RADIOABSORPTION PROPERTIES OF PROTECTIVE SCREENS

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1. Introduction

Microwave engineering is of great importance in a wide spectrum of applications, most of them related to wireless telecommunications systems, as in telephone, broadcast satellite television, or in satellite global positioning. Radar systems are also very useful for detecting mobile targets in air, sea, or ground, for air-traffic control or missile tracking radars, and for a wide variety of remote sensing systems. In addition, resonance phenomena appearing at microwave frequencies offer an opportunity for novel applications in heating systems, medical diagnosis and treatment or just new effects in basic science. In all these cases, the involved phenomena are characterized by millimeter electromagnetic waves with frequencies in the range from 500 MHz to 30 GHz.

The search for materials exhibiting outstanding properties in this frequency range is thus relevant in the development of the mentioned applications. Here, we focus on a particular family of materials, glass-coated amorphous magnetic microwires, exhibiting exciting microwave behavior with enormous technological applications as elements for absorption of electromagnetic radiation.

Glass-coated magnetic microwires are characterized by a nucleus out of a magnetic alloy, structurally amorphous and metallic conductor, with diameter between 2 and 20 μm, covered by a Pyrex-like coating 2 to 10 μm thick. The coating, in addition to insulating the metallic nucleus from corrosion and electrical viewpoints, induces strong mechanical stresses in the nucleus that coupled with its magnetostriction determine strong magnetoelastic anisotropy in the origin of a unique magnetic behaviour. The natural ferromagnetic resonance (NFMR) is of particular interest [1, 2], being observed as a consequence of the strong intrinsic magnetoelastic anisotropy.

The technological use of high and ultra-high frequencies in engineering has led to the need of creating electromagnetic protective screens. Amorphous microwires can be thus employed as radio-absorption elements when embedded in suitable matrices [3]. Here, we introduce an analysis of the opportunity of application of these materials in composite protective screens.

2. Design for protective screens

Due to their outstanding high-frequency properties, pieces of microwires have been embedded in planar polymeric matrices to form composite screens for radio absorption protection. Experiments have been performed employing commercial polymeric rubber around 2 mm thick and 30x30 cm^2 cross-section. Microwires are spatially randomly distributed within the matrix before its solidification. Concentration is kept below 8 g of microwire dipoles (2.0 to 3.5 mm long) per 100g rubber. A typical result performed in anechoic chamber is plotted in [3] for a screen with embedded $Fe_{69}C_5B_{16}Si_{10}$ microwires. As observed, an absorption level of at least 10 dB is obtained in the frequency range from 8 to 12 GHz with a maximum attenuation pick of 30 dB at around 10 GHz. In general, optimal absorption is obtained with microwires with metallic nucleus of diameter $2r_m$ = 1-3 μm and length L = 1-3 mm. Such pieces of microwires can be taken as dipoles, their length L being comparable to the half value of the effective wavelengths, $\Lambda_{eff}/2$, of the absorbed field in the composite material (i.e., in connection to a geometric resonance). We have connected the natural ferromagnetic resonance (NFMR, [1, 2]) to a geometrical resonance [3] (see Figure 1).

