Effect of Resonances on Shielding Effectiveness in Enclosure with Apertures

P. Dangkham¹, P. Sujintanarat¹, S. Chaichana¹, K. Aunchaleevarapan², and P. Teekaput¹

¹Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand
²Electrical and Electronic Products Testing Center, NECTEC, NSTDA, KMITL Bangkok, Thailand

Email: kraison.aun@ptec.or.th

Abstract—This paper presents the effect of resonances in enclosure with apertures. An analytical formulation has been employed for the shielding effectiveness. The factors such as the size and shape of aperture, sum of apertures are important to shielding performance. To improve the shielding, the use of metal piece inside enclosure is studied for removing the lowest resonance frequency. Results show that the place of metal piece can be used to evaluate shielding effectiveness for design purposes.

I. INTRODUCTION

The shielding enclosure has already been studied many times. It is frequently used to reduce the emission or to improve the immunity of the electronic equipment. Electromagnetic compatibility (EMC) of enclosures of electronic equipment is a key issue that must be taken into account in the early stages of design. The integrity of shielding enclosures is compromised by slots and apertures for heat dissipation, CD-ROMs, I/O cable penetration or other possibilities. These apertures tend to become the coupling route of Electromagnetic Interference (EMI) from interior to outside hence degrade the Shielding Effectiveness (SE) of the enclosure. This parameter is defined as the ratio between the incident field in absence of the shield and the field in the same position when the effect of the enclosure is taken into account, the definition of Electrical Shielding Effectiveness (SEₜ) will be as [1]:

\[ SEₜ = 20\log\left(\frac{E₁}{E₂}\right) \]  \hspace{1cm} (1)

\(E₁\): Electrical field without shielding;

\(E₂\): Electrical field with shielding;

There are two methods to calculate the shielding effectiveness[2], numerical simulation and analytical formulation. For numerical method that have been researched and used to calculate the shielding effectiveness include transmission line matrix (TLM)[6], finite difference time domain (FDTD), method of moments (MoM) and finite element method (FEM)[8]. These methods can model complex structures but often require a relatively large amount of computer memory and computation time to give reasonable accuracy. Although they are good at predicting the shielding of a particular enclosure, it is difficult for designers to use them to investigate the effect of design parameters on SE and SM. For analytical formulation, it provides a much faster calculating shielding effectiveness. Analytical methods include transmission line analogy and circuit theory. A simple a rectangular enclosure with an aperture at one face can be modeled by an equivalent circuit, to predict the shielding effectiveness as a function of the frequency and the size of the aperture. The size of the enclosure is often expressed in units of the wavelength of the radiation, commonly known as the electrical size of the enclosure. The apertures can behave like antennas, and their electrical size can be defined analogously to that of antennas. We employ the analytical formulation[3]. It can be calculated as functions of frequency, aperture dimensions, enclosure dimensions, wall thickness and position within the enclosure. Results show that shielding effectiveness related to the parameters above.

In this work, we present the technique to improve the shielding by metal piece. The enclosures will produce resonance frequencies. These resonances are possible to suppress or remove by resize the enclosure dimensions. While almost enclosures dimensions are fixed, the use of metal piece inside the enclosures is studied for removing the lowest resonance frequency. We found the distance from the back wall of enclosure to the metal piece influence to shielding effectiveness.

II. THEORY

A rectangular enclosure with a rectangular aperture is represented by the equivalent circuit which is shown in Fig. 1. The electric shielding, a distance \(p\) from the aperture is obtained from the voltage at point \(P\) in the equivalent circuit, while the current at \(P\) gives the magnetic shielding. The radiating source is represented by voltage \(V₀\) and impedance \(Z₀\bb{377}\Omega\) and the enclosure by the shorted waveguide whose characteristic impedance and propagation constant are \(Zₜ\) and \(kₜ\). According to Robinson et al.[3], the first process is finding an equivalent impedance for the slot and then using simple transmission line theory to transform all the voltages and impedances to point \(P\).

First, the slot impedance is calculated. The aperture is represented as length of coplanar strip transmission line. For aperture impedance \(Zₚ\), it is calculated from the short circuits at the ends of the aperture through a distance \(l/2\) to center. This is represented by point \(A\) in the equivalent circuit and include a
factor $l/a$ to account for the coupling between the aperture and the enclosure. The aperture impedance $Z_{ap}$ is defined in

$$Z_{ap} = \frac{l}{2a} j Z_0 \tan \frac{k_0 l}{2}$$

where $k_0 = \frac{2 \pi}{\lambda}$ and $Z_0$ is characteristic impedance which given by Gupta et al[5].

According to Robinson et al., to calculate the electric and magnetic shielding effectiveness, it is defined from voltage and current at point $P$, respectively.

