Chapter 1

Introduction & Literature review

Introduction and Literature Review

1.1 History Overview

Electromagnetic (EM) wave absorbers based on artificially engineered structures such as metamaterials, metasurfaces, or frequency selective surfaces, from which there is no reflection or transmission of electromagnetic waves across some desired portion of spectrum. Due to development of radar in early 20th centuary, the first substantial development of absorber began during World War II, where two absorbing configuration semi-flexible rubber sheet loaded with carbonyl powder and Jaumann absorber developed by German Projects.US project HARP (Halpern-anti radar paint) developed a rubber sheet with resonant absorption behaviour called the Salisbury Screen Absorber [1].

Due to its simplicity and scalabilty across the frequency spectrum, the practical version of such arrangement spread rapidly. The Salibury screen structure is comprised of a resistive sheet separated by a distance of one quarter wave length from the conducting plane [1]. Operating wavelengths are limited around resonant frequencies due to the resonant structure. Whereas the Jaumann absorber is consider an extension of the Salisbury screen to achieve broadband absorption performance, in which two or more resistive sheets are used.

Another type of resonant absorber consists of a single, homogeneous, highly lossy layer backed by a ground plane, and it is known as Dallenbach layer absorber. Coating such layer is useful for reducing Radar Cross Section (RCS) from complex space. Using the Dallenabch layer approach, most commercial absorbers are designed for industries, such as dielectric foam, resin, or magnetically loaded silicon rubber materials. Schematic of these traditional absorbing configuration are illustrated in Fig. 1.1.

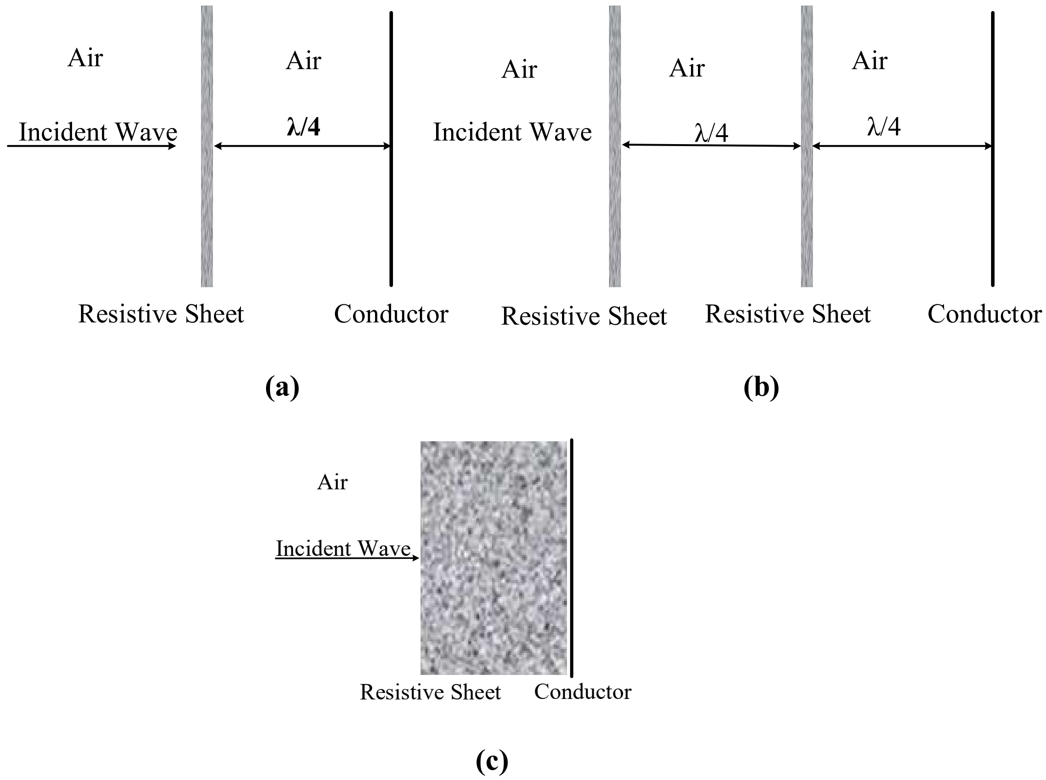
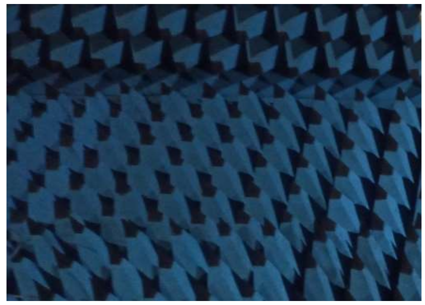


Fig. 1.1: Schematic representation of classical absorbing configuration (a) Salisbury Screen (b) Jaumann Absorber (c) Dallenbach Layer absorber.

Subsequently, the theory mentioned was put into practice, leading to the development of other absorber based specific requirements, like pyramidal absorbers, dielectric absorbers, and magnetic absorbers as shown in Fig. 1.2. Pyramydal absorbers belong to the class of broadband absorbers and were designed to address the issue of abrupt transition layers, which often result in significant reflection. In these absorbers, the impedance at the front face is close to 377 Ω and gradually reduces to 0 Ω at the back interface. They typically have a pyramidal shape with reflectivity exceeding -50 dB and are commonly used in anechoic chambers. However, a drawback of pyramidal absorbers is their bulkiness and fragilty [2]

Magnetic absorbers use high ferromagnetic materials to achieve high permeability and magnetic losses. These absorbers come in various elastomer forms. They are best suited for load application, such as in terminations, and for enclosed space



(a)

(b) **(c)**

Fig. 1.2: Subsequent development of absorber based on requirement (a) Pyramidal absorber (b) Magnetic elastomer absorber [2] (c) Dielectric foam absorber [2].

application, such as cavity resonance damping to absorb the standing waves. However, a disadvantage of these absorbers are high weight and cost [2].

Dielectric absorbers utilizes the dielectrtic loss mechanism. These absobers are manufactured using low-cost foam as well as elastomers. The main advantages of these absorbers are their afforadibilty and light weight performance in comparision to dielectric absorbers [2]. However, their application in electronic equipment is limited due to their conductive properties.

