ABSORPTION PROPERTIES OF THE RADIO ABSORBING MATERIALS

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Abstract **– In this paper the absorbing properties of a one layer radio absorbing material structure deposed on a metallic surface are analyzed. Magnetic radio absorbing materials are considered. Conditions for canceling the reflection are evaluated. After numerically solving an over determined system of equations, the dependence of the reflection coefficient on the layer thickness, tg(δ_μ), frequency range and relative magnetic permeability was graphically represented and interpreted.**

Keywords**:** *radio absorbing materials, reflection coefficient, electric losses angle, magnetic losses angle.*

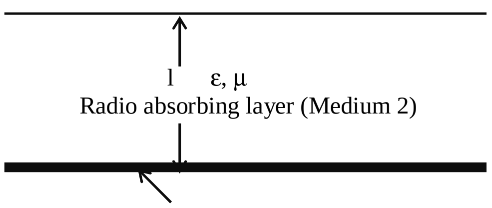
1. INTRODUCTION

The continuous evolution of the military radio systems for research and radiolocation have determined the developing of certain methods for decreasing the effective reflection surface of the objectives (SERO).One of these is referred to metallic surfaces covering with materials that absorb the energy of the incident radio waves. Materials, with certain electric and magnetic properties, that attenuate the radio waves and have a negligible reflection coefficient at the separation surface between the propagation medium and the material, in a certain frequency range, are called radio absorbing materials [1], [2],[3].

2.ABSORPTION PROPERTIES OF A MATERIAL LAYER DISPOSED ON A METALLIC SURFACE

We consider a radio absorbing material disposed on a metallic surface (Fig.1).

Incident electromagnetic wave
Medium 1



Radio absorbing layer (Medium 2)

Metallic surface (Medium 3)

Figure 1: Radio absorbing material on a metallic surface

The characteristic impedance of the radio absorbing material is:

$$Z_c = \sqrt{\frac{\mu}{\varepsilon}} = \sqrt{\frac{\mu_0 \cdot \left(\mu_r' - j \cdot \mu_r''\right)}{\varepsilon_0 \cdot \left(\varepsilon_r' - j \cdot \varepsilon_r''\right)}} = \sqrt{\frac{\mu_0}{\varepsilon_0}} \cdot \sqrt{\frac{\mu_r'^2 + \mu_r''^2}{\varepsilon_r'^2 + \varepsilon_r''^2}} \cdot e^{j\cdot\theta} \quad (1)$$

where

$$\varepsilon_r = \varepsilon_r' - j \cdot \varepsilon_r''$$

δ_μ, δ_ε are the electric and magnetic loss angles and μ_r, ε_r are the relative magnetic permeability and relative electric permittivity.
If we put:

$$\left|Z_{cn}\right| = \sqrt{\frac{\mu_r'^2 + \mu_r''^2}{\varepsilon_r'^2 + \varepsilon_r''^2}} \quad (2)$$

we get

$$\frac{Z_c}{Z_0} = \left|Z_{cn}\right| \cdot e^{j\cdot\theta} \quad (3)$$

The input impedance at the separation surface between air and the radio absorbing material is [4]

$$Z_i = Z_c \cdot \frac{0 + Z_c \cdot \mathrm{th}(\gamma \cdot l)}{Z_c + 0 \cdot \mathrm{th}(\gamma \cdot l)} = Z_c \cdot \mathrm{th}(\gamma \cdot l) \quad (4)$$

After normalization to the medium impedance relation, (4) becomes:

$$Z_{in} = \frac{Z_i}{Z_0} = e^{j\cdot\theta} \cdot \mathrm{th}(\alpha \cdot l + j \cdot \beta \cdot l) \quad (5)$$

In order to cancel the reflection at the separation surface between medium 1 and 2 the matching condition must be fulfiled :

$$Z_{in} = 1 + j \cdot 0 \Rightarrow \left|Z_{cn}\right| \cdot \frac{\mathrm{th}(\alpha \cdot l) + j \cdot \mathrm{tg}(\beta \cdot l)}{1 + j \cdot \mathrm{th}(\alpha \cdot l) \cdot \mathrm{tg}(\beta \cdot l)} \cdot e^{j\cdot\theta} = 1 + j \cdot 0 \quad (6)$$