Here we employ the analytical formulation for calculate the shielding effectiveness in difference parameters to show that the enclosure resonance. We set the enclosure dimension at 20x40x45 cm, aperture sizes are 1x18 cm, 2x9 cm and 3x6 cm, thickness at 0.2 cm and distance from the aperture $p$ is 5 cm. All apertures are the same area at 18 cm$^2$. We will compare the shielding effectiveness with the aperture of different shape. The result is shown in Fig. 2.

The calculation shows that the shielding effectiveness of the 3x6 cm aperture is better than 2x9 and 1x18 cm apertures. Shielding effectiveness decrease from low frequencies to high frequencies and resonate at the same point. We concentrate in resonance frequencies, all of them resonate at approximately 800 MHz.

Now we investigate the influence to resonance frequencies by changing the dimension of enclosure. We keep the same aperture size at 2x9 cm and measurement point $p$ at 5 cm from aperture, while we change the parameter ‘a’, ‘b’ and ‘d’. The results are shown below.
Fig. 3 shows the results which difference resonance frequencies. For ‘a’ = 20 cm, the resonance is 800 MHz. While we decrease ‘a’ to 15 cm, the resonance frequency has been shifted over 1000 MHz. When ‘a’ is increased to 25 cm, the resonance frequencies are 700 MHz and 900 MHz. In Fig. 4, the resonance frequencies are the same point at approximated value of 800 MHz. The results show difference shielding effectiveness. The 20x40x45 cm enclosure is better than 20x10x45 cm enclosure. Fig. 5 shows the results when we change ‘d’ parameter. We found that while the ‘d’ is decreased, the resonance frequency is increased.

In case of ‘d’, the parameter influences to the resonance frequency. While almost enclosures dimensions are fixed, to resize enclosures is uncomfortable. The use of metal piece inside the enclosures is studied for removing the lowest resonance frequency. It is possible to do that because these resonances will be absorbed by the metal piece inside the enclosure and it is more comfortable than changing enclosure dimension.

III. MEASUREMENTS

We set up the 20x40x45 cm aluminium enclosure for test. A rectangular 1x18 cm aperture is placed at the front face of the enclosure. There is a metal piece in the enclosure with the distance m from the back wall. Fig. 6 shows a metal piece inside the enclosure. The measurements are performed in a semi anechoic chamber. The experimental equipment are an EMI receiver with Bi-log antenna in the range of 30 MHz – 1000 MHz, signal generator, dipole antenna and ferrite clamps. A signal generator produces frequencies from 30 MHz to 1000 MHz with a step frequency of 10 MHz and 5 V peak-to-peak amplitude. We set the dipole antenna in the box for electromagnetic source. The measurement configuration is shown in Fig. 7.

IV. RESULTS

The shielding effectiveness for the enclosure under study can be observed in Fig. 8 with comparison analytical formulation and measurement. The result shows that for lower frequencies differ from expected. At range of low frequencies from the simulation result and actual measurement are different because the simulation base on free space condition but in actual base on reflection effect which depend on the size and characteristic of the chamber. In frequency range 300 MHz – 1 GHz, the both results are in good agreement. For resonance frequency, both results also agree with an approximated value of 800 MHz.

We concentrate in removing the lowest resonance frequency by metal piece inside enclosure. According to Fig. 5, we found the smaller enclosure has higher resonance frequency. Introducing a metal piece as shown in Fig. 6 produces a frequency shift due to the reflection effect. We set up the 10x20x0.2 cm metal piece inside the enclosure with 1x18 cm aperture. The difference distances from back wall m are 5, 10 and 15 cm. The result is shown in Fig. 9.

For m = 5 cm, the resonance frequency is about 820 MHz. When we increase distance to 10 cm, the resonance has been shifted to approximately 870 MHz. The enclosure with metal piece placed at 15 cm produces the resonance about 900 MHz. We found the results are similar from the Fig. 5. In that results show the resonances have been shifted to higher when the enclosure decrease dimension. According to Fig. 9, the increase distance from back wall is like decrease the dimension of the enclosure. The results show the metal piece inside enclosure can be removing the lowest resonance frequency.
V. CONCLUSION

In this paper, we propose the improvement of shielding effectiveness. The use of metal piece inside enclosure is studied for removing the lowest resonance frequency. Obtained results point out the metal piece as one of important design parameter. The effect of the placing metal piece is well seen at the resonance. When the distance from the back wall is longer, the resonance frequency will increase. Placing metal piece becomes a partial solution as long as they are designed to remove the lowest resonance frequency. Further investigations in variation of conductivity and orientation of metal piece are still needed.

ACKNOWLEDGMENT

Electrical and Electronic Products Testing Center (PTEC) is gratefully acknowledged for the measurement.