1.2 Absorber based on Periodic Surface

Over the years, a diverse range of absorber materials and structures have been explored to meet the demanding requirements of modern electromagnetic system. Among these, periodic surface, printed on grounded dielectric layer has emerged as promising candidate for achieving enhanced and versatile electromagnetic absorption. A 2D sketch of a single-

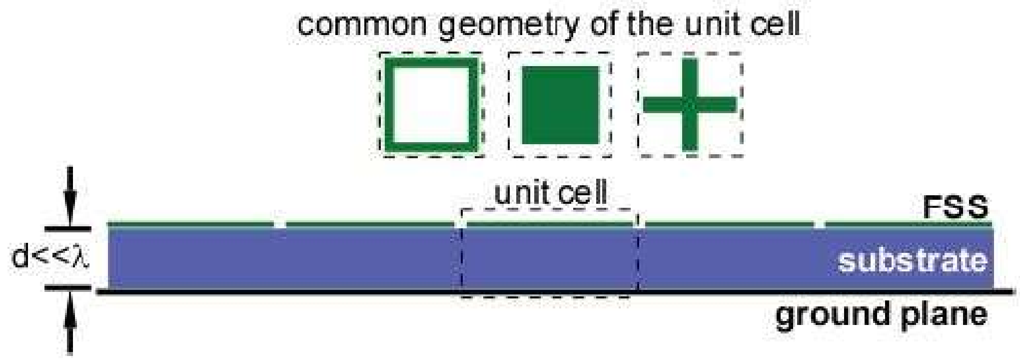


Fig. 1.3: 2D sketch of single layer absorber based on periodic surfaces with some common unit cell pattern [3].

layer absorber based on periodic surface with some common unit cell patterns are shown in Fig. 1.3.

Periodic surfaces such as metamaterial, metasurface or frequency selective surface characterized by their periodicity in scatterer, have shown the abilty to manipulate the propagation of electromagnetic waves in ways that were previously unattainable with conventional absorber design. Two dimensional equivalents of metamaterial are known as metasurface [4]. In metasurfaces, electrically small scatterer are placed juidiciously in two dimensional pattern at a surface or interface as depicted in Fig. 1.4 [5]. Over the last two decades, a large number of absorber based on periodic surfaces have been reported. These artificial engineered absorbers have gained attention due to their light weight and compact size compared to traditional absorbers. By engineering the periodicity, geometry, and material property such as permittivity and permeability, researchers can tailor absorbers to operate within specific frequency ranges and optimize their bandwidth to address the demands of contemporary technology.

1.3 Application of thin microwave absorber

Electromagnetic based absorbers have extensive applications in both military and civil sectors, spanning from microwave to optical frequencies through the THz spectrum. As

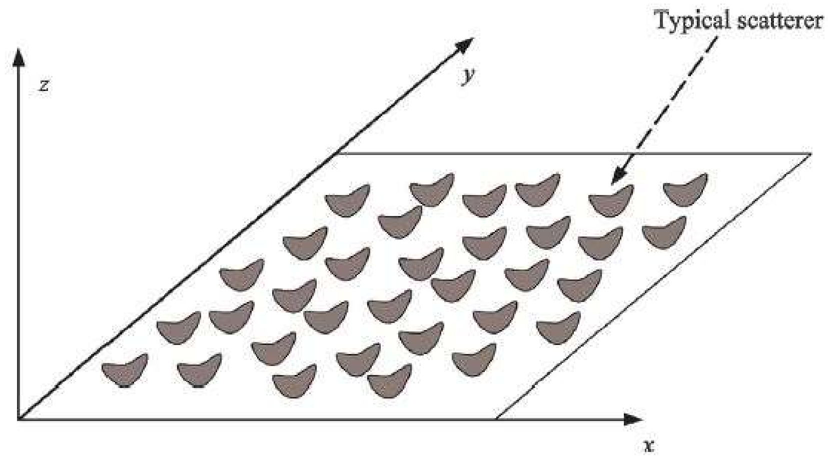


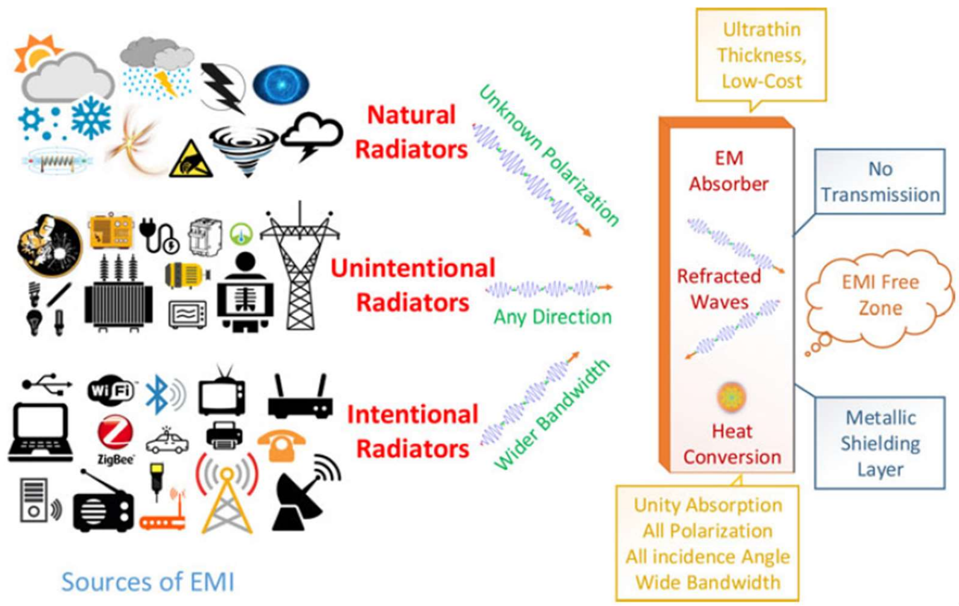
Fig. 1.4: Illustration of metasurfaces: a planar arrays of arbitrarily scatterers [5].

discussed in section 1.1, due to the rapid development of radar technology, practical versions of radar absorbing material or radiation absorbent material (RAM) have been developed. As a results of large investements in stealth technology, USA used iron ball paint, a special coatings of radar absorbing material on the first stealth bomber, the F-117, in order to reduce its radar cross-section (RCS) as depicted in Fig.1.5 (a). In civil sector, absorbers are used to reduce electromagnetic intereference (EMI) between electronics devices and improve electromagnetic comapatibility (EMC), as shown in Fig.1.5 (b) [6].

