PERFORMANCE ENHANCEMENT OF SALISBURY SCREEN MICROWAVE ABSORBER USING DUAL-LAYER FREQUENCY SELECTIVE SURFACES (FSS)

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ABSTRACT

This project presents design of Salisbury screen absorber using dual layers of frequency selective surface FSS. By using this design, the Salisbury screen able to provide dual absorbtion bands and this can improve the overall operating bandwidth. The performance improvement is obtained when frequency selective surfaces (FSS) is sandwiched between the outermost 377 V/square resistive sheet and the ground plane. In this project the dimension of the cross dipole FSS has been optimized using different length at different layers of FSS. Each FSS is positioned a quarter wavelength separation from the resistive sheet to provide impedance matching at 377ohm and therefore generating several absorption bands. The simulated result by CST Microwave Studio shows by using this strategy, three distinct absorption bands with bandwidth of 36%, 12 and 16 % centered at 6.6, 9.2 and 13 GHz respectively, this is relatively larger relatively compare to a classical Salisbury screen having the same thickness. The simulated results have been verified in measurement where the FSSs were fabricated on FR4 board over frequency range of 8 to 12 GHz. The results obtained have revealed that there are good agreements between the simulation and measurement results.

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LIST OF SYMBOLS AND ABBREVIATIONS

FSS	- Frequency selective surfaces
SS	- Salisbury screen
RCS	- Radar cross section
RF	- Radio frequency
EM	- Electromagnetic
TE	- Transverse electric polarization
TM	- Transverse magnetic polarization
PHS	- Personal hand phone system
LANs	- Wireless local area networks
λ	- Wavelength
c	- Speed of light
ε	- Electric permittivity
δ	- Skin depth
f	- Frequency
ℓ	- Length
w	- Width
h	- Thickness of substrate
C	- Capacitance
R	- Resistance
L	- Inductance
t	- The electrical thickness of the spacer

CHAPTER 1

INTRODUCTION

1.1 Introduction

RF absorbers are one of the main components in an anechoic chamber and used to eliminate reflected signals. Microwave frequency range absorber operates in frequency range of 1GHz to 40 GHz. A proper model of RF microwave absorber must be developed based on the parameters such as the absorber reflectivity, the magnitude and phase, for various angles of incidence, and for parallel and perpendicular polarizations [1].

There are various kinds of microwave absorber such as urethane pyramid, twisted urethane pyramid, wedge absorber, walkway absorber and hybrid absorber which consist of combination between dielectric and magnetic material [2]. Among such material that are commonly used to coat on the surface of the absorbers, ferrite is the most popular. Other material stated are bless, polystyrene, conducting carbon and so on. Carbon is one of the semiconductors that allow a little amount of charge flow through it [3]. It has been seen that at high frequencies the current is confined almost entirely to a very thin sheet at the surface of the microwave absorber. However microwave absorbers are extensively applied in many military and civilian applications for camouflage, radar cross section (RCS) reduction, and improvement purpose of the in room EM wave environment in anechoic chambers and indoor wireless LAN area [4].

The Frequency Selective Surface (FSS) were intensively studied since the early 1960s although in 1919, Marconi patented such periodic structures. The early work concentrated on the use of FSS in Cassegainian sub reflectors in parabolic dish antennas. FSS are now employed in radomes (terrestrial and airborne), missiles and electromagnetic shielding applications.

The structure of frequency selective surface (FSS) screens would achieve the effect on increasing the bandwidth [5]. The FSS elements reflect the incident microwave of a specific frequency range based on their sizes, geometric shapes, periodicities and the dielectric properties of the substrate. The unit cells including square, circular, cross, Jerusalem cross, ring and square loop, can form various element geometries for FSS screens.

The aim of this project is to design Salisbury screen based absorbers with relatively wider bandwidth, the performance improvement is obtained from a frequency selective surface (FSS) which is sandwiched between the outermost 377 V/square resistive sheet and the ground plane, this design will be used without incurring an increase in the thickness of the structure by using multilayer frequency selective surface.

1.2 Problem Statement

Resonant absorbs are generally constituted by placing a quarter wavelength dielectric and this includes Dallenbach layers, Salisbury Screen and Jaumann layers.

The Salisbury screen consists of a sheet of resistive material placed $\lambda/4$ over ground. Magnetic loss mechanisms are intrinsically narrow band. The Salisbury screen is considerably wideband over wide frequency and angle. In Jaumann, the operating can be further increase by using multiple layers by dielectric spacers. According to [6], the dielectric constant of the spacers controls the maximum bandwidth of the design. The lower the permittivity the larger the bandwidth [7].

For this project, an alternative Salisbury screen absorber was designed and can be employed to provide dual operating frequency resonance, this can be achieved by placing frequency selective surfaces in the dielectric between the resistive sheet and the ground plane.

The filtering behaviour of a frequency selective surface (FSS) can be flexibly adjusted by including more than one layer, thus affecting a broadband or multiband frequency response of the overall system. In general, multilayer of FSS, which are made up of similar element dimensions, have broader bandwidths and close band centre spacing when compared to those available from single layer arrays. The element and lattice geometries of the arrays, without neglecting the interlayer coupling, are prime factors in obtaining the required performance in a specific application [8].

For further enhancement of work done in [9], the potential of using multilayer off FSS that is sandwiched between resistive sheet and ground plane is investigated. This can increase the bandwidth further compared to classical Salisbury screen and Salisbury screen with single layer of FSS [10], while having the same physical thickness.

The design limit is set by focusing only on two layers of frequency selective surface, which works to increase the bandwidth when the total bandwidth increase layer at each resonance is accounted.

1.3 Objectives

The objectives of this project are as follow:

1. To design Salisbury screen microwave absorbers using multilayer frequency selective surface.

2. To optimize the performance of the bandwidth of the absorber.

3. To simulate and fabricate the prototype microwave absorbers operating in X-band.

1.4 Project Scopes

The scope of this project can be clarifies as follow:

1. The design of the frequency selective surface based absorber is conducted using potential substrate material. The potential should offer attractive additional benefits such as increase in the value of bandwidth enhancement might be achievable in the range frequency from 8 to 12 GHz. Salisbury screen absorber thickness can be dramatically reduced when the PEC ground plane is replaced by frequency selective surface.