REFERENCES

distilled aniline was mixed in a polymerization vessel that was cooled at 0 °C. In a separate flask, 1 N HCl was combined with ammonium peroxidisulfate and cooled to 0 °C. Thereafter, the aqueous ammonium persulfate solution was added slowly to the aniline/HCl solution with both solutions being precooled to 0 °C. The mixture was stirred for about 3.5 h at –5 to 0°C. The desired green emeradine hydrochloride precipitate was extracted by filtration and washed first in water and then in methanol until the filtrate became colorless. The precipitate was then treated in aqueous ammonium hydroxide solution for about 3 h to obtain the powder of polyemradine hydrochloride salt. Next, the green emeradine salt was washed by distill water and filtered until the filtrates were neutral. Finally, the obtained powder was dried in vacuum at 50 °C for 48 h and then stored in a vacuum desiccate.

For protonation doping, 2 Molar (M) maleic acid was prepared by adding 236.89 g maleic acid to 1000 ml of distilled water [10]. In order to obtain maleic acid doped polyaniline at mole ratio of 1000:1, 0.35 g of emeradine base was immersed in 2 M maleic acid solution at particular volume of 425.36 ml. The mixture was vigorously stirred and allowed to reach equilibrium for 48 h. The doped powder was filtered and dried at 60 °C for 40 h in a vacuum oven. Polyaniline doped powder was dissolved in N-Methylpyrrolidone (NMP) with the ratio of 0.5 g: 10 ml [11].

For the PANI coating process, the electrospinning of PANI solvent is used. The PANI solvent is loaded into electospin syringe and syringe to QCM substrate distance is approximately 5 cm. The electrospinning was conducted at a high voltage in the range between 10-20 kV. The photograph of a QCM sensor which used in the experiment is shown in Figure 1. It is a low-cost commercial quart crystal resonator with silver electrode. The scanning electron micrograph (SEM) showing the surface morphology of PANI coated electrode is demonstrated in figure 2. It shows that the electrospun surface is covered with mixture of micro and nano particles with diameter less than 2 μm.

IV. EXPERIMENT

The diagram of experimental system is shown in Figure 3. The humidity control system is a sealed high-quality plastic chamber with low humidity absorption. The QCM sensor and the commercial humidity sensor are placed in the chamber at the same level. The data of frequency and humidity are sent to the computer via USB port every second, the frequency output, humidity and temperature will be then recorded in the computer.
For the humidity control, water bubbler system is used. Air zero, pure and low humidity air, is split into two lines. The first line is passing through mass flow controller A and directly flown into the chamber. The second one is passing through mass flow controller B and bubbled through deionized water before entering the chamber. Initially, the chamber is filled with air zero flowing at the rate of 1000 sccm. Next, the desired humidity is input into the chamber by turning on the water bubbled air zero at a predetermined flow rate and turning off air zero from mass flow controller A. After the humidity is stabilized and the sensing response is recorded, the humidity is then dislodged by turning off the air zero flowing through the bubbler and restoring the air zero from mass flow controller A. The same procedure is repeated for different humidity by varying water bubbling flow rate.

V. RESULTS AND DISCUSSION

Typical dynamic response of the PANI coated QCM humidity sensor and the corresponding dynamic humidity measured by the commercial humidity sensor are shown in Figure 4 (a) and (b), respectively. From the figure, it can be seen that the PANI coated sensor can respond well to the controlled relative humidity of 40% to 80%. In addition, it has short response and recovery times. The response time is measured to be between 3 and 10 seconds depending on relative humidity while the recovery time is determined to be between 40 and 200 seconds. The humidity response is found to be stable and reversible over whole range of relative humidity between 20% and 80%.

Figure 5 show the measured results of frequency change of uncoated QCM sensor and PANI coated QCM sensor as a function of relative humidity. It is clear that the frequency shift of QCM sensor at a given humidity is considerably increased after PANI coating. The increase of humidity sensitivity is more that the factor of 2.2 for relative humidity between 20% and 80%. The result confirms that the PANI electrospun thin film considerably increase water vapor absorption.

VI. CONCLUSION

In conclusion, we have developed a low-cost humidity sensor made by coating a commercial quartz crystal resonator with Polyaniline (PANI) thin film. The electrospinning technique is used to coat the PANI nanometer-scale thin film to the electrode of quartz crystal. From experimental results, it
was found that PANI coating on the QCM electrode is an effective way to improve humidity-sensing characteristic of QCM sensor. The PANI coated sensor has good response to the humidity with short response and recovery times. The humidity-sensitivity of PANI coated QCM sensor is increased by more than factor of 2 compared to uncoated QCM sensor.

REFERENCES


