A New Composite Absorbing Material – Metamaterial Featuring Strong Synergistic Effect

Andrzej A. Vogt [#1], Hubert A. Kolodziej [#2], Andrzej E. Sowa [*3], Stanislaw Strzelecki [#4]

[#] *Faculty of Chemistry, University of Wroclaw*
50-383 Wroclaw, POLAND
[1]vogt@chem.uni.wroc.pl,
[2]hak.@chem.uni.wroc.pl, [4]sts@chem.uni.wroc.pl
[*]*Faculty of Electronics, Wroclaw University of Technology*
50-370 Wroclaw, POLAND
[3]asowa@ieee.org

***Abstract*— Powdered magnetic absorbing materials are necessary components of elastic, plastic or liquid absorbing composites. These materials have significantly worse magnetic parameters than solid materials do. Finally, absorbers made of such composites have a worse absorbing capacity than those made of solid materials. In the paper, the authors describe absorbing composites of their own design. These composites constitute a family of new metamaterials featuring a strong synergistic effect on magnetic material parameters and a considerably better attenuation factor in comparison to classical materials containing magnetic powder. Magnetic and dielectric characteristics of the metamaterials can be programmed and optimized in a broad frequency range.**
The characteristics of absorbers containing these metamaterials are essentially better than the characteristics of standard absorbers in many applications. Examples of absorbers utilising ferrite as a magnetic material are presented.
Key words: electromagnetic absorbing material, composite absorbing material, metamaterial, synergist.

I. Introduction

The demand for elastic and plastic absorbers has caused the need of solving a very serious problem regarding the use of powdered magnetic absorbing materials. These materials have significantly worse absorbing parameters than solid materials do.

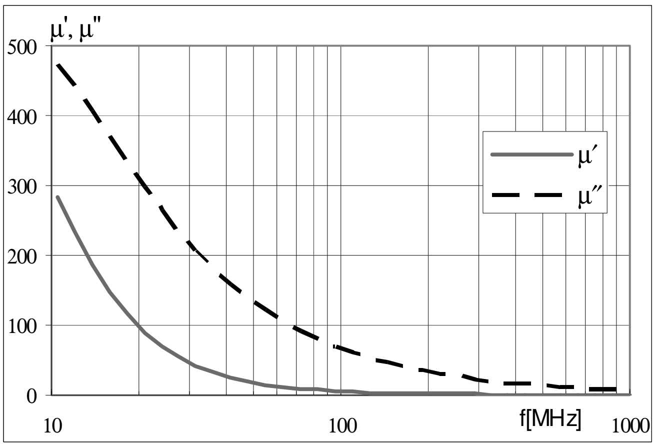

Fig.1a Magnetic permeability **μ'** and **μ"** for solid ferrite

In Fig.1 example magnetic parameters of solid (Fig.1a) and powdered (Fig.1b) absorbing material are shown for ferrite, irreplaceable absorbing material for lower VHF band.

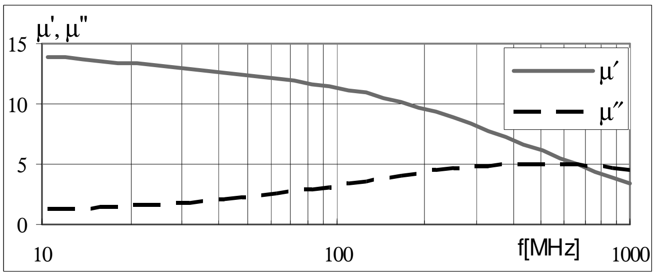

Fig.1b Magnetic permeability **μ'** and **μ"** for ferrite powder

Electric permittivity for solid ferrite is nearly constant: **ε'**≈ 14 and **ε"**≈ 0 . The parameters **ε'** and **ε"** for powdered ferrite are similar to those for solid ferrite. One can observe that **μ'** (for lower frequencies) and **μ"** (in the whole frequency range) are significantly smaller for powdered ferrite (whereas **ε'** and **ε"** are pretty unchanged).

Potential absorbing capacity of absorbing material can be initially estimated at the basis of its attenuation constant **α**. In Fig.2 the attenuation constant **α** of solid and powdered ferrite are shown.

