Chapter-8

Radar Absorbing Materials

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Microwave Radar Absorbing Radar Materials (RAM) absorbers have been used in military applications for several decades. They have been traditionally used for electromagnetic interference (EMI) reduction, antenna pattern shaping and radar cross section reduction. More recently with the rise of wireless electronics and the movement to higher frequencies microwave absorbers or “noise suppression sheets” (NSS) are used to reduce electromagnetic interference (EMI) inside of the wireless electronics assemblies. The working mechanism of RAM, different types of RAM are discussed in this chapter with a brief literature review.

1. INTRODUCTION

As the name implies Radar absorbing material (RAM) absorbs something and that something is nothing but the microwave energy. Radar is a sensitive detection device and since its development, methods for reducing microwave reflections have been explored. Microwave is a part of electromagnetic radiation with wavelengths ranging from one meter to one millimetre that is why it is called millimetre wave; with frequencies ranging from 300 megahertz (MHz) to 1000 gigahertz (GHz).

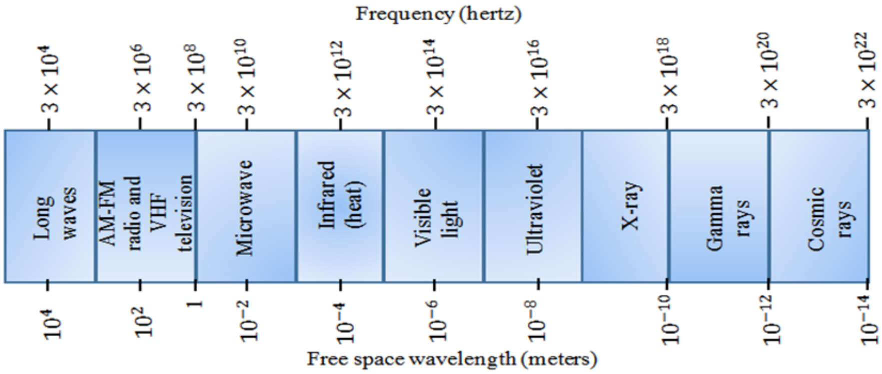


Fig. 1: The electromagnetic spectrum.

The diagram of the electromagnetic spectrum in Fig.1 illustrates the lower end of the microwave region borders radio and television frequencies, while the upper end is adjacent to the infrared and optical spectrums**.**

Most applications of RADAR technology make use of microwave frequencies in the 1 to 40 GHz range. One set of microwave frequency bands designations by the *Radio Society of Great Britain* (RSGB), is tabulated below [1]:

Table 1: Microwave frequency bands.

Designation	Frequency range (GHz)	Wavelength range	Typical uses
L band	1 to 2	15 cm to 30 cm	military telemetry, GPS, mobile phones (GSM), amateur radio

S band	2 to 4	7.5 cm to 15 cm	weather radar, surface ship radar, and some communications satellites (microwave ovens, mobile phones, wireless LAN, Bluetooth, GPS)
C band	4 to 8	3.75 cm to 7.5 cm	Long distance radio telecommunications
X band	8 to 12	25 mm to 37.5 mm	satellite communications, radar, terrestrial broadband, space communications
Ku band	12 to 18	16.7 mm to 25 mm	satellite communications
K band	18 to 26.5	11 mm to 16.7 mm	radar, satellite communications, automotive radar
Ka band	26.5 to 40	5.0 mm to 11.3 mm	satellite communications
Q band	33 to 50	6.0 mm to 9.0 mm	satellite communications, terrestrial microwave communications, radio astronomy, automotive radar
U band	40 to 60	5.0 mm to 7.5 mm	
V band	50 to 75	4.0 mm to 6.0 mm	millimeter wave radar research and other kinds of scientific research
W band	75 to 110	2.7 mm to 4.0 mm	satellite communications, millimeterwave radar research, military radar targeting and tracking applications

F band	90 to 140	2.1 mm to 3.3 mm	SHF transmissions: Radio astronomy, microwave devices/communications, wireless LAN, most modern radars, communications satellites, satellite television broadcasting
D band	110 to 170	1.8 mm to 2.7 mm	EHF transmissions: Radio astronomy, high frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner

Radar absorbing material (RAM) reduce the energy reflected back to the radar by means of absorption of electromagnetic wave produced by the radar. RAM is a basic technique for reducing the *radar cross section* (RCS). The detectability of a target is measured in terms of the radar cross section (RSC). Radar cross section is a measure of power scattered in a given direction when a target is illuminated by an incident wave. Another term for RCS is echo area [2].

The RCS-σ is a measure of reflective strength of a target defined as 4π times the ratio of the power per unit solid angle (steradian) scattered in a specified direction to the power per unit area in a plane wave incident on the scatterer from defined direction. It is the limit of that ratio as the distance from the scatterer to the point where the scattered power is measured (r) approaches infinity [2].

$$\sigma = \lim_{r\to\infty} 4\pi r^2 \frac{|E^{scat}|^2}{|E^{inc}|^2}$$

Where, E^{scat} is the scattered electric field and E^{inc} is the field incident at the target [3].

