sented and these were aimed at demonstrating the validity and accuracy of the proposed mathematical model. Modeling of conductive sheets [5] can be accomplished by employing the magnetic field formulation yielding a functional which is the dual of (6). However, when the conductive and resistive sheets are both present within the computational domain one cannot avoid the introduction of double nodes on both sides of the surface occupied by the conductive or resistive sheets. If an electric field formulation is employed as given here, double nodes must be placed on the surface of the conductive sheet. The functional in (6) must be supplemented with the additional integral

$$\frac{j}{2} k_0 Z_0 \iint_{S_c} R_m [\hat{n}_c \times (\mathbf{E}^+ - \mathbf{E}^-)] \cdot [\hat{n}_c \times (\mathbf{E}^+ - \mathbf{E}^-)] \, dS \tag{13}$$

where S_c is the surface occupied by the conductive sheet, R_m denotes its conductivity, and $\hat{n}_c$ is the normal to the sheet. Other than the requirement to introduce double nodes on S_c, the implementation of (13) is straightforward.

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E-Polarized Scattering from a Conducting Rectangular Cylinder with an Infinite Axial Slot Filled by a Resistively Coated Dielectric Strip

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Abstract—**The potential use of resistive films for damping the resonance spikes observed in the radar cross section (RCS) spectrum of a partially open rectangular cavity is investigated using a recently developed finite-difference time-domain (FDTD) method that utilizes the resistive sheet boundary condition for the modeling of resistive films. Backscattering data obtained in the first resonant region for an *E*-polarized plane wave normally incident into the slotted side of the cavity are presented. It is shown that resonance behaviors can be eliminated completely with a low-resistance film (e.g., R_S = 188.5 Ω) which attenuates significantly the impinging wave. Poorer resonance damping performance is observed as the film resistance increases to 754 Ω because more of the field is allowed to penetrate into the cavity. For the latter case, the presence of the resistive film lowers the Q-factor of the slotted cavity such that the resultant resonance spectrum is lower in strength and broader in bandwidth.**

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I. Introduction

The scattering behavior of a partially open rectangular cavity in the resonance region has been studied recently [1], [2]. Numerical and experimental results both show sharp resonant behavior in the radar cross section (RCS) spectrum which can be interpreted in terms of the internal modes of the cavity. Similar results are also reported for slotted cylindrical and spherical cavities [3], [4]. It is clear that this type of resonant phenomenon may play an important role in the area of target identification. Therefore, from the point of view of RCS management, a mean of suppressing their occurrence is highly desired.

In this communication, we consider the problem of scattering from a conducting rectangular cylinder having an infinite axial slot which is loaded by a resistively coated dielectric strip. The resistive film coating is assumed to be infinitesimally thin and is characterized by a surface resistance R_S (Ω/square). For the problem geometry shown in Fig. 1, the effects of film coating on the scattering behavior of the slotted cylinder in the first (TM_{11} mode [2]) resonance region are examined for the case of an *E*-polarized (*E*-pol) plane wave normally incident into the slotted side of the cylinder. Sinusoidal steady-state backscattering data are calculated by the conventional finite-difference time-domain method (FDTD) [5], [6] with the addition of the resistive sheet boundary condition (RBC) [7], [8] for the modeling of resistive sheet materials. Since the modeling procedures of the conventional FDTD (e.g., stability criterion, excitation source condition, lattice truncation condition, and near- to far-field transformation) are well documented in [6], and a detailed description of the newly derived resistive sheet boundary algorithm can be found in [9], only the numerical results obtained are summarized here.

