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Design, Fabrication and Characteristics of Microwave Absorbing Materials in Stealth Application: A review

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The paper presents a perspective view of the current research in developing variety of microwave absorbing materials suitable for stealth application and electromagnetic interference (EMI) minimization. The stealth technology refers to reduction in radar cross-section (RCS), a measure of aircraft signature so as to make it nearly invisible to the enemy's tracking system up to a certain distance for certain frequency, for a successful air operation. The reduction in RCS is achieved by coating the object with microwave absorbing material. The paper also describes techniques to achieve optimum absorption for specific range of operation in terms of its electric and magnetic properties, thickness and order of layers in multilayered microwave absorbing materials, including frequency selective surfaces (FSS) or circuit analog (CA), as well. These provide more design options by introducing inductive and capacitive loss mechanisms in addition to resistive loss.

Keywords: Stealth technology, Radar cross- section, Microwave absorbing material

Introduction

Stealth is one of the key factors for establishing air superiority in modern warfare by reducing the aircraft signatures and observables, so as to evade the enemy's air defense system. The stealth aircraft with precision-guided missiles has become a powerful weapon. Stealth technology is also applicable to ships, submarines, tanks, armored vehicles, etc. There has been a substantial progress in stealth technology, especially, in terms of development in microwave absorption technology in search of lightweight, high strength, durable materials. The coatings of these materials not only effectively reduce the reflection of radar waves, but also possess good physical performance for all-weather operations like resistance to corrosion, radiation, temperature and friction, having lower production cost as well.

This review gives a brief introduction of stealth technology and principle of radar operation and focuses mainly on the development of various types of microwave absorbing materials and their characteristics i.e., composition and construction, thickness, characteristic frequency of operation etc.

Stealth Technology

Aircraft stealth basically depends on the type of signatures emitted by it. The aircraft signatures can be broadly classified as active and passive. Active signatures are produced when the radar signal of the order of few hundred MHz or more sent by the enemy towards the target aircraft is reflected back by it. The characteristics of these reflected signals provide necessary information about the target. Passive signatures are generated due to the signals emitted by the aircraft as a result of its existence which cover a wide frequency range that consists of audio waves, radio waves, and radiation in the infrared and visible spectrum. Except the audio waves, all the other types of signatures are electromagnetic in nature. Passive systems have a great strategic advantage that they do not give away their location in pursuit of the target. Stealth aircraft can fly at relatively high altitudes over enemy's territory unlike conventional aircraft, giving a broader situational awareness and less fatigue to the pilot. It allows targets to be detected at a greater range, and gives a vertical bomb impact, improving the accuracy and penetration. Capable of destroying multiple targets in a single mission, they are proved to be cost effective too. These factors boost the morale and confidence of the troops. At present very limited countries have the technology to build exclusively stealth aircraft and are reluctant to share it with any other country.

Related Works

Stealth is one of the most challenging fields of research due to the advances in the target detection

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technologies. The detection devices include radars, lasers and sensors in infrared, visual, near infra-red ranges[1]. The radars are among the major threats having wide frequency range and due to the fact they are operational 24/7 in all weather conditions and provide precise information of the targets in the range. Various types of radars are used for different purposes. Lower frequency range (0.1-1GHz) radar is used for surveillance and detection in VHF(0.03-0.3GHz), UHF (0.3-1GHz) and S-Band (2-4 GHz) medium frequency radars are used for tracking the target, usually in C(4-8GHz) and X (8-12GHz) bands, and higher frequency radars are the radars onboard aircraft in Ku (12-18GHz), K (18-27GHz), Ka (27-40GHz) bands.

In countering the detection through radar, radar cross-section (RCS) of the target plays an important role. As most of the radar systems use RCS as a means of discrimination, RCS prediction is crucial in developing discrimination algorithms. Theoretically, two types of RCS prediction methods are available-exact and approximate. Exact methods use solving of Maxwell's equations which have computational problem. Some of the most commonly used approximate methods are Geometrical Optics (GO), Physical Optics (PO), Geometrical Theory of Diffraction (GTD), Physical Theory of Diffraction (PTD) etc.

