B. TECH. PROJECT REPORT

On

Frequency Selective Surface Based Switchable Absorber/Rasorber

BY

Vishal Kumar Rathore (160003060)

DISCIPLINE OF ELECTRICAL ENGINEERING
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Frequency Selective Surface Based Switchable Absorber/Rasorber

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of the degrees

of

BACHELOR OF TECHNOLOGY

in

ELECTRICAL ENGINEERING

Submitted by:

Vishal Kumar Rathore (160003060)

Guided by:

Dr. Saptarshi Ghosh

INDIAN INSTITUTE OF TECHNOLOGY INDORE

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CANDIDATE’S DECLARATION

We hereby declare that the project entitled **“Frequency Selective Surface based Switchable Absorber/Rasorber”** submitted in partial fulfillment for the award of the degree of Bachelor of Technology in ‘Electrical Engineering’ completed under the supervision of **Dr. Saptarshi Ghosh, Assist. Professor, Department of Electrical Engineering,**IIT Indore is an authentic work.

Further, I declare that I have not submitted this work for the award of any other degree elsewhere.

Signature and name of the student(s) with date

CERTIFICATE by BTP Guide(s)

It is certified that the above statement made by the students is correct to the best of my knowledge.

Signature of BTP Guide(s) with dates and their designation

Preface

This report on "**Frequency Selective Surface based Switchable Absorber/Rasorber**" is prepared under the guidance of **Dr. Saptarshi Ghosh**.

Through this report I have tried to give a detailed design of a switchable Absorber/Rasorber. All the concept leading to the final design are explained in the initial chapters one by one. I have tried to the best of my abilities and knowledge to explain the content in a lucid manner. I have also added simulated response and figures to make it more illustrative.

Vishal Kumar Rathore
B.Tech. IV Year
Discipline of Electrical Engineering
IIT Indore

Acknowledgement

I wish to thank my BTP supervisor Dr. Saptarshi Ghosh for his kind support and valuable guidance which I got throughout the project work. It is his help and support, due to which I was able to complete the design and technical report. It is my honour that I worked under his guidance. Without his support this report would not have been possible.

Vishal Kumar Rathore
B.Tech. IV Year
Discipline of Electrical Engineering
IIT Indore

Abstract

This report presents a frequency selective surface (FSS) based polarization-insensitive design, which exhibits switchability between an absorber and a rasorber structure. P-i-n diodes are used to switch the response. For absorption, it adopts the concept of circuit analog absorber during ON state, whereas, for rasorber, an additional transmission window along with the broadband absorption is obtained during OFF state. The absorption band lies from 5.04 to 11.38 GHz for both the states, covering almost c and x bands of the spectrum, whereas an additional transmission band is appearing/appears at 2.82 GHz for rasorber. Further, the proposed geometry/topology is four-fold symmetric and provides polarization-insensitive responses.

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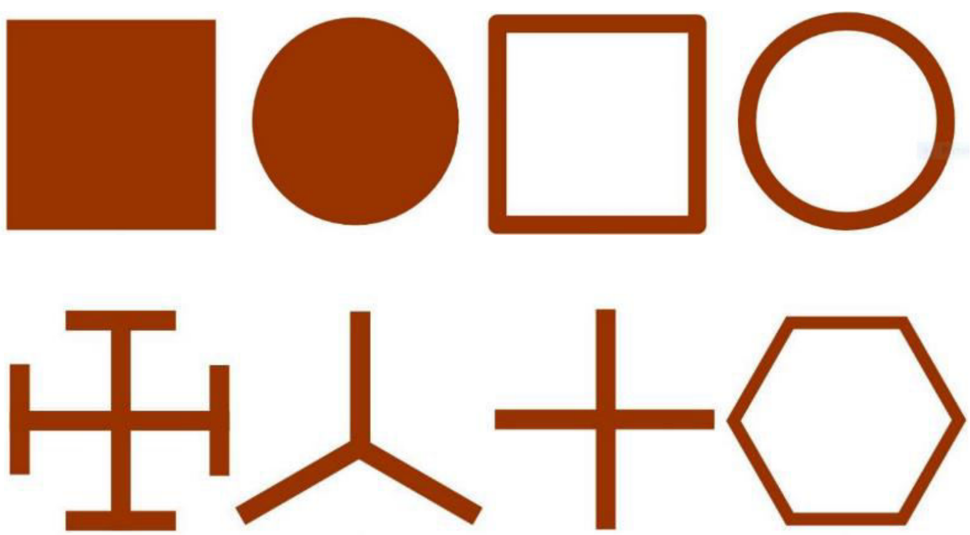
Chapter 1

Introduction

A frequency selective surface (FSS) is a periodic surface intended to selectively reflect, transmit and/or absorb incident electromagnetic (EM) wave. They are usually constructed by printing an infinite array of metallic patterns on single/both sides of a dielectric substrate. Based on the geometries, these FSSs are widely used in the designs of radomes, antennas, spatial filters, high-impedance surfaces, absorbers, polarizers, lens, reflect-arrays, and EM shielding in the microwave and millimeter-wave regimes.



Various FSS elements

Because the FSS use resonance phenomenon, they exhibit narrow bandwidth. Several techniques, such as multi-resonating structures, multi-layer geometries are implemented to increase the absorption bandwidth, but these methods fail to realize broadband absorption beyond a few hundreds of MHz. Circuit analog (CA) absorber is therefore an appropriate solution to resolve this narrow-bandwidth problem, where the broadband absorption is realized by properly placing resistive and conductive patterns on a dielectric substrate.

Although the usage of resistive patterns can enhance the bandwidth of CA based FSS absorbers, still they are passive design with static reflectivity features. Thus a passive structure might have limited applications due to inflexibility after fabrication, on the other hand an active structure(AFSS) based absorber has multiple features. By switching/tuning the absorption frequency with the external bias voltage, a single reconfigurable absorber can be used for multiple applications. A switchable absorber can serve the purpose of an absorber as well as a reflector by changing the bias voltage of the design. On the contrary, a tunable absorber, working in a wide frequency range, may substitute a broadband absorber in few applications. Additionally, tunability can compensate FSS fabrication and installation faults. Therefore, a lot of research about these reconfigurable absorbers has been carried out recently.

However, most of the earlier reported reconfigurable structures are polarization dependent, which is unwanted and create problem in many practical applications. Since the biasing networks of AFSS based polarization-insensitive absorbers have to be carefully isolated under different polarizations of incident wave, these structures are more difficult to be accomplished as compared with reconfigurable polarization-dependent absorbers. Besides, no switchable/tunable absorber has been reported for dual-band/multi-band applications till date to the best of our knowledge. Furthermore, the tuning ranges of the existing tunable absorbers are limited and need to be further improved.

Chapter 2
Absorber

The absorber structure, designed using the concept of CA, is comprised of a resistive layer printed on the FR4 substrate and backed by an air spacer. FR4 has a relative permittivity (ε_r) of 4.4, and a loss tangent (tan delta) of 0.2. The combined thickness of the substrate (tp) and the air spacer (td) have been selected such that they provide an effective height of quarter-wavelength at 9.76 GHz. The overall geometry is backed by a metallic ground plane so there is no transmission. This exhibits a dip in reflection coefficient (below -10 dB) for a wide frequency range from 5.04 to 11.38 GHz, which corresponds to a wideband absorption (having absorptivity >90%) over the same bandwidth, as shown in Fig. 2 and Fig.3. The geometry exhibits such broadband absorption for the lumped resistance of 120Ω. While varying the resistance, the bandwidth gets regulated accordingly.

