Radar Absorbing Materials Mechanism and Effective Parameters in Behavior Improving

Saba Esmaeili, Hassan Sedghi

Abstract: Radar absorbing materials were used in military fields by regarding the drones camouflage most of the high GHz range. Radar absorbing materials have excellent features such as low weight, high bandwidth, and strong absorption. So, to improve Radar absorbing material; many factors such as filler type, filler amount, polymeric matrix type, absorber material thickness, filler grain size, absorber material layers, etc. are very important. The current research, by describing Radar absorbing material and its exact mechanism such as dielectric and magnetism losses; we have been investigated effective factors for improving Radar absorbing material behavior. Finally, Radar absorbing material electromagnetism evaluation pattern was described.

Index Terms: absorption; dielectric and magnetism losses; Radar Absorbing.

I. INTRODUCTION

Airplanes and submarines camouflage was done with various forms in military wars. Different methods were used for the drones camouflage, radar cross section reducing and applying Radar absorber material in their body [1]. Researches were started for electromagnetism absorber material at 1930s [2]. The first article relates to investigation absorber materials with resonance type by using black carbon as a wave loss material and oxide titanium with high admittance coefficient to thickness reducing, and they were published in Poland at 1936. At second world war; Germans used iron carbonyl powder with 3 inches thickness and 3 GHz frequency for submarines camouflage [3].

II. RADAR ABSORBING MATERIAL

If a material by magnetism or electrical fields can destruct electromagnetism parasite waves; it named “Radar absorbing material.” Radar absorbing materials were divided into impedance matching and resonant absorber groups [4]. Impedance matching materials acted as a simple law for maximum power transfer. By creating impedance matching, all of the absorbed source productive energy and reflective energy is zero with radar section surface reach to the minimum amount which includes pyramidal, tapered and matching layers absorbers, as shown in figure 1 [5]. Two layers of microwave absorber behavior was effected from coupling interaction between the absorber layer and the matching layer. By regarding two different layers; matching layer features and weakness characteristics guide for reaching excellent microwave absorber. Resonant absorbers [6] have proportion thinner structures, but they don’t absorb all of the electromagnetism forces. They have one metal covering, as shown in figure 2 [5]. The first reflection happens for lack of absorber entrance impedance. The second reason relate to partial shift by reflecting receiver wave, and it is created from metal covering in the backward side. If distant is multiple of λ/2 by receiver wave; in this case; 2 reflections will be created outside reflection wave from phase, and also it causes to destructive intervention. Absorber resonant materials named ¼ wavelength and they contain Dallanbach layer, Salisbury screen and Jaumann layer [7].

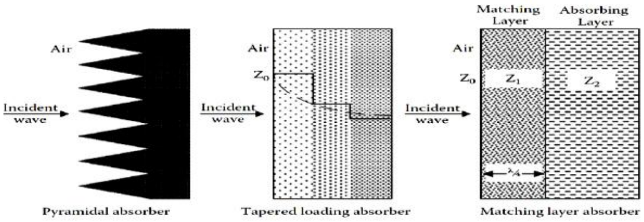

Figure 1: Schemes of pyramidal, tapered loading and matching layer absorbers [5].

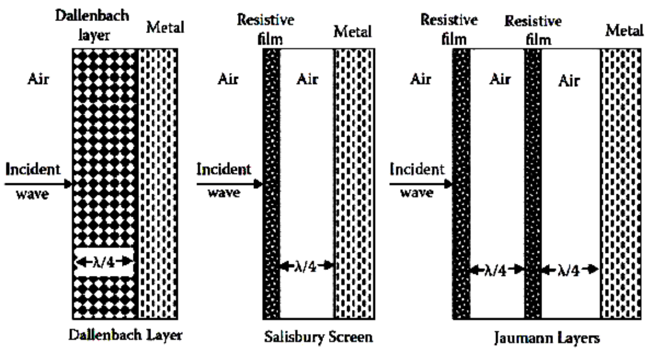

Figure 2: Schemes of typical Dallenbach layer, Salisbury screen, and Jaumann layer absorbers [5].

III. RADAR ABSORBING MATERIALS FUNCTION MECHANISM

Materials function are determined in electromagnetism fields by free electrons displacement and binding in the electrical field, their atomic movement directions in magnetism field which they have magnetism and dielectric losses [8].