RCS, which is the measure of detectability of the target, is defined as 4π times the ratio of the power per unit solid angle scattered in a specified direction, to the power per unit area of a plane wave incident on the target from a specified direction. It depends on various factors such as

(i) the size & surface geometry of the target
(ii) the relative size of the target as compared to the wavelength of the illuminating radar
(iii) the reflectance *r* of the target, which in turn depends on the polarization (perpendicular or parallel) of the incident wave as well as its angle of incidence at the target
(iv) the electromagnetic (EM) properties such as electric permittivity and magnetic susceptibility of the target material.
(v) Besides structure, target propulsion and avionics also affect the RCS of aircrafts, satellites etc.

In order to make the target invisible to radar the RCS should be as low as possible. In the following section, various RCS reduction methods are discussed.

RCS Reduction Techniques

The main techniques of RCS reduction can be broadly classified into shaping and distributed loading.

Shaping

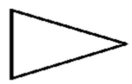
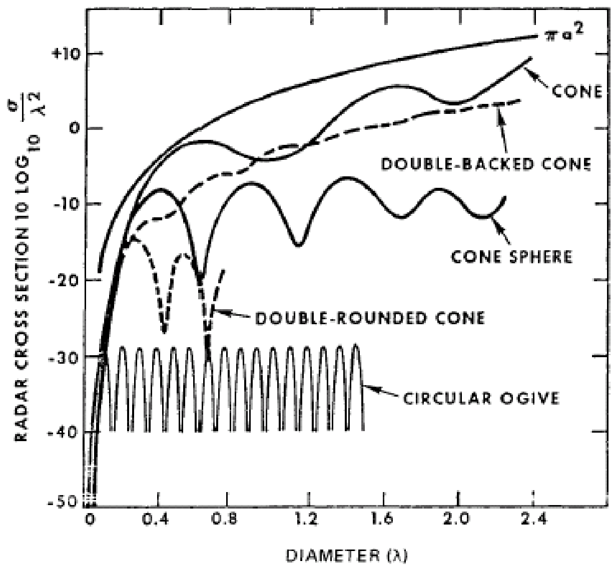
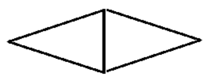
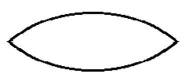
The RCS for spherical objects of radius r is given by πr^2, for cylindrical objects of radius r and length l, it is $2\pi r h^2/\lambda$, whereas for flat objects having length l and breadth b, it is $4\pi l^2 b^2/\lambda^2$. Table 1 gives the RCS for some specific shapes and are compared with that of spherical target which is the maximum among other shapes considered and is independent of frequency if operating at sufficiently high frequencies where $\lambda <<$Range, and $\lambda <<$ radius (r). The circular ogive is found to have minimum RCS with regular oscillating nature. Different parts of the target reflect the signal in different directions depending on surface geometry. The resultant RCS is a vector sum of all these returns. In fig.1 the polar plot of RCS for a re-entry vehicle as an example of cone sphere object[3] is shown that shows the dependence of RCS on aspect angle (the angle between the target heading direction to the line of sight of the radar).

The RCS for any object can be reduced by not allowing the incident wave to reflect back in the same direction, with appropriate shaping of the aircraft. This is particularly effective against mono-static radars. This is done in following two ways:

i. By adapting a compact, smooth blend external geometry as in the B-2 bomber which has low-drag flying wing appears as an infinite flat plate having many curved and rounded surfaces across its exposed airframe for deflecting the incident microwave with radar cross-section of ~0.1sq.m[4].
ii. By adapting a faceted structure having flat surfaces arranged in such a way that these are, in general, not normal to the incident EM wave, thus, minimizing the normal reflection back towards the illuminating radar as in the Lockheed F-117A having radar cross-section of ~0.001sq.m[5].

Shaping alone is not sufficient to reduce RCS to the desired level of being invisible to radar specially in stealth application. The other factors include minimizing overall size of the aircraft, by treating the interior with a thin conducting layer, using composites which have impedance nearly equal to that of air, and thus are poor reflectors of the microwave beam.

Table 1 — RCS for different shaped targets (Eugene F. Knott, "Radar Cross Section", Radar Handbook, McGraw-Hill, 1990.