There are four methods of reducing the radar cross section; shaping, active loading, passive loading and distributed loading. Shaping is the first line of reducing the backscattered signal from the object. Although shaping is very important, it redirects the radiation through specular reflection hence increasing the probability of detection from bi-static radars. It provide dramatic reductions in signature over limited aspect angles. Active and passive loading aims to reduce the scattering from hotspot regions through the application of patches. Active materials detect the incident radiation and emit signals of equal amplitude and opposite phase to cancel the signal, while passive materials are designed to modify the surface impedance so as to cancel the scattered signal. The fourth method, distributed loading involves covering the surface with a radar absorbing material that has imaginary components of permittivity and/or permeability (i.e., the electric or magnetic fields of the radiation couple with the material properties and energy is consumed) [2].

The development of increasingly sophisticated radar detection systems reduce the mission effectiveness of many types of weapons platform. Strong attention is now being given to methods of increasing survivability by reducing the detectability or reducing the RCS. Therefore Radar Cross Section Reduction (RCSR) is still a very challenging task for researcher. Although shaping is the most practical technique that can provide dramatic reductions in signature over limited aspect angles, but many situations require absorption of the incident electromagnetic energy, if design goals are to be achieved. RAM materials have attracted considerable attention through absorption mechanism due to the fact that they can absorb microwave energy [4-5]. Therefore, a proper knowledge of the design and application of radar absorbing materials is vital to the engineer whose task is to minimize the radar signature of a vehicle. Radar Absorbing Material (RAM) are used to reduce the RCS by the dissipation of incident energy within the material.

In this chapter the field of microwave (radar) absorbing materials (RAM) is reviewed with consideration of the loss mechanism of RAM, types of RAM, circuit analog and frequency-selective surface, materials behind these devices and a brief literature review.

2. LOSS MECHANISM OF RADAR ABSORBING MATERIAL (RAM)

Radar Absorbing material (RAM) are generally the combination of a filler material and a material matrix. The filler consists of one or more constituents that play the role of majority absorption. The matrix material is chosen for its physical properties (temperature resistance, weather ability, etc.).The study of the physics of electromagnetic wave absorption should begin with the microscopic or quantum theory of materials, but researcher will instead approach this topic with a macroscopic view of electromagnetics. Although the loss mechanisms through which RAM operates are macroscopic in nature (i.e., on the atomic and crystal lattice levels). RAM are based on the fact that when electromagnetic fields passing through some substances then they absorb the EM energy. Such material has complex refraction indices. The imaginary component of the index of refraction accounts for the loss in a material. The term loss refers to the dissipation of power or energy. It is analogous to the energy consumed by an electrical circuit when current passes through it. The loss is actually the conversion of electrical energy into heat. The finite conductivity of the material is the major loss for a dielectric RAM. The magnetization rotation within the domains is the principal loss mechanism for magnetic RAM absorbers.

The analysis of specular RAM is most easily handled by taking a classical transmission line approach to model the reflection and transmission properties of absorbers. The design of RAM is simply the design of a lossy distributed network that matches the impedance of free space to that of a conducting body to be shielded.

For practical purpose researcher are interested in the cumulative effect of *permittivity* and *permeability* of the material which helped to describe the effects of all loss mechanisms. [6]. Absorbers are characterized by their electric permittivity and magnetic permeability. The permittivity is a measure of the material's effect on the electric field in the electromagnetic wave and the permeability is a measure of the material's effect on the magnetic component of the wave. The complex permittivity is generally written as $\varepsilon_r = \varepsilon' - j\varepsilon''$ and complex magnetic permeability is written as $\mu_r = \mu' - j\mu''$. The terms $\varepsilon^{/}$ (and $\mu^{/}$) are associated with energy storage and $\varepsilon^{//}$ (and $\mu^{//}$) are associated with dielectric loss or energy dissipation within a material resulting from conduction, resonance and relaxation mechanisms. Both this parameters contribute to wavelength compression inside the material. Additionally, due to the coupled EM wave, loss in either the magnetic or electric field will attenuate the energy in the wave. Energy loss in a material illuminated by electromagnetic waves comes about through damping forces acting on polarized atoms and molecules and through the finite conductivity of a material [7]. If the complex permittivity and permeability of a material are known over a frequency range then the material's effect on the wave is completely known.An effective microwave absorbing material need to satisfy the impedance matching condition $\mu_r/\varepsilon_r = 1,$ at air-absorber interface where μ_r and ε_r represents complex magnetic permeability and dielectric permittivity, respectively [8].

3. TYPES OF RADAR ABSORBING MATERIAL

In general, radar absorbing materials (RAM) are fabricated in the form of sheets that consist of insulating polymer, like rubber, epoxy resin and magnetic or dielectric loss materials such as ferrite, carbonaceous particles [9-15]. The selection of RAM is a study of compromises in which advantages are balanced against disadvantage. Magnetic absorbers are used widely for operational system. The loss mechanism is primarily due to a magnetic dipole moment, and compounds of iron are the basic ingredients. Magnetic materials offer the advantage of compactness because they are typically a fraction of the thickness of dielectric absorbers. The density of the magnetic composite material for absorber is too high to use them in large quantity as filler of absorbers as it increase the weight of the absorber and are inherently more narrowband than their dielectric counterparts. Again, dielectric absorbers are thick compared to magnetic absorber leading to bulky devices and have larger impedance mismatch at the air-absorber interface [16-17]. Also dielectric absorber are too fragile to use in operational environments. With progressive development of wireless technology, the need of broadband, thin and flexible absorbers become major challenges for modern compact devices.