From (6) we have :

$$|Z_{cn}|\cdot\cos\theta\cdot(1+j\cdot tg\theta)\cdot\frac{(th(\alpha\cdot l)+j\cdot tg(\beta\cdot l))\cdot(1-j\cdot th(\alpha\cdot l)\cdot tg(\beta\cdot l))}{(1+j\cdot th(\alpha\cdot l)\cdot tg(\beta\cdot l))\cdot(1-jth(\alpha\cdot l)\cdot tg(\beta\cdot l))}=$$

$$|Z_{cn}|\cdot\cos\theta\cdot(1+j\cdot tg\theta)\cdot\frac{th(\alpha\cdot l)-j\cdot th^2(\alpha\cdot l)\cdot tg(\beta\cdot l)+j\cdot tg(\beta\cdot l)+th(\alpha\cdot l)\cdot}{1+th^2(\alpha\cdot l)\cdot tg^2(\beta\cdot l)}$$

$$\frac{\cdot tg^2(\beta\cdot l)}{}=|Z_{cn}|\cdot\cos\theta\cdot\frac{th(\alpha\cdot l)-j\cdot th^2(\alpha\cdot l)\cdot tg(\beta\cdot l)+j\cdot tg(\beta\cdot l)+th(\alpha\cdot l)\cdot}{1+th^2(\alpha\cdot l)\cdot tg^2(\beta\cdot l)}$$

$$\frac{\cdot tg^2(\beta\cdot l)+j\cdot th(\alpha\cdot l)\cdot tg\theta+th^2(\alpha\cdot l)\cdot tg(\beta\cdot l)\cdot tg\theta-tg\theta\cdot tg(\beta\cdot l)+j\cdot th(\alpha\cdot l)\cdot}{}$$

$$\frac{\cdot tg^2(\beta\cdot l)\cdot tg\theta}{}=1+j\cdot 0$$

(7)

By equalizing the real and the imaginary parts of (7) the following system is obtained:

$$\begin{cases} tg(\beta\cdot l)\cdot\left(1-th^2(\alpha\cdot l)\right)+tg\theta\cdot th(\alpha\cdot l)\cdot\left(1+tg^2(\beta\cdot l)\right)=0 \\ |Z_{cn}|\cdot\cos\theta\cdot\dfrac{th(\alpha\cdot l)\cdot\left(1+tg^2(\beta\cdot l)\right)-tg(\beta\cdot l)\cdot\left(1-th^2(\alpha\cdot l)\right)\cdot tg\theta}{1+th^2(\alpha\cdot l)\cdot tg^2(\beta\cdot l)}=1 \end{cases} \quad (8)$$

After some mathematical processing (8) becomes:

$$\begin{cases} \sin(2\cdot\beta\cdot l)+tg\theta\cdot sh(2\cdot\alpha\cdot l)=0 \\ |Z_{cn}|=\sqrt{\dfrac{\cos(2\cdot\beta\cdot l)+ch(2\cdot\alpha\cdot l)}{ch(2\cdot\alpha\cdot l)-\cos(2\cdot\alpha\cdot l)}} \end{cases} \quad (9)$$

System (9) has two equations and four unknowns so it can be solved only if we know two of them, let's say α and θ.The material losses are evaluated using the following relations:

$$\begin{cases} \dfrac{1}{2}\cdot\delta_\varepsilon-\dfrac{1}{2}\cdot\delta_\mu=\theta \\ \dfrac{\pi}{2}-\dfrac{1}{2}\cdot\delta_\varepsilon-\dfrac{1}{2}\cdot\delta_\mu=\mathrm{arctg}\left(\dfrac{\beta}{\alpha}\right) \end{cases} \quad (10)$$