	Shape	RCS as a function of diameter/wavelength (adopted [2])
Cone		
Double backed cone		
Double rounded cone		
Ogive		
Cone sphere		The RCS calculations are done for all the shapes except sphere for nose angle 40^0

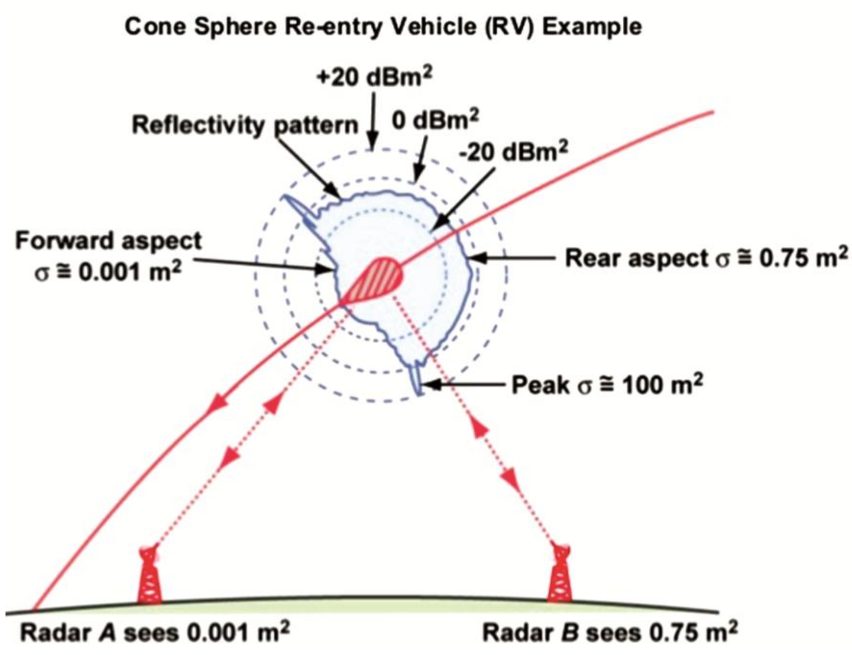


Fig. 1 — RCS of a Re-entry vehicle as an example of cone sphere (adopted[3]).

Distributed loading

Distributed loading is the technique of covering the aircraft with suitable microwave absorbent materials (MAM) or radar absorbent material (RAM). The application of RAM began before and during the WORLD WAR II with the first patent in 1936[6], in which a quarter-wave resonant type RAM from two different materials, titanium dioxide acts as high permittivity material and carbon black as lossy resistive material was proposed. In the beginning, the use of RAM was limited to defense/ military purposes. The information regarding researches in this field was rarely published due to security concerns. In the recent times, due to the rapidly growing applications of GHz electronic systems and telecommunications, the number of publications of research in the field of electromagnetic-absorber technology has increased by many folds.

When a radar signal strikes the surface of an aircraft, some part of the energy of the incident radiation is absorbed and the rest of it is reflected back. The propagation of waves through a medium depends on its refractive index n and the characteristic impedance Z_m which are defined in terms of permeability and permittivity of the medium as follows:

$$n = \pm\sqrt{\mu^* \varepsilon^*} \quad \text{... (1)}$$

$$Z_m = Z_o \left(\frac{\mu^*}{\varepsilon^*}\right)^{1/2} \tan\left[j\frac{2\pi f d}{c}(\mu^* \varepsilon^*)^{1/2}\right] \quad \text{... (2)}$$

Where c is the velocity of wave, μ^* and ε^* are the complex permeability and complex permittivity of the material and d its thickness.

The reflection coefficient is given by:

$$r = \frac{|Z_m - Z_o|}{|Z_m + Z_o|} \quad \text{... (3)}$$

or the reflection loss

$$RL(dB) = 20\log\frac{|Z_m - Z_o|}{|Z_m + Z_o|} \quad \text{... (4)}$$

where Z_o is the wave impedance of free space. It shows very low reflectance for $Z_m \cong Z_o$. Under this condition, the RAM will be able to absorb much of the energy of the impinging signal. However, most of aircrafts are made of metals that have low impedance and hence, high reflectance to radar waves. In order to absorb energy, materials must generate induced currents that are in phase with the incident fields. Carbon is mostly used for energy dissipation, but materials, like the lossy-dielectrics, whose indices of refraction are complex numbers (the imaginary part of which is responsible for losses) can also be used for energy dissipation. Rubber, polyurethane or silicone matrix loaded with ferrites fall under the category of magnetic absorbers. In the next section, the designing of different types of microwave absorbers are reviewed.

