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Narrow band polarization insensitive frequency selective surface based microwave absorber

D Sood[1]*, Shishpal[1] & C C Tripathi[1]

[1]University Institute of Engineering & Technology, Kurukshetra University, Kurukshetra, Haryana, India

*Email:deepaksood.uiet@gmail.com

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Design, fabrication and testing of a narrow band polarization insensitive, planar microwave absorbing structure using frequency selective surface and without using any loaded resistance/resistive material are presented. The unit cell of the absorbing structure consisting of a symmetric triple square ring printed on one side of a FR4 substrate. It results efficient absorption of the incident microwave energy in X-band. The optimum design was validated by fabricating a absorbing structure array of 4 × 3 unit cells by conventional lithography process. It is then tested for normal incidence on microwave test bench set-up using WR90 waveguide. Full wave electromagnetic simulation demonstrates 99.99% microwave absorption at 9.8GHz with 1.23% absorption bandwidth. The structure shows good frequency stability for TE and TM polarizations. The simulated and measured values of absorption are found to be in good agreement. Therefore, proposed microwave absorber can be suitably used for avionics applications.

Keywords: Microwave absorber, Triple square ring, Loaded resistance-less, Polarization insensitive

1 Introduction

Frequency selective surface (FSS) is a popular area of research in recent years due their numerous applications such as radomes for radar cross-section control[1,2], absorbers[3-5],sub reflectors in antennas[6,7] and spatial filters[8-11], etc. Although periodic arrangement of generally identical elements like crosses, loops, slots, patches and of any convenient shapes are known as frequency selective surfaces (FSSs) but there are two types of metallic patterns for FSS design namely aperture type[12] and patch type[13]. Aperture types FSSs are used for transmission of incident wave and patch type are used for suppression of incident wave.

Absorption of microwave frequency finds large requirements in military applications which includes reduction of radar signature of Aircraft and in civil applications for reducing electromagnetic interference between microwave components and other electronic equipments. Moreover, improvements in performance of an antenna can be achieved with the reduction in its back radiations by employing microwave absorbers. Absorption of microwaves by a material depends upon its properties such as permittivity, permeability, thickness and its dimensional parameters with respect to absorbing frequency etc. Different methods of designing conventional microwave absorbers include use of $\lambda/4$ thick dielectric/metal resistive screen[14,15] (commercially known as Salisbury screen), dielectric or magnetic composites[16-20] etc. where absorption was achieved by matching the free space impedance with absorber impedance. The disadvantage of such conventional microwave absorbers requires thicker planar structures of thickness ranging to 2.5 cm minimum. This adds to weight and complexity in the implementation of microwave absorbers particularly for avionics applications. Moreover, use of certain type of dielectric or magnetic composites[21,22] in specific desired proportion for deposition on substrate and loaded chip resistances of specific values[23] requires complex and time consuming fabrication steps. So, there is a requirement of some alternative solutions which give planar structure, simplified and high performance microwave absorbers.

FSS based periodic structures have acquired large attention of researchers in past decades due to its vast applications[2-8]. Performance of FSS based absorbers depends upon type of patch/aperture used, size of unit cell, inter element spacing, periodicity, substrate's electromagnetic parameters, thickness of substrate etc. In comparison to conventional radar absorbing materials (RAMs), FSS based absorbers can provide better absorption performance with even simplified, thinner and lighter structure[24-29].

In the present paper, a polarization insensitive metal backed, high impedance (HI)FSS based microwave absorbers using triple square ring is presented. Parametric optimization was done to match the impedance of the design with the free space at desired frequency. This impedance matching causes incident EM energy to absorb through resonant losses inside the dielectric. Electromagnetic simulations are carried out for exploring absorbing characteristics of proposed design for different polarizations of normal incident EM waves in Ansoft's HFSS version 12.

2 Principle of Operation

Basic theory behind the operation of a conventional microwave absorber is impedance matching of absorber with free space. A general equivalent circuit of FSS is represented by resistance(R), inductance (L) and capacitance(C) as shown in Fig. 1. *R* represents the loss incurred in FSS but values of *L* and *C* depend upon FSS pattern, its periodicity and inter-element gaps. On the other hand, metal backing in FSS determines another inductance[27] (*L*).FSS and metal backing is separated by substrate which causes dielectric loss to incoming plane wave.

The loss incurred in FSS i.e. '*R*' includes dielectric loss and loaded resistance loss. Dielectric loss depends upon substrate used and loaded resistance is due to some resistive loss material like certain type of composites[16-22], some specific value patch resistors[25], resistive layers[14,15] etc. Most of researchers have used any of the above said type of resistive materials to design microwave absorbers[12-18] but with the help of properly designed FSS structures, it is possible to design, narrowband loaded resistance-less microwave absorption structures. Here it is proposed the triple square ring FSS in which size of the rings is adjusted to give 99.99% absorption at 9.96 GHz. Equivalent circuit of the proposed structure is shown in Fig. 2.