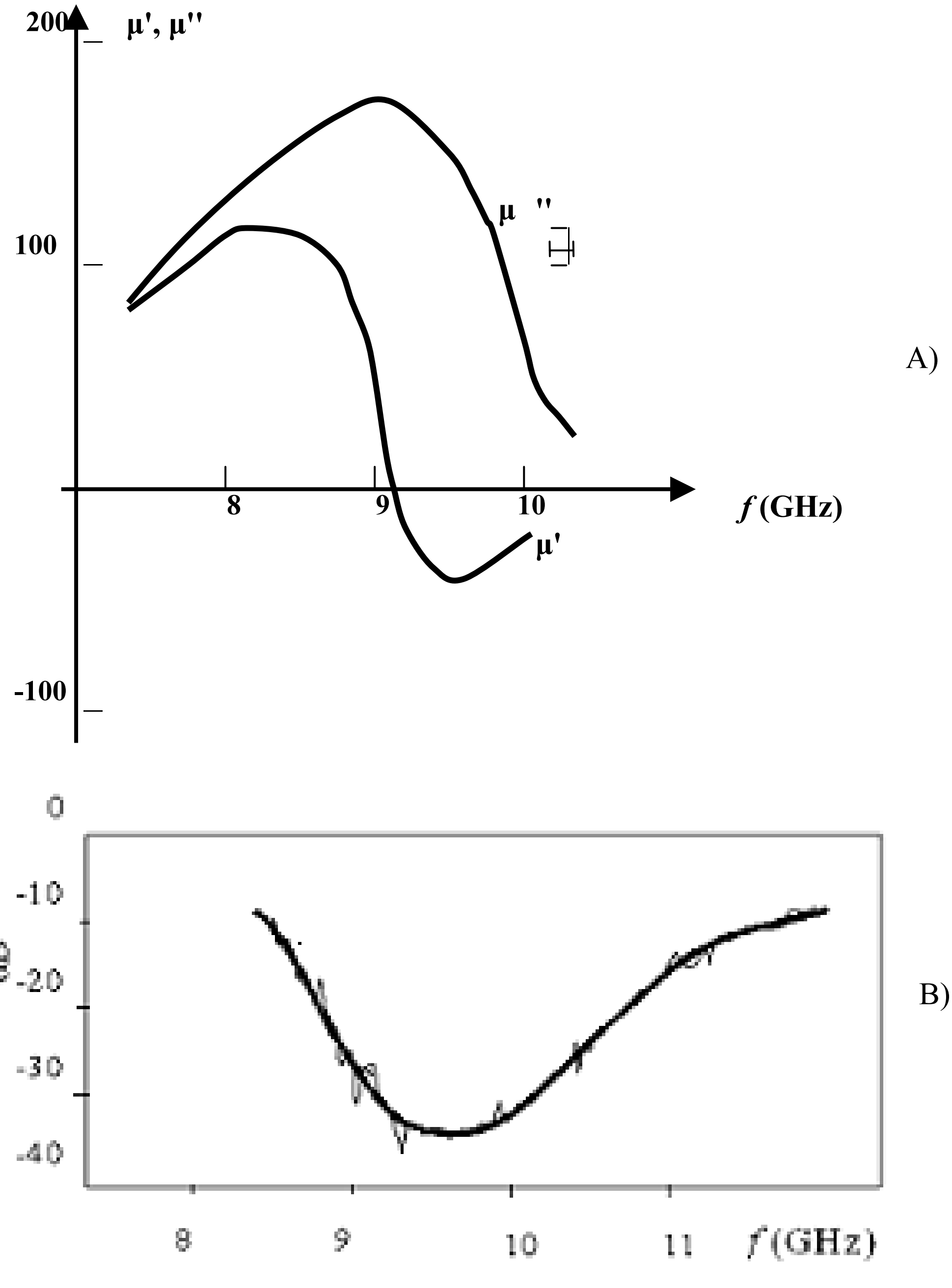

Figure 1. Dispersion of the magnetic permeability of an amorphous microwire A), and attenuation factor for this amorphous microwire as a function of the field frequency B). The relative measurement error was less than 10% for the frequency and less than 20% for the magnetic permeability. The spread of the attenuation factor measurements was 5 dB.

In fact, a wideband radio-absorption material can be created from amorphous microwires of different alloys possessing different frequencies of natural ferromagnetic resonance.

In addition, the width of the composite absorption curve can be increased by suitable dispersion of the magnetic susceptibility, which can extend the geometric resonance (NFMR, [1, 2]).

3. Theory for protective screens

Although the design of absorption screens can be based on disposing the dipolar pieces in a stochastically way, we consider, for simplicity, a theoretical analysis for a diffraction grating with spacing between wires Q < Λ (wavelength of absorbed field in free space). The propagation of an electromagnetic wave through an absorption screen with microwire-based elements is characterized by transmittance, $|T|$, and reflectance, $|R_r|$, coefficients given by

$$|T| = (\alpha^2 + \beta^2)/[(1+\alpha)^2+\beta^2]; \qquad |R_r| = 1/[(1+\alpha)^2+\beta^2], \tag{1}$$

where $\alpha=2X_r/Z_0$, and $\beta=2\,Y/Z_0$, with $Z_0=120\pi/Q$ (Q is spacing of microwires), and the complex impedance $Z= X_r + iY$.

The absorption function, G, is correlated with the generalized high-frequency complex conductivity Σ (or high-frequency impedance Z) [1]. Here, we use the analogy between the case of a conductor in a waveguide and that of a diffraction grating. The absorption function given by

$$|G| = 1 - |T|^2 - |R_r|^2 = 2\alpha / [(1+\alpha)^2+\beta^2] \tag{2}$$

shows a maximum $|G|=1/2$ for simultaneous $\alpha=1$, and $\beta=0$, for which $|T|^2 = |R_r|^2 = 1/4$. Theoretical estimations taking into account only the active resistance of microwires result in attenuation within the range 5-15 dB being much lower than experimental results, which for spacing of microwires $Q=10^{-2}$ m ranges between 18 and 15 dB, while for a spacing $Q = 10^{-3}$ m it increases up to 20 to 40 dB. Thus, it becomes clear that screens exhibit anomalously high absorption factors, which cannot be explained solely by the resistive properties of microwires.

