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CONTROLLING APERTURE RESONANCE USING NOVEL COATING TECHNIQUES: THEORY, SIMULATIONS AND MEASUREMENTS

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Abstract: In this work, we propose the use of resistive sheets to improve the shielding effectiveness of enclosures with apertures. It is found that significant reduction of electromagnetic leakage is possible by using loading techniques inspired by the transmission line interpretation of current distribution on apertures at the resonance frequency of the aperture. Results form numerical simulations as well as from laboratory measurements are presented to validate the concept presented here.

Key words: Electromagnetic Compatibility, Electromagnetic Interference, Aperture, Coupling, Finite-Difference Time-Domain Method

1. Introduction

Aperture and aperture arrays designed for air ventilation on shielding can be a path for the coupling between the interior electromagnetic source and the external electromagnetic environment. A significant body of work is available on the subject of prediction and analysis of radiation through apertures. This work introduces novel material coating techniques intended to mitigate aperture-induced radiation.

To meet electromagnetic compatibility (EMC) and electromagnetic interference (EMI) requirements, it is crucial to quantify the electromagnetic field penetration through apertures and other chassis openings such as seams and gaskets. The leakage of electromagnetic waves through apertures in enclosures is critical at high frequency where wavelength is approaching the dimension of the aperture. This work proposes new techniques to reduce the radiation from apertures without reducing their size, affecting their topology or creating any impediment to airflow.

The term "loaded aperture" will be used in this work to refer to an aperture coated or surrounded by resistive sheets. The resistive sheet concept was originally introduced in [1],[2] can be applied in an infinite number of configurations. In this work, we will confine our investigation to three configurations only. As a starting point, a resistive sheet is applied close to the shorter edges of the aperture as shown in Fig. 1. This configuration will be referred to as Configuration A. Notice that to maintain the same see-through aperture area as before the application of any sheets, the actual metallic screen cutout is enlarged and the resistive sheet is effectively covering part of the aperture. As a second configuration, we placed a resistive sheet in the region surrounding the aperture such that the perimeter of the aperture will be composed of the resistive sheet, as shown in Figs. 2 and 3. This second configuration will be referred to as Configuration B. In the third configuration, a resistive sheet is placed on top of the conducting screen from both sides of the aperture. This placement resembles a frame-like figure as shown in Figs. 4 and 5. This third configuration will be referred to as Configuration C. Notice that the area of the aperture (physical opening) remains unchanged in these configurations such that the heat transfer requirements of the shielding plane (screen) remain unaffected. Figure 6 shows a view of the aperture seen from either the interior or exterior side for configurations A and B. The parameter w in the figures designates the width of the resistive sheet.

There are infinite possibilities for the type of material used in the resistive sheets. Our choice for the material is based on market availability. The material parameters for the resistive sheets experimented with in this work are $\mu_r = 1$, $4 = \varepsilon_r = 20$, and $5 = \sigma = 30$ Ohm^{-1}m^{-1}. We emphasize here that systematic optimization of the resistive sheets material property is outside the scope of this paper and is intended for future work. Furthermore, the effect of magnetic sheets is differed to future work.

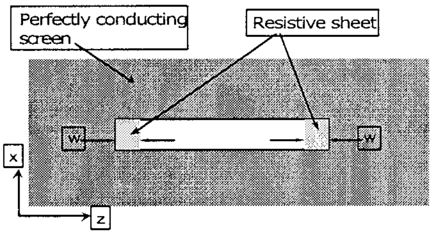

Fig. 1. Configuration A. Resistive sheets are placed close to the shorter edges of the aperture.

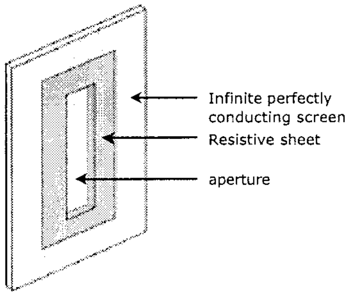

Fig. 2. Configuration B. The resistive sheets constitute an inner frame that is completely contained within the aperture.

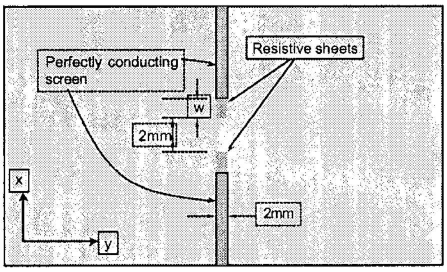

Fig. 3. Cross section (x-y plane) showing the application of resistive sheets in Configuration B. Notice that the see-through aperture size and area remained unchanged.