In the microwave frequency regime, over the last few decades, a large number of electrically thin layer absorbers based on periodic surfaces have been employed to reduce the RCS of targets [7]-[11], develop chipless RFID tags [12], enhance electromagnetic comaptibilty in electronic devices [14], [15], support electromagnetic energy harvesting (EEH) and wireless power transfer (WPT) [15], and sensor [16].

Recently, ultra-thin absorber ($\lambda < 17$) integrated with the thermal blanket of satellites are used to reduce their electromagnetic scattering [17]. Few application of these absorber are depicted in Fig. 1.6.

(a)



(b)

Fig. 1.5: Application Radar Absorbing material for military and civil purpose (a) Special coating of RAM used on Stealth Fighter F-117 (b) Illustration of Electromagnetic Radiation and absorption [6].

1.4 General Principle : Impedance matching approch

When a plane wave impinges on the surface of an electromagnetic wave absorber, some power is transmitted, some is reflected, and some is dissipated in the lossy substrate. These

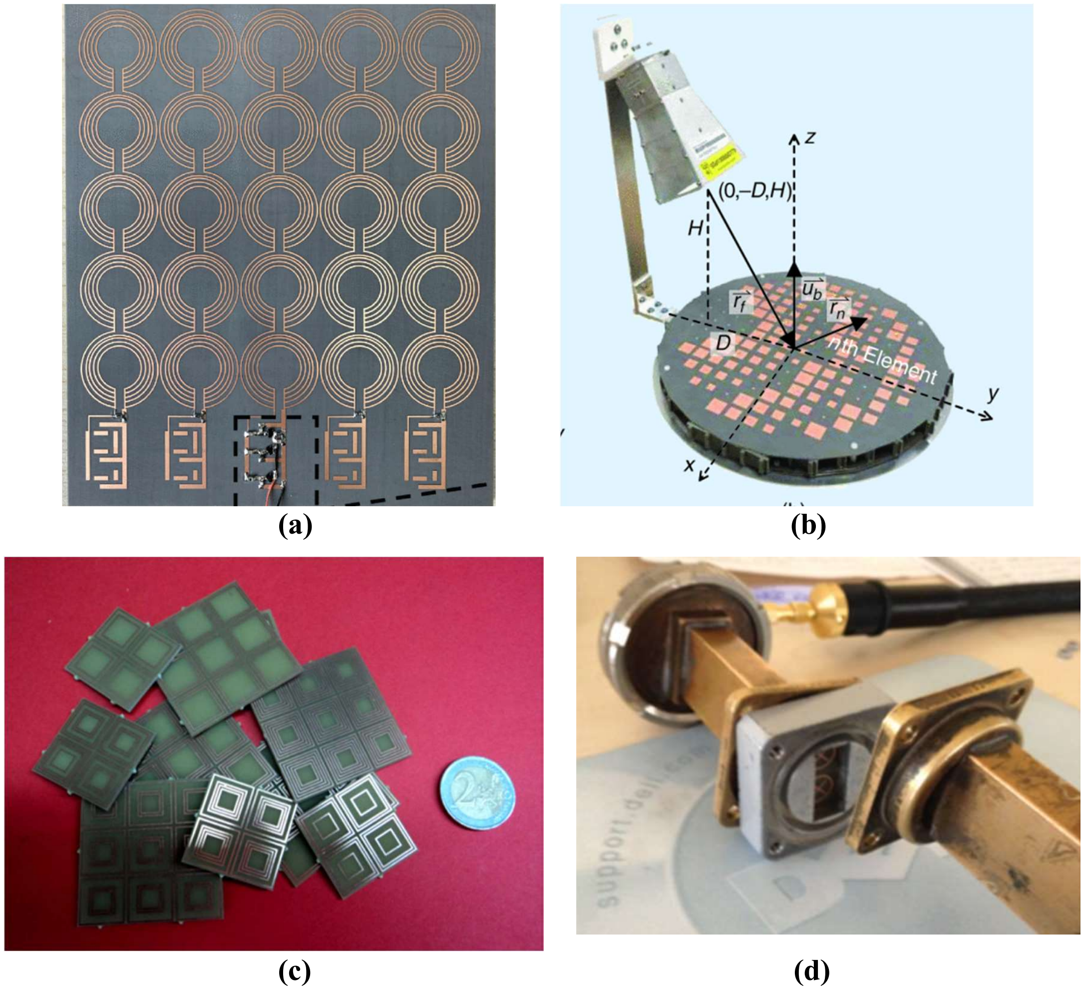
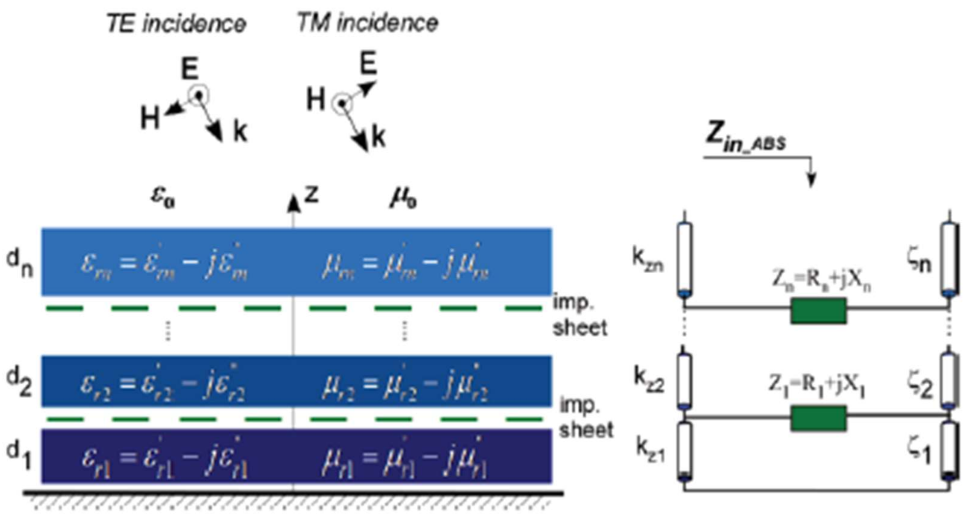