On the basis of their earlier experience on synergy of magnetic material characteristics, the authors decided to create composite absorbing material featuring elastic or plastic form and significantly better magnetic characteristics in comparison to classical materials containing ferrite powder, even for almost 100% by weight.

The authors designed a synergist whose implementation allowed for the creation of a large family of metamaterials intended for absorption of electromagnetic field energy. The characteristics of absorbers designed using these metamaterials are, in many important applications, essentially better than the characteristics of classical absorbers.

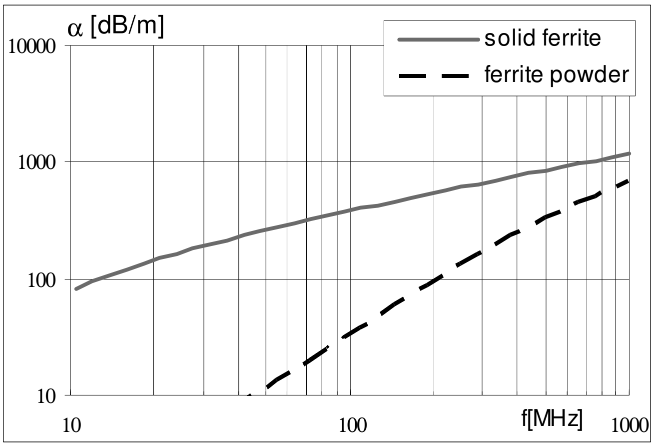

Fig.2 Attenuation constant **α** of solid and powdered ferrite

II. SYNERGIST

The synergist is a substance of spinel structure containing Fe^{+3} and Fe^{+2} ions complexed by surrounding long chain organic ligands. The dielectric and magnetic response (dielectric and magnetic absorption) appears to be very peculiar. In some range of frequency, magnetic absorption in particular shows negative values following exponential dependence. This is very typical for meta-magnetic materials. Probably, we have here a very promising material which should be thoroughly investigated in the near future.

III. SYNERGISTIC EFFECT IN AN EXAMPLE MATERIAL

The use of the new synergist in composites containing ferromagnetic materials allowed for the design of a number of absorbing metamaterials.

A. Ferrite metamaterial

The absorbing characteristics of these composites can be radically changed by the use of the synergist.

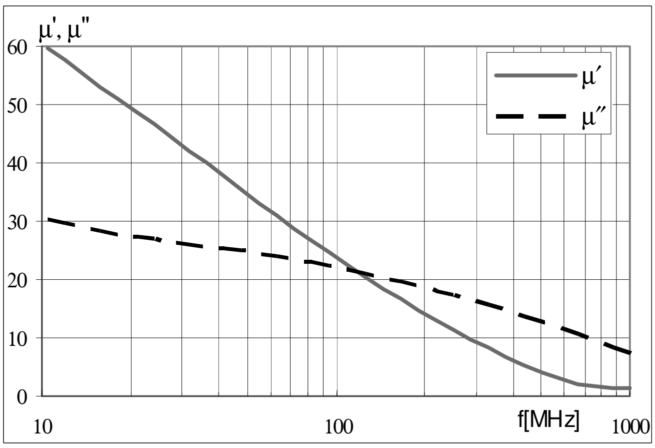

Fig.3 Magnetic permeability **μ'** and **μ"** for the ferrite metamaterial comprising 60% of ferrite by weight

A new metamaterial originated in this way can feature significant increase of both **μ'** and **μ"**.

A metamaterial using ferrite powder as a ferromagnetic material is one of the most important absorbing metamaterials. Plots of both **μ'** and **μ"** are shown in Fig.3 for an example composite comprising 60% of ferrite by weight.

Magnetic permeability **μ'** and **μ"** depends on concentration of the ferrite powder.

Dielectric parameters of the composite are defined by parameters of the ferrite powder, the synergist and additional non-magnetic components.

Additional non-magnetic components do not influence the magnetic parameters of the composite, or have only a very limited impact. This allows a very easy forming of dielectric characteristics of the composite.

Plots of both **ε'** and ε" are shown in Fig.4 for the same example composite comprising 60% of ferrite by weight.

