}} = \eta_0 \sqrt{\frac{(1+S_{11})^2 - {S_{21}}^2}{(1-S_{11})^2 + {S_{21}}^2}}$$

3.2 Design

In this project the MM based Reflector structure consists of a metallic dielectric-metal configuration. The front side and Back side design consists of copper metal based periodic structures. The dielectric (FR4 lossy substrate) is sandwiched between the front and back metallic surface (PEC and PMC). For learing purpose I designed some standard structure simulations are Ring,Square,switch type structures I shown in figure, the form different reference paper. Those structure have only SRR. I have designed with SRR(Split Ring Resonator) and CSRR (Complimentary Split Ring Resonator).In ring split ring resonator design of symmetric single split ring SRR unit cell is shown in figure 3.1. Is simulated by CST microwave by using PEC and PMC boundary conditions. this ring SRR unit cell For Design using FR4 lossy substrate with dielectric relative permittivity (ε) 4.3 and loss tangent 0.025, thickness 0.5 mm. Dimensions of substrate 6mm, ring 2mm and split gap 0.5 mm.

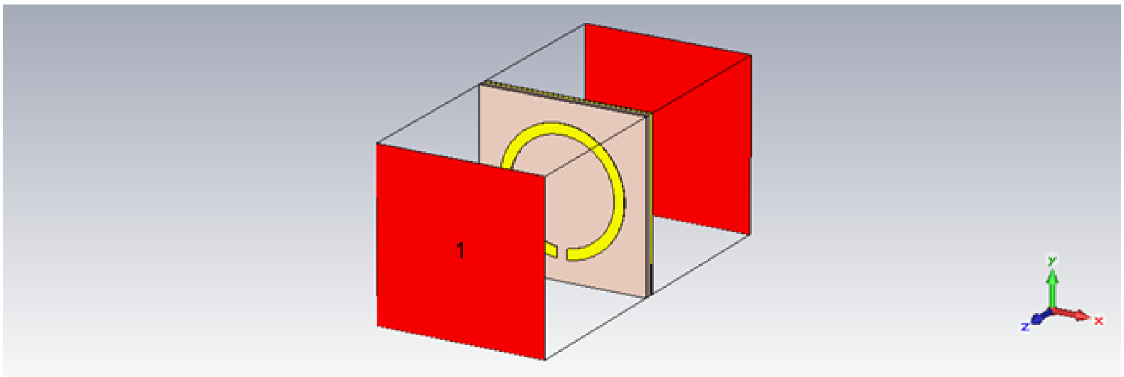


Figure 3.1: single ring structure

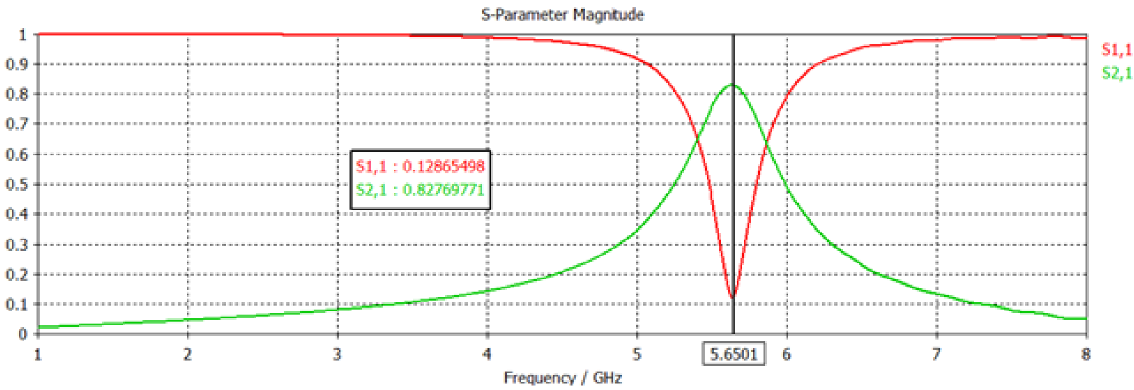


Figure 3.2: ring simulation result

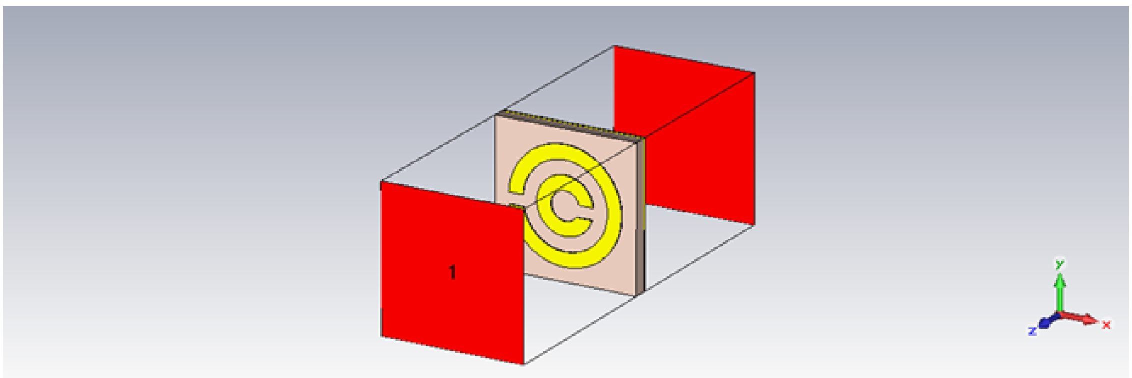


Figure 3.3: two ring structure

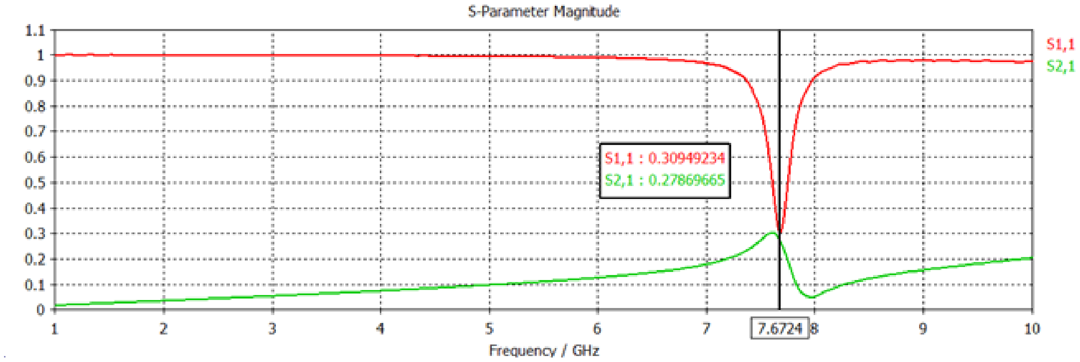


Figure 3.4: ring simulation result

The Square single SRR unit cell For Design using FR4 lossy substrate with dielectric relative permittivity (ε) 4.3 and loss tangent 0.025, thickness 0.5mm. Dimensions of substrate 10mm, square 6mm and split gap 0.5mm is shown in figure 3.5.

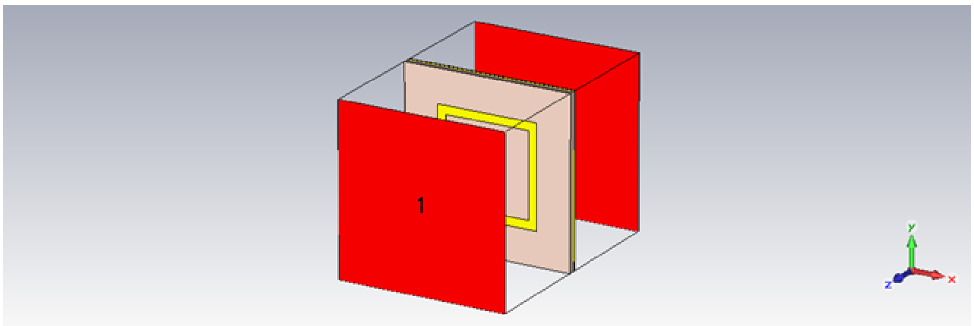


Figure 3.5: single square structure

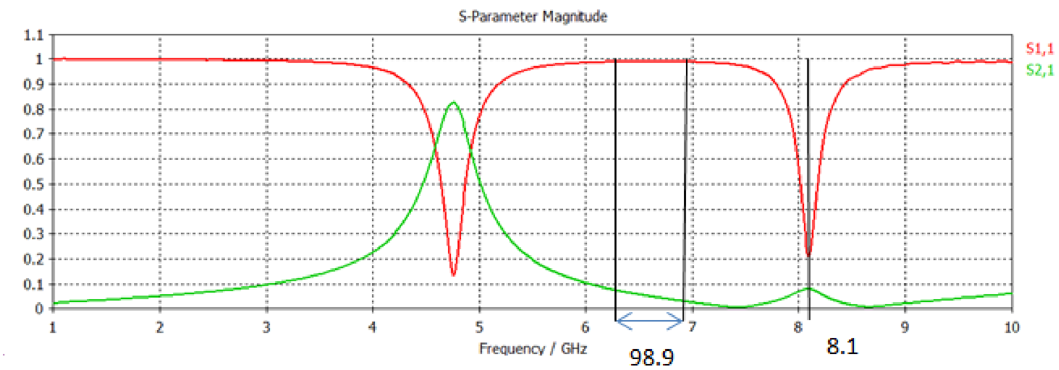


Figure 3.6: square simulation result

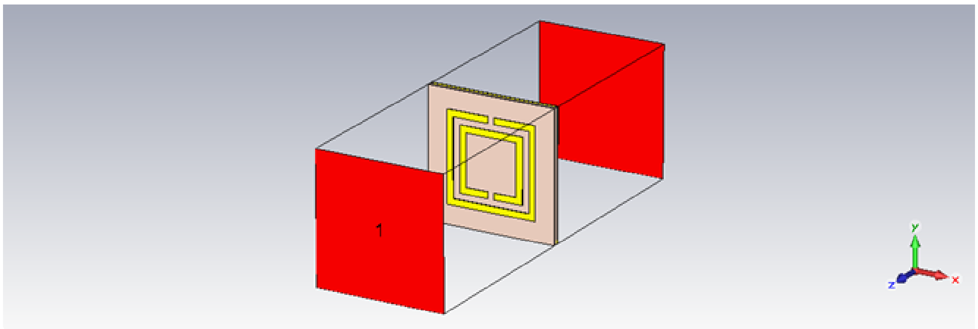


Figure 3.7: two square structure

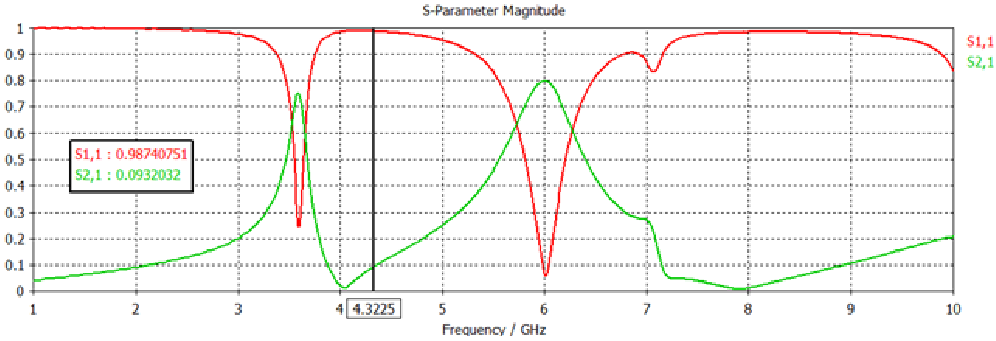


Figure 3.8: square simulation result

Switchable pattern: The electromagnetic metamaterial which is able to electronically switch a reflector and absorber. For reflection mode a split ring resonantor is