Fig. 1.6: Various application of RAM based on periodic surfaces (a) RF Energy Harvesting [15] (b) Low-RCS Antenna System [12] (c) Chipless RF Id [12] (d) Absorber based Sensor [16].

absorbers can be analyzed by Transmission Line (TL) approach. For generic metal backed absorber as shown in Fig. 1.7 (a), the magnitude of reflection coefficient is given by [3]

$$|\Gamma|=\sqrt{\frac{(\mathrm{Re}\{Z_{in\_ABS}\}-Z_O)^2+(\mathrm{Im}\{Z_{in\_ABS}\})^2}{(\mathrm{Re}\{Z_{in\_ABS}\}+Z_O)^2+(\mathrm{Im}\{Z_{in\_ABS}\})^2}} \quad (1)$$

where Z_{in_ABS} is the total input impedance of absorbing structure calculated by connecting parallel purely real impedance in case of purely resistive sheet, and complex impedance in case of periodic surface, as depicted in Fig. 1.7 (b). Series and parallel combination of lumped parameters of impedance, are determined by the nature of polarization of the



(a) **(b)**

Fig. 1.7: Transmission line model of general absorbing configuration (a) General absorbing structure (b) Equivalent circuit [3] .

incident wave [18],[19]. Z_0 is free space characteristic impedance for TE and TM polarization.

For good absorption performance, it is necessary to tailor single or multiple resonances over the frequency range of interest. Therefore, absorber design is accomplished by obtaining the form of Z_{in_ABS} expression from the TL model and imposing the following condition [3]

$$\begin{aligned} \mathrm{Re}(Z_{in\_ABS}) &= Z_O^{TE,TM} \\ \mathrm{Im}(Z_{in\_ABS}) &= 0 \end{aligned} \quad \text{where, } \begin{bmatrix} Z_o^{TE} \\ Z_o^{TM} \end{bmatrix} = Z_o \begin{bmatrix} \sec\theta \\ \cos\theta \end{bmatrix} \tag{2}$$

Since the real part of the total input impedance of the absorber matches with the free space characteristic impedance, and imaginary part is zero over the frequency range of interest, no reflection occurs from the absorber, resulting in complete wave absorption. Therefore, through careful selection of the absorber's geometry and material properties, one can ensure effective impedance matching.

1.5 Classification of absorbing configuration based on periodic surface

Based on the dominant nature of losses, absorbers based on periodic surfaces can be classified into ultra-narrowband, narrowband, wideband, or ultra-wideband configurations. In order to classify the absorbing configuration, an absorbing structure based on a periodic surface and its equivalent transmission line model are investigated, as shown in Fig. 1.8 [20]. The amount of power absorberd by this absorber is characterized by the real part of its input impedance. Therefore, analytical derivation of the total input impedance of the structure is analyzed. The structure consists of a lossy-frequency selective surface printed on a metal backed dielectric substrate. The impedance of a lossy FSS is given by [20]

$$Z_{FSS} = R_o + R_D + (1-\omega^2 LC)/j\omega C \tag{3}$$

where L, C represent the inductance and capacitance of the FSS and R_O and R_D account for ohmic and dielectric loss. The input impedance of thin grounded dielectric substrate is given by equation [20]

$$Z_d = j\frac{\varsigma_o}{\sqrt{\varepsilon_r^{'} + \varepsilon_r^{''}}}\tan(k_O\sqrt{\varepsilon_r^{'} + \varepsilon_r^{''}}\,d) \tag{4}$$

where ζ_O represent the characteristic impedance of free space, and d, $\varepsilon_r^{''}$, and $\varepsilon_r^{''}$ represent the thickness, real and imaginary part of the permittivity of the dielectric substatre.

The total input impedance of absorber is parallel connection of two complex impedance Z_d and Z_{FSS}. The input impedance of the absorber at its fundamental resonance frequency, where its imaginary part is zero, is given by equation [20]

$$\mathrm{Re}(Z_{in\_ABS}) = \frac{(\mathrm{Im}\{Z_d\})^2}{(\mathrm{Re}\{Z_d\} + R_o + R_D)} \tag{5}$$

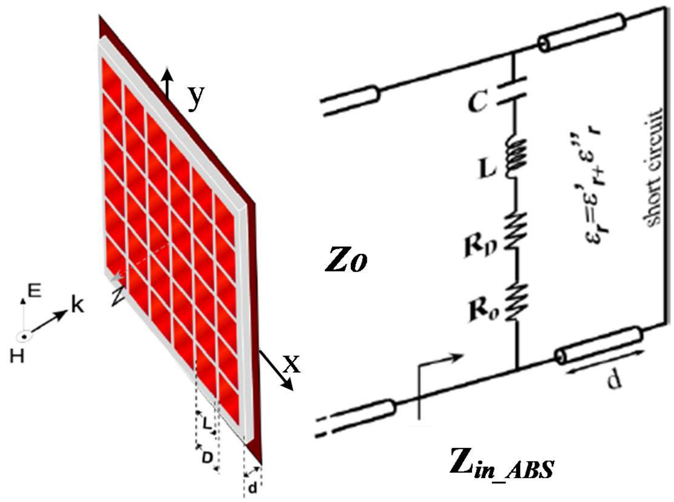


Fig. 1.8: Investigated absorbing configuration (a) Analyzed structure (b) Equivalent circuit [20].

Where R_D represents the losses due to the dielectric substrate and R_o represents the ohmic lossese due to the lossy FSS. Z_d represent the input impedance of a thin, grounded dielectric substrate. On the basis of the dominant nature of losses, absorbing configurations can be classified as [21]

- $R_D >> R_O$: Dielectric losses are high in comparision to ohmic losses. The frequency response of the structure is typically ultra-narrowband, and the structure is commonly known as a perfect metamaterial absorber. These absorbing structures are generally metallic FSS etched on low-loss dielctric substrates. Such absorber has a thickness much thinner than λ/4 and relies on the capacitive behavior of FSS impedance [3].
- $R_D \sim R_O$: Both dielectric and ohmic losses are comparable and equally responsible for the absorption of electromagnetic waves. The frequency response of the structure is typically ultra-narrowband or narrowband.
- $R_O >> R_D$: Ohmic losses dominate over dielectric losses. The frequency response of the structure is typically wideband or ulta-wideband. These

absorbing structures are generally formed by FSS made with resistive material, such as FSS embedded with a lumped resistor or FSS made with resistive ink. These configurations are commonly known as Circuit Analog (CA) absorbers [3].