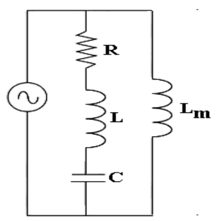


Fig. 1 — Equivalent circuit

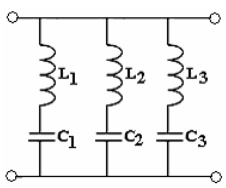


Fig. 2 — Equivalent circuit of proposed design

Equivalent circuit of single square loop FSS consists of series LC network connected in shunt branch of a transmission line. So triple square loop FSS can be represented as a parallel combination of three series LC networks[30,31]. Although frequency characteristics of a conventional triple square loop FSS consists of three frequency bands but here dimensions of square loop are so adjusted to make it possible to that triple square FSS resonate at single frequency for effective absorption. In the proposed FSS based absorber, outermost square loop decides frequency of operation. Middle and inner most loops are responsible for effective microwave absorption at resonant frequency.

3 Absorber Design Using Triple Square Ring FSS

Single unit cell of the proposed absorbing structure consists of triple square ring structure printed on one side of a printed circuit board i.e. FR4 to achieve efficient absorption of the incident microwave energy. The physical parameters of unit cell are shown in Fig. 3

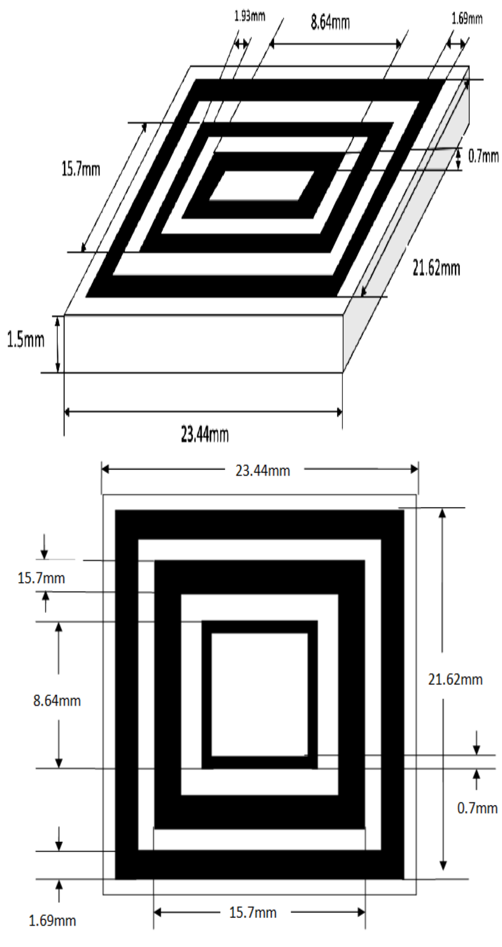


Fig.3 — (a)Geometry of unit cell (cross sectional view) and (b) FSS (Top View)

(Dark portion represents copper and white represents slotted area).

Infinite periodicity of proposed absorber is simulated through Floquet Port with periodic boundary conditions. The substrate used have relative permittivity (ε_r) and thickness (h) such as ε_r= 4.4 and h = 1.6mm, respectively.

Figure 4 shows reflection coefficient of absorber for normal incidence obtained by Ansoft HFSS v.14. It can be observed that the reflectivity (S11) is minimum i.e. −36.9dB at 9.8GHz, which indicates maximum absorption. A very small value of S11 is also observed at 9.1GHz which is due to coupling between resonances of middle and inner most loop that can be minimized by optimizing the gap between the loops.

Figure 5 shows the absorption characteristics of proposed absorbing structure as a function of frequency. The observed value of high absorption in proposed small size unit cell FSS structure as compared to thicker Salisbury screen[14,15], resistive ink[29,32] makes it a strong case for probing as FSS based absorber structures.