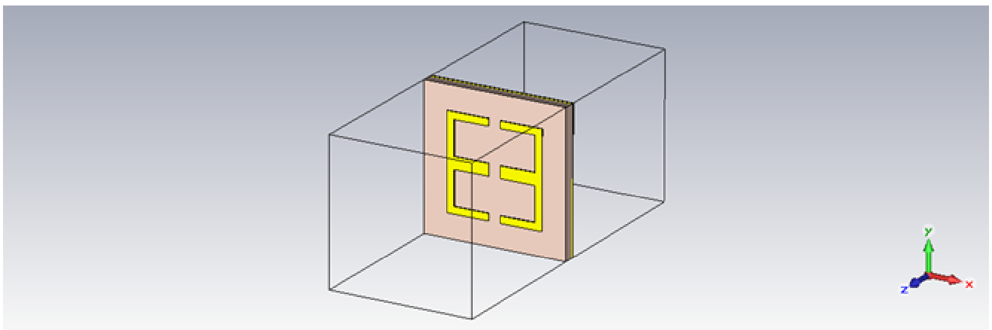


Figure 3.9: switch off state simulation pattern

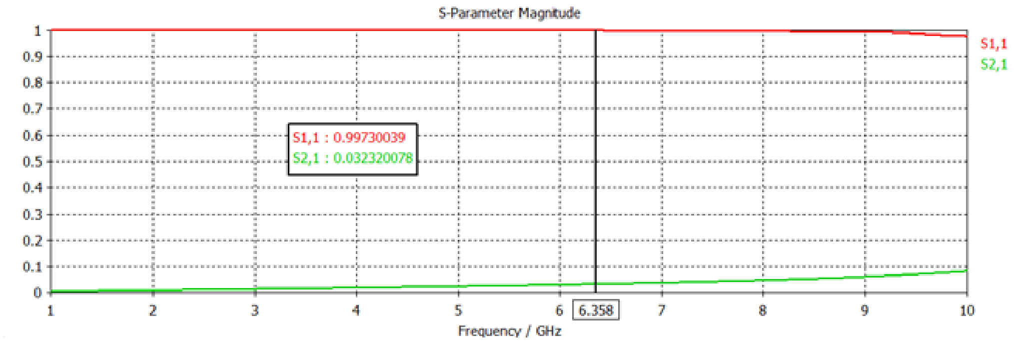


Figure 3.10: switch off state simulation result

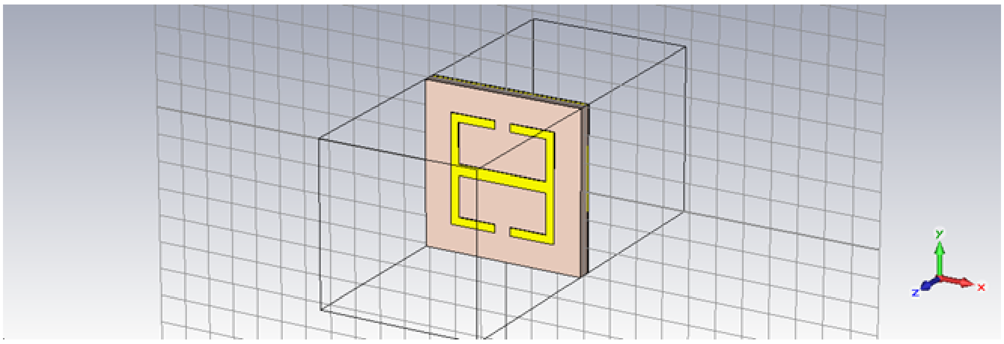


Figure 3.11: switch on state simulation pattern

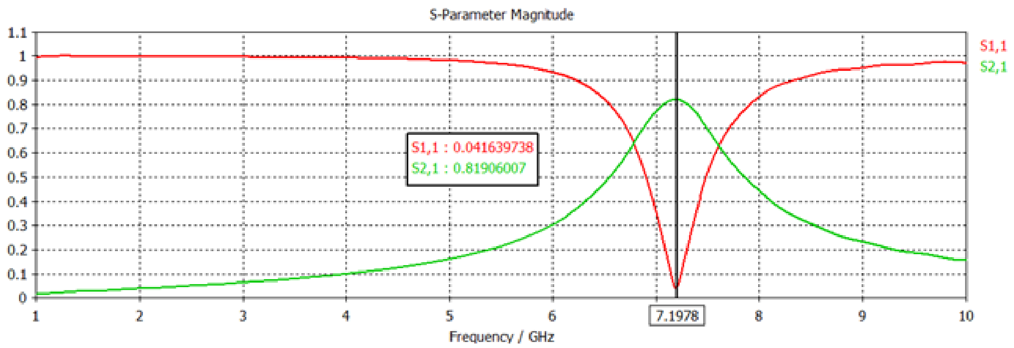
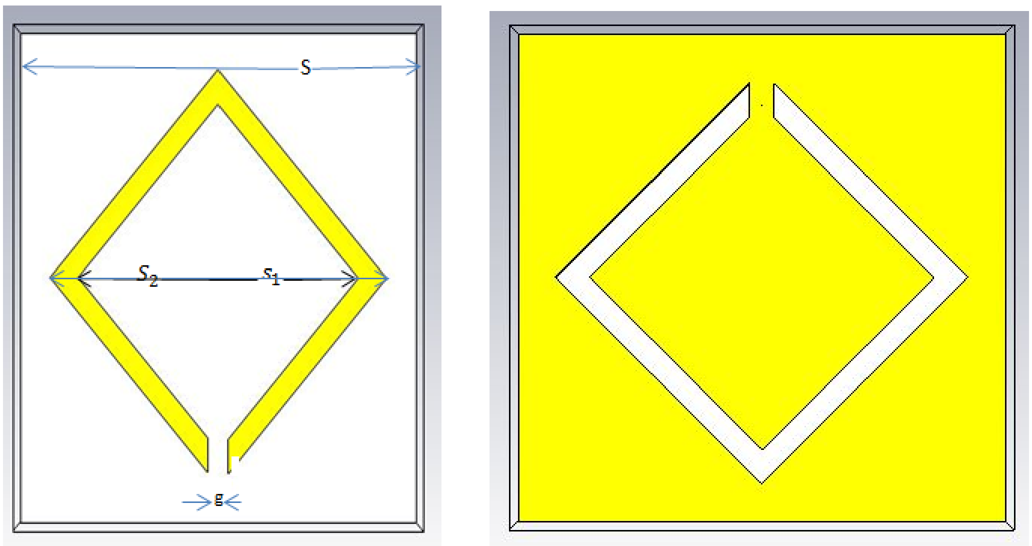