Generally, there are two types of absorbers: impedance matching or broadband absorbers and resonant absorbers. Broadband absorbers are independent of a particular frequency and can therefore be effective across a broad spectrum. The resonant absorbers are frequency-dependent because of the desired resonance of the material at a particular wavelength. Different types of resonant absorbers are the Salisbury screen, the Jaumann absorber, the Dallenbach layer, crossed grating absorbers.

3.1 Impedance matching or broadband absorbers

The challenging behind the making of a practical RAM is the impedance matching problem. Because the impedance of free space is (Z=377 ohms) and therefore the impedance at the air-absorber interface must be 377 ohm to minimize the reflection. If the impedance seen by the wave at the surface of the material is equal to 377 ohms then zero reflection taking place and the wave will be completely absorbed by the material. There are basically two classes of impedance matching RAM- pyramidal and tapered loaded absorber [18]. For making a broadband absorber the absorber should be bulky so that it has thickness one or more wavelengths.

3.1.1 Pyramidal Absorbers

A broadband pyramidal or impedance gradient absorber offering excellent absorption over a broad frequency range [19]. Pyramidal absorbers are a conventional pyramid with a square base of uniform thickness, tapered to a point. The impedance of the pyramidal absorbers are gradually decreases, starting from 377 ohm at air absorber interface towards the bottom of the absorber which is near to zero ohm i.e., minimum reflection occurred at the interface. This impedance transformation could be done by some specific shape of the absorber like pyramids such that the wave ‘sees’ a small portion of the material at the front face and a gradually increasing portion as it travels into the material as shown in Fig. 2. The height and periodicity of the pyramids tend to be on the order of one wavelength. Pyramidal absorbers thus have a minimum operating frequency above which they provide high attenuation over wide frequency and angle ranges. The disadvantage of pyramidal absorbers is their thickness and tendency to be fragile [18].

Figure 2: Pyramidal microwave absorbers

3.1.2 Tapered loading absorbers

This material is typically a combination of a low loss open cell foam sheets with stepped lossy materials (like carbon) loads. The lossy component is homogeneously dispersed parallel to the surface and made a number of layer with gradient material inclusion perpendicular to the surface as shown in Fig. 3. It is available in sheet form, it has low density, light weight, and can be custom lossy material loaded to meet high or low loss requirements. The advantage of these materials is that they are thinner than the pyramidal absorbers [18].

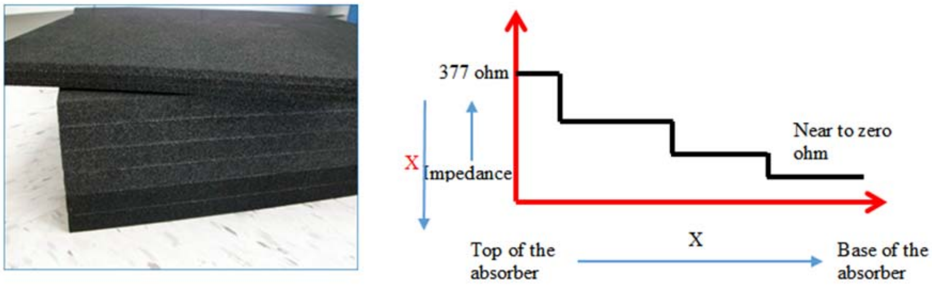


Fig. 3: Tapered loading microwave absorbers

3.2 Resonant microwave materials

Any single layer homogeneous material will resonate when its thickness is equal to 1/4 wavelength. It is also called tuned or quarter wavelength absorbers and include Dallenbach layers, Salisbury Screen and Jaumann layers. A useful visualization is that the incoming wave will be partially reflected by the front surface of the material while part is transmitted. The reflected wave undergoes a phase reversal of π. The transmitted wave then propagates through to the back of the absorber where it undergoes total reflection from the metal back and propagates back through the front face of the absorber. If the wave reflected off the front face is equal in magnitude and 180 degree out of phase with the wave reflected off the back face then the waves will cancel and there will be no total reflection. This phenomenon will occur when the material has a thickness of 1/4 wavelength [3].

Absorber design is an impedance matching problem, in this case matching the impedance of a metal surface (Z=0) to the impedance of free space (Z=377 ohms). If the impedance seen by the wave at the surface of the material is equal to 377 ohms, the wave will be completely absorbed by the material. The loss mechanism of resonant absorber will be describe by the destructive interference of ray optics as shown in Fig. 4.

