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GENERALIZED ALGORITHM FOR SYNTHESIS OF PROTECTIVE COATING AGAINST ELECTROMAGNETIC RADIATION

Abstract

In the article the analysis of existing protective coatings. Presents an algorithm synthesis of protective coating against electromagnetic radiation.

According to this algorithm, absorbing and reflective coatings have been calculated, which provide acceptable performance in the angle sector of ± 70 *degrees.*

INTRODUCTION

The coatings are an important means of protecting information from unauthorized diversion through its emission of electromagnetic waves. Despite the widespread use of coatings, still there are not enough researches, aimed at processing time-theoretical methods of designing sinks and reflective top-of. In particular, the problem of obtaining a broadband absorber of electromagnetic waves with a minimum thickness is not solved yet.

1. ANALYSIS OF THE EXISTING PROTECTIVE COATING AGAINST ELECTROMAGNETIC RADIATION

When designing and calculating absorbing coatings are generally considered absorbers with dielectric and magnetodielectric losses. It is known that the task of developing of the coating can be reduced to the creation on the reflective surface of the inhomogeneous layer, which is a matched load for the incident electron-waves. The properties of this layer should gradually change with the thickness of the absorber.

With the proper choice of electrodynamic parameters of the layer, it is possible to obtain sufficiently low reflectance coefficient in a predetermined wavelength range.

The easiest for calculation and implementation is a quarter-wave electromagnetic absorber, which consists of a conductive film with a certain nominal of the surface resistance, located at a distance of a quarter wavelength from the metal surface.

When calculating the absorbing coatings usually use the analogy between the propagation of waves in free space and the processes occurring in long lines with distributed conductivity. Nowadays, the properties of coatings with a linear, power and two-stage law of changes of loss tangent are studied.

The most promising in terms of weight and size characteristics are the resonant coatings of interference type. They, in particular, can be constructed from separate resonant elements, distributed uniformly on the metallic plane. The elements are small compared with the wavelength, and respond to the magnetic field component. As a result of the choice of the resonant resistance of an individual element, and the number of elements per unit of the area, we can achieve the incident energy to be completely absorbed and the surface becomes non-reflective.

In the quarter-wave interference coatings the thickness of the absorbent material, which acts on the electric-mechanical field, increases due to an increase of wavelength. Therefore, to obtain a small thickness of this layer, we are trying to find a coating, which reacts to a magnetic field, and have it directly in front of metal (or any other) surface, which is to be secured.

Prototype element that interacts with the magnetic field is small loop antenna. These antennas are uniformly distributed on a metal plane and supply the energy, received from the field, to the load resistance.

Coatings are loaded oscillatory circuits with size approximately twenty times smaller than the wavelength, consisting of loop antennas having an inductance, ohm resistance and small adjustable capacitors. These circuits are located in front of the shorting metal plane and create the necessary equivalent load resistance.

The absorption of the electromagnetic field in a wide frequency range can be obtained by including two resonance circuits, which have an input impedance equal to the characteristic impedance of free space. Such a coating can be implemented on the basis of the dipole array situated at a distance of a quarter wavelength from the metal surface. This series resonant circuit is simulated by dipoles, and a layer of space with a metal plane is equivalent to a parallel circuit. The best absorption occurs when the dipole length is equal to a half of the wavelength. For practical use of such a coating is important its effectiveness is not to be very dependent on the length of the dipoles and the array constant. Experiments show that when the shown parameters are changed by 10%, the reflected power increases less than by 10%. During the vertical polarization of plane electromagnetic wave, in order to effectively absorption, the dipoles must be oriented parallel to the electric field.

For the independence of effective absorption of electromagnetic energy from the random orientation of the object, which is protected, in the space, a second array, , is added to a simple dipole array. Inclusion of additional dipole elements, rotated by 90 degrees, does not provide noticeable effect to coordination of the coating at normal wave drop. In other words, the reflectance coefficient of the coating of a bypass type with a cruciform dipole array is almost independent of the angle of polarization of the incident signal. To further increase of the frequency range of resonant interference coating, we can add an additional dipole array.

There are absorbing coatings, built on the principle of "electric swamp". In their structure there are a large number of plane-parallel conductive films located at a short distance from each other before the conducting screen. Equal to the operation of the absorbent structure, in the calculation of the multilayer coating with conductive films we are based on the assumption that the electrical conductivity of absorbing films gradually increase while getting closer to the metal screen. Due to the small distance between the absorbing films the typical, for the resonant absorbing structure, property of expressly limit frequency is observed.

For a two-layer structure (dielectric layer and a conductive film) the reflection coefficient can be defined for any angle of incidence of the wave directly from the solution of Maxwell's equations.

