Electromagnetic analysis and shielding of slots on resonant and non-resonant realistic structures with MLFMM

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Introduction and Numerical Computation
Coupling and interference in electronic devices (computers, sensors, control and communication devices, etc.) is of increasing concern due to the presence of either intentional or un-intentional internal or external electromagnetic sources. Such sources can cause sufficient disruption to the circuit or chip logic to the point where the functionality and logic state of the electronic device can be altered due to such extraneous sources. Coupling into these devices can occur either from ventilation slots (Error! Reference source not found.) or though power/signal lines which penetrate into the enclosure of the cavity structure. The latter can introduce conduction noise and ground fluctuations into the signal ports. Plane wave illumination, of unity field strength, onto the microwave filter in Error! Reference source not found. was calculated to give an induced voltage of 4 mV at the 50Ω output port. The actual excitation was a pulse train with a period of 300ns with the same center frequency as the filter (2.150GHz). These calculations were carried out using a well-validated finite element-boundary simulator [1-2]. Thus, a large amplitude pulse signal of 300V/m may induce a noise signal of 0.12 V. This could potentially cause failures in logic states for digital circuits and spurious waveforms for analog amplifier circuits. Furthermore cavity enclosures can amplify the external signals by as much as 10dB to 20dB (Fig 3), especially in the overmoded region. This can be seen in Fig 3B where the EFS fluctuations due to cavity and slot resonances pose a problem for a circuit configuration in Fig 1 C). Moreover, the presence of wires through the slot enhance coupling into the cavity. This is demonstrated in Fig 3A where we show the electric field shielding factor, $\text{EFS} = -20 \log \left( \frac{E_{\text{total}}}{E_{\text{inc}}} \right)$, measured in the middle of the cavity due to a plane wave incidence, for wires penetrating through aperture and into the cavity. The penetration is through a circular slot of area 60 cm². Both the straight and bent (longer) wires deteriorate shielding quite significantly at lower frequencies and even at higher frequencies for the bent wire. It is particularly noticeable that the bent wire causes low EFS even away from the cavity resonances due to greater re-radiation of energy from external illumination into the cavity enclosure. This is computed with the well-validated MLFMM algorithm [3].

Slot Coupling Reduction Techniques
The above analyses allows us to conclude that (1) coupling to the cavity interior is primarily controlled by the resonant characteristics of the cavity, aperture and the substructures (wires); (2) non-resonant apertures can still cause high coupling levels at
cavity resonances; (3) presence of wire through slots significantly increases coupling; (4) at high frequencies, overmoded cavities give EFS responses which are much more complex. An important step toward coupling reduction is to employ some type of shielding at the slot aperture. This can be done by employing some material loading across the slot or loading losses within the cavity. However, this is not a viable option if the slot is used for ventilation and it is further a costly alternative.

In this paper, we consider slot shielding approaches (i.e. maintaining large EFS) with the following constraints: (1) maintain same or greater aperture ventilation area; (2) low cost configuration. Several approaches were considered and analyzed using a multilevel fast multiple (MLFMM) method [2, 3]. We also remark that the analysis of slot, either in isolation or in the presence of aperture has been extensively studied [4-6]. These studies have primarily focused on the analysis of slotted enclosures and validation of such analyses particularly at lower frequencies (< 1 GHz). Our study focuses on the development of shielding techniques addressing the suppressing of the induced signal within the broadband region where the slot and cavity resonance are located close together (the worst case). Two shielding approaches presented are: (1) sequence of wires across the slot to push resonances at higher frequencies; (2) plate shielding with side apertures. Using a series of wires across the aperture is a rather low-cost, effective approach (except at enclosure resonances). Near those resonances any slot opening, regardless of its size, causes poor EFS at these frequencies. The latter approach, that of using shielding plates at some small distance behind the slot, was found the best in terms of shielding effectiveness over a larger bandwidth. This is demonstrated in Fig 4 where we compare the EFS for the shielded and un-shielded slots. Evaluation of the EFS, in the presence of a realistic structure (automobile platform), through an aperture (Fig 2) shows that a resonant slot can deteriorate shielding compared to a non-resonant slot.

Some of the conclusions from this study are: (1) Low cost shielding using wire strips across the aperture can reduce coupling by 5 to 20 dB (Fig 4A) over the frequency range around the slot and cavity resonance. (2) Use of PEC plates to ‘shadow’ the slots leads to a larger improvement of 5 to 30 dB (Fig 4B) over the same frequency range.

References


Figure 1. Response of pulse train response illumination (rise time=30ns, pulse width =60ns and period=300ns) of A) computed at either I/O ports for the circuit shown in B).
Figure 2. Evaluation of the electric field coupling (EFS) through a slot placed at the dashboard of an automobile at a line of points (green) on a plane (blue) in the car’s hood.

Figure 3. EFS calculations when a straight and a bent wire is placed through the circular slot considered in A) and for a rectangular slot in B) for a rectangular overmoded cavity.
Figure 4. Shielding effectiveness of: sequence of wires (A) and slot shadowing (B), used for reducing slot coupling. Note that the EFS dip at the cavity resonance still persists, but has the narrowest bandwidth for the shielding plates.