Design of the structure

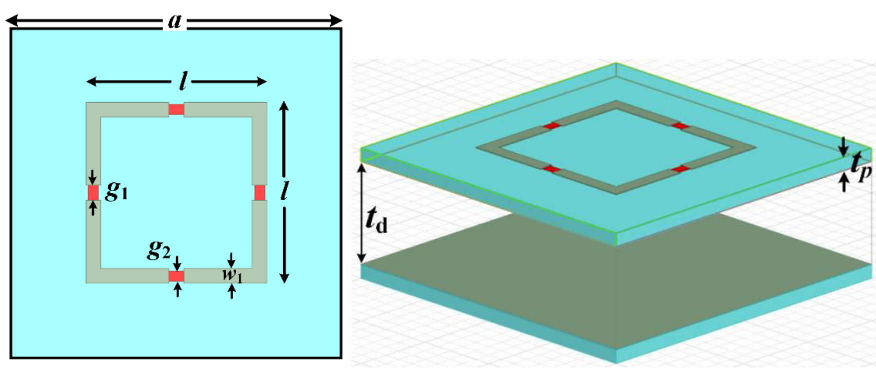


Fig.1.Design of Absorber (a) Top view (b) Oblique view.

a=20, l=11, g_1=0.9, g_2=0.6, w_1=0.9, t_d=6, t_p=0.8(all dimensions are in mm)

Simulated Results

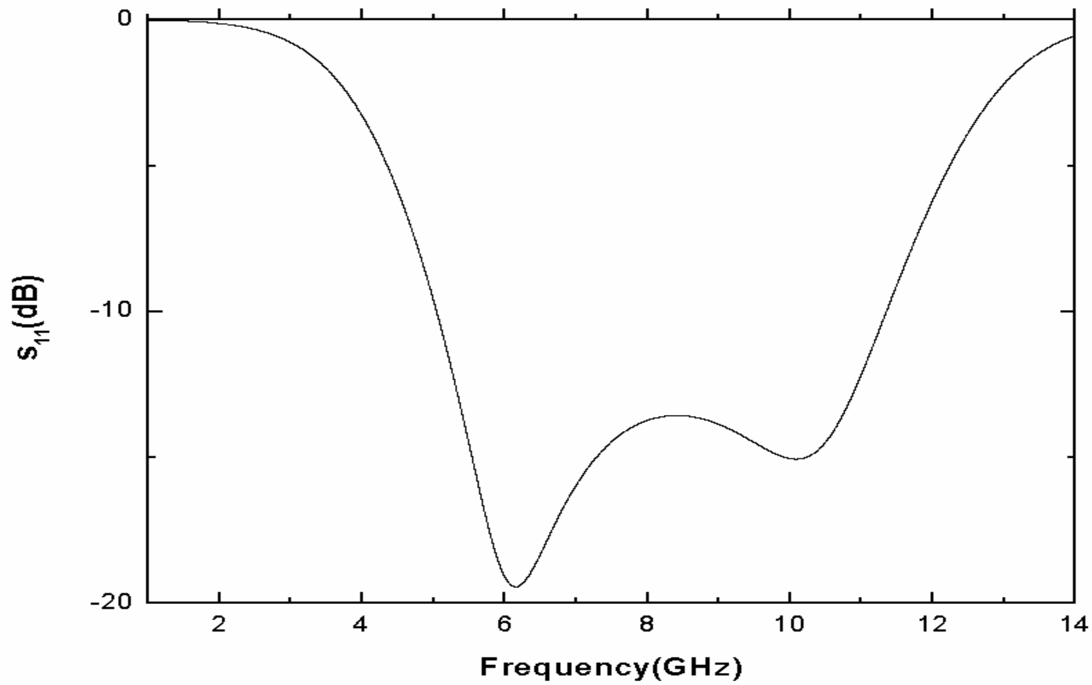


Fig.2. Reflection coefficient of absorber

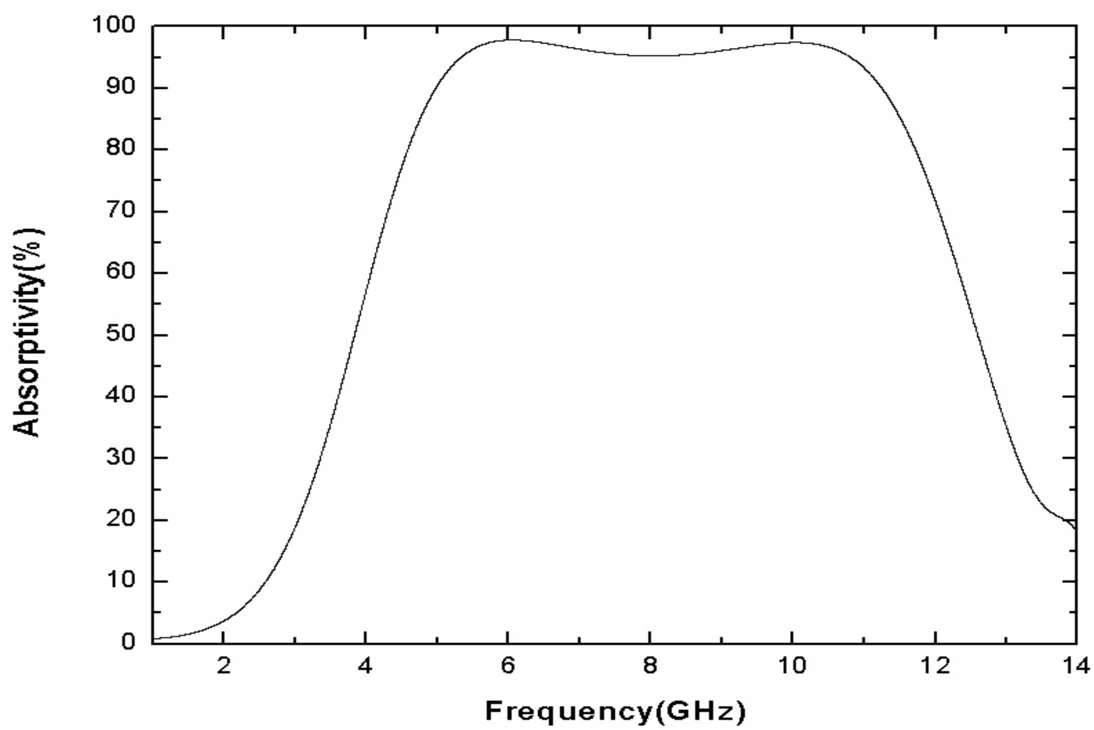


Fig.3. Absorptivity of absorber

Chapter 3

Switchable Filter

3.1 Introduction

The switchable transmission response has been analyzed in this section. A metal-printed FR4 substrate (without the presence of any air spacer or ground plane) has been made to exhibit a switching behaviour between reflection and transmission, at a particular frequency. Four p-i-n diodes are fixed across the gaps in the geometry. When the diodes are operating under forward bias, they will behave as low-valued resistors (ensuring negligible loss), and the structure behave like a full reflector. Whereas during reverse bias the diodes offer high capacitance and the structure results as a filter.