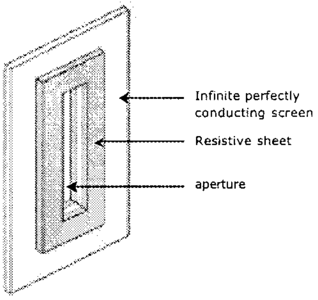

Fig. 4. Configuration C. The resistive sheets are placed on top of the conductor from both sides.

3. FDTD Aperture Model

The aperture considered in this study is rectangular, measuring 2 mm x 20mm. The aperture is positioned in an infinite, 2 mm thick, perfectly conducting screen. The commercial Finite Difference Time Domain (FDTD) code, EZ-FDTD^{TM}[3] is used for all the FDTD based simulations presented in this paper. The excitation is an impressed current source with a differentiated Gaussian temporal profile sufficient to generate appreciable energy up to 20 GHz. The current source is polarized in the x-direction for maximum aperture radiation (see Fig. 1). The electric field is captured at the other side of the aperture and transformed to the frequency domain by Fourier transformation. The source and the monitor point are each 40 mm away from the plane of the aperture in opposite directions with respect to the aperture such that the source and monitor points lie along an axis that is normal to the aperture and that intersects the aperture at its center. The FDTD method cell size is $\Delta x=\Delta y=1$ mm and Δy ranges from 0.2 to 1 mm according to the resolution requirements of the simulation. A modified version of the Perfectly

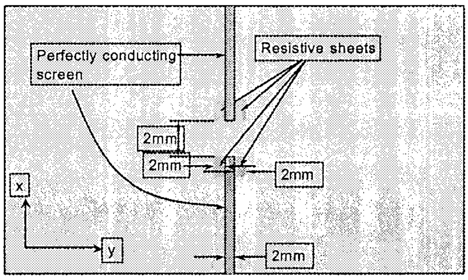

Fig. 5. Cross section (x-y plane) showing the application of resistive sheets in Configuration C. Notice that the resistive sheets are applied on both sides of the screen.

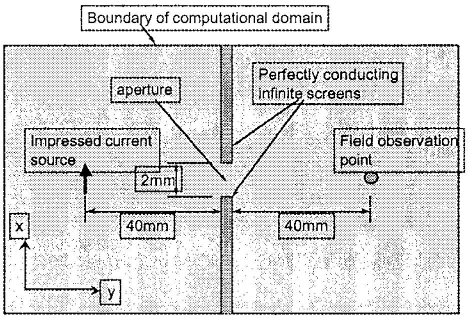

Fig. 6. Cross section (x-y plane) of the FDTD computational domain showing source and field observation point placements.

Matched Layer (PML) is used which is capable of simulating infinite conducting screens that are positioned normally to the computational domain. (Within this implementation of the PML, in effect, any perfectly conducting sheet that is positioned normally to the computational boundary is effectively stretched to infinity.) The computational domain is positioned 50-60mm away from the nearest edge of the aperture in order to minimize unwanted spurious reflections from the boundary of the computational domain.

4. Numerical Simulation of Aperture Radiation

When the aperture is not loaded, maximum radiation, within the frequency range of 1-12GHz, occurs at approximately the frequency at which the aperture becomes resonant, which, for the aperture size considered here, is approximately 7.2GHz. The resistive sheet material considered initially are given by $\mu_r= 1$, $\varepsilon_r =4$, and $\sigma =5$ $\mathrm{Ohm}^{-1}\mathrm{m}^{-1}$. In Fig. 7, we present the radiated field at the near-field monitor point (40mm away from the aperture in the normal direction) for the x-polarized electric field. The width of the resistive sheet is w=2mm. From Figs. 7 we immediately conclude that Configuration C provides the highest field reduction in comparison to the configurations A and B. In fact, one can observe an appreciable field reduction at the resonant frequency when Configuration C is used, with an approximate reduction of 12dB from the case of the unloaded aperture.

Based on the transmission line model of the aperture [1],[2], one would intuitively expect that Configuration A would yield the highest field reduction. It is important to keep in mind that the transmission line model (or interpretation) is only intended to provide a conceptual frame of reference to the field behavior within the aperture. Further insight can be gained by calculating the wave impedance within the aperture, which is defined as $|E_x/H_z|$.

The fact that Configuration C is more advantageous than the other configurations from the shielding effectiveness perspective is a very welcomed finding. Note that it was stressed earlier that the objective of this work is to maintain a mechanically robust aperture design, which also satisfies heat transfer requirements. Notice that configurations A and B require the presence of resistive sheets within the aperture. This requirement presents a challenge; as such configurations would require mechanical support due to the fragility of resistive sheets. Configuration C is mechanically stable, as the resistive sheet would be applied (coated) directly on the surface of the enclosure. For the remaining part of this paper, results will be presented only for Configuration C.

