01 Aug 2008

Aperture Modeling Using a Hybrid Method for RFI Analysis

Liehui Ren

Zhenwei Yu

Gang Feng

Francesco de Paulis

et. al. For a complete list of authors, see https://scholarsmine.mst.edu/ele_comeng_facwork/1454

Recommended Citation

L. Ren and Z. Yu and G. Feng and F. de Paulis and Y. Zhang and J. Fan and X. Dong and J. A. Mix and D. Hua and K. P. Slattery, "Aperture Modeling Using a Hybrid Method for RFI Analysis," *Proceedings of the IEEE International Symposium on Electromagnetic Compatibility, 2008*, Institute of Electrical and Electronics Engineers (IEEE), Aug 2008.
The definitive version is available at https://doi.org/10.1109/ISEMC.2008.4652135

Aperture Modeling Using a Hybrid Method for RFI Analysis

Liehui Ren, Zhenwei Yu, Gang Feng, Francesco de Paulis, Yaojiang Zhang, Jun Fan
EMC Lab Missouri University of Science and Technology, Rolla, MO 65401

Xiaopeng Dong, Jason A. Mix, Daniel Hua, Kevin Slattery
Intel Corporation, Portland USA

***Abstract*- A hybrid method is proposed for radio frequency interference (RFI) prediction of a metal enclosure with an aperture on the top wall. The structure is divided into several segments. While the fields in rectangular segments are described by cavity model, the segments with apertures are modeled by the commercial finite element solver (HFSS). Tangential field continuities along the common boundaries of different segments are enforced by the voltages and currents of boundary ports. Good agreement has been achieved between the hybrid method and full wave simulation.**

***Key words*- Aperture, cavity model, enclosure, finite element method, RFI, segmentation method**

I. INTRODUCTION

Metal enclosure is usually used to enhance the immunity of the inside PCB and reduce the interference from the inside to the outside of enclosure [1]. Cavity model with the segmentation method has been extended from microwave planar circuit to via coupling in a printed circuit board (PCB) and RFI prediction inside a complete metal enclosure [2-7]. In cavity model, simple 2D Green's functions instead of its complicated 3D counterparts are adopted to describe the field distribution in an enclosure. This is justified by the fact that the height of the enclosure is very electrically small in the frequencies of interests and there is no geometric discontinuity in height direction. Comparing with full wave methods applied to analysis of noise coupling inside PCB and enclosure [8-10], analytical cavity model is more efficient and easily implemented in a circuit simulator.

However, for an enclosure with an aperture on the top wall, cavity model cannot be used directly since the field distribution near the aperture is not constant any more along height direction. This means the aperture can excite higher order TMz modes instead of only TMz0 mode which is used in cavity model. An important observation is that these higher order modes decay rapidly away from the aperture due to the electrically small height of the enclosure. Therefore, the fields in the region a little bit far away from the aperture can still be expressed by the cavity model. On the other hand, the region containing the aperture must be analyzed by a full wave method.

In this paper, a hybrid finite element method (FEM) and cavity model is proposed to predict RFI inside a metal enclosure with a top aperture. The cavity model can be viewed as the terminal boundary condition for the FEM domain inside the enclosure while the perfect matched layer (PML) is used to truncate the FEM domain outside the enclosure. The hybrid method keeps both the flexibility of FEM and the efficiency of the cavity model. Finite element analysis using HFSS for whole structure is used to validate the hybrid method and good agreement is obtained.

II. HYBRID FINITE ELEMENT METHOD AND CAVITY MODEL

Consider a metal enclosure with an aperture on the top wall as shown in Fig. 1. The length, width and height of the metal enclosure are denoted as *a*, *b* and *h*, respectively. There is an aperture located on the center of the top wall with length of *L* and width of *W*. RFI prediction is required between the exciting port and the observation port as shown in the figure. Due to the aperture discontinuity along z-direction, traditional cavity model is not applicable near the aperture. This is due to that fact that fringing fields, which are higher order TMz modes, along the aperture are not negligible. The fields inside the enclosure region adjacent to the aperture may have all field components due to the aperture discontinuity. For the enclosure region far away from the aperture, TM_{z0} mode dominates as the higher order TMz modes decay rapidly in the frequencies of interests.