II. Numerical Examples

For the results in this section, the following structural parameters are used for the loaded slot (see Fig 1); $A = 1.5B = 19.05$ cm, $W = 0.2A$, $d = A/30$, and $\epsilon_r = 4 - j0.4$. Resistive films having R_S = 0, 188.5, 754 Ω are used to examine the effects of resistive coating on the scattering behaviors of the slotted cylinder. Echo widths are calculated over the normalized frequency range of $3.4 \le kB \le 3.6$ (with k being the free-space wavenumber) that contains the first TM_{11} (2-D) cavity mode resonance region found in the RCS spectrum of the slotted cavity with zero wall thickness [2]. For the FDTD analysis, uniform square cells having sidelength $\Delta = 0.3175$ cm $= A/60 = B/40 = d/2$ (which is about $\lambda/72$ at $kB = 3.5$) are used throughout the entire 2-D FDTD lattice in the xy-plane.

As a first example, Fig. 2 compares the RCS spectra of an air-filled and a dielectric-filled slots both with wall thickness $d = A/30$ to that of a zero-thickness air-filled slot. For the two air-filled slot cases, it's found that the resonance in the RCS spectrum of the cavity with $d = A/30$ occurs at a slightly larger kB value of 3.53,

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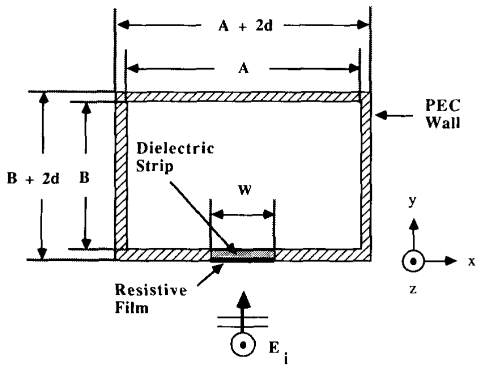

Fig. 1. Problem geometry showing an E-polarized plane wave normally incident into the slotted side of a conducting rectangular cylinder having a slot filled with a resistive-film coated dielectric strip. The entire structure extends uniformly to infinity along $\pm z$-axis.

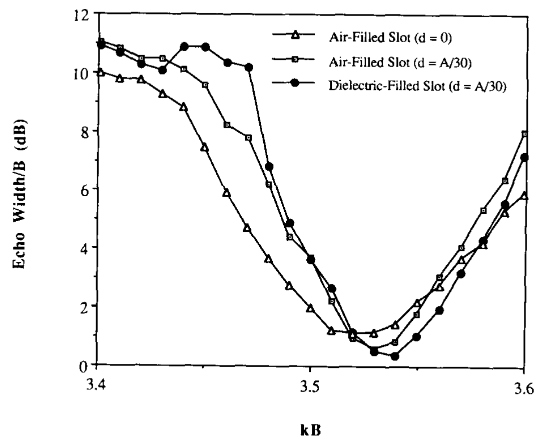

Fig. 2. Comparison of normalized echo width calculated for slotted cylinders with: a: a zero-thickness air-filled slot, b: an air-filled slot having thickness $d = A/30$, c: and a dielectric-filled slot having $d = A/30$ and $\epsilon_r = 4 - j0.4$.

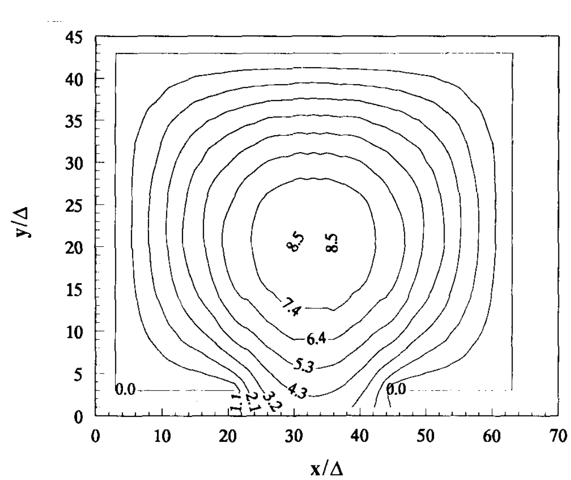

Fig. 3. Two-dimensional contour plot of $|E_z|$ induced inside a slotted cylinder with a zero-thickness air-filled slot. The cylinder occupies 60 and 40 cells each in the x- and y-direction.

