Effect of absorbing materials on shielding effectiveness of incomplete cavity

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Abstract. With the deterioration of electromagnetic environment, the electronic devices are seriously affected by the electromagnetic interference in high frequency, which makes it especially important to find protective methods. In this paper, a wireless transmission equipment was taken as an example to analyze the effect of absorbing materials on shielding effectiveness of cavity by numerical simulation. The results show that the absorbing performance is little affected by the position of absorber, but greatly affected by the direction. Furthermore, absorbing materials can effectively reduce the electromagnetic coupling of penetrating wire and increase the shielding effectiveness at resonant frequencies, but have little effect on interference transmitted by conduction, which indicates that the absorbing materials is an effective but deficient solution for electromagnetic protection of electronic equipment with complete circuit.

1. Introduction

With the rapid development of modern science and technology, integrated circuit (IC) and microelectronic devices are widely used in electronic systems. The interconnection and radiation of electronic equipment become more complicated due to the gradual increasing in operating frequency. Electronic equipment need apertures to improve the performance of ventilation, heat sinking and communication, the unavoidable apertures greatly reduce SE of metal cavity. Electromagnetic interference (EMI) will continuously reflect in the metal enclosure after entering the cavity through the aperture, which eventually resonates in the cavity at some frequencies. For the equipment that requires communication, EMI usually flows into the equipment in the form of current through coupling of wideband antenna or receiving coil, which affects the normal operation of internal circuit, even destroys sensitive devices [1-2]. A lot of research has been done at home and abroad on how to improve the shielding effectiveness (SE) of cavity with apertures and penetrating wires. The effect of absorbing materials on SE of cavity with apertures was experimentally studied by PAN et al, and a metal conduit was proposed to reduce the electromagnetic coupling of penetrating wires [3]. J.Nesic et al. [4] offer an efficient and practical method using an extra aperture as a matched load to enhance the SE of a rectangular enclosure with aperture. Bahadorzadeh et al. [5] presented placing a printed dog-bone dipole antenna structure inside cavity to improve the protective function. All of the above studies have focused on finding the protective methods of cavity with apertures but the research on the protective methods for cavity with penetrating wire or complete circuit are limited.
For better understand the effect of protective measures on SE of electronic equipment, the effect of absorbing materials on SE of the cavity, cavity with penetrating wire and cavity with complete circuit are studied by computer simulation technology (CST), respectively.

2. Calculation Model of Incomplete Cavity with and without Protective Measurement

CST MICROWAVE STUDIO includes a variety of full-wave algorithms and solvers, which can be used in their most suitable applications to achieve the best results. In this paper, the transient solver and frequency-domain solver are used to calculate electric distribution in the cavity of electronic equipment under irradiation of plane wave.

![Figure 1. Structural sketch of an electronic equipment.](image1)

Figure 1 is a structural sketch of a wireless transmission system. The cavity of equipment is hollow cylinder and the material of shell is aluminum alloy. The outer diameter \( R \) of the cylinder is 60mm, the inner diameter \( r \) is 58mm, the height \( h \) is 60mm, and the thickness \( \sigma \) of shell is 2mm. The coil is wound in the groove of the cylindrical shell and supported by Teflon. In the case of high-frequency electromagnetism, the coil can be equivalent to an inductance with special magnetic core, and the calculation formula of equivalent inductance is:

\[
L = \frac{K \mu_0 \mu_s N^2 S}{l}
\]  

(1)

Where \( \mu_0 \) and \( \mu_s \) are the relative permeability of vacuum and magnetic core, \( N \) is the turns of the coil, \( S \) is the cross-sectional area of the coil, \( l \) is the length of the coil, \( K \) is coefficient which is related to the radius and length of the coil, and the detailed meaning of symbols are given by HUANG et al, [6]. According to the parameters of coil, the equivalent inductance, \( L \) is calculated to be 57 \( \mu H \). As we can see in Figure 2(d), the coil is earthed at one end, and the capacitance of floating earth is 1.3 \( pf \) [7]. The other end is connected with internal PCB through penetrating wire. Load is equivalent to functional module in circuits and resistance of the load in this paper is 50Ω.