1.6 Working principle of perfect metamaterial absorber

The study of metamaterial based absorbers has gained attention after Landy *et al.* [22] made the first experimental demonstration of a perfect metamaterial absorber with a narrow bandwidth. These absorbers are periodic arrangements of metamaterial unit cells. To quantify the absorbing performance of the absorber, absorbance *A(ω)* is defined as [22]-[24]

$$A(\omega) = 1 - R(\omega) - T(\omega) \tag{6}$$

$$A(\omega)=1-|\Gamma(\omega)|^2-|\tau(\omega)|^2 \tag{7}$$

$$A(\omega)=1-|S_{11}(\omega)|^2-|S_{21}(\omega)|^2 \tag{8}$$

where $S_{11}(\omega)=\Gamma(\omega)$ and $S_{21}(\omega)=\tau(\omega)$ are reflection and transmission coefficient, respectively. In order to get unity absorption (100%) from the metamaterial absorber, the reflectance $R(\omega)$ and transmittance $T(\omega)$ of the structure should be low. For a perfect metal back absorber, the above equation reduces to

$$A(\omega)=1-|S_{11}(\omega)|^2 \tag{9}$$

The wave impedance of metamaterial slab is defined as [25]

$$Z(\omega) = \eta_o\sqrt{\frac{(1+S_{11})^2-S_{21}^2}{(1-S_{11})^2-S_{21}^2}} = \eta_o\,\frac{(1+S_{11})}{(1-S_{11})} \tag{10}$$

$$S_{11} = \frac{Z(\omega)-\eta_o}{Z(\omega)+\eta_o} \tag{11}$$

where $Z(\omega),\eta_o$ are the impedance of the metamaterial absorber and the free space wave impedance, respectively. Under the effective medium approximation, materials are characterized by frequency dependent relative permeability $\mu_r(\omega)$ and permittivity $\varepsilon_r(\omega)$, and therefore, their impedance is defined by [26]

$$Z(\omega) = \sqrt{\frac{\mu_o \mu_r(\omega)}{\varepsilon_o \varepsilon_r(\omega)}} \quad (12)$$

Therefore, the unity absorption condition is satisfied if $S_{11}(\omega)$ is zero. Hence, using equations (11) and (12),

$$Z(\omega) = \eta_o \quad (13)$$

$$\sqrt{\frac{\mu_o \mu_r(\omega)}{\varepsilon_o \varepsilon_r(\omega)}} = \sqrt{\frac{\mu_o}{\varepsilon_o}}$$

$$\sqrt{\frac{\mu_r(\omega)}{\varepsilon_r(\omega)}} = 1$$

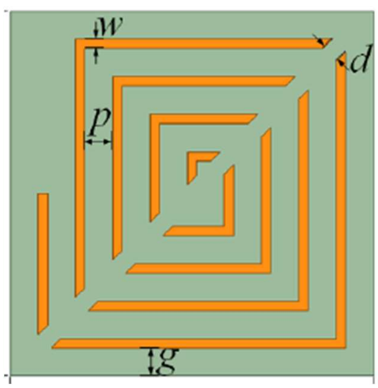
$$\mu_r(\omega) = \varepsilon_r(\omega)$$

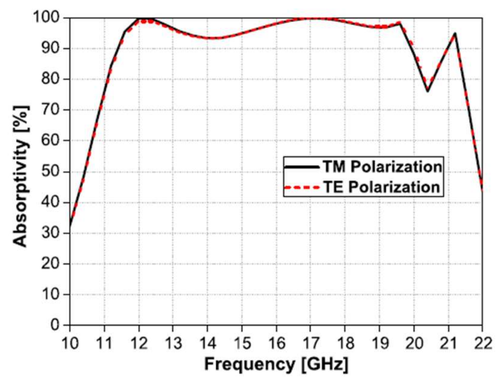
$$\mu_r^{'}(\omega) - j\mu_r^{''}(\omega) = \varepsilon_r^{'}(\omega) - j\varepsilon_r^{''}(\omega) \quad (14)$$

Therefore, by tailoring permittivity and permeability by electric and magnetic resonances, zero reflection and, hence, unity absorption can be achieved. If the metamaterial structure absorbs impinging electromagnetic waves from all angles in a very small bandwidth with nearly unity absorption ,such structure is frequently referred as a perfect metamaterial absorber.

1.7 Subsequent development of absorber based on periodic surface

This section primarily deals with absorbers based on periodic surfaces, and corresponding literature reviews are also provided in the individual chapters. Initially, interest in metamaterials arises due to their exotic electromagnetic effects, which are not possible with naturally occurring materials [27]. One of the exotic applications was the metamaterial high impedance absorber by N. Engata [28]. Subsequently, SRR-based microwave absorber [29] and an ERR with a cutwire-based perfect metamaterial absorber were developed by Landy *et al*. [22]. Traditional absorbers are rigid, bulky, neither light-weight nor provide near–perfect absorption etc. To overcome above limitations, these electromagnetic metamaterial absorbers provide effective solution by tailoring the EM properties (effective permittivity and permeability) to achieve efficient impedance matching over the desired frequency spectrum. After the first experimental demonstration of the perfect metamaterial absorber with a narrow bandwidth by Landy *et al*. [22], various types of dual [30], multiband [31], and wideband absorbers [32]-[35] have been reported. A rigid wideband absorber based on low-loss periodic surface, along with the absorptivity response, is illustrated in Fig. 1.9.