Figure 3.12: switch on state simulation result

shown in figure 3.9., employed as an switching the current path off, and for absorber mode a split ring resonantor is shown in figure 3.11, is employed as an electrical LC resonator.

The rear structure as shown in fig. 3.14b has single or two rhombus with SRR(Split Ring Resonator),CSRR(Complimentary SRR) of symmetry about the propagation axis and hence polarisation insensitive whiles the front and back structure consist of Electric LC Resonator. The ELC Resonator responses strongly electric field for incident EM wave with electric polarized along the Rhombus wire of the ELC Resonator.similarly the magnetic field of incident EM wave passes through dielectric substrate and the top ELC resonator and bottom conductor plane make anti parallel surface current structure leading to magnetic coupling [13]. Therefore, the characteristic impedance of the metamaterial is matched to free space by modifying the scale of ELC resonator's component and substrate thickness. This design also permits a wide angle on incidence of the incident EM wave without much degradation in the reflection performance. The thickness of copper metal layers and FR4 dielectric is 34 m and 0.5 mm respectively. The specification and the dimensions (front (fig. 3.13a), back (fig. 3.13b) and side (fig. 3.14a) views) of the MM reflector is listed in table 3.1 and figure 3.13.

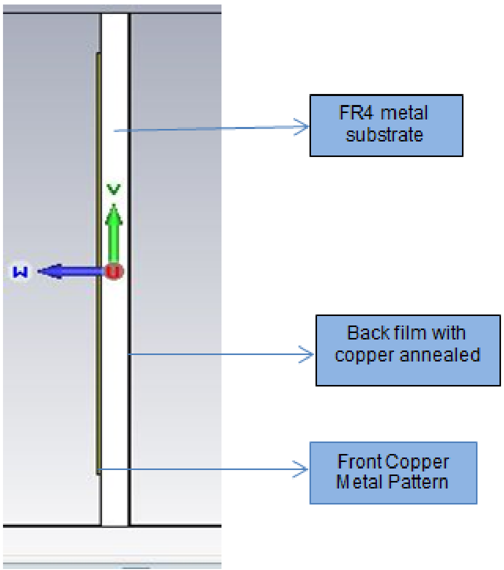


(a) (b)

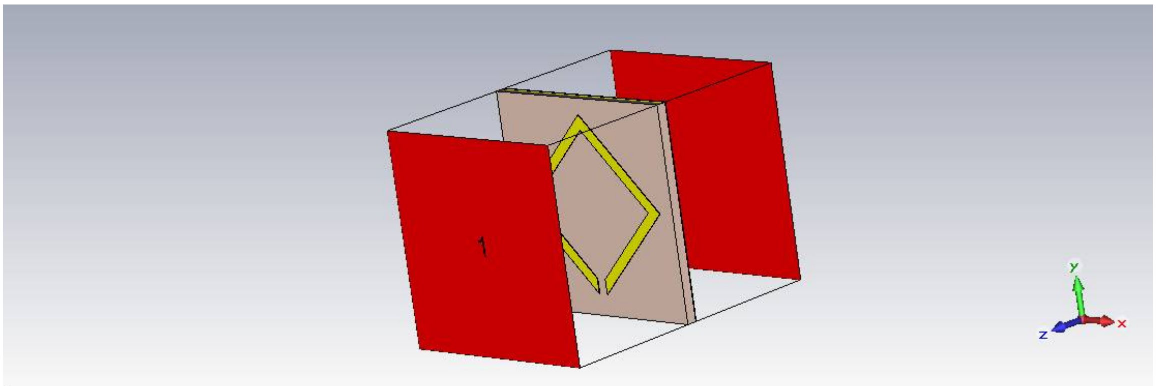
Figure 3.13: (a) Front and (b) Back

For Design using a FR4 lossy substrate with dielectric relative permittivity (ε) 4.3 and loss tangent 0.025, thickness 0.5mm, The metallic meta-material is copper with electric conductivity $5.8. \times 10^7 S/_m$.