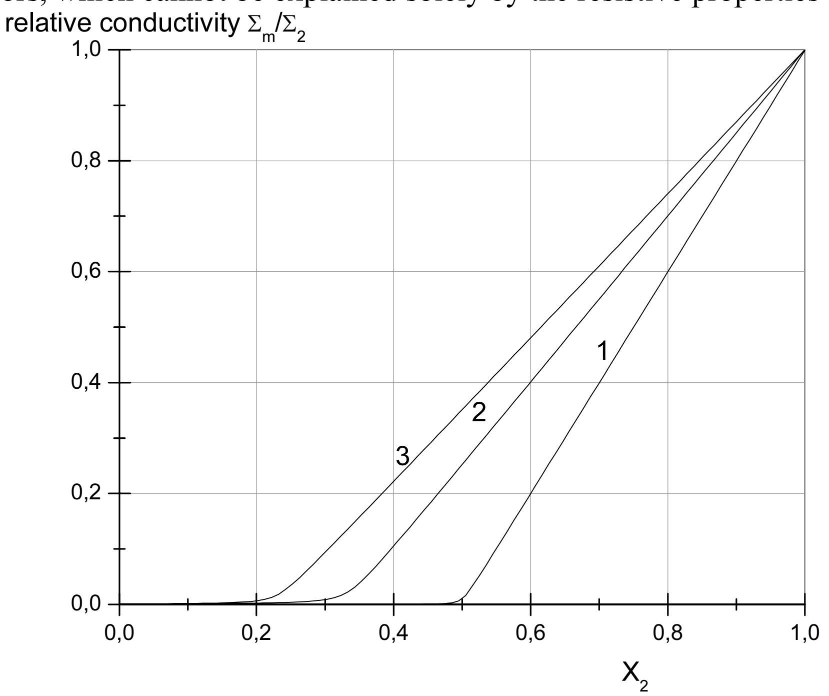

Figure 2. Relative generalized conductivity Σ_m/Σ_2 calculated by eq. (9) with $\Sigma_2/\Sigma_1 \sim 10^3$ for two thin microwires: $r_m<\delta$, $J_1=2$, $Y=0$ (1) and $r_m<\delta$, $J_1=3$, $Y=0$ (2), and a thick microwire: $r_m>\delta$, $J_1=4$, $Y/X_r=1$ (3).

The high-frequency conductivity, Σ_m, of a stochastic mixture of microwires in the polymeric matrix can be expressed as a function of the conductivities, Σ_i, of non-conducting (polymeric matrix) and conducting (microwire) elements, denoted by sub-indices *1* and *2*, respectively, as [2]

$$\Sigma_m = A + (A^2 + a\,\Sigma_1\,\Sigma_2)^{1/2}, \tag{3}$$

where $A=1/2[\Sigma_1(x_1-ax_2)+\Sigma_2(x_2-ax_1)]$; x_i representing the corresponding fractional volume, $(x_1+x_2)=1$; $a=1/(J_1-1)$, with $J_1\sim(J+Y/X_r)$ being the fractal dimension of the system, J the geometrical dimension of the system, and $Y/X_r \sim(r_m/\delta^2)$ (δ is skin depth [2, 3]).

Figure 2 shows that in case of a thick microwire ($r_m>\delta \approx 1$ μm), the conductivity of the system becomes very large, even in case of small microwires concentration, indicating the case of an antenna resonance. An effective absorption function is

$$|G_{eff}| \sim \Gamma_{eff}\,\Omega_{eff} / [(\Omega_{eff} - \omega)^2 + \Gamma_{eff}^{\,2}], \tag{4}$$

where $\Omega \sim \Omega_{eff}=2\pi c/\Lambda$ is a geometric antenna resonance frequency (with $\Lambda\sim 2L\,(\mu'')^{1/2}$, $\Gamma_{eff}\sim\Gamma$).. Absorption (see Figure 1) has maximum for $\Omega_{eff}\sim 10$ *GHz*, $\Lambda\sim 3$ *cm*, $\mu''\sim 10^2$, and $L\sim(1-2)$ mm, when the microwire concentration ($x_2<10\%$) is much less than a percolation level. Nevertheless, for very thin microwires (i.e., thinner than above mentioned 1 m diameter) embedded in a composite matrix with concentration larger than the percolation level an appreciable absorption effect should be expected.

4. Conclusion

Correlation between frequency of *NFMR* determined from dispersion of permeability and alloy composition of glass-coated microwires has been confirmed. Absorption of composite (microwire pieces embedded into polymer matrix) screens has been experimentally investigated. Parallel theoretical studies suggest that a noticeable absorption fraction can be explained by geometrical resonant effect. Positive effect is expected for thinnest microwires.

References

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