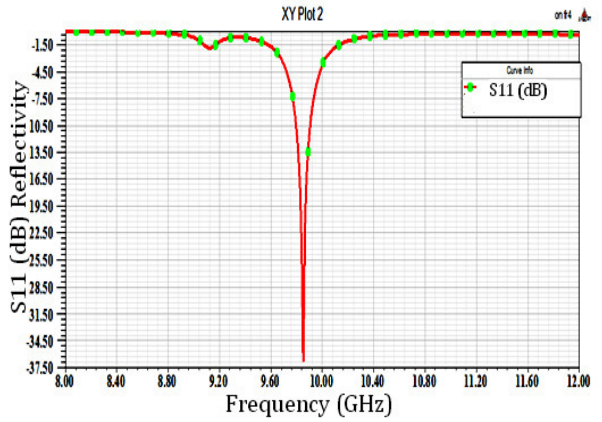


Fig. 4 — Reflection coefficient characteristics of triple square ring absorber

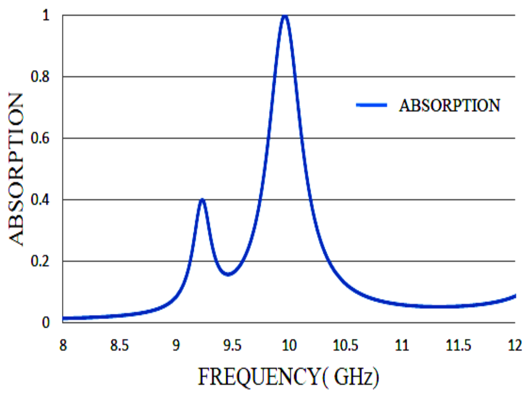


Fig. 5 — Absorption characteristics of triple square absorber versus frequency

4 Parametric Analyses

The parametric analysis of proposed triple square loop FSS structures is carried out using Ansoft HFSS v.14 and the absorbing performance based on different parametric values such as substrate permittivity, substrate thickness is presented.

4.1 Effects of Substrate Permittivity

Permittivity of substrate always plays important role in the design of FSS. In the proposed structure substrate used was FR4 having permittivity 4.4. Simulated value of S11 with variation in permittivity value is shown in Fig. 6. It is observed that as permittivity increases resonant frequency decreases but best value of absorption was obtained for ε_r=4.4. For the proposed design, this study of effect of permittivity reveals that FR4 is the most suitable material to result high absorption at intended frequency.

4.2 Effects of Substrate Thickness

In order to study the effects of substrate thickness on absorbing properties of the proposed design, the substrate thickness of 0.2, 0.402, 0804, 1.6 and 2 mm were taken for analysis and result is shown in Fig. 7. From this analysis, it has been observed that when thickness increases from 0.2 to 1.6 mm S11reduces. The minimum S11 has been observed for t=1.6 mm. It is also observed that when substrate thickness increases the peak absorption frequency slightly shifted to lower frequency side.

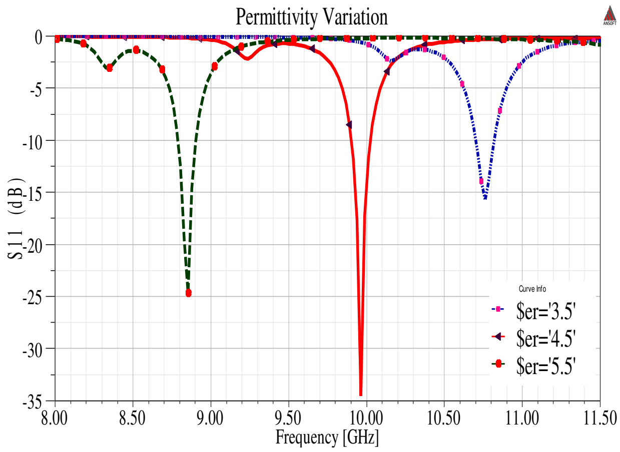


Fig. 6 — S11 characteristics with FR4 substrate permittvity variations

4.3 Polarization Insensitivity

As the polarization defines the orientation of electric field vector of incoming wave with respect to incident plane, so polarization insensitive FSS structure has the flexibility to work with both H-plane (TE) and E-plane (TM) polarization. Polarization insensitivity of the proposed Triple Square FSS structure is shown in Fig. 8. From these polarization characteristics, it is observed that the proposed FSS is frequency insensitive to TE and TM polarization i.e. proposed FSS works at the same frequency for any of the said polarization state, which makes it suitable for microwave absorber applications.

5 Experimental Verification

The validation and measurement of the proposed triple square ring based absorbing structure at X-band is carried out using WR90 waveguide terminated with Pyramidal Horn antenna. According to dimensions of waveguide (‘*a*’ is 22.86 mm and ‘*b*’ is 10.16 mm) and Horn Antenna an array of 4 × 3 triple square cells were simulated and optimized. The substrate has relative permittivity $\varepsilon_r = 4.4$ and thickness t=1.6 mm. Block diagram of measurement set-up is shown in Fig. 9.

