EMC Simulation Analysis of Enclosures

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Abstract: This paper deals with EMC simulation in the early stage of power electronics enclosure concept development. Shielding efficiency of panels with different types of openings is analyzed by numerical simulation of the Maxwell equations with COMSOL®. Therefore a virtual test chamber is set up in a simulation environment. The system is excited by a TEM wave test signal and the shielding effectiveness is calculated. In order to verify the simulation method, the resulting finite element solutions are compared with analytical results from the literature. The parametrized setup of the geometry allows fast and flexible simulations for optimization of the enclosure.

Keywords: EMC simulation, enclosures, shielding efficiency.

1. Introduction

High switching frequencies in modern power supplies demand special attention with regard to the shielding of electronic housings. From the early development stage on it is important to analyze radiated emissions in order to fulfil emission standards. It is necessary to consider openings for fans, displays, cable connections, slots, grids and many more.

EMC simulation is an efficient method in the enclosure design process to support engineering decisions and optimizations. Modern Finite Element tools like COMSOL® include ready to use models for EMC simulation which allow model parametrization and are flexible for including additional physics easily.

1.1 Enclosure Design

Modern enclosures for power electronic equipment need to be as compact as possible, include innovative lightweight materials and should have perfect thermal and EMC behavior. This means materials with high shielding efficiency and almost no enclosure openings, a concurrent condition e.g. to cable passages and openings for cooling. An example for a typical enclosure concept can be seen in Figure 1.

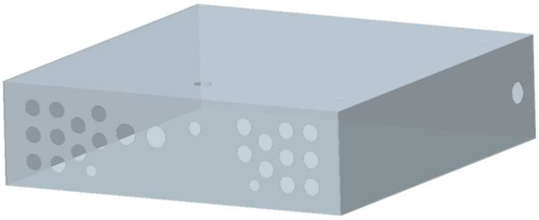


Figure 1. Typical enclosure concept with openings.

2. Finite Element Simulation Setup

Simulation analysis of the enclosure requires to solve wave excitation in 3D which can be described by the Maxwell equations in the form of the wave equation:

$$\nabla \times (\mu_r^{-1} \nabla \times \mathbf{E}) - k_0^2 (\varepsilon_r - \frac{j\sigma}{\omega \varepsilon_0}) \mathbf{E} = \mathbf{0}$$

The simulation was done in the frequency domain. To investigate the transmissibility of enclosures the electric field at a point is compared with and without housing. The shielding effectiveness can be calculated:

$$SE = 20 \log \left| \frac{E_1}{E_2} \right|$$

E1 is the electric field without shielding and E2 is the electric field with shielding. This way different types of openings in panels can be compared and optimized, as shown in figure 2.

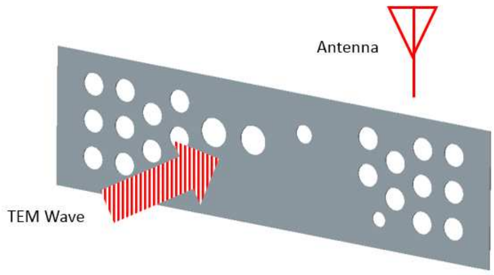


Figure 2. Typical enclosure panel simulation test setup.

The panel with opening was put in a simulation environment with a TEM wave excitation directed towards the panel. The propagation direction of the wave is set to be normal to the panel surface. Periodic boundary conditions were used to simulate a planar wave.

Simulated fields have been virtually measured in a test chamber (Figure 3). The test chamber was enclosed with PML layers to simulate far field conditions. The field damping behind the panel was compared to analytical calculations and results from the literature.

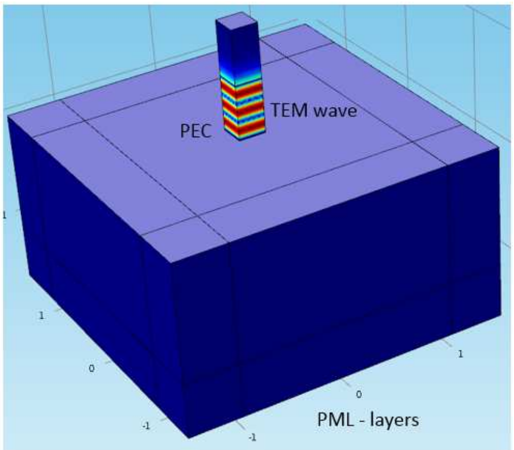


Figure 3. Test chamber.