3.2 Simulated Results

Since no capacitance is generated from the entire unit cell topology, the incident EM waves gets reflected, as shown in Fig. 4(a). Whereas in the case of reverse bias, the diodes offer large-valued capacitance. Because the outer arms of the geometry are aligned in parallel with the capacitor element, a parallel inductance-capacitance circuit is formed, thus providing a bandpass response at 2.82 GHz, as observed in Fig. 4(b). The graphs are clearly revealing the behaviour of the switchable filter geometry.

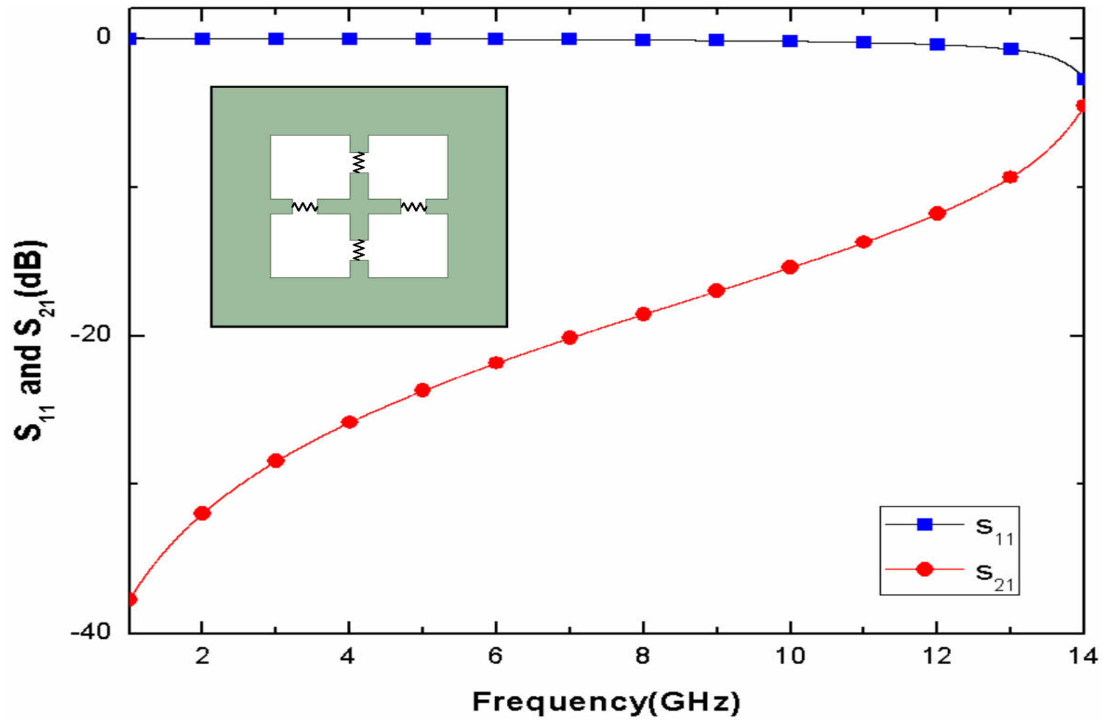


Fig.4. (a)Response of filter ON state

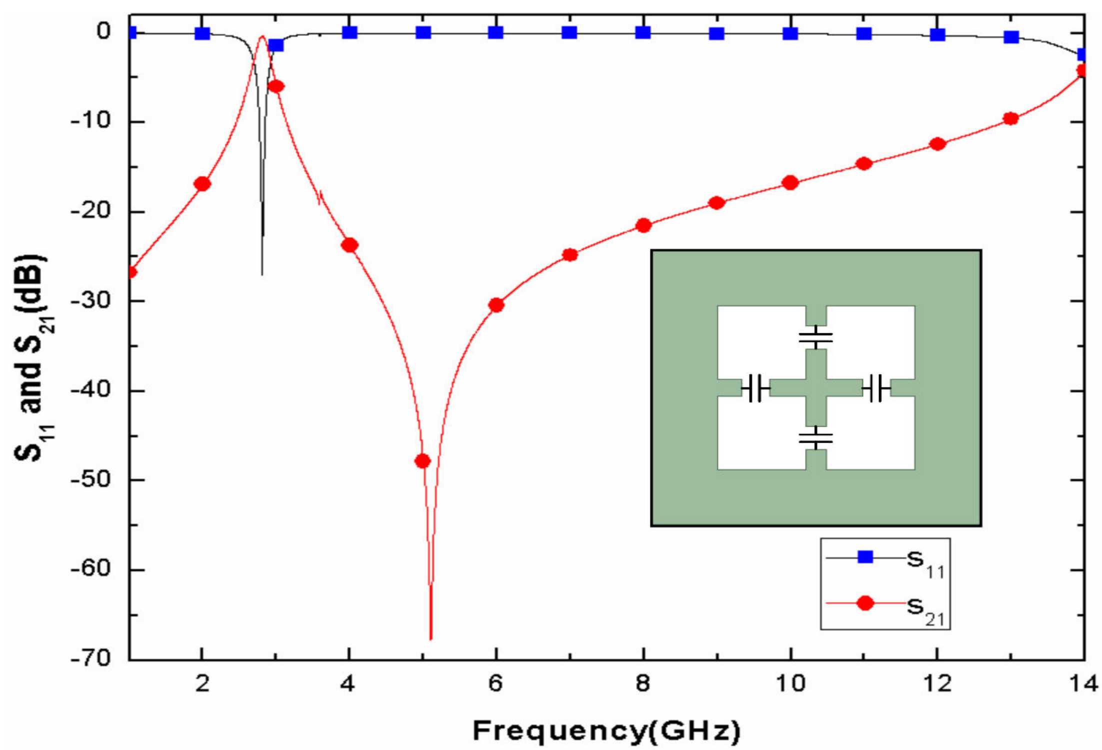


Fig.4. (b)Response of filter OFF state

3.3Variation in Transmission Frequency

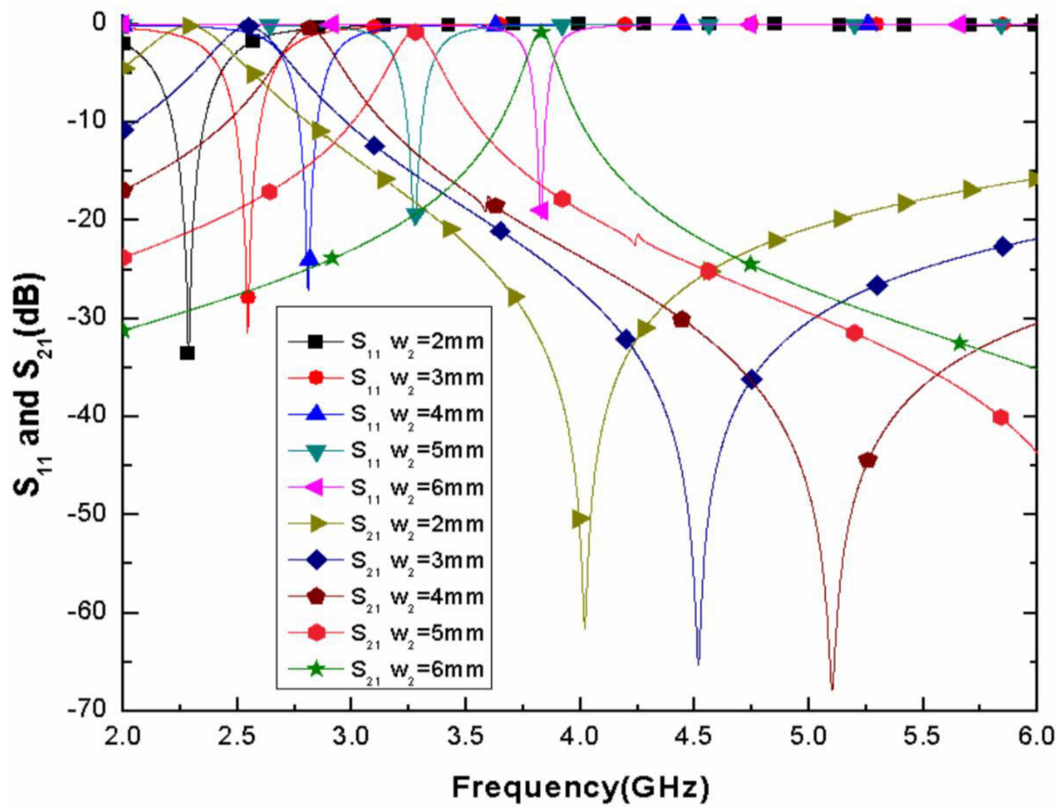


Fig.5. Variation in Transmission Frequency

The transmission frequency of the proposed filter can be regulated, either by altering the structure's geometrical measurements, or by changing the diode OFF-state capacitance value with the help of external voltage source. The width of the outer arms (w_2), while increased, shows a monotonic increase in the frequency response of the filter under OFF state, as observed in Fig. 5. With the increase in metallic arm width, the inductance of the structure is reducing, thereby causing a significant rise in the bandpass response. In a similar way, the OFF-state capacitance can be varied, thus offering a choice of the location of transmission window.

Chapter 4

Switchable Absorber/Rasorber

4.1 Introduction

A rasorber is basically the combination of an absorber and a filter, where an additional transmission window can be seen along with the absorption band. The absorber can be realized using a resistive layer at the top of the geometry, whereas the bottom layer can be made of slot type to exhibit the transmission at a desired frequency. Depending on the relative location of the absorption band and the transmission window, the rasorber can be classified in three types. These are rasorber having transmission window before absorption band, after absorption band and within absorption band.