(a) **(b)**

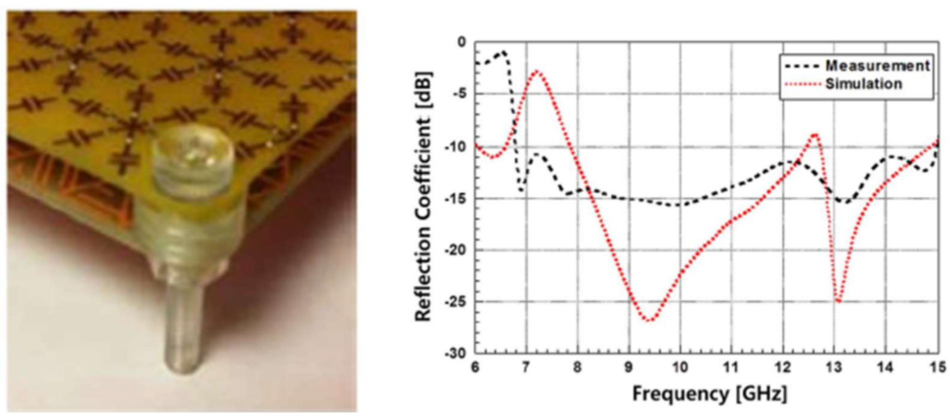
Fig. 1.9: Illustration of rigid wideband absorber based on low loss periodic surface (a) top view (b) absorptivity response [35].

However, many of the reported absorbing configurations face a limitation in the lack of information regarding their cross-polarized reflected component (CPRC) of incident waves.Cross-polarized reflection refers to the phenomenon in which when a plane wave impinges on a structure, then due to its anisotropic characteristic, one of the polarization states of the reflected wave is orthogonal to the original polarization state. This absence of data makes it difficult to definitively categorize these structures as either absorbers or reflective-type cross-polarization converters [35]-[36]. When considering the CPRC of the incident wave in estimating absorptivity, the absorptivity level experiences a significant decrease from 90% to below 20% across the claimed operating band [38]-[40]. Consequently, a substantial number of structures claiming high absorptivity are, in reality, reflective-type cross-polarization converters [38]-[40]. Hence, there is a crucial need for investigating the CPRC of the incident wave. Despite being simple unit cell configuration, achieving wideband or ultrawideband absorption with low loss metamaterials, metasurfaces, or frequency-selective surfaces without introducing a significant amount of ohmic or dielectric loss proves to be a practical challenge.The second chapter of this thesis explore these challenges. Our finding distinguishes our work by uncovering the true nature of such claimed absorbers as reflective-type cross-polarization converters, providing valuable insights for future research in the field. Our critical analysis help to prevent further misinterpretations and facilitate progress in the field of efficient absorber.

Basically, polarization converters are used to control and manipulate the polarization state of an EM wave in signal transmission, liquid crystal displays, and optical instruments [41]-[43]. Conventional polarizer has several practical limitations, such as being based on Faraday effects and optical activity crystals. They require a long distance for propagation to get the desire phase characteristic. Therefore, these structures have a particular thickness and large configuration [44], [45]. However, the above practical limitations can be overcome by these polarization converters [38]-[40], which are based on periodic surfaces. These can be efficiently designed with a small thickness and a simple configuration [46].

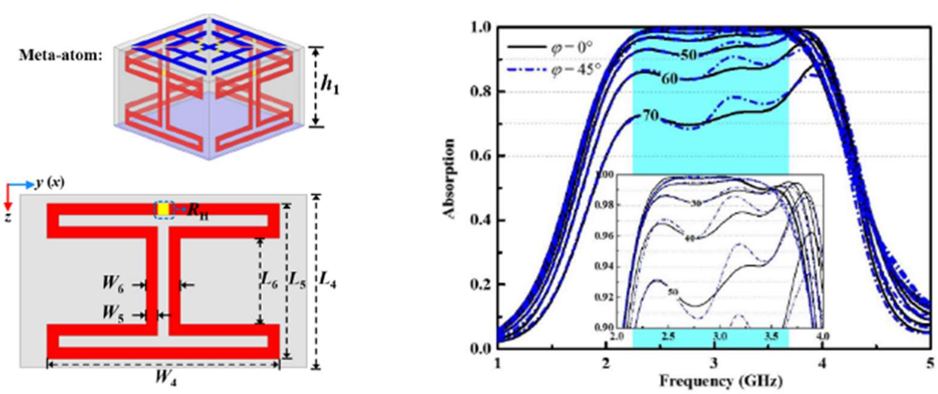
The evolution of wireless technology and electronic devices has led to a growing emphasis on designing absorbers with wideband characteristics. In the existing literature, multiple designs have been introduced to enhance absorption bandwidth through the incorporation of losses. A lossy 3D periodic structure was presented in [47]-[49], to achieve wideband absorption. However, such approach makes the absorber very thick and complex.

An alternative strategy for improving absorption bandwidth while maintaining optimal thickness performance involves employing a low-pass lossy square patch array [50]. However, these structures are characterized by multiple layers. Another method for achieving bandwidth enhancement is the customization of multiple resonances using various resonators [51]. Additionally, there are absorbers with a reasonably low profile and wide bandwidth that have been introduced [52]. Consequently, efforts to enhance absorption bandwidth include the development of wideband absorbers with dual [53],



(a) **(b)**

Fig. 1.10: Illustration of rigid wideband absorber (a) 3D view of hexagonal artificial impedance surface based absorber (b) simulated and measured reflection coefficient [49].



(a) **(b)**

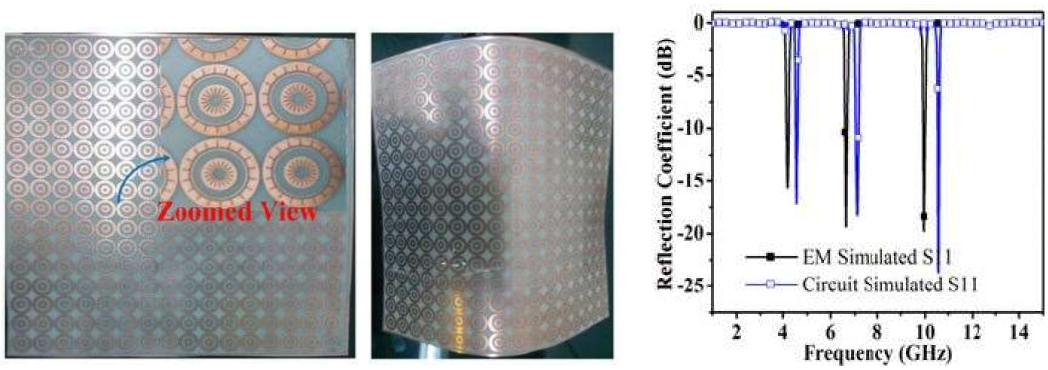
Fig. 1.11: Illustration of rigid wideband absorber (a) criss-cross mesh based meta atom (b) simulated absorptivity response under oblique angle for azimuthal angle φ= 0°, 45°[51].