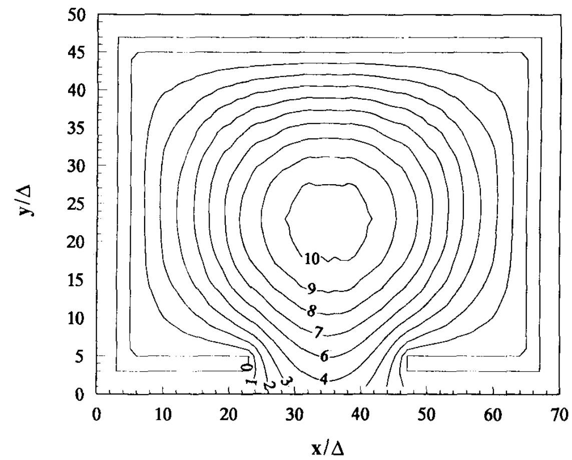

Fig. 4. Contour plot of $|E_z|$ inside a slotted cylinder with an air-filled slot with thickness $d = A/30$.

and with a slightly smaller echo width, than that of the cavity having $d = 0$. These trends continue when the slot is loaded with the lossy dielectric. Furthermore, the FDTD calculated RCS spectrum resonates at $kB = 3.52$ for the zero-thickness air-filled slot of width $W = 0.2A$, which compares favorably to the resonant frequencies of $kB = 3.7$ and 3.6 obtained by the method of moments used in [2] for the slot widths of $0.118A$ and $0.288A$, respectively.

Fig. 3 shows the 2-D contour plot of the electric field distribution at the first resonance of the cavity with zero-thickness air-filled slot. The contour plot of the electric field taken for the case of air-filled slot with $d = A/30$ is shown in Fig. 4. In both cases, the distribution of the electric field inside the cavity resembles that of the TM_{11} mode of a closed rectangular cavity (which resonantes at $kB = 3.776$). In addition, Fig. 4 shows that stronger fields are induced inside the cavity with $d = A/30$ than those shown in Fig. 3 when $d = 0$. A smaller amount of backscattered power (and echo width) is thus expected for the cavity having an air-filled slot with $d = A/30$.

Next we consider the effects of resistive film coating on the resonant backscattering behaviors of the slotted cylinder. Results obtained for films with $R_s = 0$ (i.e., pec film), 188.5, and 754 Ω are plotted in Fig. 5. Scattering data obtained for the case of dielectric loading only (i.e., $R_s = \infty$) are also shown in Fig. 5 for comparison. For $R_S = 0$ Ω, no penetration across the slot is allowed and the problem of scattering from a closed, perfectly conducting, rectangular cylinder having "exterior" dimensions of 20.32 × 13.97 cm is involved. As such, no resonance phenomenon is expected in the frequency range considered.

For $R_S = 188.5$ Ω, the flat RCS spectrum shown in Fig. 5 indicates that the interior TM_{11} mode resonance is essentially absent. This is in accordance with the high attenuation provided by a low resistance film. Moreover, when compared to the case of pec coating, the presence of the 188.5 Ω resistive film also results in about 2.5 to 3 dB reductions in the RCS magnitudes over the frequency range considered. This may be attributed to a reduction in the strength of surface current that flows over the surface of the resistive film [7], [9].