Types of microwave/ radar absorbers

Microwave absorbers are filled with dielectric materials like foams, plastics, rubbers, and poly pyrroles as the amount of energy lost depends on the frequency of the wave and the dielectric constant of the material. Absorption materials can be chosen from a wide range of materials depending on the range of frequency for the desired applications. These nonmagnetic, environmentally resistant absorbers often contain magnetic materials having high magnetic permeability as fillers. The dielectric permittivity and magnetic permeability of the composite materials can be changed to achieve maximum absorption. The goal of the researchers in the field is to balance electromagnetic performance, thickness, weight, mechanical properties and cost to have optimum results by applying various techniques. Practical microwave absorbers are, in general, resonant and graded dielectric type.

Resonant absorbers

Resonant materials, also known as quarter wavelength absorbers, include Salisbury Screen, Jaumann layers and Dallenbach layers (Fig. 2). Salisbury Screen was one of the first concepts in radar absorbent material[7], invented in 1940's (patented in 1952) applied for ship radar cross section (RCS) reduction. It consists of a resistive sheet spaced one-quarter wavelength of the incident wave from a conducting metal plate. The thickness d of the resistive sheet is such that its resistance matches with the impedance of free space i.e. 377 Ω, which is given by

$$d = 1/(\sigma Z_o) \quad \text{... (5)}$$

where σ is the conductivity of the material of the resistive sheet.

A wave incident on the surface of the screen is partially reflected and partially transmitted. The transmitted wave suffers multiple internal reflections resulting in a series of emergent waves. The sum of these emergent waves is equal in amplitude to the initial reflected portion but, 180° out of phase with it, theoretically producing no reflection at that frequency. Practically, however, absorption >30dB (99.9%) may be achieved with it. The biggest disadvantage with the Salisbury Screen is that it works well only at the frequency for which it is designed. The enemy, thus, just has to change the wave frequency to beat its purpose as stealth. Another disadvantage is its increased thickness, especially at lower frequencies. So, to cover a frequency band a multilayer Salisbury Screen is required which again adds to the thickness, degrading the aerodynamic performance of the screen.