2. CST Microwave Studio was employed to optimise the performance of the Salisbury screen and obtain the physical dimensions of the unit cells for an absorber designed to operate at X-band.

3. The measurement is conducted with the facilities standard horn antenna, coaxial cables, Agilent PNA vector network analyser with operating frequency in x-band.

4. Use multilayer frequency selective surface to obtain spectral responses multiband than the single layer ones. The first layer of FSS acts on the highest frequency region and bottom layer on the lowest frequency band providing in-phase reflection characteristics. When the FSS is designed to deliver nearly constant phase over a broad bandwidth, substantial results enhancement can be achieved over a wide range of frequencies

1.5 Thesis organization

The thesis organization has been arranged as follows.

- Chapter II discusses about the literature review of miniaturized FSS and the kinds of microwave absorber, and also explains about the researches that have been done associated to this project.

- Chapter III of this thesis explains about the methodology that has used in order to complete this project. Details about the software and equipment's that has been used also were described.

- Chapter IV of this thesis describes about the simulation and measurement that has obtained. Analyses for both of the results were also explained.

- Lastly, Chapter V of this thesis highlights the conclusion, and also explains several recommendations to upgrade this project. There is additional part, which talks about the reference.

HAPTRE 2

LITERATURE REVIEW

2.1 Introduction

An electromagnetic (EM) wave absorber is used to absorb the reflected wave that occurs on the wall of the chamber. The demand for various kinds of electromagnetic wave absorbers has increased, particularly in industries equipped with high-speed wireless data communication systems operating at 1.9 GHz for personal hand phone system (PHS) and 2.4 GHz for wireless local area networks (LANs) to suppress the delay spread due to multireflected waves [11].

The pyramidal absorber structures are normally mounted to form a continuous wall that is used to attenuate stray signals resulting from chamber confinement. Since the anechoic chamber is used as a place to do a precise EM measurement, the reflected signal from the wall must be eliminated. In addition, it is to ensure that the wave received by the receiver is directly from the transmitter. Normally in the absorber construction, among such materials that were used to coat the absorbers, ferrite were in the lead. However high cost of materials, their transportation and editing, beside with the big densities, force to search for alternative designs, in particular, on the basis of carbon fillers and metallized geometrical designs[8].

The main requirements for an absorber are high absorption of electromagnetic wave, high heat conductivity and good adhesion on the substrate [11]. All these characteristics are strongly dependent on the material used, the shape and the production process of the absorber.

Conventional passive microwave absorbers such as the Salisbury screen, or the multiple-layer Jaumann absorber, use resistive sheets spaced in front of a conducting back- plane to form a structure which provides low reflectivity at chosen resonant frequencies. The reflectivity-bandwidth performance of these structures can be enhanced by adding a reactive component to the resistive layer to produce what is often termed a circuit analog absorber [12]. In absorber designing, the reactive component of the sheet impedance is chosen to help counteract the frequency dependent variation in spacer electrical thickness in such a way as to maintain a free-space input impedance match over a band of frequencies. A practical method of achieving a reactive impedance component is to incorporate a FSS into the layered structure of the absorber, either in addition to a resistive sheet or by replacing such a sheet with a FSS which contains loss [13]. Although the use of a FSS can increase the bandwidth of resonant absorber, they remain passive structures with fixed reflectivity characteristics. However, if the impedance of one or more of the constituent layers of the absorber can be varied in response to an applied electrical or optical control signal, then it is possible to realize an active, or adaptive, absorbing structure [14].

2.2 Pyramidal Absorbers

Pyramidal absorbers are typically thick materials with pyramidal or cone structures extending perpendicular to the surface in a regularly spaced pattern. Pyramidal absorbers were developed so that the interface presents a gradual transition in impedance from air to that of the absorber. The height and periodicity of the pyramids tend to be on the order of one wavelength. For shorter structures, or longer wavelengths, the waves are effectively met by a more abrupt change in the impedance. Pyramidal absorbers thus have a minimum operating frequency above which they provide high attenuation over wide frequency and angle ranges. These absorbers provide the best performance. The disadvantage of pyramidal absorbers is their thickness and tendency to be fragile. They are usually used for anechoic chambers.

A more robust flat "pyramidal" absorber has been fabricated using multilayers with a pyramidal type structure being described by resistive sheets. [10]. Figure 2.1 shows the pyramidal absorbers.

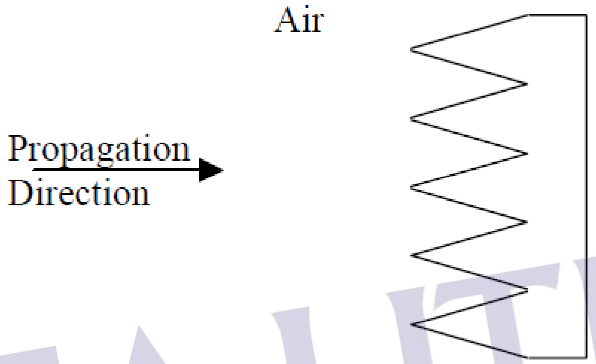


Figure 2.1: Pyramidal Absorbers.

2.3 Resonant Absorber

Resonant materials are also called tuned or quarter wavelength absorbers, include Dallenbach layers, Salisbury Screen and Jaumann layers. In this class of materials the impedance is matched between incident and absorbing media and the material is thin so that not all the power is absorbed.

2.3.1 Dallenbach (Tuned) Layer Absorber

A Dallenbach layer [11] is a homogeneous absorber layer placed on a conducting plane. The layer's thickness, permittivity and permeability are adjusted so that the reflectivity is minimised for a desired wavelength.

The Dallenbach layer relies on destructive interference of the waves reflected from the first and second interfaces. Optimisation of Dallenbach layers has been investigated [12] and shown that it is not possible to obtain a broadband absorber with only one layer; however several layers stacked together showed increased bandwidth [13]. A modified Powell method has been used to optimise reflectivity as a function of incident angle and frequency [14]. Figure 2.2 shows the Dallenbach layer structure.