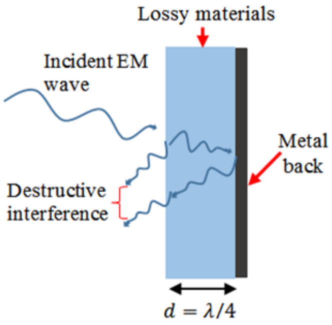


Fig. 4: Loss mechanism of resonant microwave materials

3.2.1 Dallenbach (Tuned) Layer Absorber

The Dallenbach (Tuned) Layer Absorber consist of a homogeneous lossy layer backed by a metal plate. The reflection at the air-absorber interface is due to the impedance mismatch between the two media. Therefore, for a material whose impedance relative to air is same then there will be no reflection at the surface. In such case the attenuation will depend on the loss properties of the material (complex parameters i.e., permittivity and permeability) and the layer's thickness for a desired frequency range. The Dallenbach layer relies on destructive interference of the waves reflected from the first and second interfaces. For the reflectivity to result in a minimum, the effective impedance of the layer at the air absorber interface should be $Z_0 = 377\ ohm$.

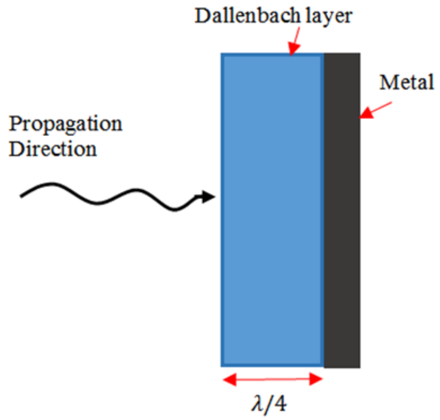


Fig. 5: Dallenbach Layer

Several layers are stacked together to obtain broadband absorber from Dallenbach Layer. The approach employed is the same as that for pyramidal and other geometric transition absorbers-slowly changing the effective impedance with distance into the material to minimize reflections.

3.2.2 Salisbury Screen

The Salisbury screen is a resonant absorber created by placing a resistive sheet on a low dielectric constant spacer in front of a metal plate. Fig. 6 illustrate the geometry of the Salisbury screen.

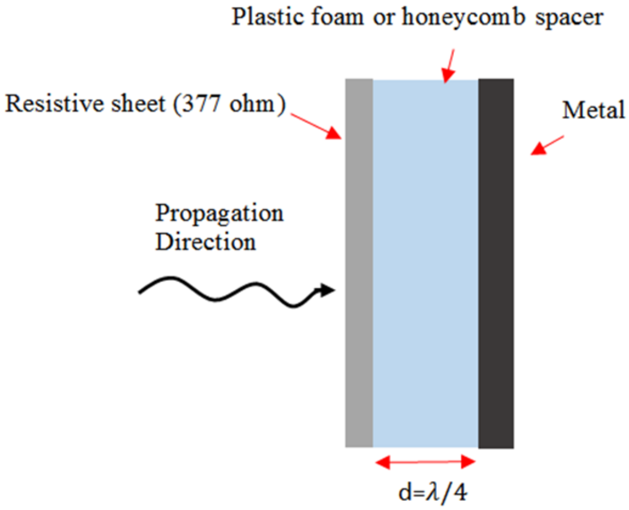


Fig. 6: Salisbury screen

For zero reflectivity, a Salisbury screen requires a 377 ohm/sq resistance sheet set at an odd multiple of an electrical quarter-wavelength in front of a perfectly reflective backing. Higher dielectric spacer may reduce the bandwidth. To absorb at lower frequency region, the spacing must be increased because the wavelength becomes larger. For increased the mechanical rigidity, plastic, honeycomb, or higher density foams may be used as spacers. The thickness of such absorber should be decreased by using higher dielectric constant spacer are paid for in reduced absorber bandwidth.

3.2.3 Jaumann layers

The bandwidth of a Salisbury screen can be improved by adding additional resistive sheets and spacers to form a Jaumann absorber. To provide maximum performance, the resistivity of the sheets should vary from a high value for the front sheet to a low value for the back. The bandwidth of such absorber is depend upon the number of sheets. Multilayer Jaumann devices consisting of low loss dielectric sheets separating poorly conductive sheets. The simplest Jaumann absorber consisting two equally spaced resistive sheets in front of the conducting plane is shown in Fig. 7 to increasing the bandwidth. As with the Jaumann absorber, where sheet resistance values are tapered to reduce reflection, a graded dielectric can be used to help match the impedance between free space and a perfect conductor. The optimum method for design of such absorber would be to determine analytically the μ and ε required as a function of distance into the material to limit the reflection loss over a given frequency range, subject to incidence angle and thickness constraints.

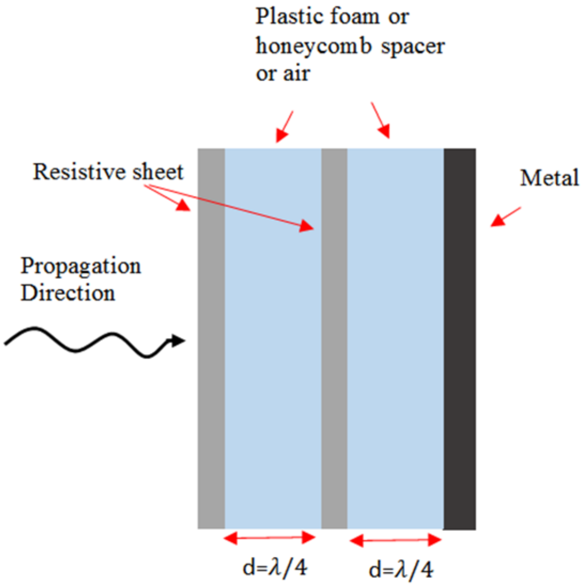
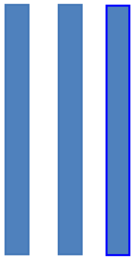