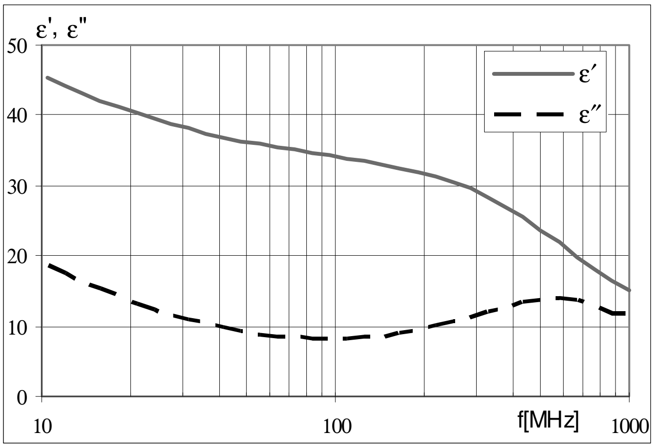

Fig.4 Electric permittivity **ε'** and **ε"** for the example ferrite metamaterial comprising 60% of ferrite by weight

B. Comparison of magnetic and dielectric material properties

In Fig.5 the magnetic permeability **μ'** and **μ"** is compared: for the pure ferrite powder (Fig.1b), for an example composite comprising ferrite powder and polypropylene [1] and for the new ferrite metamaterial comprising 60% of ferrite by weight (Fig.3).

For the metamaterial one can observe the increase of both **μ'** and **μ"**. Moreover the shape of the plots changes when comparing the pure ferrite powder and the composite comprising ferrite powder and polypropylene.

As mentioned earlier, the potential absorbing capacity of absorbing material can be estimated at the basis of its attenuation constant **α**. Therefore, a comparison of the attenuation constant for different materials can be used as a proper measure allowing comparison of their absorbing potential.

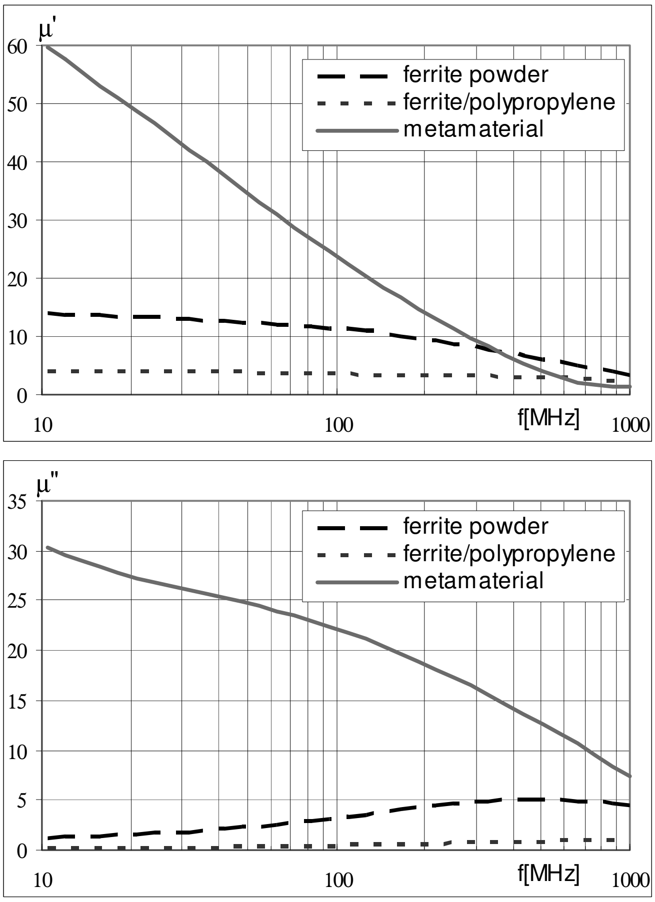

Fig.5 Magnetic permeability **μ’** and **μ”** for the pure ferrite powder, the composite comprising ferrite powder and polypropylene [1] and the ferrite metamaterial comprising 60% of ferrite by weight

In Fig.6 the attenuation constant **α** is compared for the pure ferrite powder (Fig.2), for the composite comprising ferrite powder and polypropylene and for the ferrite metamaterial comprising 60% of ferrite by weight.