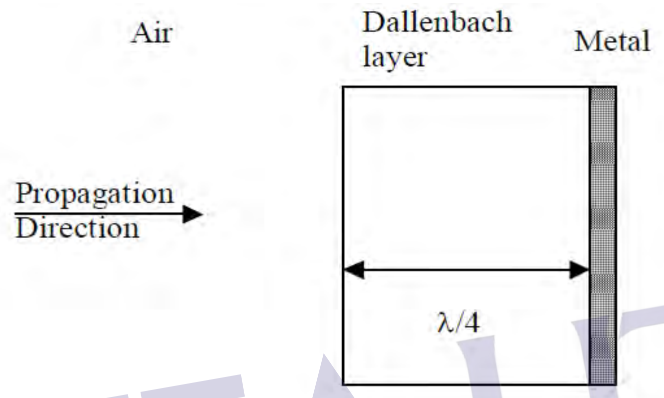


Figure 2.2: Dallenbach Layer [15].

2.3.2 Salisbury Screen

The Salisbury Screen (patented 1952) [16] is also a resonant absorber, however, unlike the tuned absorbers it does not rely on the permittivity and permeability of the bulk layer. The Salisbury Screen consists of a resistive sheet placed an odd multiple of ¼ wavelengths in front of ametal (conducting) backing usually separated by an air gap. A material with higher permittivity can replace the air gap. This decreases the required gap thickness at the expense of bandwidth. In terms of transmission line theory, the quarter wavelength transmission line transforms the short circuit at the metal into an open circuit at the resistive sheet. Figure 2.4 below shows the Salisbury screen.

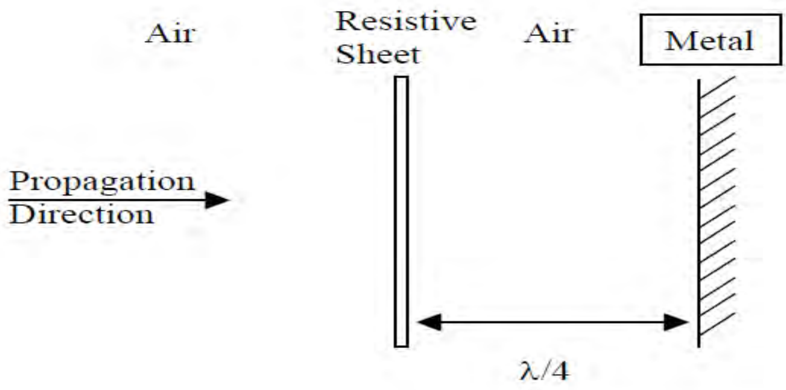


Figure 2.3: Salisbury Screen [17].

The effective impedance of the structure is the sheet resistance. (If the gap is a half wavelength then the short circuit reappears and perfect reflection occurs). If the sheet resistance is 377 ohms/square (ie the impedance of air), then good impedance matching occurs. An analogue of the electrical screen would be to place a magnetic layer on the metal surface, resulting in a thinner device [18]. The -20 dB bandwidth of the Salisbury Screen at the resonant frequency is about 25%. Salisbury screens have been fabricated and the reflectivity calculated [19]. Initial structures were made of canvas on plywood frames with a colloidal graphite coating on the canvas [20].

Conventional passive microwave absorbers such as the Salisbury screen, use resistive sheets spaced in front of a conducting back-plane to form a structure which provides low reflectivity at chosen resonant frequencies. The reflectivity-bandwidth performance of these structures can be enhanced by adding a reactive component to the resistive layer to produce what is often termed a circuit analog absorber.

2.3.3 Jaumann layer

Jaumann layers [21] are a method of increasing the bandwidth of the Salisbury screen. It consists of two equally spaced resistive sheets in front of the conducting plane was mathematically shown to produce two minima in the reflectivity, thus leads to increasing the bandwidth. A six-layers device was capable of about 30 dB decrease in the reflectivity from 7-15 GHz. It makes it so difficult in the manufacture of layers to contain much of the material. It need to a large number of the layers for the absorption and an increase in the bandwidth. Figure 2.3 below shows the jaumann layers.

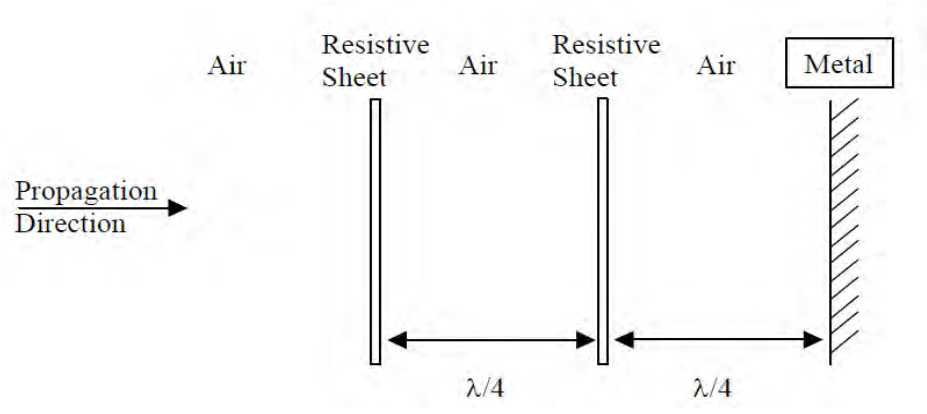


Figure 2.4: Jaumann Layers [22].

2.4 Frequency Selective Surface (FSS)

Frequency selective surfaces are widely used in the microwave and millimeter wave regions of the spectrum for filtering signals. They are used in telecommunication systems for multi-frequency operation or in instrument detectors for spectroscopy. The frequency selective surface operation depends on a periodic array of elements resonating at prescribed wavelengths producing a filter response. The size of the elements is on the order of half the electrical wavelength, and the array period is typically less than a wavelength for efficient operation.

A comprehensive study of the previous methods in design of frequency selective surface revealed that in general they obey a fundamental constraint on the length of elements of the surface, the dimensions of the elements must be about half of the electromagnetic wavelength at the frequency of operation. On the other hand, one can intuitively deduce that a smaller periodicity in a periodic array leads to less variability in the induced electric current distribution, which in turn results in a frequency response less sensitivity to the incidence angle. With this background, design of the new frequency-selective surface was started with the goal of producing inherent frequency selectivity in the surface.