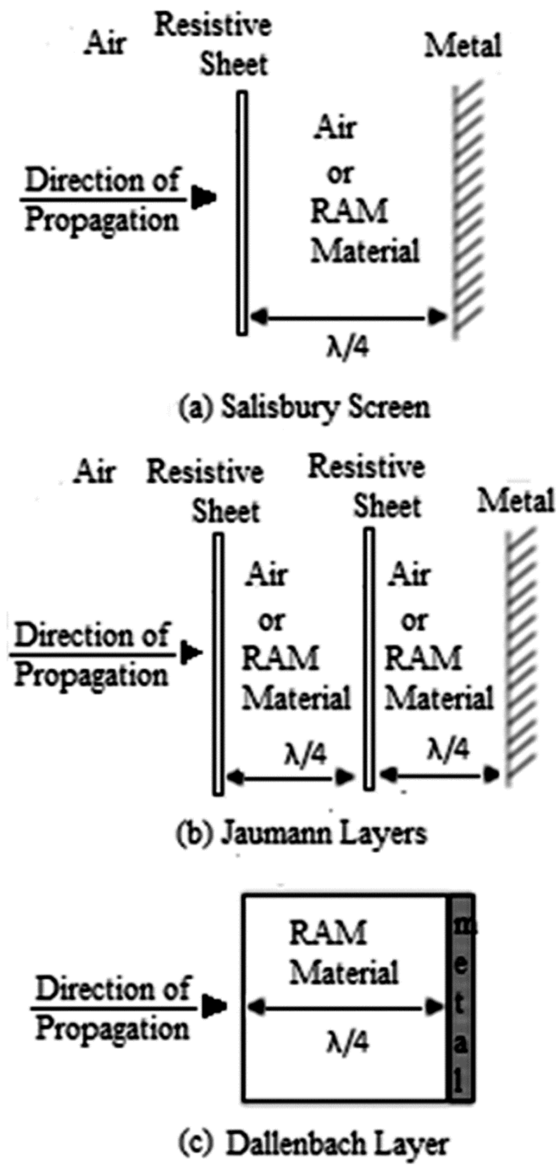


Fig. 2 — Resonant absorbers

An advancement over the Silsbury screen, the simplest Jaumann layers depicted in Fig. 2(b) are designed[8], consisting of two equally spaced resistive sheets in front of a metal plate, increases the band width as it produces two minima in the frequency versus reflectivity plot. Resonant materials can also be produced to absorb at multiple frequencies by controlling the magnetic/dielectric loading and thickness of each layer. To increase the flexibility of the resonant absorbers, a conducting sheet in geometrical patterns like dipoles, crosses, triangles etc. are used which are known as frequency selective Surfaces (FSS) or the circuit analog (CA) absorbers,

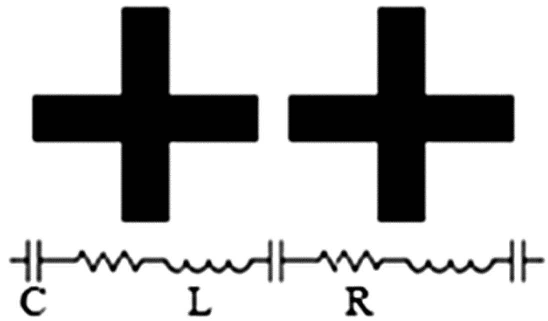


Fig. 3 — Circuit analog of sheet crosses.

as the geometrical patterns are often defined in terms of their effective resistance R, capacitance C, and inductance L. Figure 3 shows a circuit analog of sheet of crosses along with its RLC equivalent circuit. The space between the crosses gives rise to capacitance and the length of the cross represents the inductance whereas the resistance depends on the material used, which in turn, depends on the conductivity of the material used for the geometrical pattern.

The performance of the resonant absorbers decreases as the angle of incidence increases. However, materials have been developed for the absorbers suitable for large values of angles of incidence. These absorbers are generally thin and heavily loaded with fillers.

A Dallenbach layer is slightly different from above two types. It consists of an absorber layer placed on a conducting plate. The thickness, permeability and permittivity of the layer are adjusted for minimum reflectivity at a desired wavelength/ frequency. To achieve a broad band absorber, several Dallenbach layers are stacked. The optimization of reflectivity as a function of frequency and angle of incidence is also studied. Dallenbach layers have been designed using ferrites [9] and silicone rubber sheets filled with carbide, titanium dioxide and carbon black[10].

Graded-dielectric absorbers

In a graded-dielectric microwave absorber, absorption is caused by gradual tapering of impedance from that of free space to a highly “lossy” state. The absorbing medium is basically a conductive carbon in polyurethane foam. The transition can be smooth or stepped. In anechoic chamber materials, gradual tapering is achieved via pyramidal shape of the absorber (Fig. 4). Pyramidal absorbers are thick materials with pyramidal or cone structures in

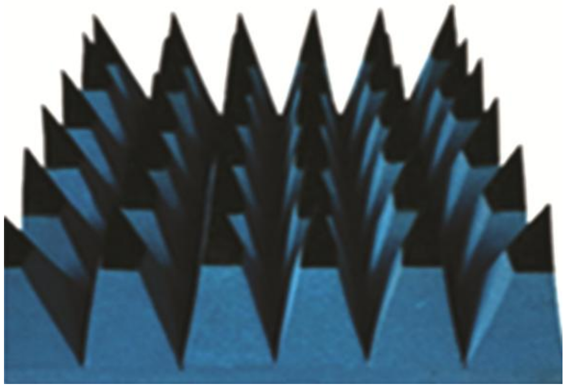


Fig. 4 — Pyramidal absorbers.

regularly spaced pattern. The height and periodicity of the pyramids are of the order of the wavelength. Due to their shape, there exists a gradual transition in the impedance of air to that of absorber, more abrupt change in the impedance is found in relatively shorter structures for longer wavelengths. The disadvantage of these absorbers is their fragility which is overcome by designing flat pyramidal absorbers using multilayers. A gradual impedance transition is achieved via a conductive carbon coating. This method of gradual transition can be applied to other materials as honeycombs and netting also. These absorbers are light weight so may be useful for aircraft manufacturing[11].