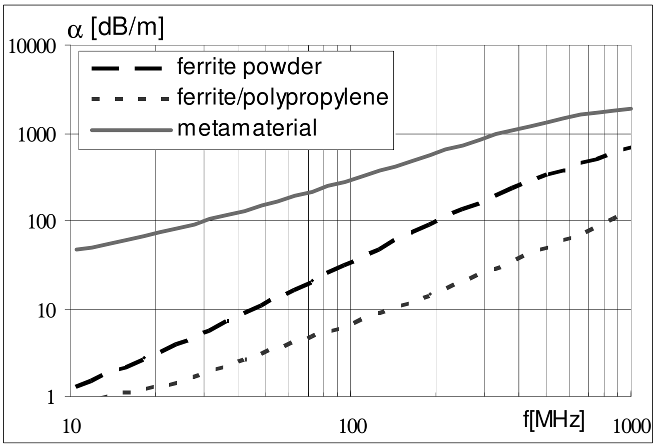

Fig.6 Attenuation constant **α** for the pure ferrite powder, the composite comprising ferrite powder and polypropylene, and the ferrite metamaterial comprising 60% of ferrite by weight

Fig.6 allows absorbing potential of the new metamaterial to be evaluated. The attenuation constant **α** increases many times. According to the frequency, the increase reaches from 45dB/m for 10MHz up to 1200dB/m for 1 GHz.

Consequently, the potential absorbing capacity of the metamaterial is significantly better than that of the pure ferrite powder and of the ferrite/polymere composite.

C. Remarks on absorber design

Final material parameters **μ’, μ”, ε’** and **ε”** of the metamaterial can be programmed to a certain extent.

Wide possibilities of material parameters programming are of a great importance for certain absorber applications. This especially refers to broadband free space absorbers. It demands effective matching of frequency characteristics of magnetic permeability and electric permittivity in the whole range of interest [2].

The new metamaterial creates exceptionally high possibilities of adequate characteristics matching, allowing effective broadband absorber performance.

IV. Examples of absorbers

D. Pyramidal absorber

Pyramidal absorbers belong to the group of broadband free space wave absorbers. They are used in anechoic chambers and for outside elements for special use.

Traditional pyramidal absorbers made of carbon loaded polyurethane foam are characterized by excellent reflectivity and unfortunately huge pyramid height for lower VHF range.

Because of the latter, during recent years new absorbers have been designed using magnetic absorbing material. This allowed for radical decrease of the pyramid (or cone) height.

These absorbers use some absorbing materials containing ferrite powder.

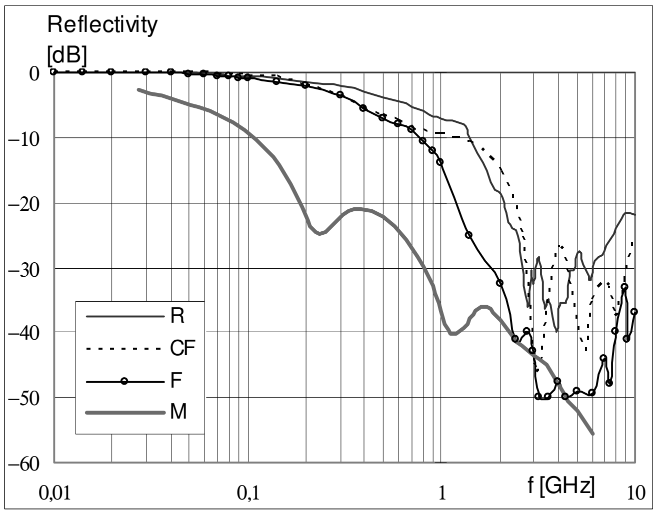

Fig.7 Reflectivity for: - (R) pyramidal absorber made of polypropylene and ferrite, pyramid height 8 cm [1]; - (CF) pyramidal absorber made of plastic and ferrite with the pyramid height 8 cm [3] – (F) cone absorber made of polychloroprene and ferrite (60% by volume), pyramid height 9.2 cm [4]; - (M) pyramidal absorber made of the ferrite metamaterial comprising 60% of ferrite by weight, pyramid height 6 cm [5].

Fig.7 shows a reflectivity plot vs. frequency for pyramidal absorber made of polypropylene and ferrite with the pyramid height 8cm [1], for pyramidal absorber made of plastic and ferrite with the pyramid height 8cm [3], for cone absorber made of polychloroprene and ferrite (60% by volume) with the cone height 9.2cm [4] and for pyramidal absorber made of the ferrite metamaterial comprising 60% of ferrite by weight with the pyramid height 6cm [5]. The reflectivity of the latter was computed using multilayer homogenization method of absorber parameters [6] and transmission line method.