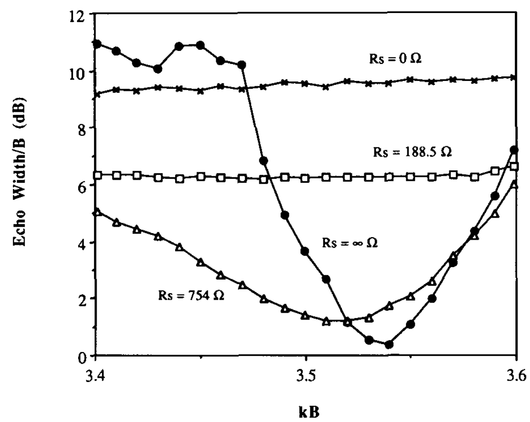

Fig. 5. Normalized echo width calculated for cylinders with dielectric-loaded slot which is coated by resistive films having surface resistance of: a: $R_S = 0\ \Omega$ (i.e., PEC film), b: $R_S = 188.5\ \Omega$, and c: $R_S = 754\ \Omega$. For comparison, data obtained in the absence of film coating (i.e., $R_S = \infty$) are also displayed. ($\epsilon_r = 4 - j0.4$.)

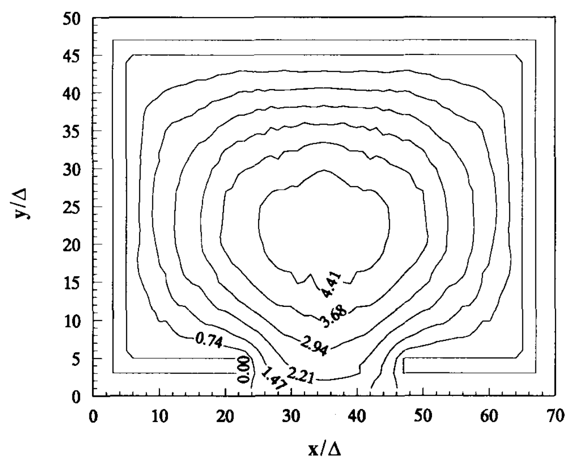

Fig. 6. Contour plot of $|E_z|$ inside a slotted cylinder with a resistively coated dielectric strip. ($R_S = 754\ \Omega$, $\epsilon_r = 4 - j0.4$, and $d = A/30$).

Finally, by increasing R_S to 754 Ω, more fields will be allowed to penetrate into the cavity such that the resonant RCS spectrum observed in Fig. 5 is expected. This also appears to be responsible for the further reductions in echo width when compared to those with $R_S = 0$ and 188.5 Ω. Compared to the case of $R_S = \infty$, the resonance spectrum found in this case is shallower but broader. The broadening in the RCS spectrum indicates that the presence of the resistive film, which attenuates signal passing through it, lowers the Q-factor of the cavity. On the other hand, its slightly larger echo width at resonance suggests that smaller fields are induced inside the cavity when the 754 Ω resistive film is present. This is verified by comparing the strength of the electric field distribution inside the cavity shown in Fig. 6 for $R_S = 754\ \Omega$ with that shown in Fig. 4 for $R_S = \infty$.

III. Conclusion

In summary, this research successfully demonstrates the potential use of resistive films for damping and/or removing resonance spikes in the RCS spectrum of a slotted rectangular cavity reported in [1], [2]. It is shown that resonant behavior can be eliminated completely with a low-resistance film (e.g., $R_S = 188.5\ \Omega$). With increasing film resistance (e.g., $R_S = 754\ \Omega$), field penetration into the cavity increases. As a consequence, resonance in the RCS spectrum can also appear but with a lower Q-factor than the case of dielectric loading only.

For the three film resistances studied, increasing film resistance tends to lower the echo width over the frequency range considered. At lower resistance values, since contributions from the interior cavity are expected to be small (due to the low penetration level), the reduction in echo width is mainly due to the smaller current strength present on the surface of the resistive film [7], [9]. On the other hand, increased field coupling into the cavity when film resistance increases may be responsible for the further reduction in the echo width.

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Efficient and Accurate Evaluation of External Mutual Coupling Between Compound Broad Wall Slots

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Abstract—**The efficient and accurate evaluation of external mutual coupling between compound broad wall slots cut in rectangular waveguides is addressed. The special case of longitudinal slots is also consid-**

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