We obtain:

$$\begin{cases} \delta_\mu=\dfrac{\pi}{2}-\mathrm{arctg}\left(\dfrac{\beta}{\alpha}\right)-\theta \\ tg\delta_\mu=\dfrac{1-\dfrac{\beta}{\alpha}\cdot tg\theta}{\dfrac{\beta}{\alpha}+tg\theta} \\ tg\delta_\varepsilon=\dfrac{1+\dfrac{\beta}{\alpha}\cdot tg\theta}{\dfrac{\beta}{\alpha}-tg\theta} \end{cases} \quad (11)$$

and

$$\begin{cases} |Z_{cn}|=\sqrt{\dfrac{\mu_r'^2+\mu_r''^2}{\varepsilon_r'^2+\varepsilon_r''^2}} \\ tg\delta_\mu=\dfrac{\mu_r''}{\mu_r'} \\ tg\delta_\varepsilon=\dfrac{\varepsilon_r''}{\varepsilon_r'} \end{cases} \Rightarrow \frac{\mu_r'}{\varepsilon_r'}=|Z_{cn}|\cdot\frac{\cos\delta_\mu}{\cos\delta_\varepsilon}=|Z_{cn}|\cdot\frac{\dfrac{\beta}{\alpha}+tg\theta}{\dfrac{\beta}{\alpha}-tg\theta} \quad (12)$$

A certain relation between the wavelength and the material parameters can be obtained:

$$\frac{1}{\lambda}=\frac{\alpha\cdot\cos\theta\cdot\sqrt{\left(\dfrac{\beta}{\alpha}\right)^2-tg^2\theta}}{2\cdot\pi\cdot\sqrt{\mu_r'\cdot\varepsilon_r'}} \quad (13)$$

Considering that Z_{cn} and θ don't depend on frequency and the attenuation and phase constant are direct proportional with frequency, the working band can be determined such as the reflection coefficient to remain less than a certain value. If the reflection coefficient in power is ρ^2, from (8) we obtain the relative band:

$$B=\frac{2\cdot|\rho|\cdot\cos(\delta_\varepsilon-\theta)\cdot sh(2\cdot\alpha\cdot l)}{\beta\cdot l\cdot\cos\theta} \quad (14)$$

3. MAGNETIC RADIO ABSORBING MATERIALS

For the magnetic materials there are no electric losses. From (9) we have [5]: (9)

$$tg\delta_\varepsilon=\frac{1+\dfrac{\beta}{\alpha}\cdot tg\theta}{\dfrac{\beta}{\alpha}-tg\theta} \quad (15)$$

hence

$$tg\delta_\varepsilon=0\Rightarrow\alpha=-\beta\cdot tg\theta.$$

Replacing the attenuation constant in the first equation from (9) we obtain the following equation:

(10) $$\sin(2\cdot\beta\cdot l)=-tg\theta\cdot sh(-2\cdot\beta\cdot l\cdot tg\theta) \quad (16)$$

The graphical solution of (16), for constant θ is presented in Fig.2.

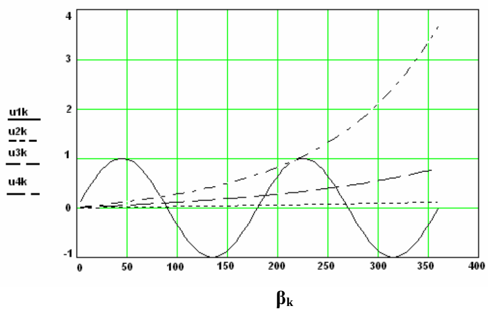


Figure 2: Graphical solution of (16) ($\beta_k=\beta\cdot l$ in degrees).

Representation have been performed as follows:

- solid line for the LHS,
- point line for RHS θ =-5°
- dashed line for RHS θ =10°
- dash-dot for RHS θ =-14.8119°

From Fig.2 it can be observed that (16) have a finite number of solutions.
They are the intersection points of the graphical representation of the RHS and LHS.
Solving numerically (16) it can be found that there is a solution, $\beta\cdot l$, in $[0, \pi/2]$ for $\theta \in [-45^{\circ}, 0^{\circ}]$.
In figures 3, 4, 5, 6, 7 the variation curves of the parameters that describe the radio absorbing materials, without electric losses, are presented. The interval for $\beta\cdot l$ is $[0^{\circ}, 90^{\circ}]$.

