ELECTROMAGNETIC ABSORBING MATERIALS

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Key words: electromagnetic waves, magnetic composite, ferromagnetic materials, microwaves, measurements

Abstract: Around 15 years have passed since the wireless technologies started with rapid development. During that time, different fields of electromagnetic waves have become more active.

As a result of rapid advances in technology the use of wireless communication and radar systems is expanding quickly, which leads to a significant increase in the levels of background electromagnetic (EM) radiation /1/.

To avoid potential health effects from high exposure to electromagnetic waves, unnecessary EM waves should be eliminated to protect human bodies, especially expectant mothers and children /2/.

In European Pre-standard ENV 50166-2:1995 – Human exposure to electromagnetic fields – High frequency, is stated that electromagnetic fields interact with the human body and other systems through a number of physical mechanisms. Therefore, it is necessary to protect all of these systems.

As mentioned in ENV standard, it is recognized that additional considerations have been made by some countries, regarding the reference levels as minimum requirements in certain frequency ranges. Those considerations resulted in additional reference margins /3/.

This is the reason why is nowhere a background of electromagnetic waves including many reviews of diverse articles on topics of electromagnetic materials.

We decided to bring out that summery to deliver this diversified information to all types of readers, both technical and non-technical.

Absorberji elektromagnetnega valovanja

Kjučne besede: elektromagnetno valovanje, magnetni kompoziti, feromagnetni materiali, mikrovalovi, meritve

Izvleček: Okoli 15 let je minilo, odkar se je začel hiter razvoj brezžične tehnologije. Med tem časom so postala bolj aktivna tudi različna območja elektromagnetnih valov.

Kot rezultat hitrega razvoja tehnologije, se je uporaba brezžičnih komunikacij in radarskih sistemov naglo razširila. To vodi v znatno povišanje koncentracije elektromagnetnega sevanja v okolici /1/.

V izogib potencialnemu vplivu, pri visoki izpostavljenosti elektromagnetnemu valovanju, bi morali elektromagnetno sevanje omejiti oz. odstraniti, da bi zaščitili ljudi, posebno matere in otroke /2/.

V evropskem pred-standardu ENV 50166-2:1995 – Izpostava ljudi elektromagnetnemu polju – Visoke frekvence, je navedeno, da elektromagnetno polje vpliva na človeško telo in druge sisteme s številnimi fizikalnimi mehanizmi. Zato je potrebno vse te sisteme zaščititi.

Kot je zapisano v ENV standardu, so bile v nekaterih državah narejene dodatne raziskave, o minimalnih varnostnih zahtevah v zvezi z izpostavljenostjo v določenih frekvenčnih območjih. Ugotovitve teh raziskav so vodile v določenih državah do dodatnih, strožjih ukrepov. /3/.

Zgoraj omenjena dejstva in ugotovitve so povod, da smo v tem članku opisali ozadje elektromagnetnega valovanja in pregled različnih člankov na temo elektromagnetnih materialov.

1. Introduction

We have a different type of electromagnetic sources. The first one is natural source. Electromagnetic fields are present everywhere in our environment. Electric fields are produced by the local build-up of electric charges in the atmosphere and released with thunderstorms. Electromagnetic fields at low frequencies exist whenever a positive or negative electrical charge is present. Besides natural sources, the electromagnetic spectrum also includes fields generated by human-made sources. Various kinds of higher frequency radiowaves are used to transmit information – whether via TV antennas, radio stations or mobile phone base stations and radar produce high RF fields. And for example in the workplace: computers, fax machines, fluorescent lights, printers, scanners, telephone switching systems, electrical instruments, electric engines and other electrical devices. Additional sources are household appliances, such as stereo systems, refrigerators, blenders, portable heaters, clothes washers and dryers, coffee makers, vacuum cleaners, toasters, microwave ovens and others.

Like electric fields, magnetic fields are strongest close to their origin and rapidly decrease at greater distances from the source. Materials, such as building materials and trees, provide some shielding capability. Therefore, the electric fields from power lines outside the house are reduced by walls, buildings, and trees. Conductors, such as metal, provide very effective shield. However, magnetic fields are not blocked by common materials, buildings' walls, for example.

The protection from electromagnetic radiation is an up to date theme. Since the discovery that electromagnetic fields can affect our health, researchers have investigated these phenomena in vivo and in vitro, in animals /4-6/ and humans /7-13/.

A multiphase study has been performed to find an effective protection and method to evaluate systems and patients exposure to electromagnetic field (EMF). We have two typical ways. We can shield from EMF or use the absorbing method. But the shielding materials cannot eliminate or weaken EMI radiation, and moreover the reflected wave may interact with the incident wave, which causes disturbance to other devices. Another way is usage of electromagnetic absorbers like multipart materials that absorb incident electromagnetic radiation in limited wave spectrum. Only by using electromagnetic wave absorbing materials and transferring the electromagnetic energy to other forms can the radiation be attenuated to the furthest extent /14/.