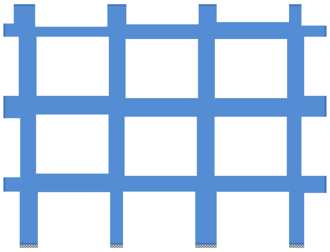
Fig. 7: Jaumann Layers

4. CIRCUIT ANALOG RAM AND FREQUENCY-SELECTIVE SURFACE

The design of specular RAM is equivalent to a transmission line matching problem of microwave circuit technology, where the goal is to limit the reflection seen at the input caused by a short-circuit termination. Improvement can be made on the bandwidth and attenuation of the resonant absorbers (Jaumann layers and Salisbury screen) by employing materials that take advantage of other loss mechanisms. The Salisbury and Jaumann absorbers use resistive sheets, which have only the real part of the admittance, as the matching elements. The imaginary part of the admittance can be obtained by the replacing the continuous resistive sheet by conducting material whose have appropriate geometrical shaped like dipoles, crosses, triangles etc. as shown in Fig. 8.

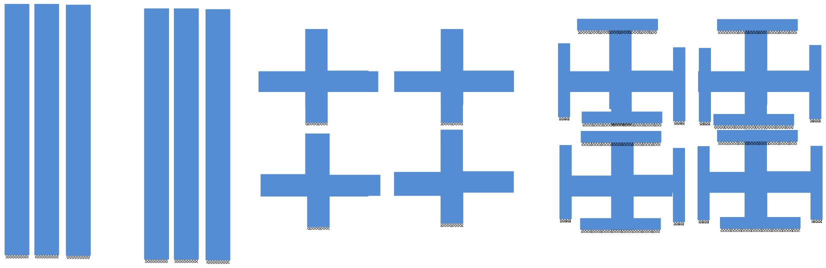


(a)Strips/ wires



(b) Intersecting wires

(c) Dipoles

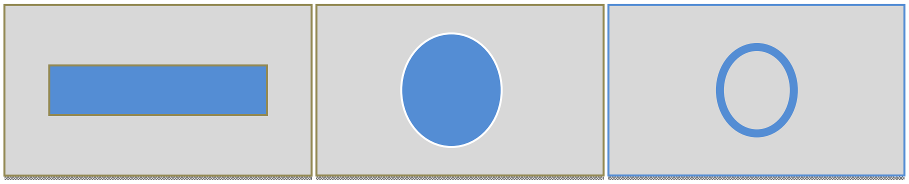


(d) Crossed Dipoles (e) Dual period strips (f) Jerusalem cross

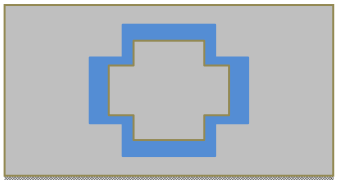
Fig. 8: Typical circuit analog element geometries.

The resistive loss comes from the conductivity of the material used for the patterns. The spacing between the elements of the patterns gives rise to a capacitance and the length of the element gives rise to an inductance. The term circuit analog is derived from the fact that the geometrical patterns are often defined in terms of their effective resistance, capacitance, and inductance. These materials show improved reflectivity and bandwidth performance and tend to be thinner absorbers.

A design problem closely related to that of circuit analog sheets is that of bandstop or bandpass surfaces. However, in contrast to circuit analog RAM, such frequency selective surface (FSS) do not absorb RF energy. Here a highly conductive pattern is used to get a purely imaginary impedance, and the design relies on changing in reactance with frequency to provide appropriate bandpass or bandstop characteristics. Typically, circuit analog and FSS designs consist of elements, such as dipole or slots, that are on the order of a half-wavelength long.



(a) Rectangular Slot (b) Circular Slot, Circular Hole (c) Angular Slot



(e) Four-Legged loaded Slot

Fig. 9: Typical frequency selective surface element geometries.

5. MAGNETIC RAM

Magnetic absorber have been based on carbonyl iron and hexaferrites. These materials have absorb in the MHz and GHz ranges. RAM performance is a function of particle size, and in the ideal situation individual particles contain a sufficient of number of magnetic domains that they are isotropic, but small enough that self-shielding is not a problem. To achieve a good RAM, the conducting particles are pack into a non-conducting matrix with a limit that packing density should not much more to get the *percolation limit* (begin to touch each other) and long current paths form [2].

Ferrites are ferromagnetic substances composed of iron oxides and other metallic oxides. Ferrites naturally provide a high packing density of magnetic material due to the non- conducting nature. Also the lattice structure and the metallic elements used to dope ferrites can be varied and controlled, electromagnetic properties of ferrites can be tailored to meet the specific requirements. Low value of saturation magnetization of ferrite compared to iron is one of the big disadvantage over the many advantages. However, the ability to resist oxidation to a nonmagnetic form, to obtain high packing densities, and to allow synthesis of properties through appropriate doping make ferrites widely used in magnetic RAM. The different types of material used for making RAM and their results are discussed in the literature review [2].