However, most of the existing rasorber designs are passive structures, such that their behaviour cannot be altered after the fabrication of the design. This limited reconfigurability option restricts the geometries from using in other applications (such as where only absorption is required). To resolve this problem, various active absorber topologies have been proposed in which the performance can be changed post fabrication, through external control. In last few years, these active rasorbers have attracted significant attention towards them. A few articles have been presented on the tunability of the transmission frequency but the overall function of structure remains same (i.e. rasorber). A recent paper exhibiting switchable response between rasorber and absorber has been reported, but the topology is complex and polarization dependent.

4.2 Design

Firstly, a broadband absorber has been designed using the circuit analog concept having resistive layer at the top and complete metallic layer as the ground plane.To make it a rasorber, the metallic ground can be replaced with a FSS based bandpass filter geometry. The desired transmission frequency can easily be obtained by the slot type pattern which provides a parallel LC circuit. To achieve this objective, a topology of the absorber/rasorber is proposed as shown in Fig.6. The top layer placed on the FR4 substrate, consists of a metallic square loop having four lumped resistances each mounted at the middle of each arm, which makes the top layer resistive to get a wideband absorption response.

The bottom layer is made up of a metallic cross patch inscribed by a square loop of copper, and is periodically patterned on FR4 substrate. The bottom layer is kept apart from the top layer by an air spacer. To realize an adaptive ground plane, four p-i-n diodes are placed across the gaps in the bottom layer topology. The optimised dimensions are also stated in Fig.6. P-i-n diodes are exhibiting an ON state resistance of 3 Ω, and an OFF state capacitance of 517pF.

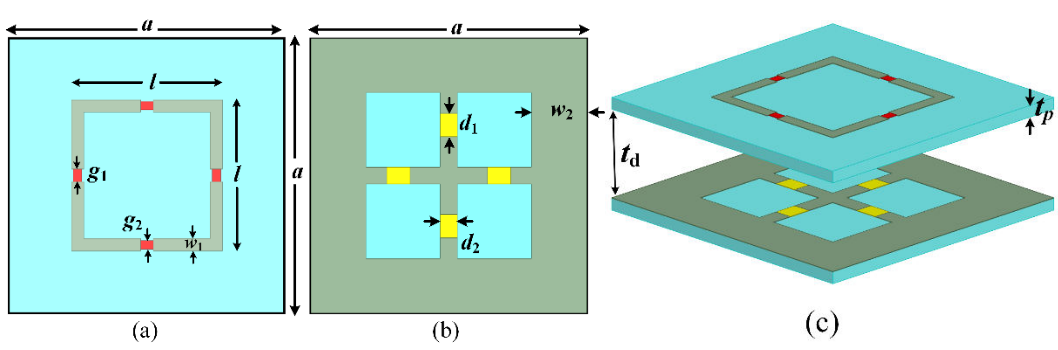


Fig.6.Proposed design (a) Top layer (b) Top view of bottom layer, (c) Oblique view. The optimized dimensions are as follows: a=20, l=11, g_1=0.9, g_2=0.6, w_1=0.9, w_2=4, d_1=1.7, d_2=1.25, t_d=6, t_p=0.8(all dimensions are in mm)