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If a guide material is located in alternating magnetism field; an induction current is created in the material which it causes energy diffusing. This phenomenon named "Eddy current losses." Mentioned parameter depends on material thickness and electrical conduction. Magnetic hysteresis losses are created at the result of fields irrevocability movements, and magnetic moment slewing in magnetic material and it depends on magnetic permeability. Magnetic losses except with eddy current losses and Magnetic hysteresis losses named "remained losses." In low frequencies, the main reason of remained losses relates to magnetic delaying losses which they include thermal and fluctuations and also movement some of electrons and ions to balancing position at the effect of exerted magnetic field. In high frequencies; remained losses are created at the result of field wall intensity. When alternating electrical field act on absorber material by certain electrical conduction; conductance current is generated, and energy is distributed in thermal energy form. Conductance losses depend on electrical conduction [9]. An absorber material under electrical field is polarized and also if polarization changes are slower than the electrical field; in this case Dielectric deeply damaged losses will be generated. Generally, polarization contains dipolar rotation, electronic displacement polarization, and ionic polarization. Time of electronic and ionic displacement polarization is very small. So, this kind of polarization cause energy losses in high and extraordinary frequencies. In high frequencies, the dipolar rotation has a vital role for deeply damaged losses. Intensity losses are originated from inducted intensifying effect by atoms, ions or absorber material inside electrons vibration. Intensify phenomenon is generated from two mechanisms such as magnetic field wall and ferromagnetic intensity.

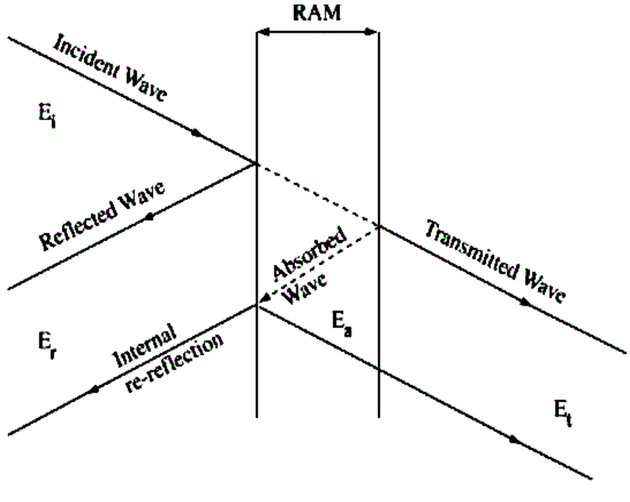

Figure 3: Interaction of electromagnetic waves propagation with RAM.

IV. EFFECTIVE FACTORS IN ELECTROMAGNETIC WAVES ABSORBER

The ability to absorb and attenuate the electromagnetic wave is called absorption. This phenomenon which can be regarded as the attenuation of an electromagnetic wave inside material is usually associated with three main mechanics; the reflection of the incoming radiation, absorption of the radiation, and multiple reflections of the radiation, see figure 3. By developing absorbers novel generation; composite materials have a significant role. They relate to surface simple application, controllability of various mechanical and electromagnetic features. Materials responses are determined against electromagnetic waves by three related parameters such as permittivity, permeability and electrical conduction [10]. In applied conditions; electromagnetic energy transformation to heat will depend to which permittivity it is a complex number.

$$\varepsilon = \varepsilon' - i\varepsilon'' \qquad (1)$$

The real part of this relation named dielectric constant and it shows combining ability in polarization at the result of the external electrical field. The imaginary part of this relation is dielectric loss component, which it expresses with electromagnetic energy transformation output to heat or it present by waves absorption amount in the regarded complex. Sometimes we use tangent for computing loss amount.

$$\tan\delta_\varepsilon = \frac{\varepsilon''}{\varepsilon'} \qquad (2)$$

We conclude from dielectric losses tangent; being larger of complex permittivity cause to wave more absorption. Another basic parameter is μ complex permeability which is a function of electromagnetic wave frequency:

$$\mu = \mu' - i\mu'' \qquad (3)$$

It has similar function with permittivity constant. Increasing conduction, cause increasing eddy current losses and conductance losses. These materials have very small skin depth, and most of the electromagnetic wave is reflected by mentioned material. Material with zero skin depth is regarded as an excellent electrical conductor. So, it has low electrical conducting and high ability for inside material in electromagnetic scattering. Also, skin depth depends on frequency. Based on formulae (4),

$$\delta = \frac{1}{\sqrt{\pi f \mu_o \mu_r \sigma}} \qquad (4)$$

In preparing of radar absorber material, we pay attention to many parameters. For example, we can refer to weight, thickness, size, shape, filler percent, filler type, particles distribution, fillers intrinsic conduction, frequency range, environmental resistance and mechanical strength [11]. By developing nano technology; nano microwave absorbers have main features such as strong absorber, high- frequency range, low density, and low thickness. Nano matrix materials, composite and fillers are in the dielectric, conductor and ferromagnetic forms and they are obtained with a combination of dielectric and magnetic loss.