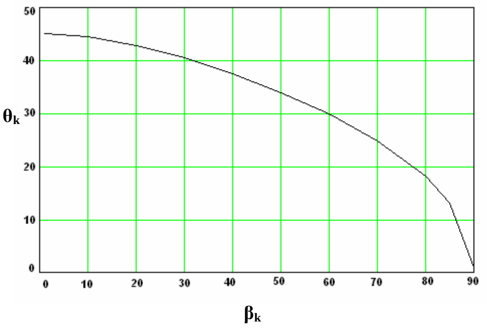


Figure :3 The variation of the semi difference between the magnetic and electric losses angles vs. $\beta\cdot l$ in degrees

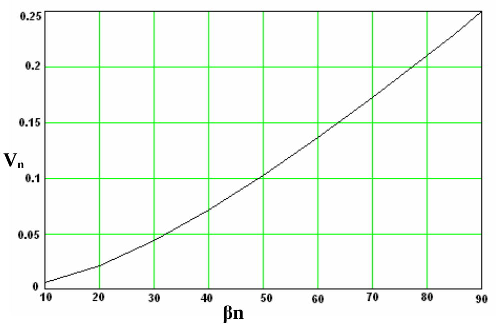


Figure 4 :Variation of $\frac{1}{\lambda}\cdot\sqrt{\mu_r^{'}\cdot\varepsilon_r^{'}}$ vs. $\beta\cdot l$ in degrees

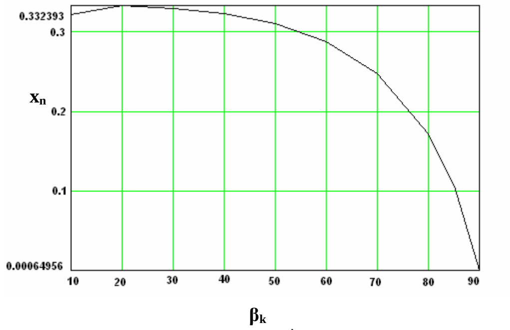


Figure 5: Variation of $\frac{\mu_r^{'}}{\varepsilon_r^{'}}$ vs. $\beta\cdot l$ in degrees

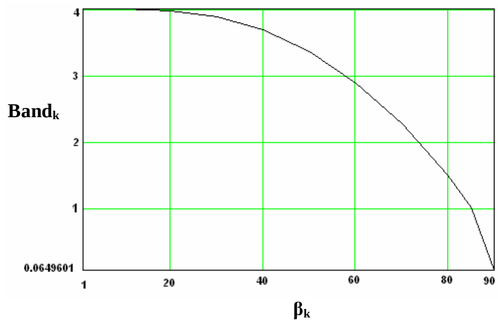


Figure 6: Variation of $\frac{B}{|\rho|}$ vs. $\beta\cdot l$ in degrees

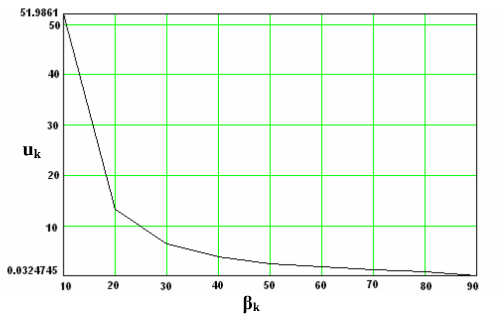


Figure 7 : Variation of $tg(\delta_{\mu})$ vs. $\beta\cdot l$ in degrees

In figures 8, 9, 10 , 11şi 12 are represented the same parameters for $\beta\cdot l \in [180°,270°]$.