Figure 2(a) shows the model after removed coil and connecting circuit. Absorbing materials is placed in P2 and its thickness \( t \) is 1mm. The model mainly verifies the influence of absorbing materials at different positions on SE. Figure 2 (b) is the model used to analyze the influence of the absorber placed in different direction on SE. Figure 2 (c) is the model of cavity with a penetrating wire, in which the absorber is located on the upper side of the inner wall. Figure 2(d) shows a complete circuit comprised of the load, PCB, penetrating wire, equivalent inductance, grounding capacitance and cavity, which is mainly used to study the influence of absorbing materials on SE of cavity with complete circuit.

The model shown in Figure 2 was built in CST software, where both the cable and the passive components were replaced with lumped elements. The source of interference is plane wave, which is used to simulate far-field interference. The direction of transmission of plane wave is Y-axis and the direction of polarization is parallel to axis of cylindrical cavity, ensuring maximum coupling between interference and coil. The interference is simulated by Gauss pulse, the amplitude of pulse is 1V/m and the frequency range from 0.5 GHz to 2.5 GHz.
Figure 2. Simplified simulation model (a) Different position of absorber in cavity (b) Different direction of absorber in cavity (c) Absorber in cavity with penetrating wire (d) Absorber in cavity with complete circuit.

3. Simulation results and discussions
In this part, the effect of absorbing material on SE of cavity, cavity with penetrating conductor and cavity with complete circuit is mainly calculated. The results of simulation show that the absorbing performance of absorber is varied in three different situations.

3.1. The influence of Absorber on cavity
In order to improve SE of metal cavity with aperture, absorbing materials of microwave can be coated on the inner wall of cavity to reduce reflection of electromagnetic wave, thereby raise SE at resonant frequency.

Figure 3 shows the frequency dependence of SE under different arranged position of absorbing materials. It can be seen from the figure that SE near resonant frequency improved by 50dB. While for other frequencies changes slightly or even decreases. In addition, the reflection of electromagnetic wave can be suppressed by adding absorbing material, resulting in the increase of SE at resonant frequency. But the phase was changed when electromagnetic wave penetrates absorbing material, which affects the superposition of electromagnetic field in the cavity and make SE have a smaller decline in some frequencies.

Position of absorbing material has little influence on SE of empty enclosure. The results obtained from Figure 3 that the position of absorbing material arranged in P4 has the best absorbing performance, followed by the absorber arranged in P1, and the worst condition is the absorber arranged in P2 and P3. This indicates that the effect of absorbing materials on the radiation field is mainly to suppress the reflection of electromagnetic wave, and the loss of absorption is small. Therefore, in electromagnetic compatibility (EMC) design of electromechanical system, the absorbing material should be arranged on the wall of shell as far as possible, so that it can maximize the performance of absorbing materials and is easy to install.

Figure 4 shows the SE of cavity as a function of frequency under different placed direction of absorbing materials. It can be seen that the absorber placed in X-direction and Y-direction are better than those placed in Z-directions, and the resonant points will also be offset slightly. According to Maxwell's equation, the tangential direction of electric vector and magnetic vector must be continuous
when the electromagnetic wave arrives from one medium to another [8]. So it is as shown in formula (2):

\[ E^1_t = E^2_t, \]
\[ H^1_t = H^2_t \]  \hspace{1cm} (2)

Where \( E^1_t \) and \( E^2_t \) are the tangential electric intensity of medium 1 and medium 2, \( H^1_t \) and \( H^2_t \) are the tangential magnetic intensity of medium 1 and medium 2.