Multi-layered Absorption Layers for optimum Absorption

To increase the absorption multi-layered absorption sheets are used of different materials A metal plate coated with multilayer microwave absorber is depicted in Figure 5. The thickness, complex permittivity, complex permeability and intrinsic impedance of the i th layer for the multi-layer absorber are represented by t_i, ε_i, μ_i and $Z_{m,i}$,respectively. For the normal incidence of the wave, the reflection loss is given by

$$RL(dB) = 20\log\frac{|Z_{m,n}-Z_o|}{|Z_{m,n}+Z_o|} \quad \dots (6)$$

Here n is the total number of layers.

To get the optimum reflection loss with minimum thickness that is cost effective too, various composite materials of different material layers are considered and optimized. Genetic Algorithm (GA) is very powerful tool for this purpose. The method is very well described in earlier works[12,13]. The fitness function (F) for optimization given by equation (7) is to minimized to optimize different parameters

$$F = |RL_{computed} - RL_{observed}|^2 \quad \dots (7)$$

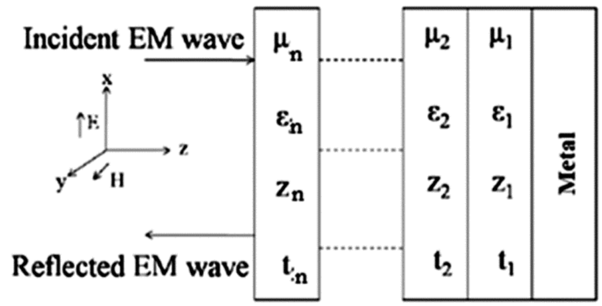


Fig. 5 — Multi-layered absorption material backed by metallic layer.

In a recent study[14], a method for designing microwave absorbers with carbon nanocomposite layer assembly is demonstrated using a numerical optimization algorithm for deciding the layer sequence, material configuration and thickness of the absorber. The method is experimentally verified by manufacturing three multilayered structures and measuring their microwave reflection coefficient in the frequency range of 2–18 GHz.

Microwave absorbers using ferrites

The ferrite materials like hexa ferrite and spinel ferrite are established as one of the main constituents in magnetic radar absorbing materials. Ferrites are metal oxides having good dielectric properties along with spontaneous magnetization. Recent research is on designing various composite materials suitable for RAMs having high absorption in GHz range, wide bandwidth and decreased thickness suitable for all weather conditions which is cost effective too. Many microwave absorbing materials are fabricated using various methods and their dielectric and magnetic properties along with radiation loss is studied and reported in literature [15-18]. New compositions have been developed comprising of composite powders to fulfill the need of large absorption peak, wide frequency range and thin absorption layer.W-type barium ferrites with rare-earth elements (RE) substitution was prepared by chemical co-precipitation method[15]. The analysis of the effects of rare-earth elements (RE) substitution on microstructural and electromagnetic properties show that Dy-substituted ferrite composite has excellent microwave absorption properties with peak absorption of -51.92 dB at a matching thickness of 2.1 mm and bandwidth more than 8.16 GHz. Fe/Ferrite composite prepared by chemical reduction method showed that with the increase in temperature, the ferrite magnetic resonance peak shifted towards lower frequency[16].

The absorption performances of microwave absorbers made of ferromagnetic films was studied using Ni–Zn–Co ferrite film and iron nano film with periodic multilayer structure. These absorbers have good absorption performances in broadband microwave frequency range[19].

Microwave absorbers with nano particles composites

Variety of nano particles materials such as alumina, micro and nano sized SiC, SiO_2, zinc, calcium carbonate, carbon black nanoparticles, carbon nano tubes etc. are used as fillers to enhance material properties of polymer nano composites. Studies of magnetic and electromagnetic wave absorption properties are reported for α – Fe (N) nanoparticles[20]. Similar studies for magnetic –thermoplastic natural rubber nanocomposites[21] showed that with the increase in the filler content in the composite, the maximum attenuation is shifted to lower frequency and the bandwidth is increased. Reflection loss also increases with increasing sample thickness but in the lower frequency range. The absorbing properties of composites with multi- walled nano tubes (MWNTs) and carbonyl iron are studied under the application of strain[22]. The study of absorption properties of toroidal shaped composite prepared using carbon black nano powder mixed in poly urethane (PU) matrix[23] shows maximum absorption of -32.74dB at 13.52 GHz for 6mm thickness. A wave absorber was produced by using MWCNTs and magnetic ferrite nanoparticles nucleated on reduced graphene oxide sheets (rGO–Fe_3O_4) in biphasic polymeric blends of polycarbonate and poly(styrene-co-acrylonitrile) (SAN) had excellent electromagnetic wave absorption (-50.7dB at 18 GHz), greatly enhanced in comparison to blends containing either only MWNTs or only rGO–Fe_3O_4[24].