In physics, absorption of electromagnetic radiation is procedure by which the energy of a photon is taken up by matter, typically the electrons of an atom. Thus, the electromagnetic energy is transformed to other forms of energy, for example, to heat.

According to the wave absorption mechanism, traditional wave absorbers can be divided into three types as electric loss, magnetic loss and dielectric loss materials. Carbon materials and conductive polymers are electric attenuation absorbents, which have higher electric loss tangent (tan δ_e) and the electromagnetic energy is mainly attenuated as resistor. Ferrites and fine powder are magnetic loss absorbents, which have higher magnetic loss (tan δ_m), and attenuate and absorb electromagnetic energy by polarisation mechanisms such as hysteresis loss and magnetic domain resonance. Metal fibre and many ceramic materials such as barium titanate belong to dielectric loss absorbents, which mainly attenuate electromagnetic energy by electronic and ionic polarisation. Most of the metal based absorbants used in cement matrix composites are steel fibres and ferrites, for which Japanese institute have made many studies /15/.

The reflection curve of an electromagnetic absorber is a function of a complex interplay between the permittivity, the permeability and the thickness of the absorber. From material point of view both permeability and permittivity can be varied, whereas with design an additional degree of freedom is obtained (thickness).

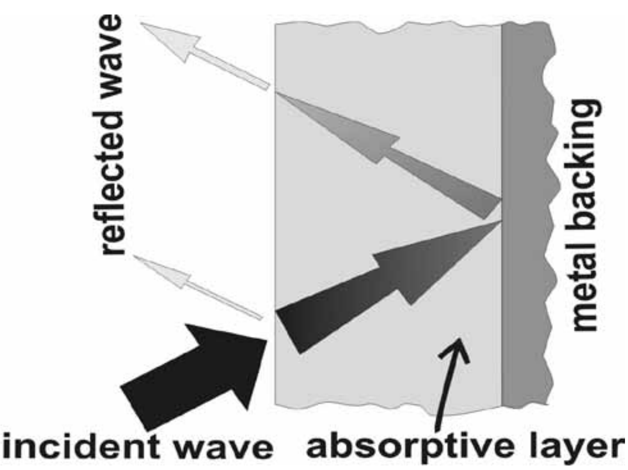

Fig. 1: Scheme of a simple, one-layer absorber.

Absorptive layer can be made from either dielectric or soft-magnetic materials with appropriate loss tangent. Usually the absorber layers are made from composite materials, mixtures of dielectric (carbon black, aluminum flakes…) and/or soft-magnetic (ferrites, carbonyl iron) particles in some matrix; however, excellent absorbers can be made from ferrite ceramics for use at lower frequencies. Since every material has advantages and disadvantages, the selection of materials is difficult and depends on actual application.

Characterization of absorbers can be made directly with standardized measurements of reflection in free space or indirectly through measurements of constituent materials' electromagnetic properties. The latter method is greatly used in the designing phase, since in general the reflection from the absorber can be analytically calculated from known materials' characteristics and geometry /1/.

For simple one-layer absorber with metal backing the equation for reflection is:

$$R(dB) = 20 \cdot \log_{10}\left(\frac{iA\tan(kd) - 1}{iA\tan(kd) + 1}\right)$$

$$A = \sqrt{\frac{\mu}{\varepsilon}}$$

$$k = \frac{2\pi f}{c} \cdot \sqrt{\mu\varepsilon}$$

where μ and ε are complex permeability and permittivity respectively, f is the frequency of the incident EM wave, c is the speed of light in vacuum, and d is the thickness of the absorbing layer. From this we can see that the key parameters that can be varied are complex permeability and permittivity of material and thickness of layer, whereas frequency of the incident EM wave is external factor. An example of the reflection curve as a function of frequency is shown in Figure 2.

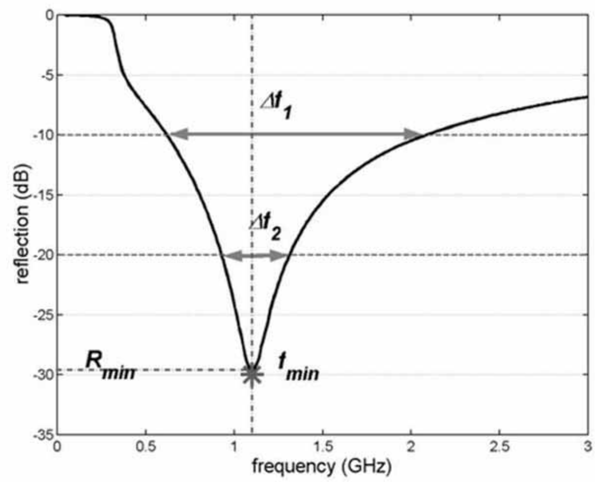

Fig. 2: Reflection of one-layer absorber as a function of frequency. Reflection levels −10 dB and −20 dB correspond to 10% and 1% reflection of energy respectively.