All Dimensions:



(a)



(b)

Figure 3.14: (a)Side view (b) Design of wave guide ports

- Substrate-10mm
- Rhombus and gap-1mm
- Strip gap-0.5mm
- Complimentary square
- Back filem with copper annealed

Substare	10mm
S1	6mm
S2	4mm
g	0.5mm

Table 3.1: Fabrication parameters

- Substrate thickness 0.5mm
- Metal thickness 0.034mm

3.2.1 SRR (Split Ring Resonator):

A split-ring resonator (SRR) is an artificially produced structure common to metamaterials. Their purpose is to produce the desired magnetic susceptibility (magnetic response) in various types of metamaterials up to 200 terahertz[11, 12]. A single cell SRR has a pair of enclosed loops with splits in them at opposite ends. The loops are made of nonmagnetic metal like copper and have a small gap between them. The loops can be concentric, or square, and gapped as needed. A magnetic flux-penetrating the metal rings will induce rotating currents in the rings, which produce their own flux to enhance or oppose the incident field. A double SRR is a highly conductive structure in which the capacitance between the two rhombus balance its inductance. A time-varying magnetic field applied perpendicular to the rhombus surface induces currents which, in dependence on the resonant properties of the structure, produce a magnetic field that may either oppose or enhance the incident field, those resulting in-positive or negative effective (μ).

3.2.2 Complementary Split Ring Resonator:

Structures complementary to single or double split Rhombus/rings/square were designed and produced by applying the babinet principle to the split rhombus. These complementary split ring resonator(CSRR) create negative ε instead of μ in a narrow range near the resonance frequency.whereas the SRR can be mainly considered as a resonant magnetic dipole that can be excited by an axial magnetic field, the CSRR essentially behaves as an electric dipole (with the same frequency of resonance) that can be excited by an axial electric field. In a more rigorous analysis,the cross-polarization effects in the SRR should be considered and also extended to the CSRR.

3.3 Simulation of unit cell

The simulation is done on metamaterial unit cell using CST Microwave Studio by setting up appropriate boundary conditions and port excitation.fig3.15, Perfect Electric and Perfect magnetic boundary conditions with waveguide ports on either sides of the structure were used in the simulation to compute the scattering parameters S_{11} and S_{21} as shown in figure 3.15.

The maximum Reflection rate 99.25% at 6.02GHz. The Reflection component of the designed metamaterial unit cell at normal incidence as a function of frequency

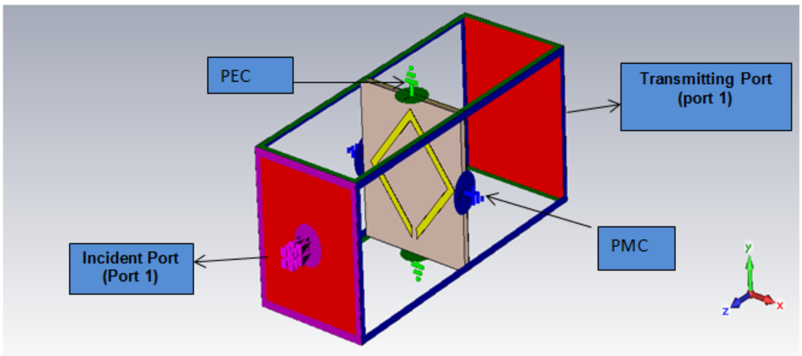
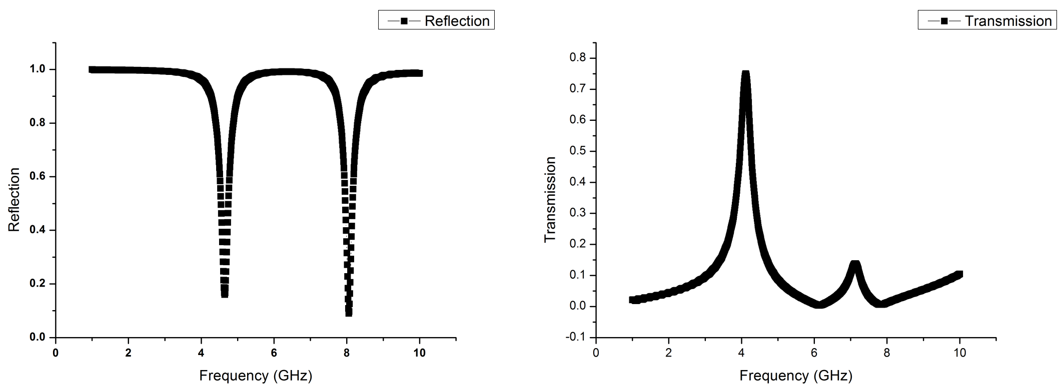


Figure 3.15: simulation of unit cell



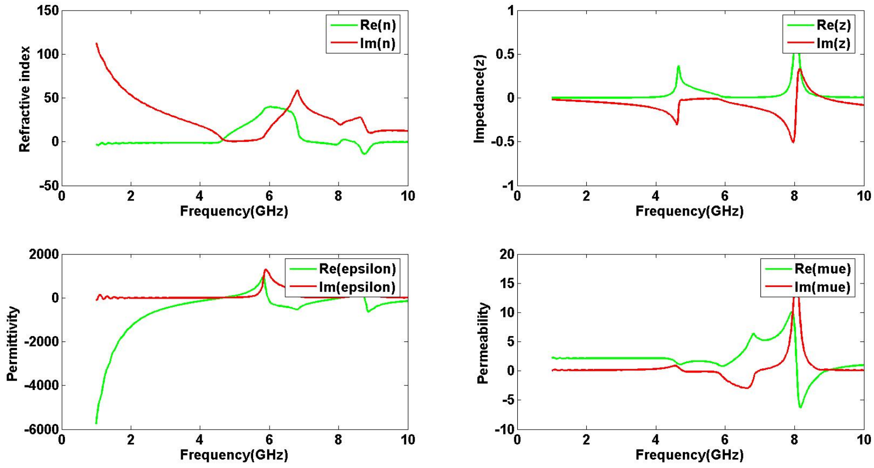
(a) (b)