3. Panel with One Circular Opening

At the position where the TEM wave hits the test chamber different types of panels can be inserted virtually. Figure 4 shows a panel with one circular opening.

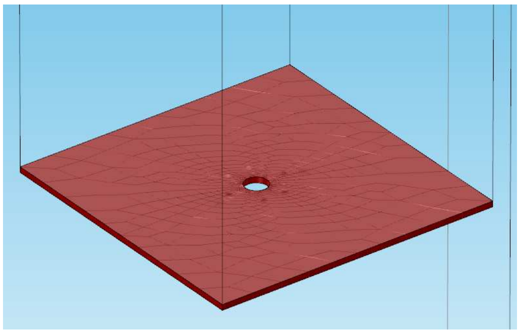


Figure 4. Panel opening.

A parametric setup allows fast simulation of different circular opening diameters or panel thickness. For this configuration analytical results are available from literature [1, 2]. To validate the results Figure 5 shows finite element simulations in comparison with analytical results. For frequencies up to 1MHz shielding is limited by the electromagnetic field passing through the panel itself. An increase of frequency leads to eddy currents opposing the external field. The field passing the panel is still a planar wave with reduced amplitude. From 1MHz upwards the round opening becomes the dominate quantity with regards to shielding effectiveness. The eddy currents are interrupted by the opening and therefore the external field is able to pass the panel. The opening on the other side of the panel becomes a point field source as shown in Figure 6. Because of the round nature of the opening, the shielding effectiveness is independent of the polarization of the incoming wave. For higher frequencies, where the opening is dominating, the shielding is slightly dependent on the panel thickness d, which is not considered in the analytical approach. The finite element simulation shows this influence, where the shielding is slightly higher for thicker panels.

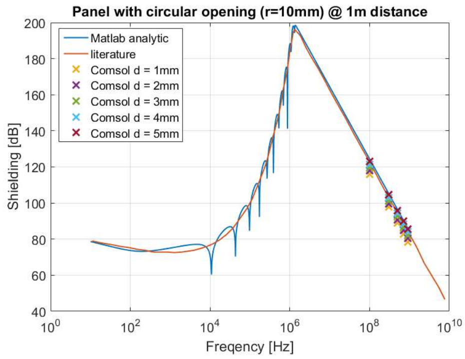


Figure 5. Results for variable panel thickness d.

Figure 6 shows the electric field behind the panel.

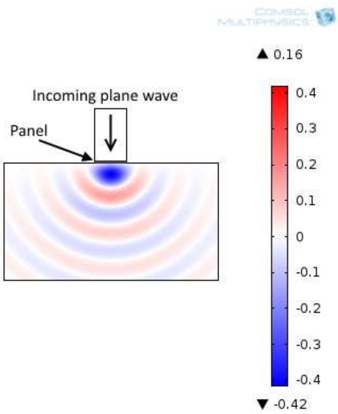
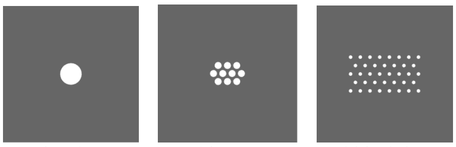


Figure 6. Electric field behind the panel (y-component).

4. Multiple Circular Openings

The next step is to combine several openings. In the same way a parametric setup e.g. for opening diameter, opening thickness, opening distances allows fast parameter variation for design studies. In this study we have compared one opening to several openings in different topological configurations. The total opening area is constant for all geometry variants. Splitting up one opening into several smaller openings can be done, if the opening is used for cooling reasons. Even though the pressure drop is slightly higher for several smaller openings, the shielding performance increases considerable. Three different arrangements of openings are shown in figure 7.



N=1/r=23.7mm N=10/r=7.5mm N=38/r=3.85mm

Figure 7. Arrangements for multiple round openings.

The results in Figure 8 show the shielding on a central point behind the opening in distance of 0.5m. The shielding effectiveness can be enhanced by splitting up a single opening into multiple openings with smaller diameter. Compared to the single round opening, the shielding can be increase for up to 20dB. The eddy currents which can flow in between openings induce a field which oppose the external field and therefore increase the overall shielding effectiveness.