Microwave absorbers using meta materials

Meta materials are a new class of ordered composites that exhibit exceptional electromagnetic properties, which are, generally, not found in naturally occurring substances. These materials are also known as left handed materials (LHMs) as in such materials *E*, *H* and *k vectors* of a plane electromagnetic wave form a left-handed system and have negative refractive index. These are prepared from microstructures having size smaller than the wavelength of operation having desired permittivity and permeability for any selected range of frequency. The discovery of the artificial/meta materials is assumed to be originated in 1898 when Sir J. C. Bose showed that the plane of polarization of the wave is rotated by man-made twisted structures, now known as artificial chiral structures. Veselago[25] theoretically predicted the electro-dynamic characteristics of media with negative permittivity and permeability. But no attention was given to his work as no material existed in nature with these properties. In 2000, Smith[26] constructed Wire/SRR (split ring resonator) structure having negative permittivity and permeability in microwave region now known as meta material. Since then, a number of studies regarding the characteristics of these materials have been reported in literature. Magnetic field tunability was demonstrated for low loss negative index materials in microwave region using yttrium iron garnet and periodic array of Cu wire[27]. The tuning frequency measured was 5GHz with the 0.9GHz bandwidth. Tao *et al.*[28] have reported fabrication of meta material only 16μm thick producing 97% absorption at 1.6THz. Wang *et al.*[29] designed a polarization dependent wide angle three dimensional meta material absorber with near unity absorption 99.2% composed of coplanar electric and magnetic resonators with no metallic backing plate and resistive sheet, greatly reducing its weight as well as thickness. These materials can have other applications including as humidity sensor, phase compensator, cloaks, antenna, besides applications in stealth technology[30].

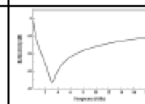
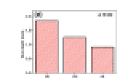
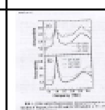
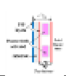
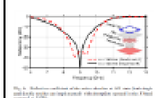
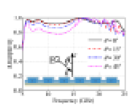
Tunable absorbers

For multi-frequency and multi- functional applications, passive components with tunability are required. Tunable absorbers now days are designed using tuning components like PIN diodes, ferro-electric varactors, liquid crystal polymers etc.[31-35]. However, their venerability to extreme temperature conditions and electromagnetic radiation from high power microwave energy tracking radar system put a limit on their application as microwave absorbers.

Plasma absorbers

The concept of plasma as a microwave absorber was first put by Arnold Eldredge, in 1956, who proposed using a particle accelerator in an aircraft to create a cloud of ionization that would refract or absorb incident radar beams[36]. In 1962, Nihmias proposed radioactive coating applied to the surface of an aircraft, to create plasma cloud around it to absorb electromagnetic wave[37]. The attenuation of electromagnetic waves by the ionized medium was mainly due to the free electrons in the plasma. The

Table 2 — Absorbers using different materials along with their characteristic frequencies.