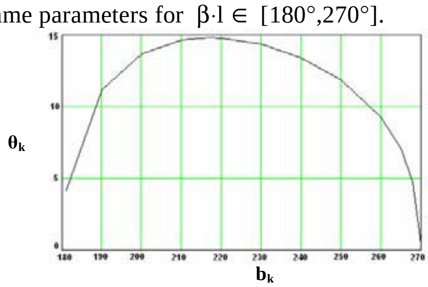


Figure 8: The variation of the semi difference between the magnetic and electric losses angles vs. $\beta\cdot l$ in degrees

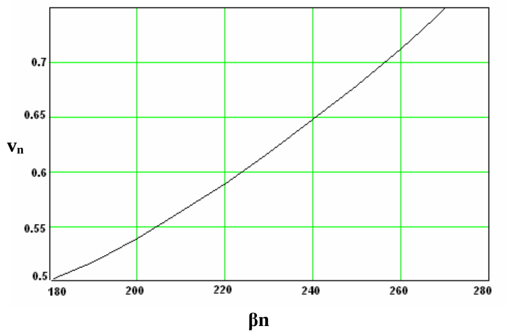


Figure 9: Variation of $\frac{1}{\lambda}\cdot\sqrt{\mu_r^{'}\cdot\varepsilon_r^{'}}$ vs. β·l in degrees

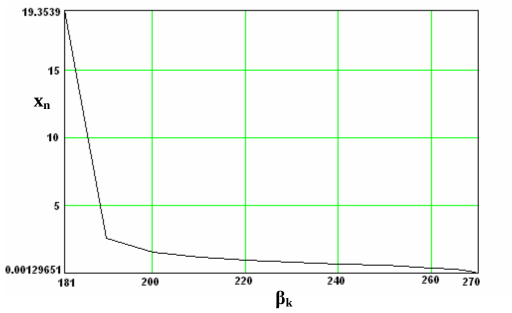


Figure10 : Variation of $\frac{\mu_r^{'}}{\varepsilon_r^{'}}$ vs. βl in degrees

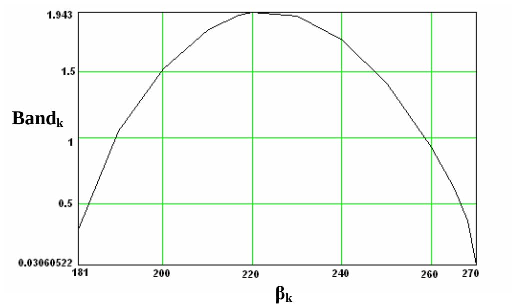


Figure11: Variation of $\frac{B}{|\rho|}$ vs. β·l in degrees

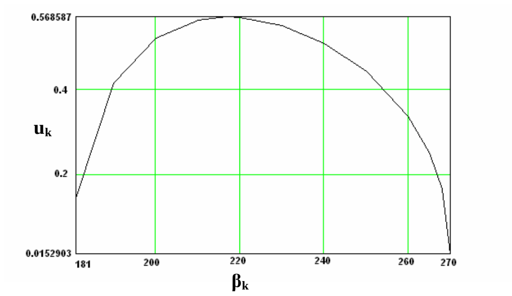


Figure 12: Variation of $tg(\delta_\mu)$ vs. β·l in degrees

The magnetic losses angle belongs to [0°, 29.623°]. The right limit corresponds to β·l=217°.The maximum value of B/|ρ| is 1.943.Comparing Fig.3 and Fig.4 it can be noticed that $tg(\delta_\mu)$ and the frequency range are bigger and the layer thickness is smaller when β·l has values in [0°, 90°].

4.CONCLUSIONS

Canceling of the reflections at the separation between the propagation medium and the radio absorbing layer leads to a system of two equations with four unknowns. Solving this system is possible only by choosing the values of two unknowns. System (9) has a finite number of solutions (relation (16) and Figure 2) for materials without electric losses (magnetic materials). The solution number depends on magnetic losses angle δ_μ.One solution is obtained if $\delta_\mu\in$[29.6239°, 90°] and three solutions if $\delta_\mu\in$[0°, 29.6238°] (Fig. 2).The frequency range is bigger if β·l has values in [0°, 90°] (Fig.6 and 11).The necessary value of $tg(\delta_\mu)$ decreases with the thickness growth of the radio absorbing material (Fig.7 and Fig.12) Radio absorbing materials without electric losses have a smaller frequency range (Fig.6 and 11).In can be increased if we use materials with almost equal electric and magnetic losses or multilayer structure. Further researches will involve this type of structures

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