The polarization of the external interference source is Z-direction. When the electromagnetic wave enters absorber perpendicular to X-axis or Y-axis from air, more electromagnetic wave enters absorbing material and consumes soon, so the reflected wave is greatly reduced. Therefore, the absorbing performance of absorber perpendicular to X-axis and Y-axis is better than absorber perpendicular to Z-axis.

\[ \text{Figure 3. SE of cavity under different arranged position of absorbing materials.} \]
\[ \text{Figure 4. SE of cavity under different placed direction of absorbing materials.} \]

3.2. The influence of Absorber on metallic enclosure with penetrating wire

In practical applications, EMI usually enters the cavity not only through apertures, but also external penetrating wires. At this time, the electromagnetic field inside the cavity is the superposition of radiant field of apertures and wires, which results in sharply decline of SE. Figure 5 is the simulation result of model(c) in time and frequency-domain. It can be seen from the figure that SE at resonant point increases by nearly 10 dB after adding absorbing materials. The electric intensity at the probe decrease from 0.123V/m to 0.052V/m after adding absorber. The electric intensity in cavity decreases greatly, and the loss of electromagnetic energy becomes faster, from 30 ns before adding absorber to 10 ns.

The distribution of electromagnetic field in the cavity becomes more complex after the penetrating wire is added. The SE of the cavity decreases by 40 dB compare to that with only aperture, and there is an additional resonant point appears. SE of the cavity decreased because external coil can couple a lot of electromagnetic energy, and the wire inside the cavity is equivalent to an antenna. EMI irradiate on the coil and flows into cavity through penetrating wire, then the electromagnetic energy radiates in the cavity in the form of antenna. Compared to that with only apertures, more energy entered cavity, causing the decrease of SE. When absorbing materials are added, electromagnetic wave lose a part of energy each time it passes through or contacts with absorbing materials, so the loss of electromagnetic energy will be much faster than that without absorbing materials.
3.3. The influence of Absorber on metallic enclosure with complete connection

In our daily life, the one we use the most is the cavity which is loaded installed with complete circuit. At this time, EMI not only interferences the internal electronic devices in forms of radiation, but also destroys devices in forms of conduction.

Figure 6 is the simulation result of model (d), it is the SE of the cavity with coil and its circuit with and without absorbing materials. It shows that the resonance in the cavity becomes extremely complex. This is because each part of the circuit can be regarded as a radiant source, the electric intensity at the probe is the superposition of radiant fields of serval sources. The phase and amplitude of each radiant field are different, which makes the distribution of electromagnetic field in the cavity become very complex, so the SE curve will also be complex.

After the application of absorbing materials, SE has been improved and the number of resonant point decreased, but it’s still complicated compared to that with only cavity. Absorbing materials can improve SE of cavity, mainly because it can restrain the reflection of electromagnetic wave. When there is a complete circuit, electromagnetic wave transmits by both radiation and conduction. Absorbing material can not restrain the effect of conduction, so after adding absorbing material, it can only improve the resonance of electromagnetic wave in cavity to a certain extent, but not completely.

Figure 5. Effect of absorbing material on SE of cavity with penetrating wires (a) Frequency dependence of SE (b)Time dependence of electric intensity at electro-field probe.

Figure 6. Effect of absorbing material on radiation and conduction.
Figure 7 shows the waveform of voltage of load. The voltage on the load is 0.006V before adding absorbing materials and 0.0014V after absorbing materials is added, voltage of load decreases by four times. The results consistent with the results of simulation in frequency-domain above.

4. Conclusions and Outlook

The wireless power transmission system was taken as an example to analyze the electromagnetic distribution in the cavity under three different conditions: cavity, cavity with penetrating wire and cavity with complete circuit. The final conclusions are as follows:

(1) In the case of empty cavity, absorbing materials can greatly restrain resonance and improve SE. The performance of absorber is little affected by the position of absorbing materials. Besides, the results of simulation show that the wall of cavity is the best position to arrange absorbing materials, and the absorbing performance are greatly affected by the direction of the maximum cross-sectional area of absorbing materials; the absorbing material reaches a best state when the direction of the maximum cross-sectional area is parallel to the direction of polarization.

(2) After the penetrating wire was added to the cavity, SE is greatly reduced and resonant points are increased. Furthermore, the resonance can be suppressed by the absorbing materials and electromagnetic energy in the cavity drops sharply after the absorber is added.

(3) For the cavity with complete circuit, the resonant points in the cavity increase sharply. Moreover, the absorbing materials can greatly reduce the effect of radiant field on electronic devices in the cavity, but have limited impacted on the energy transmitted by conduction.

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