Material used	formula	Thickness	Absorption	Bandwidth	Reference
Absorbers using Ferrites	(i) Rare earth substituted Ferrite $Ba(MnZn)_{0.3}Co_{1.4}R_{0.01}Fe_{15.99}O_{27}$ with R as Dy, Nd and Pr (optimized Result for Dy)	2.1mm	-51.92 dB ~14GHz	8.16GHz	[15]
	(ii) the Ni–Zn–Co ferrite ($Ni_{0.22}Zn_{0.52}Co_{0.03}Fe_{2.23}O_4$) to meet the optimal absorption condition 620 units with the sandwich structure used	0.62 mm	~ -36 dB		[19]
Absorbers using nano particle composites	(i) α – Fe(N) nanoparticles prepared by adding (0.4 at %N) to α –Fe	1.6mm	-37.5 dB at 10.4 GHz	4.5-18GHz	[20]
	MWNTs and magnetic ferrite nanoparticles nucleated on reduced graphene oxide sheets in biphasic polymeric blends of polycarbonate and poly(styrene-co-acrylonitrile) (SAN)		-50.7dB at 18 GHz),	Minimum skin depth for10 wt% rGO–Fe_3O_4 nanoparticles 	[24]
	Toroidal shaped composite samples having Carbon black nano powder (CBP) as filler thoroughly mixed in Poly-urethane	6mm	- 32.74 at 13.52GHz	12.88 GHz - 14.16 GHz	[23]
Absorbers using Meta materials	media with negative permittivity and permeability. Terahertz metamaterial absorber consisting of two metallic layers and two dielectric layers Each dielectric layer, t1 and t2, is 8 µm thick.		0.96 at 1.6 THz and,		[28 .
Plasma Absorbers	When the shells are electrified, the encapsulated gas ionizes to emit, reflect, or absorb EM energy. 	Typical sizes of plasma-shells range from 0.5 to 10 mm Min. at10.2mm	-50dB at 9GHz		[38]
Absorbers using water	a water cylinder placed between a cylindrical resin cap and a bottom spacer layer made of polymethyl methacrylate (PMMA). 	Optimized values h_s=0.8mm h_d=3.8mm t_c=1mm	90% over entire 5.58 to 24.21 GHz		[41]

degree of attenuation depends on the thickness of the absorbent layer, the densities of the molecules, atoms and electrons in medium and the frequency of the electromagnetic wave. The density of electrons, in turn, depends on the intensity of radioactivity. The radioactive substance used should have no adverse biological effects, longer half-life and sustainability to high temperatures, about 500°. Also, it should be available in sufficient quantity and at a reasonable price. Of the known radioactive substances fulfilling the above requirements, strontium 90 is preferable, having a half-life of 28 years which emits relatively soft beta particles having an energy of 0.5Mev and converting to yttrium 90 having a half-life of 61 hours. Neither strontium 90 nor yttrium 90 is gamma ray emitters[38]. Not much work has been reported since then. However, in a very recent study, the feasibility of devising a practical large-scale wideband absorber based on plasma technology is investigated which showed that absorption center frequency band and bandwidth of the passive absorber fabricated by integrating plasma shells with circuit analog absorbers can be controlled by altering the plasma frequency. They claimed that their novel approach is an improvement over other absorbers in harsh and dynamic electromagnetic environment making it applicable in stealth applications.

Absorbers with water resonators

During the last few years, water has been used in designing various types of microwave antennas not only due to its low cost, easy accessibility and low pollution causing properties but also it shows a high dielectric loss, at microwave frequencies. The dependence of real part of the permittivity of water strongly on frequency has added advantage of an ultra-broad operating bandwidth. A meta material absorber using periodic water droplets was proposed for the first time, covering the range of 8–18 GHz[39]. Pang *et al.*[40] have proposed a thermally tunable broadband meta material absorber based on a water substrate. Ren &Yin[41] have investigated the design of a cylindrical-water-resonator-based absorber with an absorptivity more than 90% over entire 5.58 to 24.21 GHz frequency band, applicable in a wide range of angles of incidence and exhibiting a weak temperature dependence. The low cost ultra-broad operating band, good wide-angle characteristics, and thermal stability make these absorbers promising for applications in antenna in antenna measurement, stealth technology and energy harvesting. Table 2 presents the responses of various absorbers, including optimized thickness, absorption, bandwidth etc.

Conclusions

This paper briefly covers the history of the development of stealth technology and discusses the application of radars in stealth technology in establishing air superiority. Various RCS reduction techniques are discussed along with the methods for fabrication of RAMs with different materials, ranging from ferrites, nanocomposites, meta materials, plasma, foam, plastics, rubber and metals etc., for achieving maximum absorption in microwave range, using optimizing techniques for designing them depending upon the frequency range for the desired application. The reported studies show that the electromagnetic and absorption characteristics including percentage absorption and the bandwidth can be greatly enhanced by varying the relative composition of composites components. Recent developments in microwave absorber technology have resulted in materials which in addition to effectively reducing the reflection of electromagnetic signals, possess good physical performance like strength weatherabilty, etc. with lower production cost, as well.

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