In order to characterize the absorber properties three key parameters are used: width of absorption band Δf, frequency range where reflection is below some level, usually –10 dB (10% reflection) or –20 dB (1% reflection); frequency of minimum reflection f_{min}; and level of reflection at f_{min}, R_{min}. An evaluation of quality of the reflection curve is rather arbitrary and depends on the desired frequency range and level of absorption, which usually differ for various applications.

2. Review of existing experimental work

Electromagnetic materials are advantageous for applications of microwave and millimeter wave protection.

Many characteristic can influence on materials absorbing properties. In present article I will mention some significance evaluation of efficiency of electromagnetic absorbing materials dependent on chemical structures, concentrations, sizes, shapes and syntheses. Different characteristic of electromagnetic materials with various methods have been studied by many authors /16-21/.

Research group from India investigated the microwave absorption of M-type hexaferrite-polymer composites prepared with different ferrite ratios of 50 wt.%, 60 wt.%, 70 wt.%, 80 wt.% in polyurethane matrix. Investigated have been in 8,2-12,4 GHz frequency range. It was found that the absorption properties in the composites are greatly improved with increasing ferrite contents in the polymer matrix. The composite with 80 wt. % ferrite content has shown a minimum reflection loss of -24,5 dB at 12 GHz with a -20 dB bandwidth over the extended frequency range of 11-13 GHz in a quite thin sample with a thickness of only 1,6 mm /22/. The permittivity, permeability and absorbing properties of coatings with carbonyl-iron particles as absorber and epoxy-silicone resins as matrix was also represented. The properties were investigated with different weight concentrations in the frequency range of 2-18 GHz. The plate shape (flake) particles of a carbonyl-iron have a size of 2-5 μm and about 1 μm thicknesses. The content of carbonyl-iron particles was 50 wt.%, 55 wt.%, 60 wt.%, 65 wt.%, 70 wt.% and 75 wt.%. Both the values of the real and imaginary parts of the permittivity increase with the carbonyl-iron weight concentration. The initial permeability increased more or less linearity to 70 wt. % and rapidly increased from 70 to 75 wt. %. A minimum reflection loss value of -42,5 dB was obtained at 10,6 GHz for the containing 55 wt. % carbonyl-iron. When the coating contains 75 wt.% carbonyl-iron particles, the region of reflection loss values less then -10 dB is below 2 GHz /23/.

Lots of studied showed that the microwave properties of electromagnetic absorber materials depend on particle size, shape and granulate.

The goal of next work was investigation of absorbing properties for different shapes and aggregated states of carbonyl-iron particles dispersed in epoxy resin matrix at various volume concentrations of 0,3-0,6 vol.%. The de-aggregated flake–shaped carbonyl-iron particles have higher permeability, lower permittivity and better absorbing properties in the frequency range of 2-18 GHz then aggregated sphere-shaped particles. The flake-shaped composite for 60 vol.% has the minimum reflection loss value -12,2 dB at 4,4 GHz for a 1 mm thickness layer /24/. Spherical and monodisperse $Co_{20}Ni_{80}$ particles were prepared, in the micrometer and sub-micrometer size range. The particle are with a mean diameter 1,4 μm, a narrow size distribution, and a low degree of agglomeration. The particles of second sample are smaller with a mean diameter 0,33 μm. Particles were randomly dispersed in epoxy resin. Microwave properties of composites were measured in 0,1-18 GHz. The micrometer size particles exhibit a permeability curve with a single resonance bands. The submicrometer size particles exhibit a behavior with three resonance bands /25/.

Some studies indicate that the hexagonal strontium ferrite is also good microwave absorber /26-27/. It is more adaptable than ferrites with spinel and garnet structure in case of a high frequency. However, susceptibility of ferrites at these frequencies is low, which makes it difficult to further improve their microwave absorption property. The susceptibility of metal powder is higher /28-29/ and such materials are typically used for frequencies up to 30 GHz.

In literature we can find researchers reports that plated layer on absorbers materials can improve absorbing properties of electromagnetic radiation. Modifying the properties of one material by coating it with another type of material has been a popular approach widely documented in the literature /30-34/.