FSSs most commonly take the form of planar, periodic metal-dielectric arrays in two-dimensional space. Frequency behaviour of an FSS is entirely determined by the geometry of the surface in one period (unit cell) provided that the surface size is inflnite. A periodic array of patch elements is shown in figure 2.5. This array is shown to have a capacitive frequency characteristic. Although taking different shapes, conventional FSSs have similar operation mechanisms that can be explained by the phenomenon of resonance. Consider an array of elements on a planar surface.

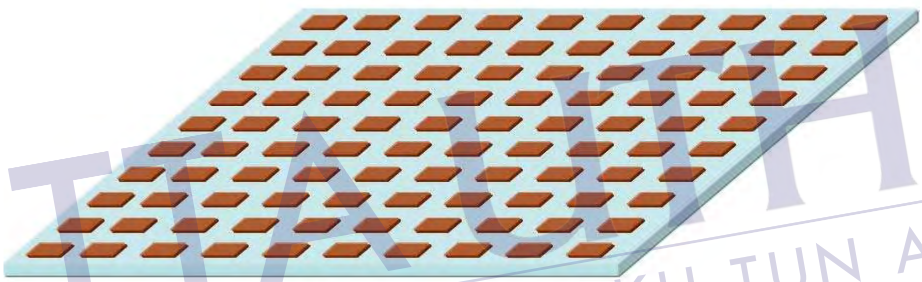
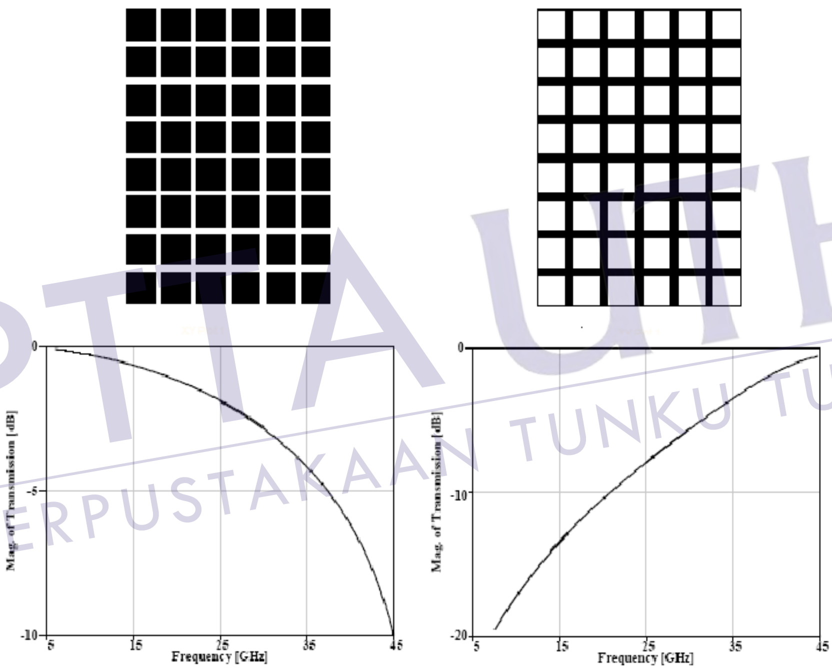


Figure 2.5: Two-dimensional periodic array of patch elements [23].

FSS structures are periodic arrays of special elements printed on a substrate. For numerical analysis, such arrays are assumed to be infinite in dimension as FSSs usually consist of many elements. The infinite array approximation reduces the whole problem of analysis to calculate the frequency response of a single element in the array given the periodic nature of the FSSs. A brief overview of the available FSS elements is provided in the following:

2.4.1 Element Geometries

In general, the FSS structures can be categorized into two major groups: patch-type elements and aperture-type elements. A simple structure consisting of periodic array of metallic patches. Figure 2.6 (a) has been shown to have a low- pass characteristic [24]. Once hit by a plane-wave, this surface transmits low-frequency content of the wave and reflects the higher frequencies. Another observation is to consider such an array as a capacitive surface given its frequency response provided in figure 2.6 (a).



(a) (b)

Figure 2.6: Periodic structures comprising of complimentary elements, patches and slots (wire-grid), and their surface impedance- The patch-array produces a capacitive response, whereas the array of slots is inductive [24].

Over the years, a variety of FSS elements were introduced for bandpass and bandstop applications. A complete list of these elements is collected in [25]. This list includes an array of the following: circular shapes [26]. Metallic plates such as rectangles and dipoles [27], cross-poles, tripoles and Jerusalem cross [28], three- or four-legged dipoles [29], rings [30], square loops [31], and gridded square loops [32], etc. (see figure 2.7).

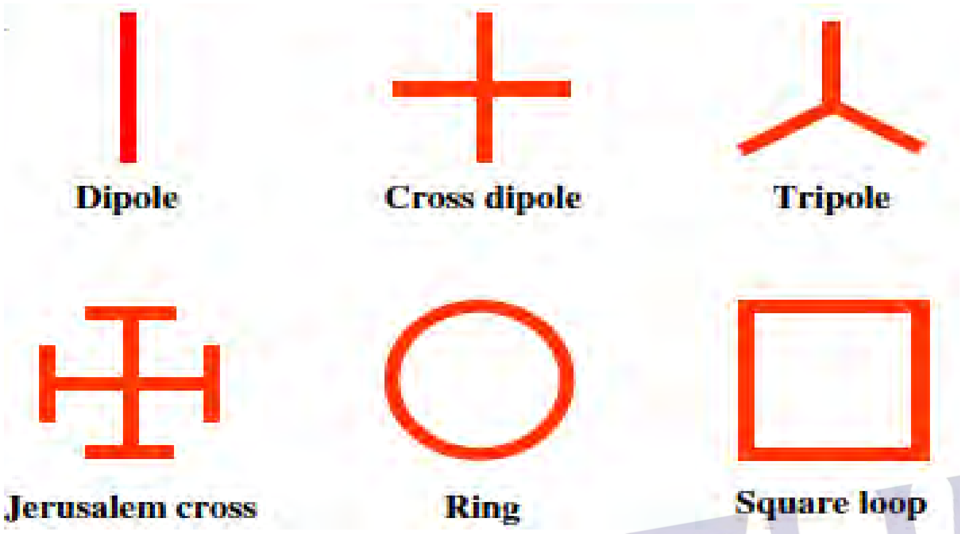


Figure 2.7 : FSS element (patch/aperure) shapes[34].

