RCS STUDY OF CYLINDRICAL CAVITY-BACKED APERTURES WITH OUTER OR INNER MATERIAL COATING: THE CASE OF E-POLARIZATION

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I. Introduction

Cavity-backed apertures (CBA) are encountered as parts of any airborne or spaceborne radar targets. Most familiar of them are, probably, air inlets and engine tubes, known to contribute a great deal to radar cross section (RCS) of jet aircraft. More often than not, this contribution is considered as undesired and is to be suppressed. To this end, the walls of the cavity are covered with some lossy material.

There are several techniques to solve these kind of problems and the discussion on the comparative advantages of different techniques is still continuing (see [1] and the list of references). For certain canonical geometries, there exists an accurate approach of analytical-numerical nature which ensures any desired accuracy of the obtained results. This is the dual-series-based Riemann-Hilbert Problem (RHP) approach of complex variable theory. In the present study, the dual-series-based solution is obtained for the scattering of an E-polarized plane wave from a cavity-backed aperture which is formed by a slitted infinite circular cylinder coated with absorptive material. The material coating can be done on the inner or outer surface of the cylinder. For both cases, numerical results are presented for the RCS and comparisons of the suppression of RCS are given for two different realistic absorptive materials. To the best of our knowledge, this is the first study made so far to solve the problems of CBAs with non-homogeneous space inside or outside with this approach.

II. Technique

The geometry is a circular shell formed by a zero-thickness, perfectly-conducting screen having a radius of "a" and an opening of width 2θ. Arbitrary-thin lossy material is introduced as a concentric layer on either inner or outer surface of the shell of the thickness "t". The radius of the absorptive layer is either a-t or a+t depending on whether the coating is from inside or from outside, respectively. The objective is to analyze the radar scattering behavior of this geometry for various frequencies. The problem is scalar, so the total field can

0-7803-1246-5/93/$3.00

be characterized by the single E_z component. The scattered field expansions in three regions are assumed to be

$$E_z^{sc} = \sum_{(n)} \left\{ \begin{array}{ll} A_n H_n(k_o r) & r > a \\ B_n J_n(kr) + C_n H_n(kr) & b < r < a \\ D_n J_n(k_o r) & r < b \end{array} \right\} e^{in\varphi} \qquad (1)$$

where $k = k_o\sqrt{\mu_r \epsilon_r}$, k_o is free space wave number and ϵ_r and μ_r are the relative permittivity and permeability of the absorptive material, respectively. J_n and H_n represent the Bessel and Hankel functions of first kind and order n, respectively.

By applying boundary conditions, the problem is reduced into dual-series equations and then solved by the RHP technique of complex variable theory. The details of the solution technique are given in [2]. The main advantage of this technique over all others like [1] is that it is based on the idea of partial inversion of scattering operator. Final matrix equations are proven to be of Fredholm 2nd kind, so the solution exists and it can be approximated through truncation. What is also important is that, the solution is equally effective for any angular width of the shell. The size of the matrix is determined by the electrical radius of curvature, and fairly large structures can be treated accurately. The numerical data obtained can obviously bring a better understanding of the scattering behavior of loaded cavities.

III. Numerical Results

Numerical results are obtained for RCS behavior of a CBA which is coated either from inside or from outside with absorptive materials. The associated formula for RCS is given as

$$\sigma_b = \lim_{r\to\infty} 2\pi r \frac{|E^{sc}(\pi)|^2}{|E^{in}|^2} \qquad (2)$$

The RCS is normalized with respect to πa which is the geometrical optics values of the closed circular cylinder. The normalized RCS results are presented in Figures 1 to 2 as a function of frequency for different coating materials which are shellac, natural XL ($\epsilon_r = 3.45 + 0.25i, \mu_r = 1$) [4] and poly-2.5-dichlorostyrene ($\epsilon_r = 7.3, \mu_r = 0.91 + 0.32i$) [5]. The thickness of the absorptive layer is 10% of the radius of the screen and θ is taken as 30°.