4.3 Simulated Results

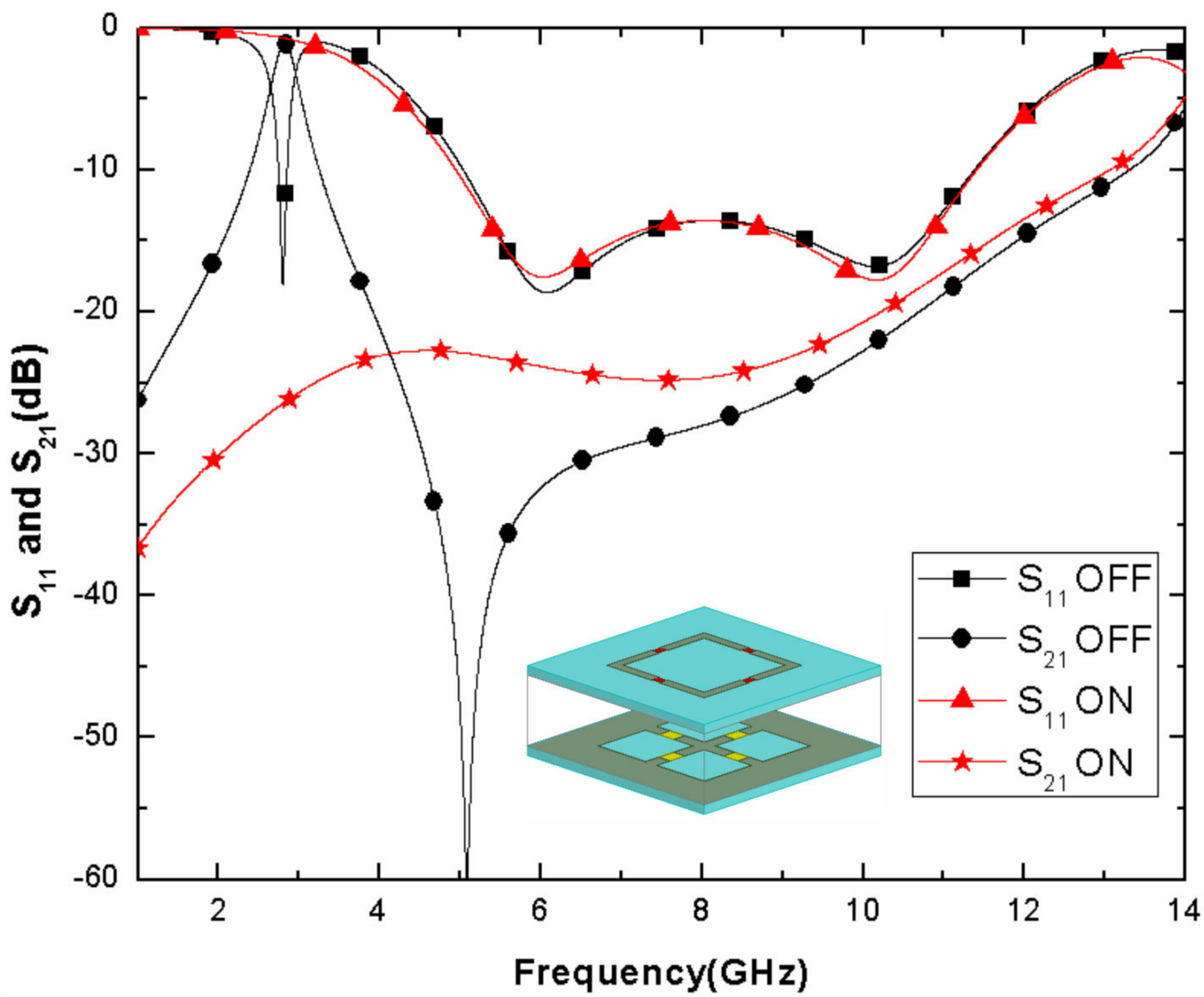


Fig. 7. S-parameters of Absorber/Rasorber design under ON and OFF state

When the above absorber and switchable filter geometries are combined together (by replacing the ground plane of the absorber structure with the switchable topology), the proposed switchable absorber/rasorber design is obtained. Fig. 7 shows the simulated scattering parameter response, where it is observed under ON state that the transmission coefficient (S21) is below -20 dB from 5.04 to 11.38

GHz, and the reflection coefficient (S11) is less than -10 dB in the same frequency range. This leads to a broad absorption bandwidth having absorptivity above 90% for the same frequency range. On the other hand, during OFF state, a transmission band is appearing around 2.82 GHz (with insertion loss of -- dB), while the absorption band remains unaffected. This results in an accompanying transmission band to the absorber, thereby giving rasorber behaviour.