2. EXTENSION OF THE WORK OF ABSORBING COATING

We can expand the range of work of the absorbing coating, if multiple conductive and dielectric layers are used. In this case, it is possible to manufacture high-quality wide-range coating whose reflectance coefficient in the field is less than 10% in this wavelength range, and for the greatest wavelength the coating thickness is one-third. If the coating thickness is equal to the wavelength, the reflectance coefficient is about 3% and for a thickness equal to three wavelengths may be less than 1%. The thickness of the coating can be significantly reduced while introducing magnetic materials having magnetodielectric losses. However, in this case, the difficulties of manufacturing of such coatings are significantly increased.

As shown by theoretical and experimental studies, the wide-range coatings with a reflection coefficient on the field less than 3% or 1% have an attenuation, which continuously increases in the direction of wave spread. Applying the layered coatings, the satisfactorily low reflectance coefficient in a wide band cannot be achieved, because they increase the reflectance coefficient as soon as the thickness of each layer becomes the half of a wavelength. Continuous improvement of attenuation in such environments of parallel layers is not possible to be achieved, because it is technologically difficult to make a layer with uniformly decreasing resistance.

If you place the cones, pyramids, or wedges, the tops of which are oriented in the direction of the incident wave, then the attenuation increases with an increase in the surface of the coating to the main surface. This increase in absorption occurs continuously, although the surface resistance remains constant.

Despite the technical difficulties, coatings with the continuous change in the parameters of the layer are considered to be the most promising. However, their methods of calculation are so complex that it is impossible to develop a suitable methodology for manufacturing of such coatings yet. This is due to the difficulty of solving the Maxwell equations for the environments, the characteristics of which are varying according to the coordinates.

3. GENERALIZED ALGORITHM FOR SYNTHESIS OF PROTECTIVE COATING

Below is shown a generic algorithm for the synthesis of coatings, built on the basis of the theory of inverse spectral problems [1] (it is assumed that the plane electromagnetic wave incidents on the coating):

1. According to the spectral function of a linear differential operator of the second order, by the method [1] is built the function $f(\tau, y)$ of Fredholm integral equation

$$f(\tau,y)+\int_0^{\tau} f(s,y)K(\tau,s)ds+K(\tau,y)=0; y<\tau.$$

2. From the solution of this equation the wave impedance of the dielectric coating layer is determined

$$Z_в(\tau)=\sqrt{\frac{\mu(\tau)}{\varepsilon(\tau)}}=Z_в(0)\left[1+\int_0^{\tau}K(\tau,t)dt\right]^{-2},$$

where μ, ε, τ - respectively permeability, permittivity and time delay of the dielectric coating layer.

3. Find the wave resistance of TE and TM waves

$$Z_{BTE}=\sqrt{\frac{\mu(z)}{\varepsilon(z)}}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon(z)\mu(z)}\sin^2\varphi_0}^{\,-1},$$

$$Z_{BTM}=\sqrt{\frac{\mu(z)}{\varepsilon(z)}}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon(z)\mu(z)}\sin^2\varphi_0},$$

where φ_0 - the angle of incidence of the wave from the environment with parameters $\varepsilon_0\mu_0$ on the irregular layer. Time delay of the layer is given by

$$\tau_\beta=\int_0^z\sqrt{\varepsilon(z)\mu(z)-\varepsilon_0\mu_0\sin^2\varphi_0}dz.$$

4. Determine the objective function of the coating. To do this, it is advisable from a layer with a continuous wave impedance switch to a layered environment, consisting of homogeneous layers, wave resistance and the delay time of which can be found from the expressions

$$Z_{BTE}=\sqrt{\frac{\mu_i}{\varepsilon_i}}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon_i\mu_i}\sin^2\varphi_0}^{\,-1},$$

$$Z_{BTM}=\sqrt{\frac{\mu_i}{\varepsilon_i}}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon_i\mu_i}\sin^2\varphi_0},$$

$$i=1,2,...,M,\ t_i=l_i\sqrt{\varepsilon_i\mu_i}\sqrt{1-\frac{\varepsilon_0\mu_0}{\varepsilon_i\mu_i}\sin^2\varphi_0},$$

where l_i - thickness of the layer with number i, M - number of homogeneous layers. It should be noted that the formula for determining the time delay t_i is equal for TE and TM waves.

If the objective function does not meet the specifications, it is necessary to modify the spectral function and repeat the above procedure.

CONCLUSIONS

According to this algorithm, absorbing and reflective coatings have been calculated, which provide acceptable performance in the angle sector of ± 70 degrees.

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