The effect of the presence of the absorptive material on the outer and inner wall of CBA are demonstrated in Figures 1 and 2, respectively for the case of aperture in the illumination region. Strong resonances are observed in the RCS of the uncoated CBA which are due to the excitation of the damped natural modes of the screen as a cavity-backed aperture The damped modes originate from the eigenmodes of the circular cavity, being shifted in frequency, and those shifts have been calculated previously [3]. As observed in Figure 1, coating from outside has no effect on the internal resonances but it helps only to decrease the amplitude of the incident field entering into cavity-backed aperture. Therefore, the sharp minima cannot be suppressed, but the average level of RCS is decreased. However, resonances of higher order modes can be suppressed by coating the screen with the absorptive material from inside as seen in Figure 2. To reduce the lowest order resonance peak, one needs to use magnetic absorptive material, since the magnetic field which is not zero on the screen can be suppressed by using magnetic absorptive material which results a lower back scattered power. As observed in Figure 1 and 2, lossy magnetic material is more effective than lossy electric material for the absorption.

IV. Conclusions

Accurate numerical results are obtained for the RCS of the cylindrical CBA coated with absorptive materials using the RHP technique. Moreover, it is much better to make coating from inside to suppress the resonances when the interior resonance is the dominant one in the backscattering characteristics. Otherwise, coating from outside can also be preferable to reduce the average level of the RCS. Finally, it is possible to adjust the thickness of the absorptive layer at a specific frequency so that RCS has a minimum value.

References

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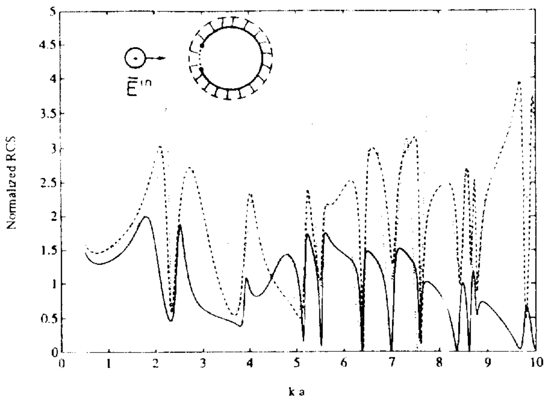

Figure 1: The normalized RCS of an uncoated and outer-coated CBA for two different absorptive materials with CBA having 60° aperture size, $\varphi_o = 180°$ and the coating radius b=1.1a; solid line: $\epsilon_r = 7.3, \quad \mu_r = 0.91 + 0.32i$; dashed line: $\epsilon_r = 3.45 + 0.25i, \quad \mu_r = 1$; dotted line: uncoated cylinder, i.e. $\epsilon_r = 1, \quad \mu_r = 1$.

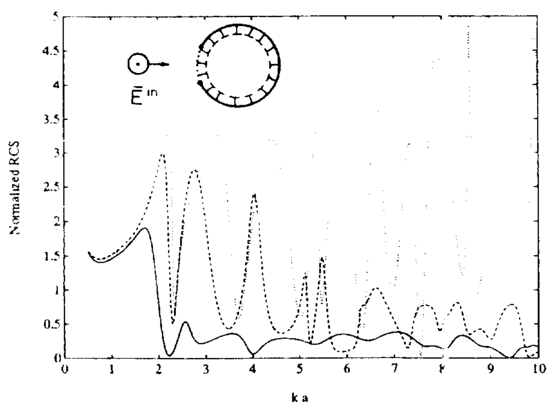

Figure 2: The normalized RCS of an uncoated and inner-coated CBA for two different absorptive materials with CBA having 60° aperture size, $\varphi_o = 180°$ and the coating radius b=0.9a; solid line: $\epsilon_r = 7.3, \quad \mu_r = 0.91 + 0.32i$; dashed line: $\epsilon_r = 3.45 + 0.25i, \quad \mu_r = 1$; dotted line: uncoated cylinder, i.e. $\epsilon_r = 1, \quad \mu_r = 1$.