[54], or multiple resonances [55]. Some rigid and thick wideband absorbers based on lossy periodic surfaces, along with their frequency response, are illustrated in Figs. 1.10 and 1.11. While many of the absorbers documented in the literature showcase improved bandwidth performance, a notable drawback is the inability to independently adjust each resonant frequency. Consequently, the design flexibility of these absorbers is limited when it comes to adapting to a variety of devices in practical scenarios.The fourth chapter of this thesis provides effective solutions of these challenges.

In the stealth technology alongwith wideband absorption one of the most important feature of radar absorbing surface is polarization insensitive performance with high obliquie incidence characteristic. Polarization insensitive is realized when the structure is four fold symmetric [27], [56]. As disscussed, the wideband performance of the absorber depends on specific thickness requirements. However, as the thickness increases, the absorber becomes more sensitive to higher angles of incidence due to inherent difficulties in impedance matching to free space [57]-[61]. Therefore, polarization-insensitive characteristic with high obliquie performance are mainly limited to a single narrowband [60]-[62], multiband [65]-[68], wideband [69], [70], [71]. However, the majority of these reported polarization insensitive structure have complicated geometry and limited bandwidth at high obliquie incidence. The fundamental reason for the bandwidth reduction at the higher obliquie incidence is that the parallel magnetic field component reduces to zero and is unable to cause antiparallel surface current at the top and bottom metallic layers of the absorber [27]. Thus angular and polarization state stabilty along with wideband absorption are one of the main requirement for the researchers for the development of thin absorber.

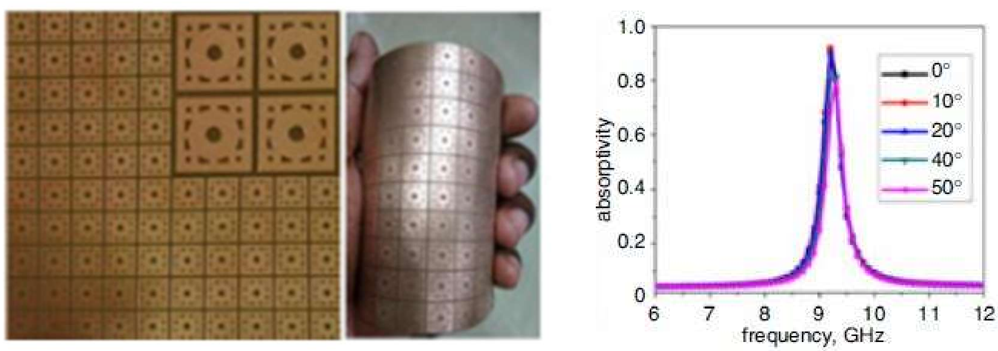
For the civil, military, and other practical applications, where surfaces are not planar, all these rigid absorbers [7]-[9], [15]-[17], [19], [22]-[24], [29]-[37], [47]-[56], [61]-

[71] have very limited scope. In practical scenarios where absorbers need to be deployed over curved surfaces, there is growing demand for conformal absorbers. As a result, the substrate needs to exhibit flexible or conformal properties to fulfill these criteria. Different additive manufacturing techniques have been explored for creating conformal absorbers based on various periodic surfaces, such as metamaterials (MTMs), metasurfaces, and frequency-selective surfaces (FSSs) [72]-[85]. Over the last decade, various attempts have been made to achieve single-band [72], dual-band [73], and dual- and-triple-band [74], [75] conformal absorbers. Illustrations of such conformal multiband and narrowband absorbers are given in Figs. 1.12 and 1.13, respectively.



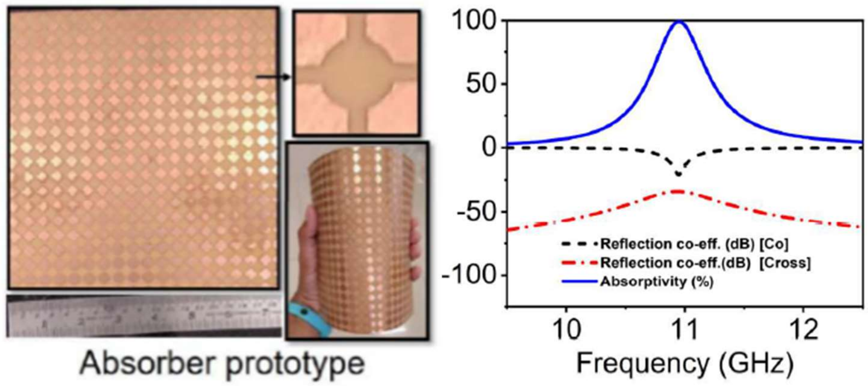
(a) **(b)** **(c)**

Fig. 1.12: Illustration of thin multiband conformal absorber (a) for flat surface (b) for curve surface (c) EM and circuit simulated reflection coefficient response [74].



(a) **(b)**

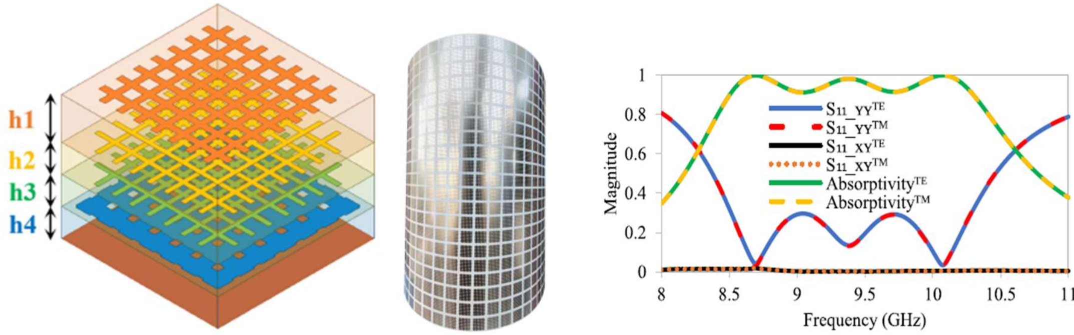
Fig. 1.13: Illustration of flexible narrowband metamaterial absorber (a) fabricated absorber(b) absorptivity response under different oblique incidence for TE polarization [72].