Although taking different shapes, conventional FSSs have similar operation mechanisms that can be explained by the phenomenon of resonance. Consider an array of elements on a planar surface. Upon contact with a plane-wave, the elements of the periodic surface resonate at frequencies where the effective length of the elements is a multiple of the resonance length, [35]. Corresponding to the phase front of the wave, these elements have a certain phase delay. As a result, the scattered radiations of individual elements add up coherently. An example of such arrangement of elements is Marconi and Franklin's reflector [36]. This reflector is very much similar to the most famous FSS design, an array of half-wave dipoles. A large reflector antenna constructed using wire-grids.

2.4.2 Element Dimension

As mentioned above, FSSs are traditionally designed based on the resonant elements. A planar array of strip dipoles, for example, produces a frequency response consisting of multiple notches at frequencies where the length of the dipoles is a multiple of half a wavelength. A similar effect can explain the operation of other elements. The square loop element, for example, can be imagined as two dipoles that are connected to one another at each end. Using the same argument as that of the dipole, a loop resonates when the length of the two sides equals the length of a resonant dipole $\lambda/2$. In other words, each side of the loop is about $\lambda/4$.

Although the shape of the elements has the utmost importance effect in the frequency response, the way these elements are arranged in the array format is also part of the design work. Moreover, the response also depends on the characteristics of the substrate used. This is where the miniaturized-element FSS design comes to picture.

Elements that are much smaller than the wavelength are designed to create capacitive gaps and inductive traces. By thinning and miniaturizing the unit cell, capacitive junctions in the form of shunt or series capacitors are achieved. Inductive traces are also held very close to one another to produce a larger inductive effect as a result of mutual magnetic coupling. FSS can be classified in four main groups.

Classification of FSS Planar Surfaces are summarized into four main groups such as group one which is the center connected or N-poles, such as the multiple straight elements, three legged element, anchor elements, the Jerusalem cross, and the square spiral. Group two which the loop types such as the three-and four- legged loaded elements, the circular loops, and the square hexagonal loops. Group three which the Solid interior or plate types of various shapes and group four which Combinations. The list is endless. The shapes of the groups are shown in figure 2.8.

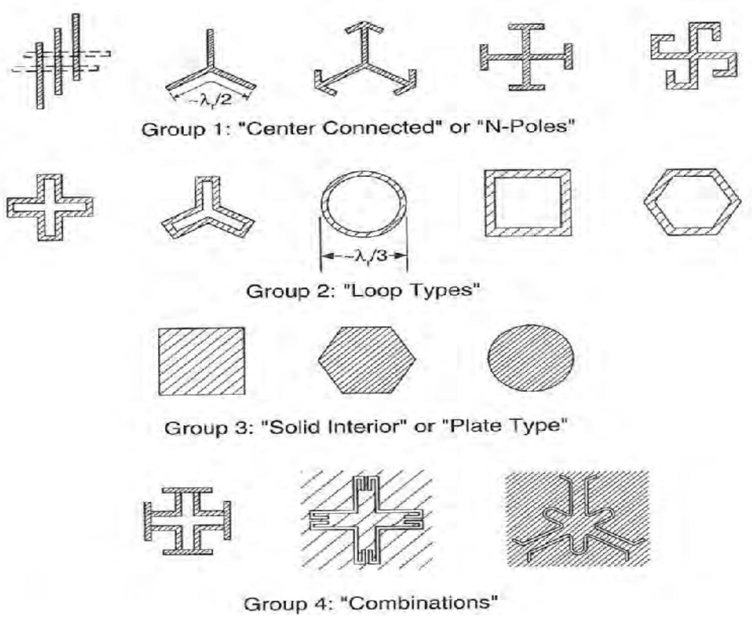


Figure 2.8: Different Groups of EBG Planar Surfaces [37].

The EM transmission characteristics of FSS elements depend on several design parameter such as shape, dimension and array of the periodicity of FSS elements, the permittivity, and the thickness of dielectric substrate, angle of incident and the polarization of the incident EM wave, figure 2.9 shows that, the incident angle and the polarization of the apertures of the FSS arrangement for the different array of FSS. The rectigular array is used most widely. The tringular array has periodicity in the x-direction and skewed y`-direction, when $\alpha = 90^0$, the triangular becomes the rectangular array, the rectangular array can array FSS element very densely, while the tringular array has larger periodicity than the rectangular array.

Therefore, the array periodicity of FSS elements is design parameter to control the resonant frequency and minimum transmission loss of transmitted EM waves. If the array periodicity of FSS element is larger than wavelength of the incident wave, the secondary main beam, called grating lobe that is necessary, occurs in the different direction from the main beam. Therefore, the array periodicity of FSS element should be smaller than the wavelength at the resonant frequency to avoid grating lobe. Specially, in the case of large incident angle, it should be smaller than the half wavelength of the incident EM wave in free space.

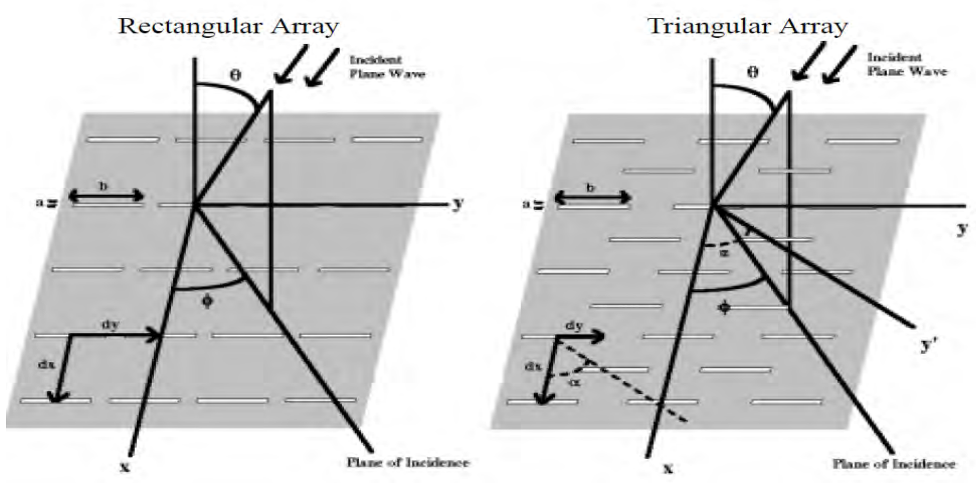


Figure 2.9: Arrangement of aperture /slot of FSS

(a) Rectangular array, (b) Triangular array [38].