4.4 Parametric Variations

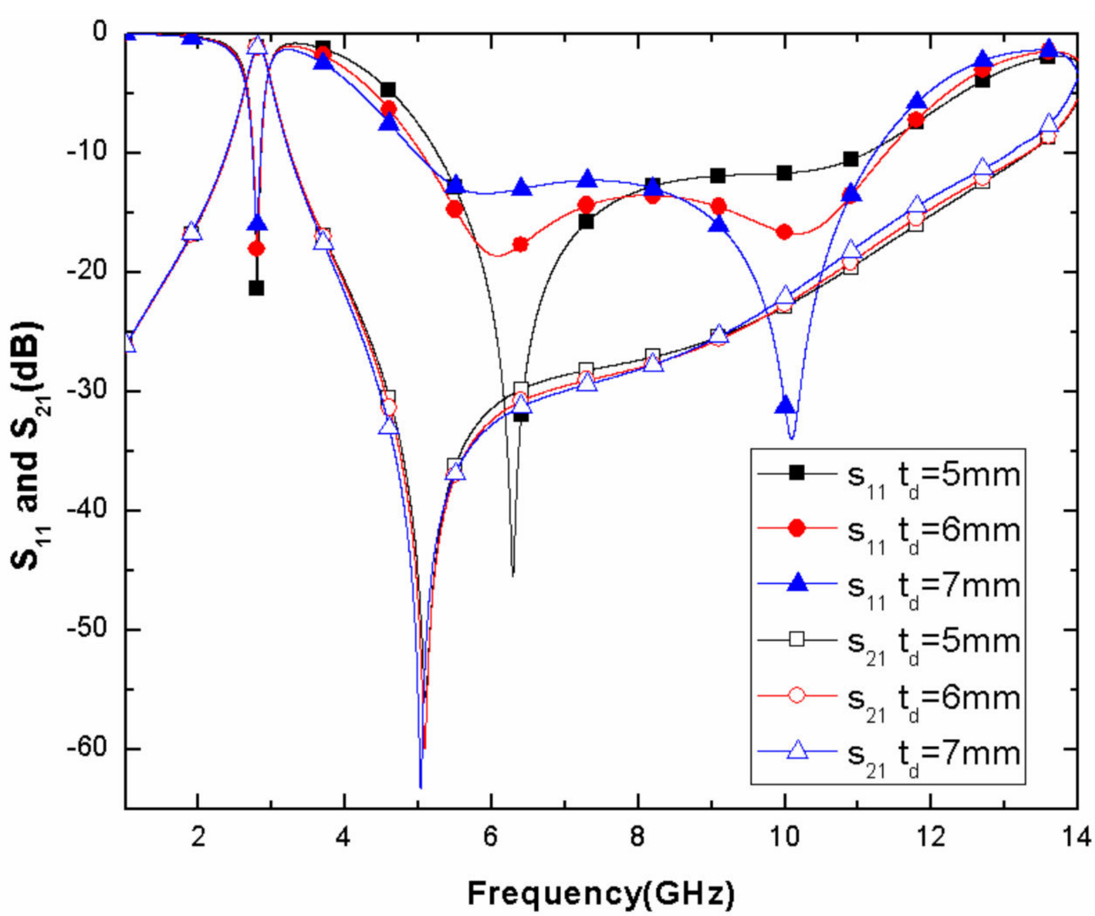


Fig.8(a) Variation of air space thickness

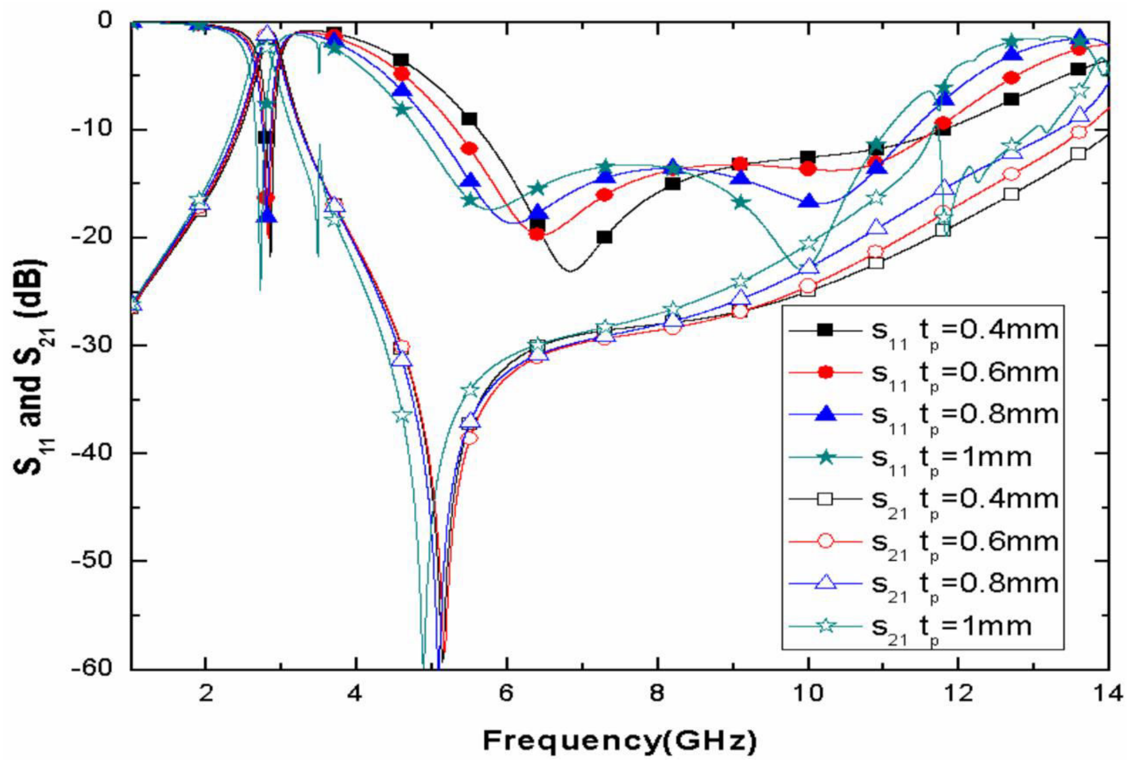


Fig.8(b)Variation of substrate thickness

Since the centre frequency of the absorption bandwidth is determined by the effective distance between the resistive layer and the bottom layer, the combined thickness of the air spacer (t_d) and the substrate (t_p) together determine the location of the absorption band. The closer the transmission window to the absorption band is, more the insertion loss will be. So the loss can be reduced by keeping the transmission and absorption bands enough apart by optimizing various parameters. Figs. 8(a) and 8(b) show the contribution of different values of t_d and t_p, respectively, in shifting the absorption band in different directions. Reduction in thickness between the layers leads to the shifting of the absorption band towards higher frequency. Similarly, as stated in the previous section, the transmission window can be varied over frequency range. This independent movement ofabsorption band and transmission window facilitates a decent reduction in insertion loss.

4.5 Polarisation Insensitive and Angular Stability

Due to the four-fold symmetric topology, the proposed rasorber is polarization-insensitive. Fig. 9(a)depicts the frequency response of the scattering coefficients under different polarization angles ranging from 0^o to 90^o.

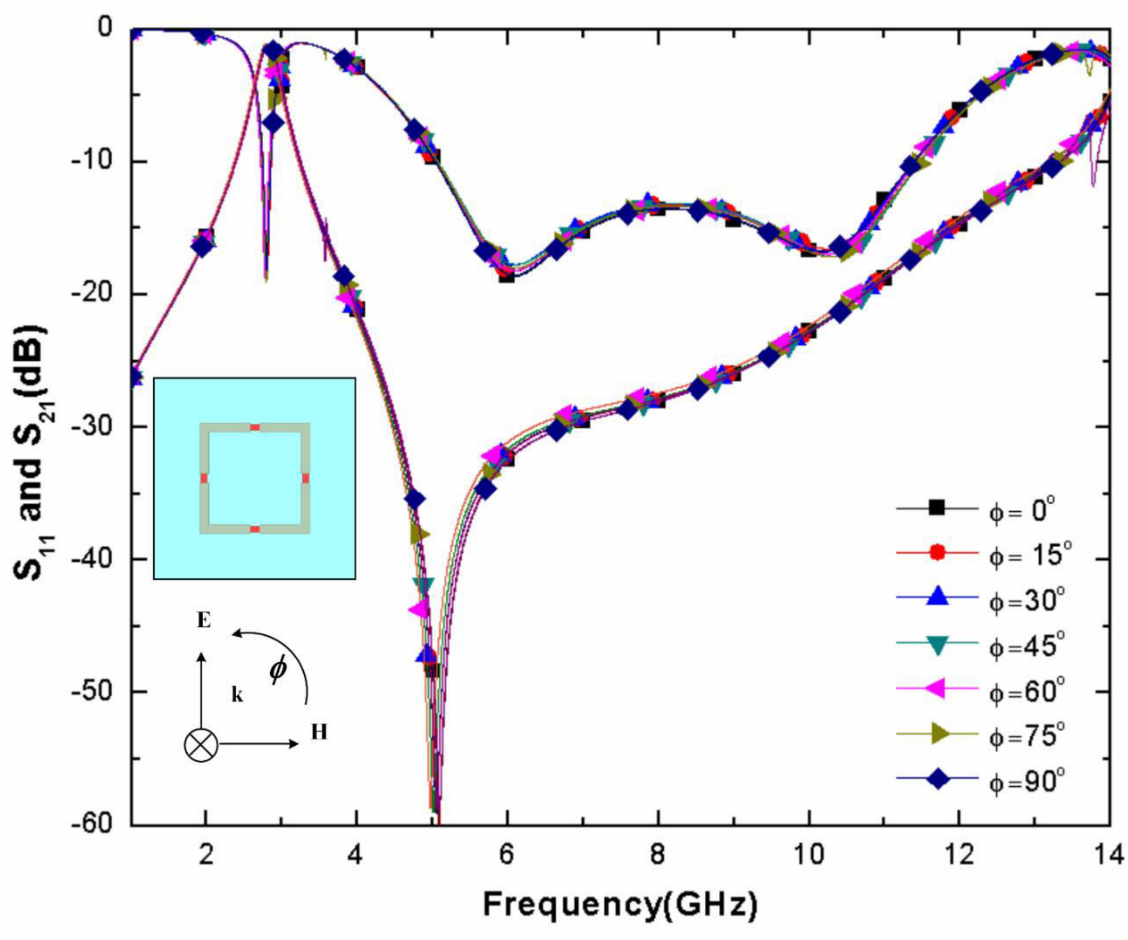


Fig. 9 (a) variation of polarisation angle

The response under oblique incidence has also been studied, as observed in Fig. 9(b), where a good angular stability is obtained up to 30^{o}under transverse electric (TE) mode.