Shanghai's Jiao Tong University worked on the synthesis of anatase coated barium ferrite composite particles suitable for microwave absorption applications. They reported on core-shell (barium-anatase) structures of magnetic particles that exhibit unique magnetic properties. The results of prepared sample with 75 wt.% ferrite in epoxy resin, in the frequency range of 2-12 GHz show that the titanium coverage on barium ferrite has a great influence on its microwave properties. The maximum reflection loss was obtained at the Ti:Ba ratio of 1:10 /35/. It is found that the complex permeability of the sintered ferrite Ni_2Y (Y-type hexagonal ferrite, $Ba_2Ni_2Fe_{12}O_{22}$) is higher than that of the ferrite composite Ni_2Y. Because the ferrite composite is composed of the ferrite particles coated with non-magnetic layer, its complex permeability is decreased. The complex permeability of the ferrite absorber is dependent upon frequency, but the complex permittivity is nearly constant. In those ferrite bodies most of the loss is mainly attributed to magnetic loss, while their dielectric loss is negligible /36/. China's Shanghai University has reported that the best way to solve this problem is fabricating the composite of ferrite and metal powder efficiently. They prepared a new type of Ni-coated strontium ferrite magnetic nanosized powder (Ni/

$SrFe_{12}O_{19}$) with electroless plating enchased by ultrasonic wave at room temperature. Their results show that the powder possesses excellent microwave absorption properties. The microwave absorption properties were measured from 5 to 15 GHz. They shown that the maximum microwave loss of the composite powder reach -41,3 dB. The bandwidth with the loss above -10 dB was 8 GHz /37/.

Japan scientists already presented a NiZn ferrite spin sprayed film, 3 μm thick, as a material exhibiting strong magnetic loss (reaching 67% attenuation of magnetic field at 3 GHz) and also reflection loss weak (smaller then 7%) enough to be practically applied to noise suppressors operated up to several GHz /38/.

Development of new magnetic materials and their understanding on a smaller – nano scale is a cause of advance in many areas of materials science. For a variety of important applications show promise for future, because of its large specific surface areas and the nano particles are much less then the incident wavelength, so it can greatly reduce the reflection from the surface, which make better impedance matching /39/. Researchers from Tokyo University achieved similar results by combining reverse-micelle and sol-gel techniques to create high-performance millimeter wave (30-300 GHz) absorber composed of a series of ε-$Al_xFe_{2-x}O_3$ nanomagnets with particles size between 25 nm and 50 nm. These materials show natural resonance in the region up to 182 GHz, which is the highest frequency for magnetic materials. The absorption peaks in millimeter wave range for samples: 30 wt. % (x = 0), 26 wt. % (x = 0,06), 24 wt. % (x = 0,09), 30 wt. % (x = 0), 29 wt. % (x = 0,21), 29 wt. % (x = 0,3) and 34 wt. % (x = 0,04) were observed at 112, 125, 145, 162, 172 and 182 GHz, respectively /40/. The α-Fe/$C_{(amorphous)}$ and $Fe_3C_{(amorphous)}$ nanocomposites have been prepared. The epoxy resin compacts with 40 vol.% α-Fe/$C_{(amorphous)}$, and $Fe_3C/C_{(amorphous)}$, were characterized in frequency range of 0,05-26,5 GHz. Powders provided good electromagnetic wave absorption performances (reflection loss < -20 dB) in ranges 4,3-8,2 GHz, and 9-26,5 GHz over absorber thicknesses of 1,8-3,3 mm and 1-2,4 mm, respectively /41/.

Behave of materials and device structures whose characteristic feature sizes are on nanometer scale are reported /42/.

There are numerous electromagnetic materials on the market designed for a wide variety of applications.

This short section show that is in specified field of work many different opportunities for further investigations exist for absorbing materials.

3. Conclusion

Electromagnetic materials are becoming more and more important for our society. We can find applicability in many different fields, for example in electronics or medicine.

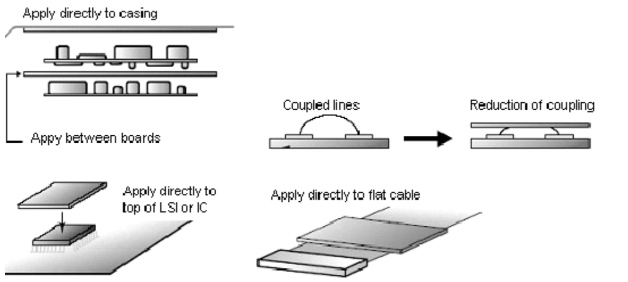

Fig. 3: Examples of applications soft-magnetic composites for reduction of electromagnetic noise.

Which type of electromagnetic protection should be used depends on the requirements and technical limitations.

With electromagnetic absorbing materials we can decrease the effects of EM waves on the human body and other systems.

Different scientists from around the word are looking for better and better materials with new, different properties, with higher effectiveness and efficiency.

However, as long as there is a possibility to do something better, a need for new materials and their new properties research will exist.

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Prispelo: 27.05.2010 *Sprejeto: 24.06.2011*