2.5 Previous Work

The integration of layered FSS in the construction of microwave absorber, either be the addition of a resistive sheet or by replacing such a sheet with a FSS which contains loss, the widening of the absorption band is achieved by creating an additional resonance in the vicinity of the primary resonance, the λ/4 resonance of the grounded dielectric slab. In these cases the thickness of the absorber remains still considerably large. Artificial impedance surfaces, or high-impedance surfaces, have been used to create electrically thin electromagnetic absorbers. These absorbers relate closely to the Salisbury absorber. The resonance is achieved by using the properties of the high-impedance surface and the absorption by a separate resistive sheet [39]. The resistive sheet can be realized by using commercially available resistive materials on top of the capacitive sheet or between the metallic parts of the capacitive sheet [40], or by connecting resistors between the adjacent metallic parts of the capacitive sheet of the high-impedance surface [41].

The absorbing panel consists of a conventional high-impedance surface comprising lossy frequency selective surfaces over a thin grounded dielectric slab, shown figure 2.10. The FSS array, made up of capacitive cells, behaves as a capacitor in the low frequency region but its impedance becomes inductive after the first resonance [42].

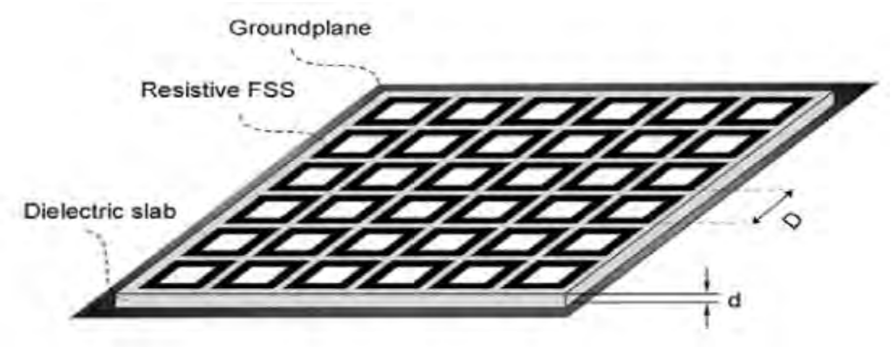


Figure 2.10: Three-dimensional sketch of the analyzed configuration.

A.Tennant and B Chambers [43] uses active frequency selective surface (FSS) controlled by pin diodes. Thus, creating a tunable operating frequency range over obtaining the frequency band from 9 to 13 GHz. The dipole elements are connected in parallel strings by a dc bias line which is incorporated into the FSS design, as shown schematically in Figure 2.11.

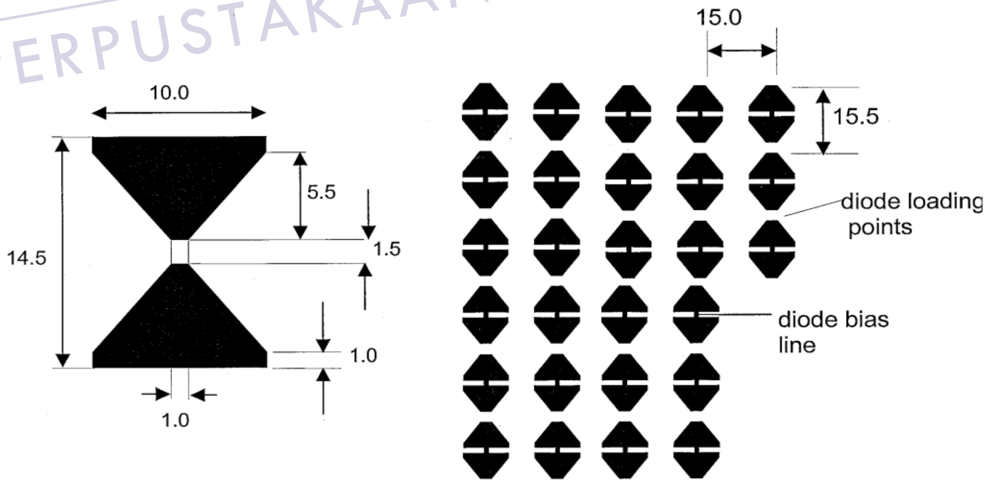


Figure 2.11: Details of the active FSS geometry.

A diode bias current level is of approximately 0.08 mA provides reflectivity level of less than -20dB is achieved from 9.5 to 12.5GHz as shown in figure 2.11. For further increases in bias current, the reflectivity curve shows a single null at around 10.5 GHz and resembles the response of a single layer Salisbury screen, but with increased bandwidth. The reactive impedance of the FSS layer resulted in an absorber that is considerably thinner than of that comparable Salisbury screen absorber.

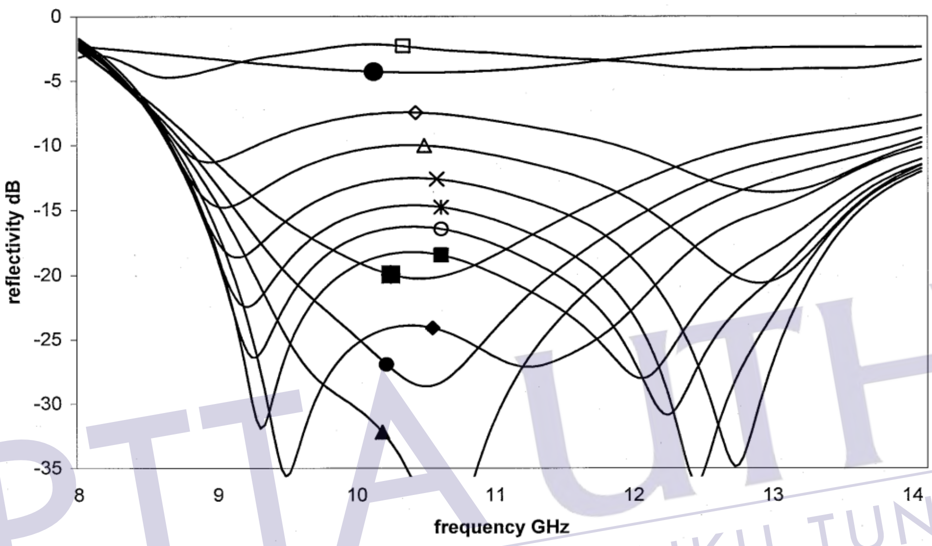


Figure 2.12: Measured absorber reflectivity as a function of diode bias current.□=0.0mA, ◊=0.025 mA, Δ=0.05 mA, x=0.06 mA,*=0.07mA, O=0.075 mA, ▪=0.085 mA, ▲=0.1 mA, ●=0.11 mA, ■=0.13 mA, ●=1.0 mA.