Figure 3.16: (a) Simulation Reflection (b) Transmission

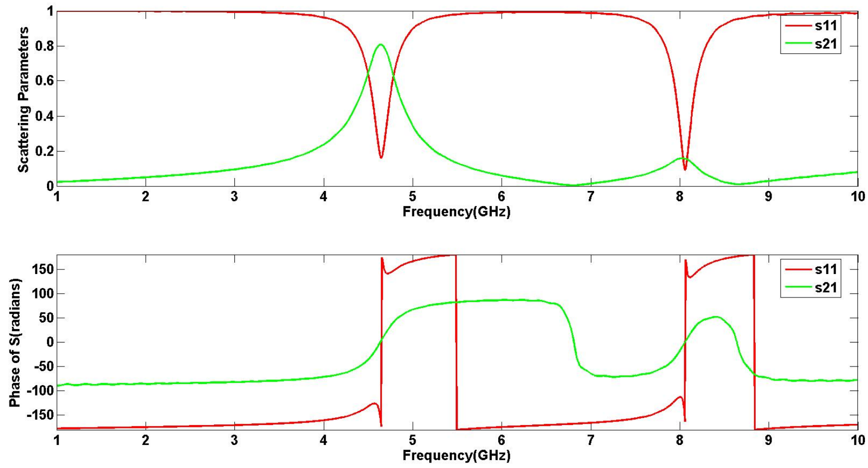
obtained in the simulation is presented in fig. 3.15.

3.4 EM Parameters

The electrical permittivity (ε), the magnetic permeability (μ), refractive index (η) and impedance (Z) parameters were retrieved at the electrical and magnetic resonance is



(a)



(b)

Figure 3.17: (a) EM parameter linear part (b) EM parameter phase part

displayed in figure 3.3. The linear and phase parts of (ε)and (μ), contributes towards the propagation of the EM wave while the imaginary part of (ε) and (μ) describe the loss. The values of impedance Z, (ε) and (μ), at resonance is shown in figure 3.5. The large values of the imaginary part of (ε) and (μ), show that the losses are increased there by maximizing the Reflectivity.

3.5 Simulation of stacked structure

The simulation is done on metamaterial stacked structure with a distance (D) and air medium as the medium between individual unit cell with shown in figure 3.6 using CST Microwave Studio by setting up appropriate boundary conditions and port excitations. Perfect Electric and Perfect magnetic boundary conditions with waveguide ports on either sides of the structure were used in the simulation to compute the scattering parameters S_{11} and S_{21} results shown in figure 3.18, it has one absorption peak at 7.91GHz.

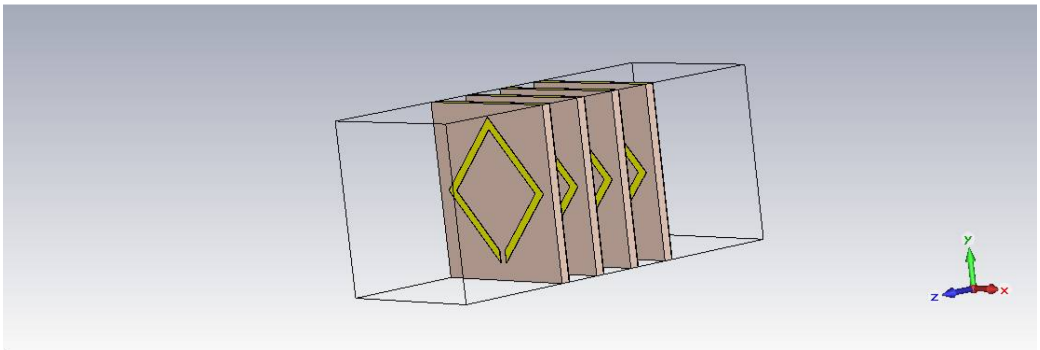


Figure 3.18: design of stacked structure

Substrate (mm)	Thickness (mm)	SRR gap (mm)	ε_r	Simulated Frequency (GHz)	Reflection rate
10	0.5	1	4.3	6.02	99.25%
10	0.8	1	4.3	6.49	98.88%
10	1	1	4.3	6.33	98.60%
10	1.5	1	4.3	6.20	98.11%
10	1.8	1	4.3	6.20	97.74%

Table 3.2: Design with different Thickness

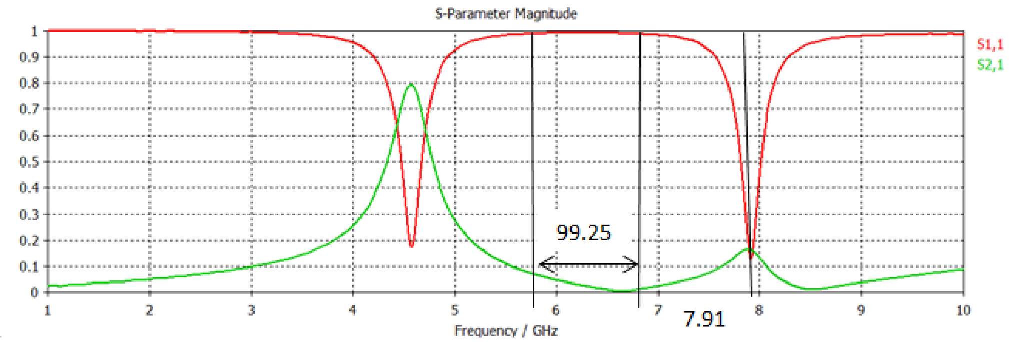


Figure 3.19: s-parameter result

Two Rhombus structure pattern:

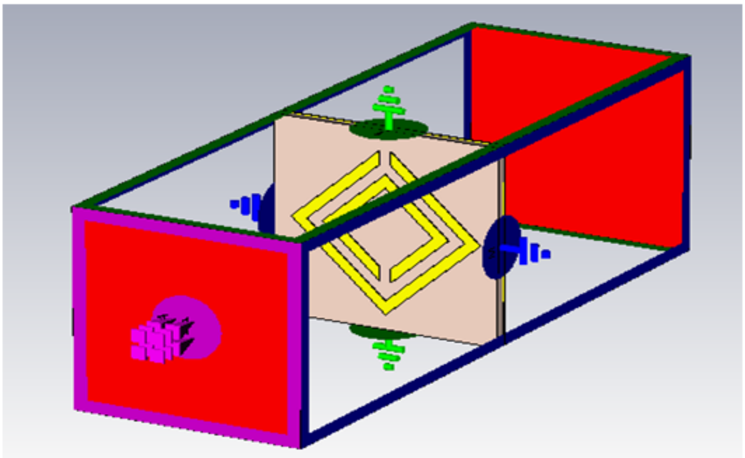


Figure 3.20: Two Rhombic Structure

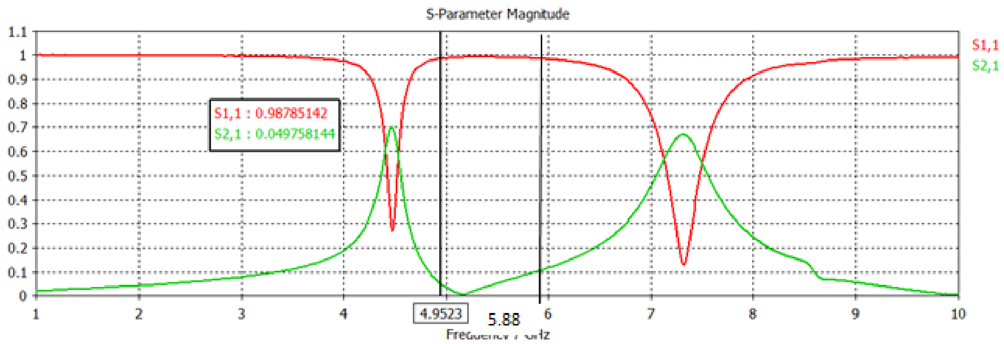


Figure 3.21: simulation result

Chapter 4

Experimental results

The prototype has 25cm*25cm of unit cell and FR4 substrate has a dielectric of 4.3, a loss tangent of 0.02 and thickness of 0.5mm. The enlarged view of the fabricated EMI shield (front and rear side) is shown in figure 4.1 respectively. The block diagram representation of the proposed experimental setup is displayed in figure 4.2.

The proposed experimental setup consists of a pair of wide-band horn antenna (Make: Vidyut Yantra Udyog, Model: X5041) chosen to transmit and receive the EM wave propagating across the stop band shield for its directivity and antenna gain. The entire experiment is setup in the anechoic chamber designed for X-band