6. REVIEW OF LITERATURE

The development of radar absorbing materials has been reviewed in several papers [20-21] and books [22]. Exploitation of radar absorbing materials started in the 1930's shortly after the advent of radar. Absorber design has incorporated materials with different loss mechanisms and has made use of physical optics to optimise over wide bandwidth. Some recent work on EMI shielding materials at microwave frequencies are briefly discussed below.

Yang et al. [2011], China, prepared iron nanoparticle or nanowire and epoxy resin composites. The complex parameters of these composites were measured by a cavity perturbation method from 7 to 14 GHz. The iron nano wire composites exhibited superior microwave absorbing properties compared to iron nanowire composites. The optimal absorption peak of iron nanowire composites reached -10.5 dB (>90% power absorption) and -15.5 dB (>97% power absorption) with a thickness of 2 and 3 mm respectively. The maximum -10 dB BW was found 0.5 GHz at resonant frequency 9 GHz with reflection loss -15.5dB [23]. In this work the developed thin absorber has very narrow -10 dB bandwidth and low reflection loss.

Han et al. [2011], China, investigated the complex permittivity and permeability of FeCo/carbon nanotubes (CNTs)-paraffin composites at microwave frequencies between 2-18 GHz. Microwave absorption of the composites were enhanced when the mass ratio of the fillers approaches percolation threshold limit of about 34 wt. %. Meanwhile the maximum absorption were found to shifts to thinner thickness and lower frequencies by increasing the filler content. The maximum absorption was found to be -37.5 dB at 11.2 GHz with layer thickness of 8 mm in the composites with 30 wt. % FeCo/CNTs nanocomposites [24]. The developed absorber has good reflection loss with a wide -10dB bandwidth, but they had to compromise with the thickness.

Micheli, Davide, et al. [2011], Rome, designed of a nanostructured multilayer absorber, carried out with the aid of a genetic algorithm (GA). Waveguide measurements were performed to complex parameters analysis of CNT, MWCNT, CNF and fullerene-based composites materials. Developed code minimizes both the reflection and transmission coefficients under the thickness minimization constraint. The multilayer absorber exhibited a loss factor greater than 90% in most of the band, for a thickness of about 1 cm. It was demonstrated that the nano fillers with higher aspect ratio mainly contribute to the EM absorption [25]. The developed absorber has good reflection loss with a wide -10dB bandwidth, but they had to compromise with the thickness which was about 1 cm.

H. Bayrakdar [2012], Turkey, synthesized ferrite-polymer nanocomposite structures and theoretically and experimentally investigated electromagnetic propagation at microwave frequencies between 8-20 GHz. The microwave properties were investigated by transmission line method, and reflection loss of -59.50 dB was found at 12 GHz for an absorber of 2mm with 2 GHz of -10 dB BW [26]. The proposed absorber has high reflection loss but the BW is unable to cover a single frequency band (X- band).

Y.G. Xu et al. [2012], China, prepared composites of silicone rubber filled with carbonyl iron particles and multi-walled carbon nanotubes and investigated the complex permittivity and permeability at microwave frequencies between 2-18 GHz. The RL of the composites changed insignificantly with the weight percent of MWCNT. Composites filled with flaky CIPs the absorption BW increased at thickness 0.5mm (RL value lower than -5 dB in 8-18 GHz) and the absorption ratio increased at lower frequency (minimum -35 dB at 3.5 GHz) [27].The -10dB bandwidth of the developed flexible absorber has zero value for higher frequencies (X-band) with reflection loss lower than -5dB.

S Vinayasree et al. [2013], India, fabricated flexible and thin single layer microwave absorbers based on strontium ferrite-carbon black-nitrile rubber composites and their reflection loss were studied in the X-band. The incorporation carbon black not only reinforces the rubber by improving the mechanical strength but also modifies the dielectric permittivity of the composites. The composites then be employed to tune the microwave absorption characteristics. The microwave absorption characteristics of composites were modelled in that an electromagnetic wave incident normally on the metal terminated single layer absorber, and reflection loss of -25 dB was found at 9.8 GHz for 2.5 mm thickness absorber with -10 dB bandwidth of 1 GHz [28]. The developed absorber has fulfilled three important requirement, like, high reflection loss, flexible and thin, but it has narrow -10 dB bandwidth about 1 GHz.

Wang et al. [2014], China, the complex parameters of Zn or Zn (Fe) nanoparticles with core-shell structure were investigated for frequencies from 2-18 GHz. The resonant frequency of the absorber containing Zn/ZnO nanocapsules was not shifted with changing the thickness of the absorbent. However, with doping Fe in Zn, the position of the absorption was shifted to lower frequencies with increasing the thickness of the absorbent [29]. In this work the absorber was used as a switchable one for different frequencies by varying the doping concentration of the filler.