Table 1 shows the summary of the designs in terms of advantages and disadvantages. The good in the designs of the table is that most of them they have good centre frequency stability while the weakness is that most of them have complicated design.

Table 1: Comparison of the previous studies

Author	Description	Advantages	Disadvantages
A. Tennant and B Chambers [43].	A Single-Layer Tuneable Microwave Absorber Using an Active FSS	1- Provides low reflectivity at chosen resonant frequencies between 9 to 13 GHZ. 2- The outer dielectric layer formed by the circuit board provides increased bandwidth, as well as a protective outer skin.	1- They remain passive structures with fixed reflectivity characteristics. Although the use of a FSS can increase the bandwidth of resonant absorbers. 2- Low and loss of foam dielectric. 3- A detailed electromagnetic analysis is beyond the results.
H. Y. Chen, X. Y. Hou, and L. J. Deng [44].	A Novel Microwave Absorbing Structure Using FSS Metamaterial	1- Low loss and low cost. 2-The absorbance is equally with 87% at w = 12.8 GHz	1-More complicated arrangement, in the design. 2-Depended on the material of the substrate for attaining high absorbance.
YE Chunfei and LI Erping [45].	Finite Difference Time Domain Simulation for Multi-layer Microwave Absorber with Frequency Selective Surface	1-Improve the bandwidth. 2-Decrease in the reflection coefficient of frequency.	1-The increase in the thickness. 2- Uses two types of layers.
F. Che Seman R. Cahill V.F. Fusco G. Goussetis[46].	Design of a Salisbury screen absorber using frequency selective surfaces to improve bandwidth and angular stability performance	1-Signals incident at angles up to 40. 2- Improve performance of the Salisbury screen and obtain the physical dimensions of the unit cells. 3-The -10 dB reflectivity bandwidth is shown to be 52% larger than a conventional Salisbury screen of the same thickness.	1-Unsuitable for deployment in applications where the major design driver is to reduce physical thickness. 2-This application unsuitable for broadband operation.
Olli Luukkonen, Filippo Costa, Student Member, IEEE, Constantin R. Simovski, Agostino Monorchio, Senior Member, IEEE, and Sergei A. Tretyakov, Fellow, IEEE[47].	A Thin Electromagnetic Absorber for Wide Incidence Angles and Both Polarizations	1-Increase the absorption band for the TM polarized oblique incidence. 2-Reduce the effect of the incident angle.	1-The high cost of high frequency lumped resistor and the number of spot welding. 2-The increase in capacitance values lead to a decrease in bandwidth.

An experiment of single-layer active microwave absorber is described. The absorber is a planar structure based on the topology of a Salisbury screen. A single layer active microwave absorber which uses a pin diode loaded FSS has been described. The result shows that the structure can be tuned to provide a variable reflectivity response over a band of frequencies from 9–13 GHz. The reactive impedance of the FSS layer results in an absorber that is considerably thinner than a comparable Salisbury screen absorber, and also shows the increase of bandwidth.

H. Y. Chen, X. Y. Hou, and L. J. Deng [44] used a novel absorbing structure in the microwave range with metamaterial frequency selective surface (FSS). The absorber is a simple unit cell layer planar structure based on two metamaterial resonators. The resulting structure which consists of metallic elements has superior absorption characteristics compared to conventional passive absorption of thickness, as shown in Figure 2.13.

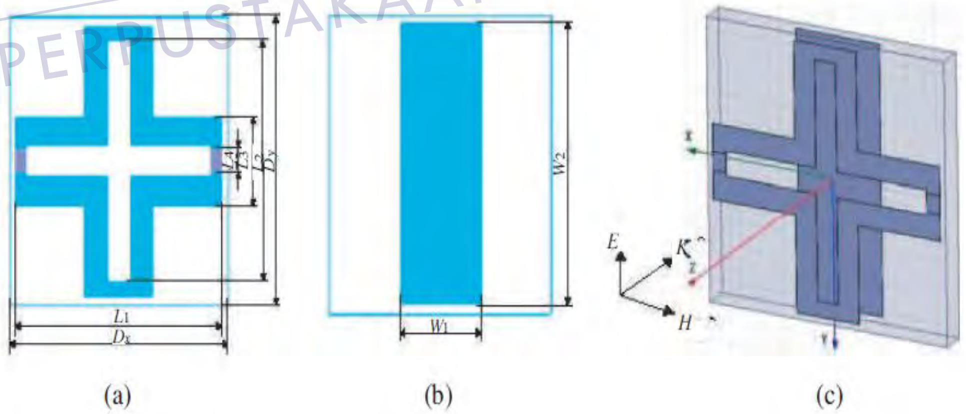


Figure 2.13: (a) Electric four-legged loaded resonator and (b) cut wire. Dimension notations are listed in (a) and (b). The unit cell is shown in (c) with axes indicating the propagation direction.

The design used copper with a conductivity of δ = 5:80 x 107 s/m. The proposed substrate is FR4 with a dielectric constant of 4.4. The absorbing structure is as shown in figure 2.13. Experimental results are presented and compared to obtained from a finite difference time domain (FDTD) approach, demonstrates a peak absorbance greater than 87% at 12.8 GHz ,as shown in figure 2.14. The design was optimised numerically by (FDTD), and showed the increase of bandwidth greater than conventional Salisbury screen.