(a) **(b)**

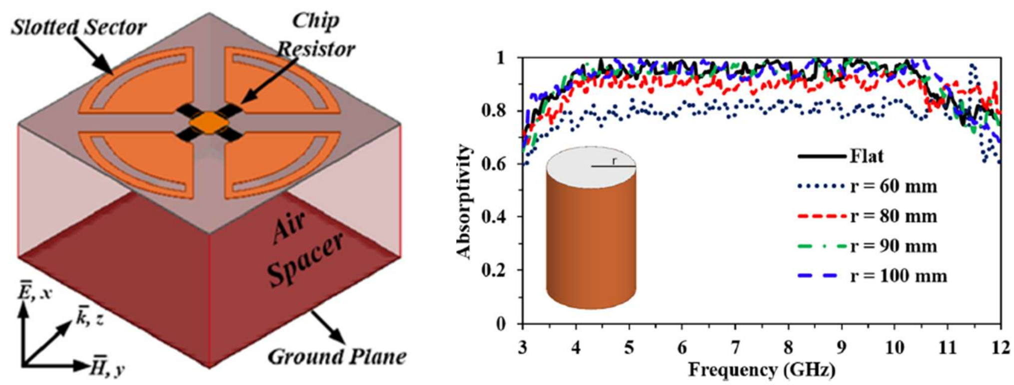
Fig. 1.14: Illustration of low cross polarization level flexible narrowband absorber (a) fabricated prototype (b) simulated absorbance and reflection coefficient [76].

In recent developments, a low cross-polarization level, narrowband absorber was created using a convolved FSS, as illustrated in Fig. 1.14. Nonetheless, these absorbers face challenges associated with narrowband issues due to their resonant properties [76]. Bandwidth can be improved by using lossy FSSs/MTMs with the help of various additive manufacturing method. Inkjet printing technique was used to print the high-cost silver nanoparticle conductive ink on multilayer paper [77]-[80]. One of the inkjet-printed broadband conformal absorbers, along with frequency response, is depicted in Fig. 1.15. Screen printing technique was used to print graphene nanoflakes [81], carbon based paint [82]. While these additive manufacturing methods were more straightforward, they concurrently encounter challenges related to optimal surface resistance. This issue arises because optimal surface resistance depends on uniform coating, and for periodic surfaces, it is contingent on the thickness, permittivity, and substrate thickness of the structure. On the contrary, lumped resistors offer precise resistance values, and by loading them with periodics surfcae, broadband [83], wideband absorption [84], [85] have been achieved. One of the lumped resistor-loaded broadband conformal absorbers, along with its frequency



(a) **(b)** **(c)**

Fig. 1.15: Illustration of broadband inkjet printed conformal metamaterial absorber (a) isometric view (b) fabricated prototype (c) simulated co-, cross- polarized reflection coefficient and absorptivity reponse [77].



(a) **(b)**

Fig. 1.16: Illustration of lumped resistor loaded wideband conformal metamaterial absorber (a) fabricated unit cell geometry (b) absorptivity response for different bending radius [75].

response, is depicted in Fig. 1.16. As previously mentioned in the context of rigid absorbers, in the literature, various conformal absorbers ([72]-[74], [81]- [85]) also suffered from lack of information regarding the CPRC of incident wave. Additionally, most of the reported conformal absorbers demonstrate their flexibility on curved surfaces, but they rarely discussed about bending angular stability [72], [77]. The third chapter of this thesis overcomes all these issue and presents a low cross polarization level conformal ultra-wideband absorber along with bending angular stabilty performance.

1.8 Motivation behind the present thesis

The motivation behind this thesis is design, modeling, and analysis of artifitial engineered structure based ultra-wideband absorber for planar and conformal application with optimal performance. Existing literature has notable gap in the critical analysis of wideband absorber, which hinders the development of efficient ultra-wideband absorbers. A crtical analysis is necessary to show that anisotropic geometry is not a good choice for the development of ultra-wideband absorbers and to uncover the true nature of such claimed absorbers. Since the cross-polarized component may be excited in the geometry, therefore the derivation and evaluation of radar cross section performance by incorporating cross-polarized reflected component of the incident wave in the estimation, are urgently needed. The design of ultra-wideband absorber is increasing day by day with the advancement of electronic equipment and wireless technology. In contemporary times, researchers need to take into account essential factors such as scalability across a broad frequency range, a low-profile design, independent control over the operating band, and some degree of miniaturized performance. All these considerations must be incorporated while ensuring the absorber maintains conformal characteristics for practical applications.

In conclusion, this thesis addresses existing limitations and simultaneously realizes the key characteristics mentioned above in the development of absorbers. It provides solutions that are both practically impactful and theoratically robust.

1.9 Organization of thesis

This thesis comprises five chapters. Chapter 1 begins with a historical overview and discusses the limitations of traditional absorbers and their solutions through an artificially engineered-based periodic surface. The absorption mechanism is elaborated based on the impedance matching approach and the concept of the transmission line model. Transmission line models for generic metal back absorbers are utilized to classify absorbing configurations. Furthermore, a state-of-the-art review of various absorbing configurations based on periodic surfaces is discussed, and research gaps are identified as motivation for presenting this thesis. Finally, the motivation and structure of the thesis are presented.

Chapter 2 delves into the difficulties associated with designing wideband or ultra-wideband absorber using low loss periodic surfaces. This chapter provides a critical analysis of the manuscript published by Si-Jia-Li *et al.* [33].

In Chapter 3, focus is on the design, modeling, and analysis of ultra-wideband absorber utilizing two concentric resistive serration ring metasurfaces. The proposed absorber exhibits conformal behavior along with low cross-polarization level and low radar cross section characteristic.

Chapter 4 presents a the design, modeling, and analysis of conformal ultra-wideband absorber using three concentric resistor embedded rings. In this chapter, along with low profile, ultra-wideband performance, low cross-polarization characteristic, we have designed absorber in which each resonant frequency and hence operating bandwidth can be independently controlled to adopt variety of devices.

Chapter 5 concludes the major contribution and future possibilities of the thesis.