From the above empirical analysis, we conclude that a reduction of the radiated field of up to 13dB can be achieved if Configuration C is used with ε_r and σ both lying within the ranges considered, and with a sheet width, w, of 6mm. Amongst the material design parameters considered in this study, the width of the sheet was found to be the most sensitive factor in affecting the shielding effectiveness of the coated aperture. Based on the results presented in Fig. 7, the relationship between the loaded aperture radiation and sheet width is a complex one, and is clearly highly frequency dependent. It is important to keep in mind that the radiation through the aperture is due to the direct field penetration through the aperture, and is also due to the electric current that is induced on the external side of the screen, especially in the immediate vicinity of the aperture.

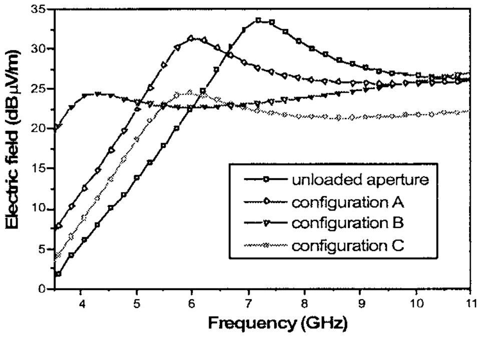

Fig. 7. Radiated electric field (x-polarization) at a distance of 40mm from the aperture.

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5. Experimental Validation

A small stainless steel box measuring 25cm X 20cm was constructed and an aperture measuring 2mm X 2cm was positioned at one side of the box. The details of the box construction and other dimensions are omitted here for brevity. A field probe (S-parameter measurements) was placed 4cm directly normal to the aperture. The source (excitation) was a probe positioned in the center of the box (through an SMA connector). The induced voltage (S12) was measured with and without a thin sheet of coating (approximate values: $\varepsilon_r= 4$, $\sigma=20$-30 /Ohm-meter). The results of the measurements are shown in Fig. 8 which indicates that appreciable reduction in aperture resonance is possible using the concept of aperture coating.

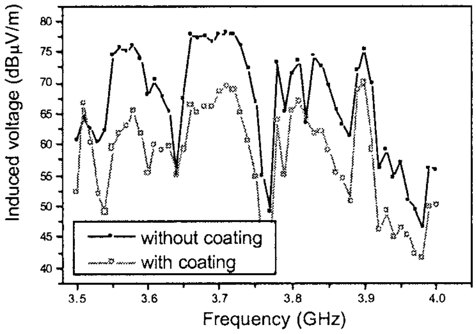

Fig. 8. Radiation reduction as a result of aperture loading

6. Summary and Discussion

This paper presents the novel use of resistive sheets to reduce electromagnetic penetration through apertures while maintaining robust mechanical design. The use of resistive sheets or coating, was motivated by the interpretation of the aperture and the oscillating field within the aperture as a transmission line system. Based on this interpretation, a resistive material was applied in different configurations to minimize aperture resonance. Several resistive sheet configurations were tested numerically using the FDTD method. One of the configurations tested was found to yield optimal field results with up to 13dB reduction in the aperture radiation in comparison to the case of the unloaded aperture. Such appreciable reduction in the field was made possible using only a 6mm wide strip of a resistive sheet on both sides of the aperture. Finally, it is emphasized that this study is empirical. A more exhaustive optimization is the subject of a future study in which the material properties and topology of the resistive sheets are considered.

As a final note, we make a comparison between the loaded aperture discussed in this work and the work performed previously on loaded monopole and dipole antennas. In earlier works, resistive loading, consisting of coating an antenna with lossy material, was used with great effectiveness in increasing the broadband potential of the antenna and thus its potential for effective matching to a purely resistive transmission line system (there are numerous publications on the use of resistive coating of antennas; the interested reader is advised to study the original paper on this subject by Wu and King [4]). Based on Babinet's principle, the aperture is the dual of the monopole and one would expect that a resistively loaded aperture, in the context of the definition used in this work, would have an analogous effect to that of the resistively loaded dipole. In fact, loading the dipole typically achieves a broadband behavior, however, at the cost of decreased efficiency. It is interesting that one notices a highly similar scenario in the case of the loaded aperture. Careful observation of Fig. 7, for instance, shows an increase in the broadband potential for the loaded aperture, i.e., an increased radiation at frequencies below resonance while an appreciable decrease in radiation at resonance. It is obvious that our objective in this work was to reduce radiation at resonance, but one can also think of this objective as widening the impedance bandwidth of the aperture.

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