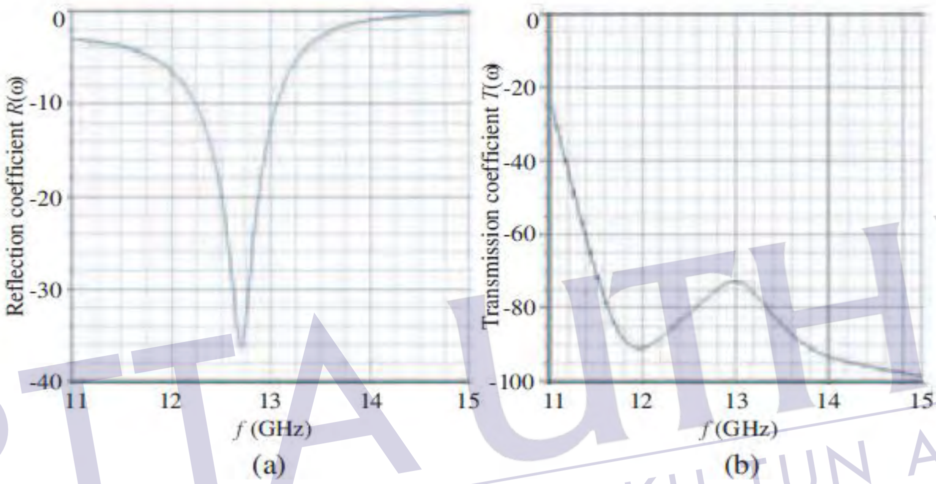


Figure 2.14 .Simulated result of the absorbing structure .The reflection coefficient (R (ω))and transmission coefficient (T(ω)) are plotted on (a) and (b) respectively.

Table 1 shows some advantages of this design obtained to the absorbance with 87%, due to their low loss, and flexibility in adjusting the frequency at 12.8GHz, so when comparing between this design and another design in [43], it is observed that both achieve low in the value of reflectivity and the increase of the bandwidth.

YE Chunfei and LI Erping [45] introduce novel structure for broadband microwave absorption is introduced. It consists of multi-layer lossy materials with frequency selective surface on the interfaces and is backed by metallic ground plane. In this process, an efficient technique is used to absorb microwave. This kind of microwave absorber consists of 2D-periodic arrays of metallic patches (FSS) immersed in multilayer lossy dielectric substrates backed by a metallic plate as shown in figure 2.15 and is called FSS absorber. By using the technique, coated with the features of thinness, low-reflectivity and broadband absorption may be achieved. Table 1 shows the summary of the design.

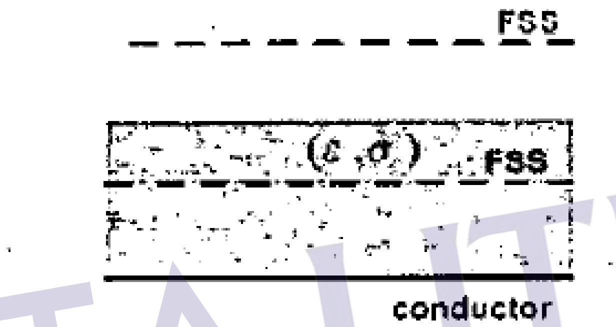


Figure 2.15: Microwave absorber with frequency selective surface.

The patch of FSS is rectangular as shown in figure 2.16 with a = 15 mm, w =6 mm. The distance "d" between to patches is changeable.

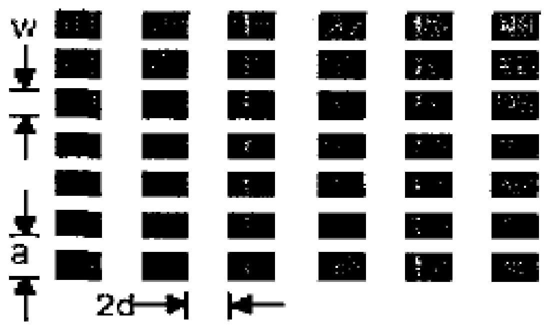


Figure 2.16: Patch of FSS in simulation.

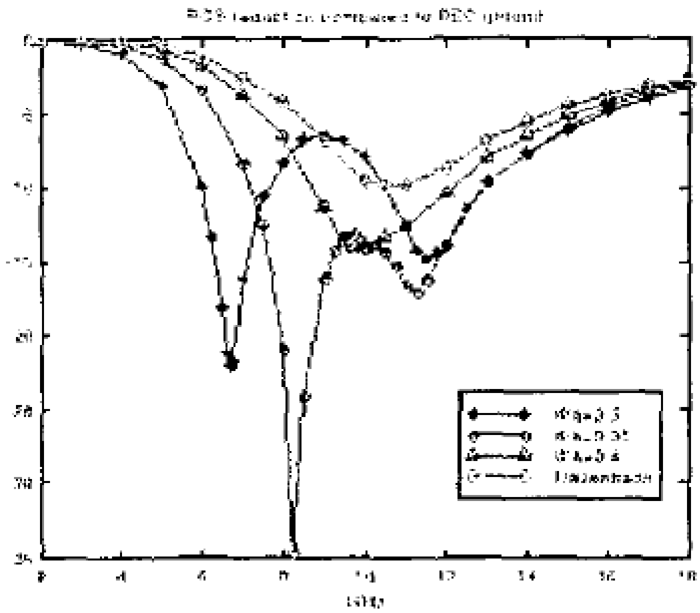


Figure 2.17: Simulated result of RCS reduction for incidence angle

Table 1 presents the advantages of this design, as well as investigates the RCS reduction for incidence at ϴ=20° for TE and TM waves. It is observed that for a proper configuration of the geometrical parameters, the absorption is not very sensitive to the incident angle and the polarization.

F. Che Seman, R. Cahill, V.F. Fusco, G. Goussetis [46] used a new design method that greatly enhances the reflectivity bandwidth and angular stability beyond what is possible with a simple Salisbury screen is discussed. The performance improvement is obtained from a frequency selective surface (FSS) which is sandwiched between the outermost 377 V/square resistive sheet and the ground plane. A multiband Salisbury screen is realised by adjusting the reflection phase of the FSS to position one null above and the other one below the inherent absorption band of the structure. Alternatively by incorporating resistive elements midway on the dipoles, it shows that the three absorption bands can be merged to create a structure with a -10 dB reflectivity bandwidth which is 52% larger and relatively insensitive to incident angle compared to a classical Salisbury screen having the same thickness. Figure 2.17 shows the structure of this design.

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