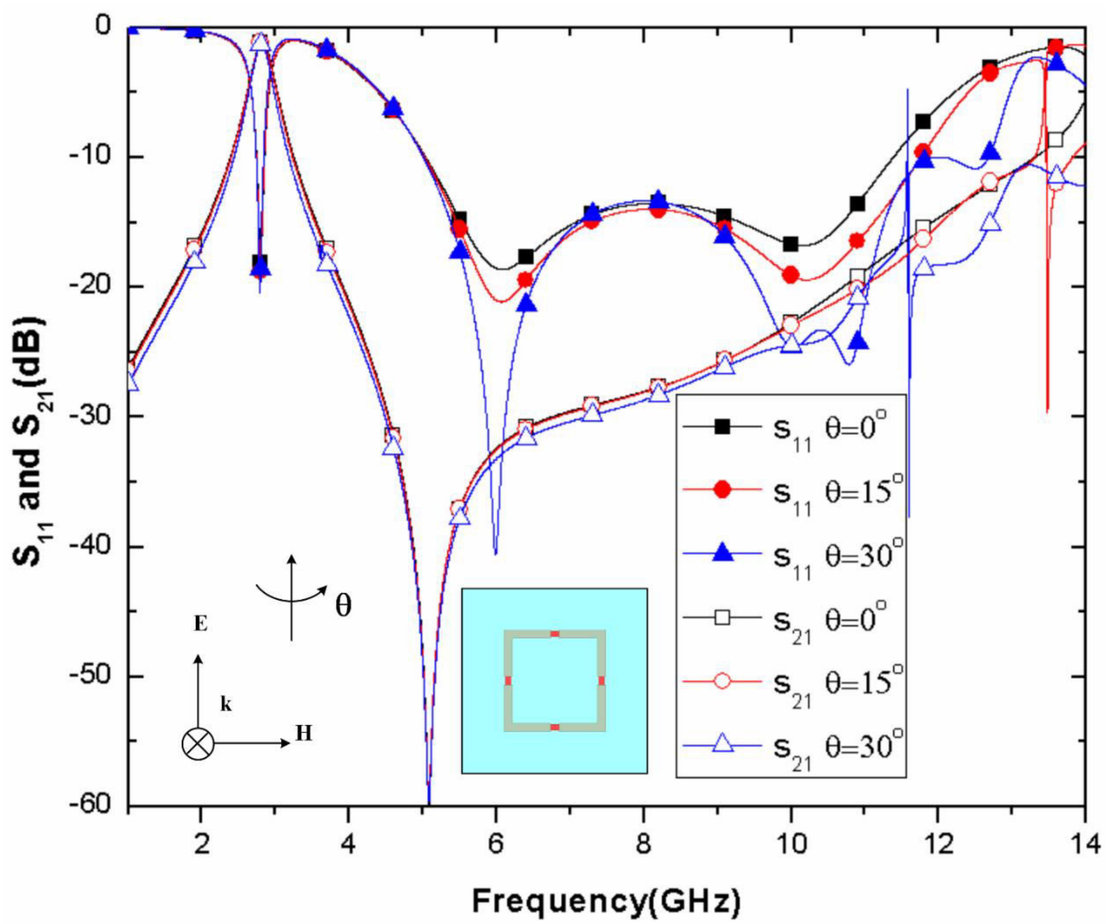


Fig. 9 (b) variation of angle of incidence

Chapter 5
Practical Realisation

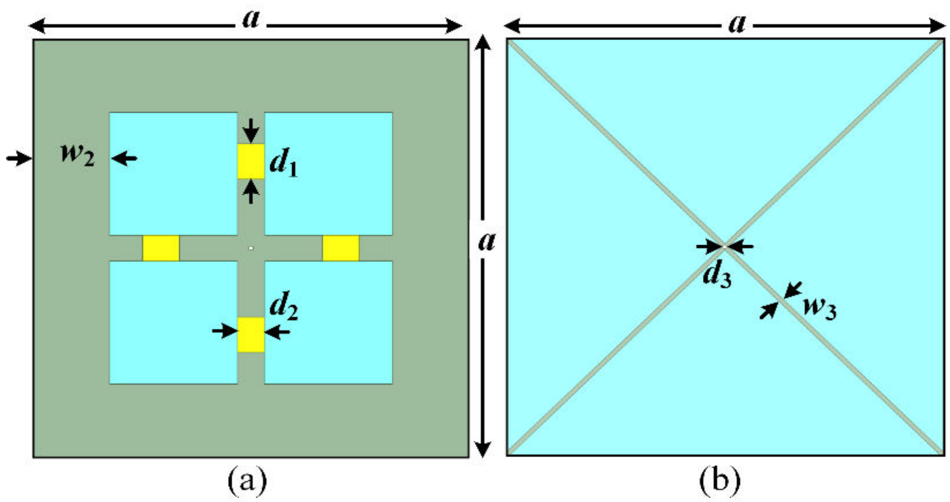


Fig. 10. Bottom layer with biasing arrangement. (a) Top side, and (b) bottom side.

The proposed rasorber structure can be possibly realized through a commercial printed circuit board etching technique. The metallic patterns can be printed on FR4 substrates, whereas the lumped resistors of 120 Ω can be placed across the gaps in the square loop in the top layer. P-i-n diodes from NXP BAP70-03, having the similar property as used in the simulation, can be mounted in the bottom layer. To provide the required supply voltage across the diodes, a diagonal cross-dipole has been etched at the bottom side of the bottom layer, connected to the diodes, through a metallic via at the center of the unit cell topology. Fig. 10 illustrates the possible configuration of the proposed rasorber structure. The width of the cross-dipole is 0.2 mm, and the radius of the via is 0.28 mm.

To regulate the p-i-n diodes, the anodes and cathodes should be connected to the positive and negative terminals, respectively, of an external voltage. In the proposed design, the diodes are oriented in such a way that the cathodes of all the diodes are connected together through the outer arm, and the anodes are connected together through the metallic vias. Further, the via is connected to the diagonal cross-dipole. Since the metallic outer arm of each unit cell is connected to that of its neighbouring unit cells (and similar connection for the cross-dipole), there is no need to give d-c voltage across each of the diodes in the unit cells individually. The cathodes (as well as the anodes) of all the diodes are connected together, and a single voltage source applied at one corner of the fabricated prototype will bias all the diodes simultaneously.

A comparison between the proposed topology with and without the biasing grid (a combination of the diagonal cross-dipole and the metallic via) has been shown in Fig. 11 for both ON and OFF states. During ON state, there is no effect of the biasing grid in the overall behavior of the structure, except a small glitch around 6 GHz. That glitch, having very small deviation, does not influence the overall behaviour of the absorber structure. However, during OFF state, a small shift in the transmission band is observed due to the diversion of the surface current through metallic via. A possible solution will be to increase the OFF state capacitance to nullify the deviation, by suitably choosing some alternative p-i-n diodes having larger value of OFF state capacitance.