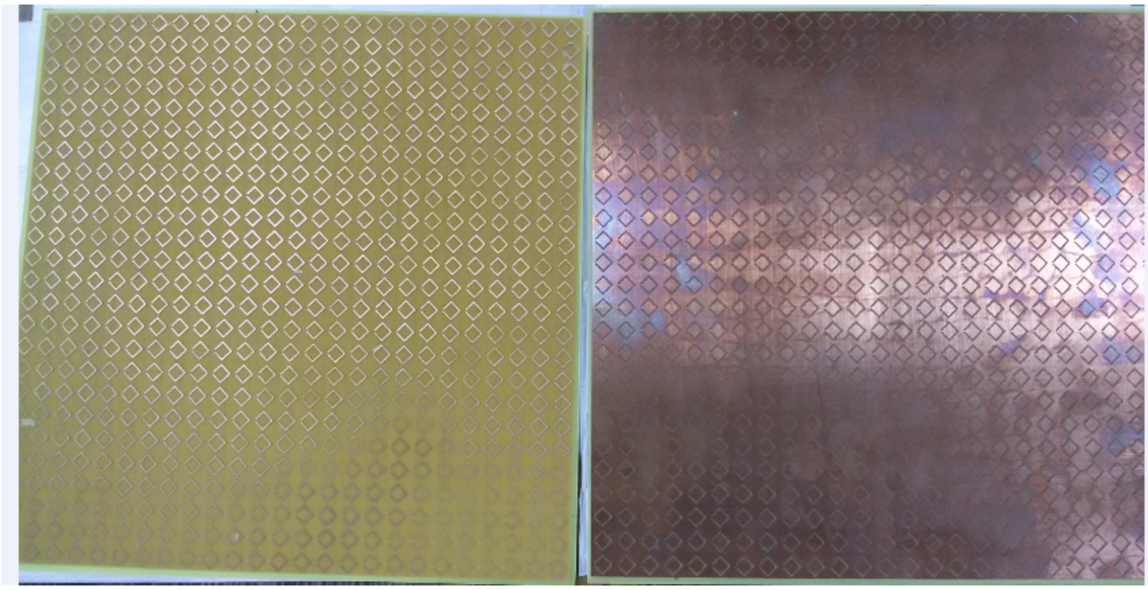


Figure 4.1: Front and Back view of fabrication plates

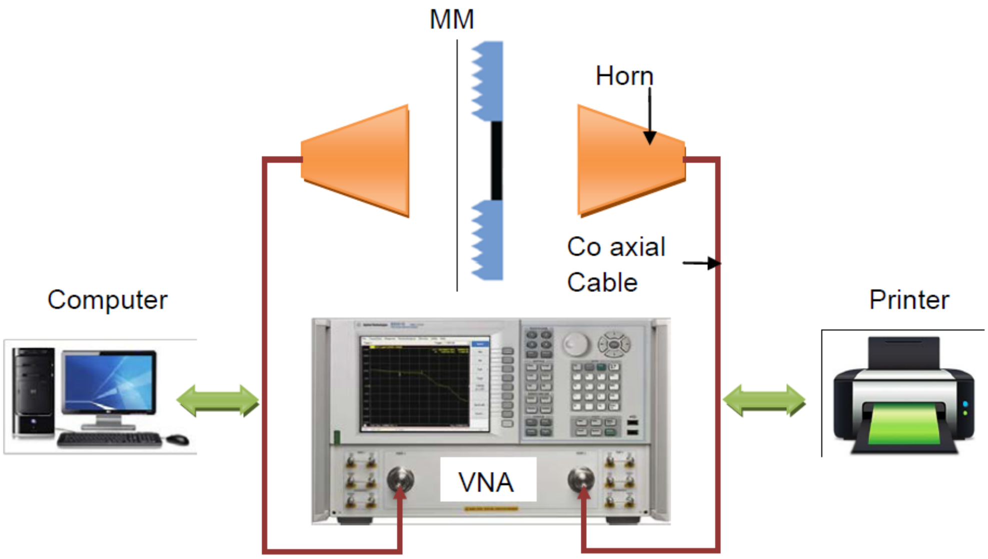


Figure 4.2: Block diagram of the experimental setup

applications. The distance between each antenna and the EMI shield is optimized for improving the S parameter measurement. its performances are Measured in Vector Network Analyzer(VNA).

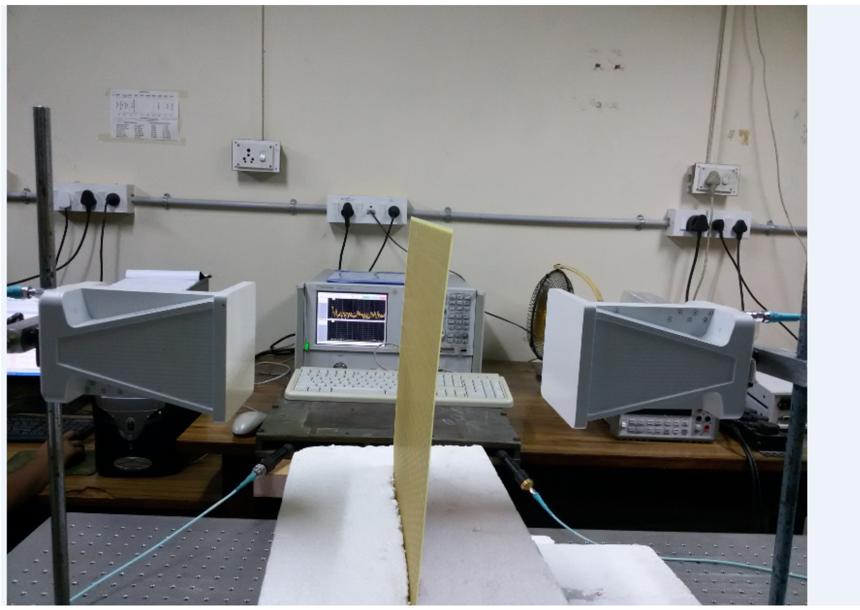


Figure 4.3: Arrangement of antennas in the experimental setup

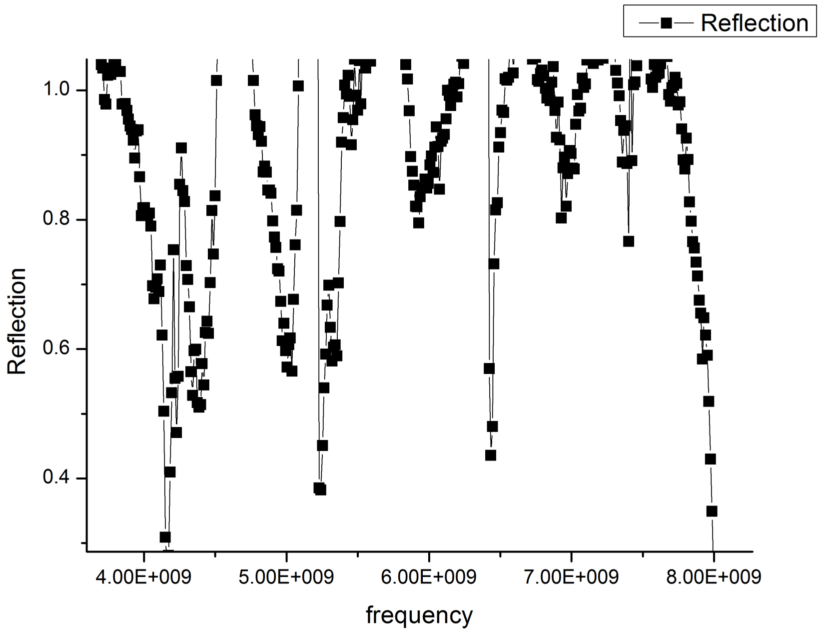


Figure 4.4: Experimental result of reflection

The experiment was performed with the fabricated sample placed between the two wide-band horn antennas (at the midpoint) separated at a distance of 56 cm. The sample was held at a normal angle of incidence with the help of a clamp arrangement as shown in figure 4.3 and the measured results is shown in figure 4.4**??**. It has perfect reflection between two frequency range with 99.25% at 6.02GHz. The frequency shift in peak of measured SE in the single layer and three layer stacked configuration may be because of the additional reactance that arises due to arraying of unit cells and reactance between each layer of MM shield.

Chapter 5

Conclusion

In this project we have designed a metamaterial based Reflector for the purpose of EMI shielding. The band stop resonant frequency is independent of polarisation and angle of incidence making it very suitable for practical EMI shielding applications. The proposed MM Reflector consists of a FR4 dielectric substrate with SRR and CSRR structure on the front and back structure consist of Electric LC Resonator. The simulation results show an perfect reflection between two frequency range with 99.25% at 6.02GHz resonant frequency. Good shielding efficiency is demonstrated through both simulation and measurement. The reflectivity can be improved by optimizing the fabrication process. This can be used in many applications like protection surface against high-power irradiation, detection and sensing, imaging, spectroscopy, integrated photonic circuits, solar cell etc.

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