Vinayasree et al. [2014], India, designed a flexible single layer microwave absorber by incorporating appropriate amount of carbon black in a nitrile butadiene rubber matrix with magnetic counterpart, namely, barium hexaferrite for applications in S, C and X-bands. Cavity perturbation method was used for material characterization and microwave absorption characteristics were studied by employing a model in which an electromagnetic wave is incident normally on a metal back single layer. Reflection loss exceeding -20 dB was obtained for all the samples between frequency range 2-12 GHz when an appropriate absorber thickness between 5 and 9 mm was chosen [30]. The proposed absorber thickness is high enough to use in various applications although it has good reflection value over the 2-12 GHz frequency range.

J P Gogoi et al. [2014], India, developed expanded graphite-novolac resin composites as dielectric absorber material in the X-band. Practical reflection loss measurements were carried out using free space technique. The 5 wt. % composites showed RL peak of value -43 dB at 12.4 GHz. The -10 dB BW was found to be 1 GHz for conductor backed single layer absorber with 7,8 and 10 wt. % EG/NPR composites [31]. The proposed absorber was light weight with -43 dB reflection loss but the bandwidth was only 1 GHz.

J P Gogoi et al. [2014], India, designed and developed double layer microwave absorbers with paired combination of 5 wt. %, 7 wt. %, 8 wt. % and 19 wt. % expanded graphite-novolac phenolic composites, in the frequency range of 8.2-12.4 GHz. The total thickness of the fabricated double layer microwave absorber was varied from 3mm to 3.4mm. The maximum -25 dB and -30 dB absorption BW of 2,47 GHz and 1.77 GHz respectively, were observed for the double layer structure with (5 wt.%-8 wt.%) EG-NPR composites with total thickness of 3.2mm, while -10 dB BW covers the entire X-band range [32]. The developed absorber has cover the whole X-band with -10dB BW but the thickness and flexibility has to be compromised.

Osman Balci et al. [2015], Turkey, demonstrated active surfaces that enable electrical control of reflection, transmission and absorption of microwave absorber. Instead of tuning bulk material they had done electrostatic tuning of the charge density on the atomically thin electrode, which operated as a tunable radar-absorbing surfaces with reflection suppression ratio up to -50 dB with operation voltages -5 V [33]. The developed absorber was a

Salisbury type absorber with -50 dB reflection loss and 4.2 GHz BW over the X-band.

B. Zhang et al. [2016], China, prepared composites of surface modified $Fe_{50}Ni_{50}$-coated poly (acrylonitrile) microspheres, reduced graphene oxide (RGO) and epoxy resin. The -10 dB band width was found 4.4 GHz in the range of 10-14.5 GHz, with a matching thickness of 2.5 mm. The density of the composites was 0.25-0.34 g/cm^3, therefore it was considered as a light weight microwave absorber [34]. The matching thickness was compromised to get a good absorbing result.

Y Xu et al. [2016], China, prepared a silicone rubber composite filled with carbonyl iron particles (CIPs) and four carbonous materials (carbon black, graphite, carbon fibre or MWCNTs). The complex parameters were measured using a vector network analyser at frequency of 2-18 GHz. The reflection loss result showed the added carbonous materials enhanced the absorption in the lower frequency range, the RL decrement value being about 2 dB at 4-5 GHz with a thickness of 1 mm. The reflection loss of -14 dB was found at 4.5 GHz for an absorber of 1mm with 3.5 GHz of -10 dB BW [35]. The designed absorber has cover only the lower frequency range, it is not useful for X-band or higher frequencies.

7. CONCLUSION

A good broadband RAM performance is predicted getting the RF energy into the RAM and then providing sufficient loss to absorb the necessary energy within the allowed RAM thickness. These two requirements often conflict, because high loss material has poor impedance matched, and thus suffer high front-back reflection. To overcome these drawback one can used tapered loss from front to back of the absorber as employed in Jaumann, graded dielectric, and geometric transition absorber.

However higher broadband absorption is accompanied by increased thickness. Some reduction in thickness can be obtain through use of circuit analog and FSS sheet to replace the resistive sheet, again the design complexity and cost might create a problem here. One can use material which has both high loss and an intrinsic impedance near that of free space, which means high value of complex parameters i.e. complex permittivity and permeability. Again there exist only a very limited material over a particular frequency band due to the resonant nature of the permeability of the material. Here also one can use multilayer techniques of different magnetic material to extend the bandwidth at the cost of RAM thickness and complexity.

This chapter has catalogued typical types of RAM and discussed their performance characteristics. Many of the absorber structures considered here would be useful for military applications. Coatings in the form of Dallenbach layers, although not broadband, would be useful for reducing the RCS from intricate shapes. Jaumann layers would be appropriate for broadband lightweight absorbers. If the military is to move to composite materials for ships or super structures then frequency selective surfaces and circuit analog absorbers should be embedded into the composite. Combined electric-magnetic materials offer the best potential for thin broadband absorption. Magnetic materials are limited to carbonyl iron and ferrites, raising a question of corrosion resistance.

Therefore finally, one can find the best RCS reduction solution only with the proper knowledge of RAM performance, familiarity with the types of RAM and a good engineering judgment.

BIBLIOGRAPHY

[1] https://en.wikipedia.org/wiki/Microwave

[2] Knott, E. F. Radar cross section measurements, Springer Science & Business Media, 2012.

[3] Borkar, V. G., Ghosh, A., Singh, R. K., & Chourasia, N. K. (2010), Defence Science Journal, **60**(2), 204.