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V. FILLETING MECHANISM

The Created filler type in polymeric matrix plays an important role in better absorption. Dielectric and magnetic fillers increase mentioned materials electromagnetic features, and we will face with absorption rising. Ferrites have excellent dielectric and magnetic features, and they are one of the best choices for electromagnetic absorber material, but they are expensive and heavy. Polymers are used as a polymeric matrix because of light, flexibility and cheapness and ferrite are added as a filler. Radar absorber materials for polymeric matrix and fillers include conductor polymer, carbon, iron particles, and dioxide titanium. These radar absorber materials named hybrid matrix which they have magnetic and electrical weakness capability simultaneously [12].

Fillers are usually used as an element in order to improve design of electromagnetic absorber electromagnetic absorber designing improving. They apply in conduction and absorption, and sometimes they effect on internal features such as permittivity and permeability. Composites electromagnetic, frequency of resonance and bandwidth features can coordinate effectively with different partials amount of created filler materials phase. Therefore, filler materials controlling effects on absorber bandwidth and absorption amount [13]. Increasing of ferrite amount in absorber material will cause in increasing absorption amount, but its mechanical features reduce mutually. Filler amount has an effect on absorber material thickness, low reflection loss, width frequency range. According to ¼ wavelength principal, increasing ferrite amount will cause in increasing absorption amount and finally reduce composite thickness [14].

Generally, microwave absorbers are generated by using a polymeric matrix. Sometimes, polymers act as partial section of the absorber in the polymeric composite complex. A polymeric matrix such as epoxy resin, polyurethane and plastics help to electromagnetic wave absorber features. Composites complex with polymer-based and low density, low thickness, high bandwidth, and electromagnetic waves high losses act as ideal absorber material. In addition, for polymeric composites; polymer has an important role in reducing particles aggregation. Polymers absorption features such as low weight, non-corrosiveness, mechanical strength and dielectric adjusting cause to multiple applications with optical accommodation and magnetic nano particles survey. By combining ferrite and conductor polymers; increase ferrite particles absorption because their high electrical resistance reduces ferrite eddy current loss. There are various insulator and conductor polymers which is used as a composite matrix [15]. In recent decades, conductor polymers cause to create of novel and new generation of materials by regarding high conduction, induced electrical features, proper and simple production [16]. Polypyrrole (PPY) has unique and special features with environmental stability, and it is one of the promised conductive polymers. Poly ethylene with the poly aniline name is another conductor polymer that it uses as a polymeric matrix extensively, because of simple production and environmental stability. Also, Poly aniline acts towards multipurpose conductive polymer. By helping features such as heat stability, chemical thermal and low special mass, controllable conduction, high conduction in microwave frequency between polymers; epoxy is a proper choice for ferrite combining [17]. This polymer uses a thermos set matrix to improve composites structure by excellent mechanical features, low cost, simple production and stick in kind of layers and suitable chemical resistance [18]. Pure epoxy act as an electrical insulator and its electrical conduction amount is nearly 10-15 S/cm [19]. Therefore, polymers are important because of features such as low weight, stability and standing capacity in well atmospheric conditions, low thickness, function in high bandwidth and low reflection, high temperatures bearing and resistance, low gasification and low cost.

Electromagnetic waves absorber features depend on applied materials, thickness and frequency [20]. Generally, by increasing thickness, increase in electromagnetic waves absorption percent and it is the true adverse case. Therefore, the high thickness isn't proper to various applications [21]. A proper absorber not only has high bandwidth but also it has at least low thickness. Optimum conditions for maximum electromagnetic waves absorber thickness is lower than 4mm. Based on reports [22], ferrites with high loss have a low thickness, which is equal to 3mm. Increasing thickness will cause reduction in reflection loss. Therefore, we can say:

$$f_m = \frac{c}{2\pi\mu' d} \qquad (5)$$

f_m= frequency of matching with minimum reflection loss, c= light velocity, d= thickness of sample; Matching frequency by increasing in thickness is the basis for change in low frequency direction. In other words, by increasing thickness; resonance frequency will change in direction to low frequency [23]. By advancing nano technology; nano absorbers in microwave range play an effective role as a new electromagnetic absorber. These absorbers have features such as strong absorption, high-frequency width, low thickness, and light density. Nano materials were effected by small size, surface and also anisotropy shape of absorption function mechanism which improves system toward GHz range. Based on natural resonance equation [24]; we can say:

$$2\pi f_r = rH_a \qquad (6)$$

$$H_a = \frac{4|K_1|}{3\mu_0 M_s} \qquad (7)$$

r= ratio of gyromagnetic, H_a= Anisotropy field, K_1 = coefficient of anisotropy; Frequency of resonance in magnetic materials cause in changing direction toward high frequencies. Anisotropy field increases as a result of grain and particle sizes effect. Anisotropy filed increases significantly in nanometer (nm) scale. Also, increase of surface anisotropy field is effected by rise of small grain size.