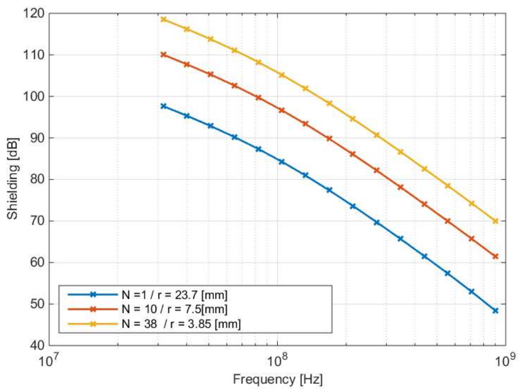


Figure 8. Shielding of multiple round openings.

4. Rectangular Openings

Rectangular openings can often be found in electronic housings, since displays and connectors often have a rectangular shape. Figure 9 shows configurations results of rectangular openings having the same area, but different aspect ratio.

r=23.7mm a/b=1 a/b=1.966 a/b=17.6

Figure 9. Comparison of different openings

Contrary to the circular opening, rectangular openings are dependent of the polarization of the incoming wave. The incoming electric field induces eddy currents which flow parallel to the exiting field. If the long side of the opening is placed normal to the exiting E-field, the eddy currents are forced to flow around the longer side of the opening and are therefore interrupted on a larger area. The results in Figure 10 show the worst case, where the electric field is normal to the long side of the opening. Openings with high aspect ratio have considerable less shielding effectiveness, than openings with low aspect ratio. With this kind of polarization between incoming wave and opening orientation, the rectangular opening acts like a circular opening with the largest dimension of the opening as diameter.

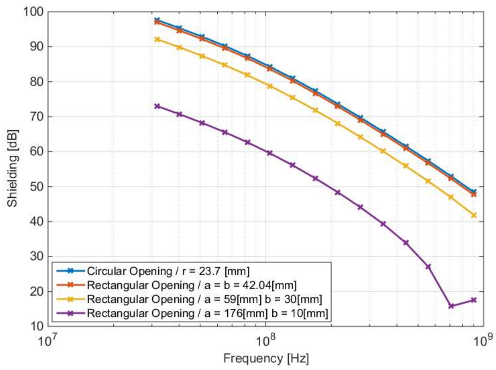


Figure 10. Shielding of rectangular openings with different aspect ratio.

4. Gap Splitting

The influence of large gaps on the shielding effectiveness can be enhanced by dividing the gap into several smaller gaps. The eddy currents which have been flowing around the gap, are short circuited to the opposite side of the gap. The impact of splitting is shown by comparing three different opening configurations depicted in figure 11.

a/b = 17.60   a/b = 8.84   a/b = 5.90

Figure 11. Multiple rectangular openings.

The total opening area and gap width is the same for all three configurations, while the opening is split up into two and three parts. The effect on shielding effectiveness is shown in figure 12.

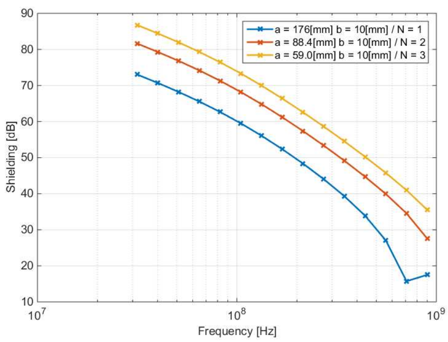


Figure 12. Shielding of multiple rectangular gaps

By splitting up the gap in two parts the shielding is raised by 10dB. Dividing the gap in three parts enhances the shielding by 15dB. Like at the single gap the worst case is, where the polarization of the electric field is normal to the gap. The configuration acts like an array of round openings with the diameter of the largest single gap dimension.

5. Conclusions

The impact of openings in housings with regards to shielding of electromagnetic waves can be investigated by finite element simulation and in the case of simple geometric arrangements by analytic formulas. A comparison between simulations and analytic results shows good agreement. The shielding is mainly dependent on the eddy currents opposing the external field. Openings in the housings interrupt those currents and therefore decrease the shielding of the housing. The decrease of shielding is dependent on the dimensions of the opening and the polarization of the incoming wave. The shielding can be increased either by keeping the large dimensions of the opening small or by adding additional path for the eddy currents to flow. This can be done by keeping the aspect ratio small or by splitting up a single opening into multiple openings.

6. References

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2. Schwab Adolf, Kürner Wolfgang. *Elektromagnetische Verträglichkeit*, Springer, Heidelberg (2011).

10. Acknowledgements

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