The comparison clearly shows the advantage of the metamaterial.

E. Absorbing (EMC) cables

Absorbing (EMC) cables are one of the most important areas of new metamaterial application. The absorbing layer is applied directly on a wire conductor or it is applied on a cable screen surrounding a wire (wires). Absorbing cables can be in the form of single-core cables, two- and three-core power cables, screened multi-paired cables, coaxial cables (single and double screen) and others.

The authors' designed elastic ferrite metamaterial dedicated for use in cables [7]. Fig.8 shows comparison of the attenuation constant **α** for this material and classical ferrite/elastomer absorber used in EMC cables.

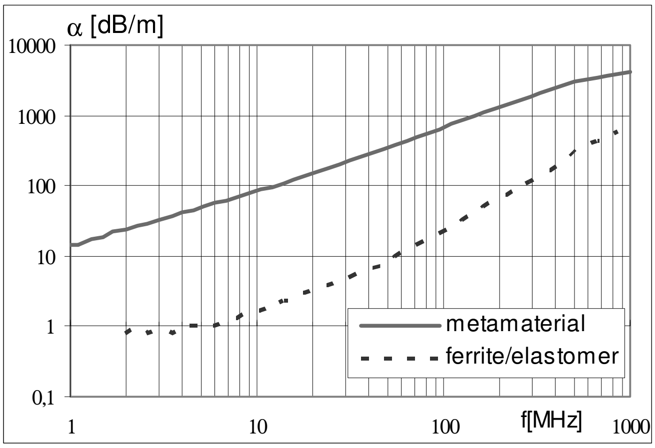

Fig.8 Attenuation constant **α** ferrite cable metamaterial and classical ferrite absorber used in EMC cables

Fig.8 allows evaluating absorbing potential of the new cable metamaterial.

The attenuation constant **α** increases many times. Consequently, the potential absorbing capacity of the metamaterial is significantly better than that of the classical ferrite absorber used in EMC cables.

For example, Fig.9 illustrates the effect of metamaterial application to an absorbing power cable. In this figure an attenuation of 2m cable vs. frequency is shown for a 230V cable without absorber, with classical ferrite/elastomer absorber [8] and with ferrite cable metamaterial [7].

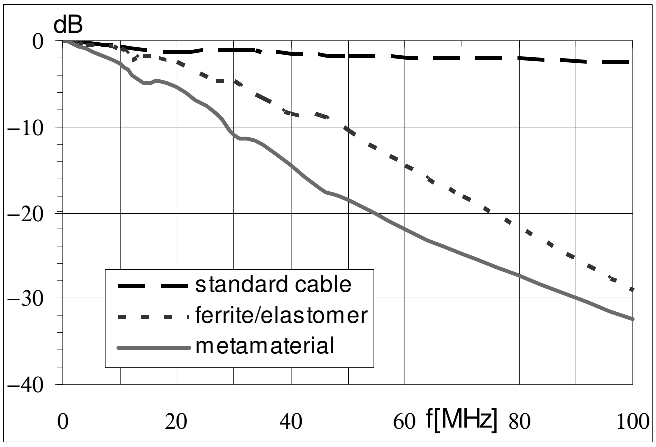

Fig.9 Attenuation of 2m of 230V power cable vs. frequency for: a cable without absorber, with classical ferrite/elastomer absorber [8] and with ferrite cable metamaterial [7].

As can be seen, the use of the ferrite cable metamaterial secures higher attenuation of the power cable. This higher attenuation is achieved for thinner layer of absorber than in the case of standard absorber.

V. CONCLUSION

The authors designed a highly effective synergist which use allowed for creation of large family of metamaterials intended for absorption of electromagnetic field energy and featuring exceptional absorbing performance in different areas of use.

Magnetic and dielectric characteristics of the metamaterials can be programmed and optimalized in a broad frequency range.

In many applications, absorbing parameters of the new metamaterials significantly surpass the parameters of other materials.

Mechanical parameters of the metamaterials allow their easy application.

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