[4] Zhuo, R. F., Qiao, L., Feng, H. T., Chen, J. T., Yan, D., Wu, Z. G., & Yan, P. X. (2008), Journal of Applied Physics, **104**(9), 094101.

[5] Chen, Y. J., Cao, M. S., Wang, T. H., & Wan, Q. (2004). , Applied physics letters, 84(17), 3367-3369.

[6] Knott, E. F., Springer Science & Business Media, 2012.

[7] Qin, F., & Brosseau, C. (2012), Journal of applied physics, **111**(6), 061301.

[8] Srivastava, R. K., Narayanan, T. N., Mary, A. R., Anantharaman, M. R., Srivastava, A., Vajtai, R., & Ajayan, P. M. (2011). , Applied Physics Letters, **99**(11), 113116.

[9] Ohlan, A., Singh, K., Chandra, A., & Dhawan, S. K. (2008), Applied physics letters, **93**(5), 053114-1.

[10] Guo, Z., Park, S., Hahn, H. T., Wei, S., Moldovan, M., Karki, A. B., & Young, D. P. (2007, Journal of applied physics, **101**(9), 09M511.

[11] Micheli, D., Apollo, C., Pastore, R., & Marchetti, M. (2010)., Composites Science and Technology, **70**(2), 400-409.

[12] Feng, Y. B., Qiu, T., & Shen, C. Y. (2007)., Journal of Magnetism and Magnetic Materials, **318**(1), 8-13.

[13] Kim, J. B., Lee, S. K., & Kim, C. G. (2008, Composites Science and Technology, **68**(14), 2909-2916.

[14] Ren, F., Zhu, G., Ren, P., Wang, K., Cui, X., & Yan, X. (2015, Applied Surface Science, **351**, 40-47.

[15] Esfahani, A. S., Katbab, A. A., Dehkhoda, P., Karami, H. R., Barikani, M., Sadeghi, S. H. H., & Ghorbani, A. (2012)., Composites Science and Technology**,** **72**(3), 382-389.

[16] Xu, F., Ma, L., Huo, Q., Gan, M., & Tang, J. (2015). , Journal of Magnetism and Magnetic Materials, **374**, 311-316.

[17] Xu, Y., Yuan, L., Cai, J., & Zhang, D. (2013), Journal of Magnetism and Magnetic Materials, **343**, 239-244.

[18] Saville, P. (2005). (No. DRDC-TM-2005-003). DEFENCE RESEARCH AND DEVELOPMENT ATLANTIC DARTMOUTH (CANADA).

[19] http://www.mvg-world.com/en/system/files/pyramidal_absorbers_0.pdf

[20] Gaylor, K., (No. MRL-TR-89-1), Materials Research Labs Ascot Vale (Australia), 1989.

[21] Lederer, P. G., (No. RSRE-85016), Royal Signals and Radar Establishment Malvern (England), 1986.

[22] Knott, E. F., Springer Science & Business Media, 2012.

[23] Yang, R. B., Liang, W. F., Lin, W. S., Lin, H. M., Tsay, C. Y. and Lin, C. K, Journal of Applied Physics, **109**(7), 07B527, 2011.

[24] Han, Z., Li, D., Wang, X. W. and Zhang, Z. D., Journal of Applied Physics, **109**(7), 07A301, 2011.

[25] Micheli, D., Pastore, R., Apollo, C., Marchetti, M., Gradoni, G., Primiani, V. M. and Moglie, F., IEEE Transactions on Microwave Theory and Techniques, **59**(10), 2633-2646, 2011.

[26] Bayrakdar, H., Progress in Electromagnetics Research M, **25**, 269-281, 2012.

[27] Xu, Y., Zhang, D., Cai, J., Yuan, L. and Zhang, W., Journal of Materials Science & Technology, **28**(1), 34-40, 2012.

[28] Vinayasree, S., Soloman, M. A., Sunny, V., Mohanan, P., Kurian, P. and Anantharaman, M. R., Composites Science and Technology, **82**, 69-75, 2013.

[29] Wang, Z. H., Jiang, L. W., Li, D., Jiang, J. J., Ma, S., Wang, H. and Zhang, Z. D., Journal of Applied Physics, **115**(17), 17A527, 2014.

[30] Vinayasree, S., Soloman, M. A., Sunny, V., Mohanan, P., Kurian, P. and Anantharaman, M. R., Composites Science and Technology, **82**, 69-75, 2013.

[31] Gogoi, J. P., Bhattacharyya, N. S. and Bhattacharyya, S., Composites Part B: Engineering, **58**, 518-523, 2014.

[32] Gogoi, J. P. and Bhattacharyya, N. S., Journal of Applied Physics, **116**(20), 204101, 2014.

[33] Balci, O., Polat, E. O., Kakenov and N. Kocabas, C., Nature communications, **6**, 2015.

[34] Zhang, B., Wang, J., Wang, J., Huo, S. and Tang, Y., Journal of Magnetism and Magnetic Materials, **413**, 81-88, 2016.

[35] Xu, Y., Yuan, L. and Zhang, D., Journal of Physics D: Applied Physics, **49**(15), 155001, 2016.