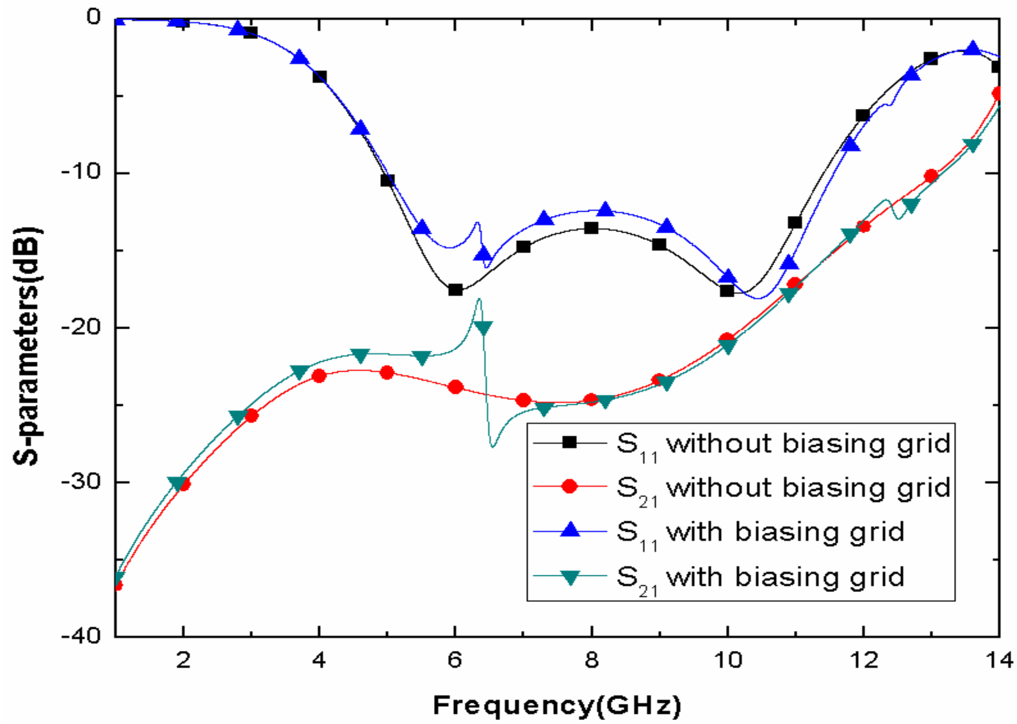


Fig.11(a) S-parameters of Absorber with and without Biasing Grid

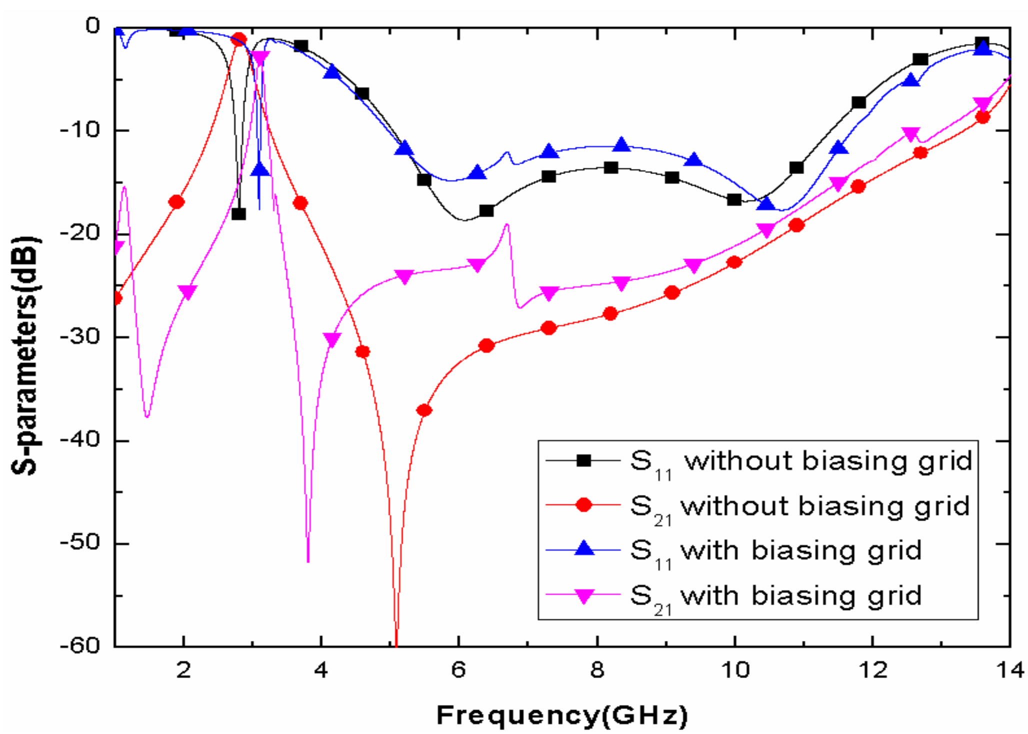
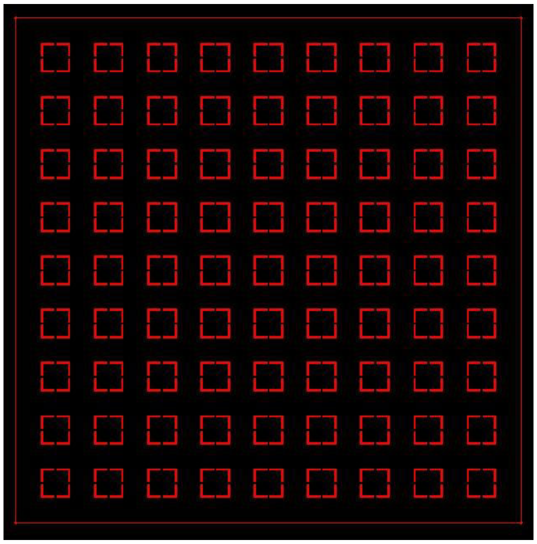
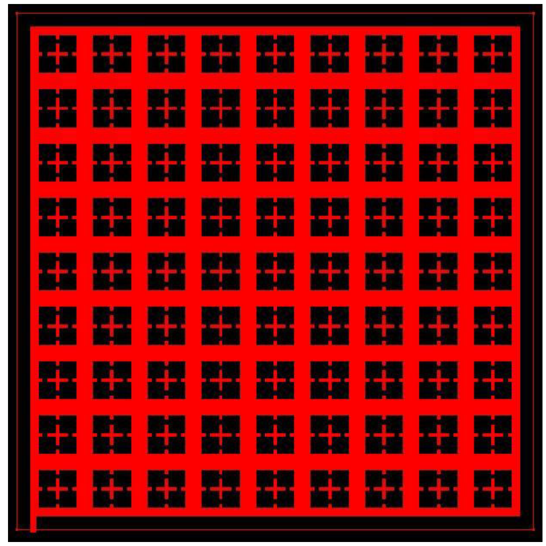


Fig.11(b) S-parameters of Rasorber with and without Biasing Grid

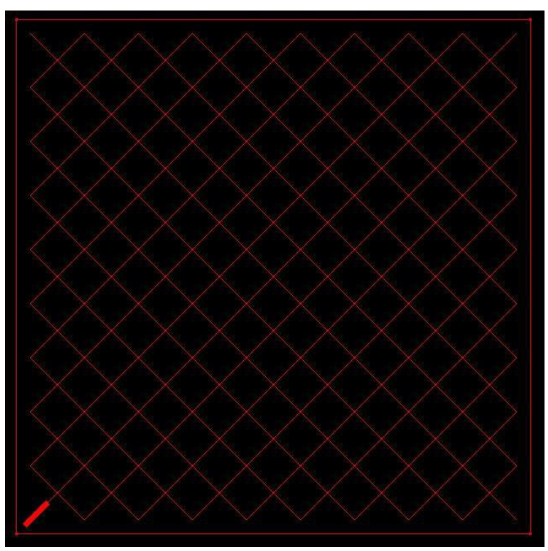
Gerber Files



Top Layer



Bottom Layer



Biasing Grid

These are the gerber files which are used for the final fabrication.

Chapter 6

Conclusion and Future Scope

Thus, with the help of a simple absorber structure and adaptive filter, as mentioned in chapter 2 and 3 respectively, a polarization-independent structure, showing a switchable response between a broadband absorber and a rasorber, has been presented. The reconfigurable property of the structure is realized by the use of active p-i-n diode that results in the absorber structure during ON state and rasorber response during OFF state. A possible biasing arrangement has also been shown to regulate the diodes through external voltage source.

In future the bandwidth of the absorber can be increased, further, as in the proposed design the transmission window is before the absorption band, so it can be designed such that the transmission windowlies after or within the absorption band.

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