Therefore, every grain size with anisotropy shape and size play a significant role in many anisotropy fields generation inside particle or grain. In a certain range, increase in absorption frequency bandwidth anisotropy fields. Similarly grains small size effect is the main factor in magnetic resonance [25]. Nano ferrites have well behavior in GHz range. The capability of more electromagnetic waves absorption in nano powders relate to more surface area, more atoms surface and multiple reflections which they cause in dielectric and magnetic losses. Surface area, dangling bonds number, and unsaturated coordination on the surface, rise at the result of nano crystal particle in nanometer range [26]. This process creates middle polarization and multiple dispersion and it is suitable to more absorption of microwaves. By reducing particles diameter, increase surface effect and its case will be effective for anisotropy coefficient and attenuation parameters [27]. Nanometer nature is different from the bulk. For example, we can say, the effect of quantum size, size of surface and effect of tunneling increase bandwidth of absorption with loss more than -10 dB [26]. Providing energy level distant located in microwave energy inside range surface; electrons can absorb energy and they transfer base energy level to induced level, and it increases microwaves absorption. By reducing particles size from micron to nanometer scale; microwave absorption increases and current subject is described by quantum size effect [28]. In crystal nano particles, electronic energy level break with quantum size effect and it increases spaces between adjacent energy states, and adversely it increases by particles amount. If the average size of the absorbing particle is insignificant, the transferring energy can be absorbed from one level to another level on the condition that the energy level is separate and located within microwave energy range [29]. Thus by decreasing frontier or ridge width, increase in particles size seen. Finally coupling interaction will increase frontier or ridge width. The high surface area in finer particles generate more dipoles, and it enhances microwave absorber features [30].

VI. Electromagnetic Evaluation

Generally, an ideal absorber material must have these conditions:

1) EM wave impedance adjusting at the result of maximum EM wave from air to material

2) EM wave must contain weak inside material completely

For EM waves absorber, approximately 90% of the material and reflective loss must be lower than -10dB based on the following formulae (8) [21]:

$$RL = 20\log\left(\frac{Z_{in}-Z_0}{Z_{in}+Z_0}\right) \tag{8}$$

Z_0 is free space impedance in ideal conditions for reflective loss with Z_{in}=377Ω. To achieve mentioned aim; material Z_{in} certain impedance must be adjusting free space inside impedance which equals to Z_{in}=377Ω.

$$Z_{in} = Z_0\sqrt{\frac{\mu_r}{\varepsilon_r}}\tanh\left(j\left(\frac{2\pi fd}{c}\right)\sqrt{\mu_r\varepsilon_r}\right) \tag{9}$$

In this equation (9), ε_r is relative permittivity; μ_r is relative permeability constant; f is frequency; d is the thickness of absorber and c is free space light velocity. Absorber features, ε and μ change with absorber material changing. So, researchers have been presented various methods for permeability and permittivity constants estimation. One of the models is Maxwell Garnett method [31] which it expects particles shape percent fraction and determines EM effective features in circular fillers and isotropic matrix. After material anticipation and construction; matrix dispersion components and elements are determined by a vector network analyzer. All of the parameters include the requirement for information in absorber material investigation. Complex permeability constant and complex permittivity constant can be exploited by different methods such as Nicolson model [32]. Table 1, presented various absorbing materials studies and construction results.

Table 1: The properties of core samples.

Composites (RAM)	Thickness (mm)	Frequency (GHz)	Reflection loss (dB)	Ref.
Ni-Zn Ferrite Nano-Particle based nano composite	3	12.27	-12.93	[33]
Carbon nanotube @ barium titanate @ polyaniline	3	10.7	-28.9	[20]
Carbon fibers and gradient dispersion of Fe nanoparticles	2	4.9	-26.8	[18]
Minkowski loop patterned waste composite	2.9	3.6	-28.4	[34]
Pani/HA/TiO_2/Fe_3O_4 without chemical treatment (40%)	2.5	11.5	-13	[35]
Pani/HA/TiO_2/Fe_3O_4 after chemical treatment (40%)	2.5	10.5	-48.9	[35]
Natural rubber+(50% ferromagnetic powders+6.5% graphite and 1.5% carbon fibre)2.5mm	4	8-18	-16 (oblique incident)	[36]
Natural rubber +45% high structure of carbon fillers)1.5mm			-18 (normal incident)	[36]

VII. Conclusions

By developing electromagnetic absorbing materials, we must study effective factors to absorbers well function with related applications. By investigation of radar absorber material function mechanism, we understand to reach strong absorber, at first, selective materials should have magnetic and dielectric loss features combining. Dielectric and magnetic fillers complex percent are very important in the polymeric matrix. So, we can observe more frequency range by fining fillers particles size and this relates to different anisotropy fields conception in various particles size.

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The main principal in radar absorber material design is an accurate investigation of created materials in reaction with different frequencies and reflection amount. Absorber features based on different applications must be coordinate with various frequencies.

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