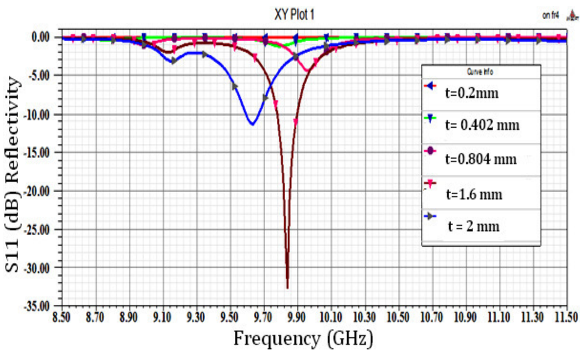


Fig.7 — S11 characteristics with substrate thickness variations

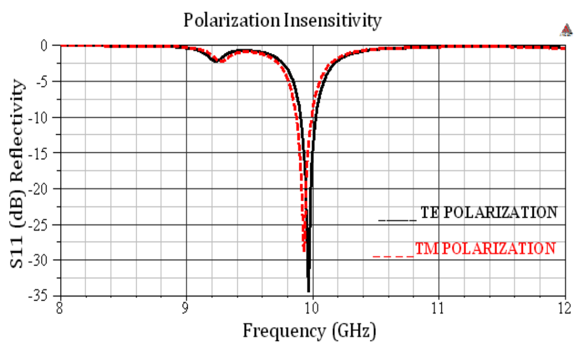


Fig.8 — S11 charateristics for TE and TM polarization

The measurements were performed using commercially available microwave test bench set-up using X-band waveguide horn antenna and power meter as shown in Fig. 10. The prototype was so fabricated using conventional lithography technique suggested in Ref.33 that it can easily be mounted at the open flared mouth of Horn antenna. Fabricated prototype is shown in Fig. 11.

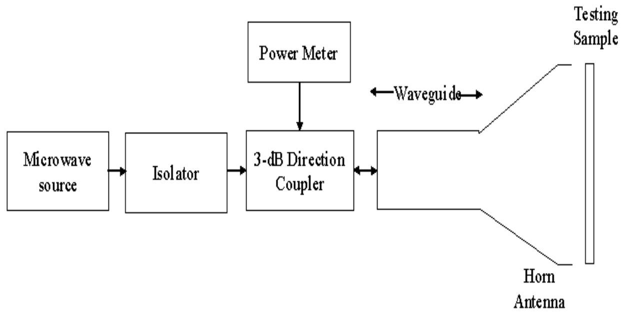
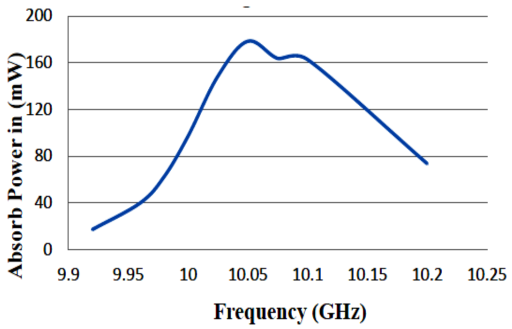


Fig. 9 — Block diagram of measurement set-up

Fig. 10 — Experimental testing set-up

Fig. 11 — Fabricated prototype



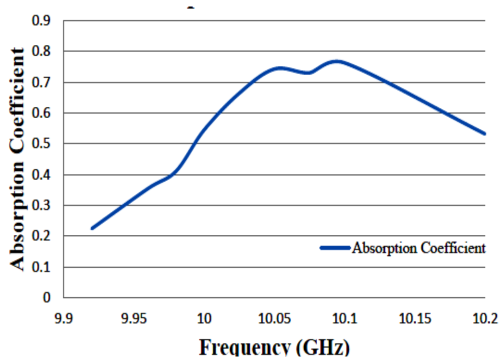


Fig. 12 — (a) Measured values of absorption in mW and (b) measured values of absorption coefficient

The measured results of absorption power and absorption coefficient for TE polarization under normal incidence i.e. 0^0 are shown in Fig. 12(a and b), respectively. It can be observed that there is a slight frequency shift in measured results which is due to finite periodic boundaries during experimental verification as compared to infinite boundary environment during simulation (shown in Fig. 5). Moreover, the measured value of absorption peak is not very sharp due to open air testing environment.

6 Conclusions

A planar polarization insensitive narrowband FSS based microwave absorber for X-band has been designed and implemented. A triple square loop FSS periodic structure in a 4×3 array printed on FR4 substrate has been found to result high absorption of 99.99% at 9.8 GHz. Effects of structural parameters on absorbing characteristics have been studied in depth. From the effects of variation of substrate thickness on absorption properties, it reveals that for a good FSS based X-band microwave absorber the optimum thickness of 1.6 mm is essentially required. The effect of permittivity variations for proposed primitive unit cell also validates that FR4 is most suitable for a narrowband FSS based planar microwave absorber. Moreover, proposed design is quite thinner and polarization insensitive (i.e. it has good frequency stability irrespective of polarization state TE or TM) as compared to existing narrowband microwave absorber which makes it useful for avionics applications. Effectiveness of the proposed design is validated by fabricating a prototype array of 4×3 elements and tested through microwave X-band bench set-up using Horn antenna.

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