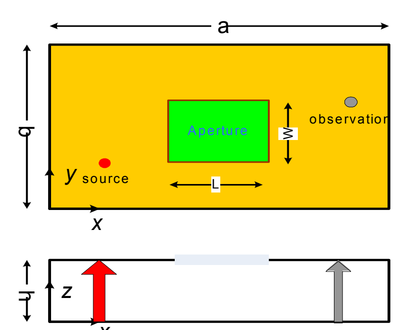
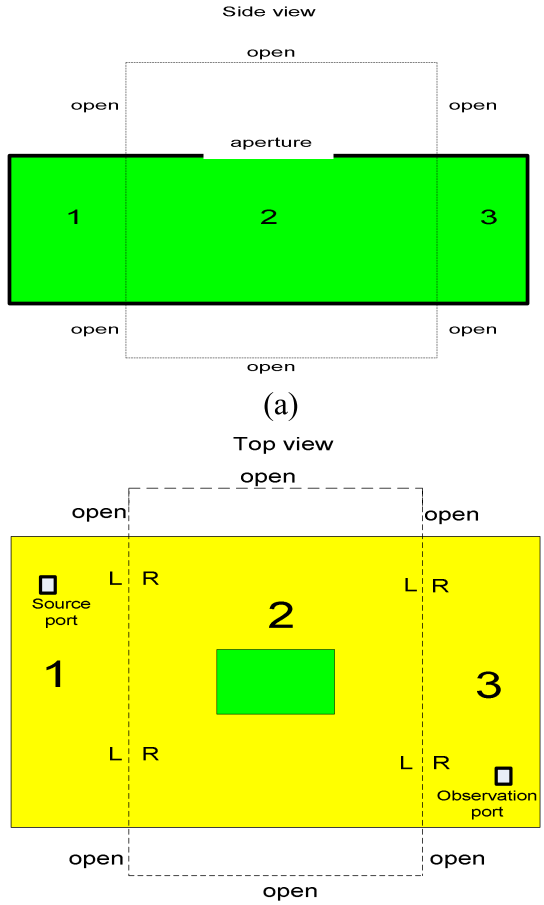


Figure 1 Schematic of a metal enclosure with an aperture on the top wall

978-1-4244-1699-8/08/$25.00 ©2008 IEEE



(b)

Figure 2 (a) Side view of segment division (b) Top view of the structure and the left and right ports boundaries.

This observation leads to a hybrid finite element method and cavity model proposed here to obtain the RFI in the structure. As shown in Fig. 2 (a), the whole structure is divided into three parts or segments along x-direction. Cavity 1 and 3 are rectangular cavities with top/bottom PEC plates but 3 PEC and 1 PMC sidewalls. For Cavity 2, finite element method is used as the geometry is not regular. Its two PMC sidewalls inside the enclosure located a short distance away from the aperture to make sure all higher order TMz modes are negligible. The boundaries outside the enclosure are set to be open in HFSS.

Fig. 2 (b) is the top view of the segments. To enforce the continuities of tangential fields, many boundary ports are set on the left and right sides along the common boundaries between segment 1 and 2 or segment 2 and 3. Therefore there are three kinds of ports: internal ports including source and observation ports, left and right ports. To facilitate the description of the segmentation method, the port voltages and currents of these three ports are represented by vectors $\mathbf{V}_p, \mathbf{V}_L, \mathbf{V}_R$ and $\mathbf{I}_p, \mathbf{I}_L, \mathbf{I}_R$, respectively. Exciting the ports one by one using the constant z-direction currents will result in z-direction port voltages on all ports. This indicates we have following impedance matrix

$$\begin{bmatrix} \mathbf{V}_p \\ \mathbf{V}_L \\ \mathbf{V}_R \end{bmatrix} = \begin{bmatrix} \mathbf{Z}_{pp} & \mathbf{Z}_{pL} & \mathbf{Z}_{pR} \\ \mathbf{Z}_{Lp} & \mathbf{Z}_{LL} & \mathbf{Z}_{LR} \\ \mathbf{Z}_{Rp} & \mathbf{Z}_{RL} & \mathbf{Z}_{RR} \end{bmatrix} \begin{bmatrix} \mathbf{I}_p \\ \mathbf{I}_L \\ \mathbf{I}_R \end{bmatrix} \qquad (1)$$

Where $\mathbf{Z}_{ab}, a, b = p, L, \text{or } R$ are impedance matrices. While the impedance matrix elements in segment 1 and 3 are obtained by cavity model, their counterparts in segment 2 are calculated by finite element method (HFSS). The following equations are required to satisfy the boundary conditions between the left and right boundary ports

$$\begin{aligned} \mathbf{V}_L &= \mathbf{V}_R \\ \mathbf{I}_L &= -\mathbf{I}_R \end{aligned} \qquad (2)$$

Substituting (2) into (1) and deleting the voltage and current vectors $\mathbf{V}_L, \mathbf{V}_R$ and $\mathbf{I}_L, \mathbf{I}_R$, yields

$$\mathbf{V}_p = \begin{bmatrix} \mathbf{Z}_{pp} - (\mathbf{Z}_{pL} - \mathbf{Z}_{pR}) \\ \cdot(\mathbf{Z}_{LL} - \mathbf{Z}_{LR} - \mathbf{Z}_{RL} + \mathbf{Z}_{RR})^{-1} \\ \cdot(\mathbf{Z}_{Lp} - \mathbf{Z}_{Rp}) \end{bmatrix} \mathbf{I}_p \qquad (3)$$

This formula gives the impedance matrix among the source and observation ports. This procedure simplifies the segmentation connection scheme and makes automatic connection for many segments. The impedance matrix in each segment can be obtained by different methods. Eq. (3) provides an easy way to implement the hybrid algorithm. Next section will provide some numerical results to show the hybrid method proposed above.

III. NUMERICAL EXAMPLES

The metal enclosure length, width and height are 10cm, 5cm and 2cm rectangular cavity with a 2×2cm square aperture on the center of top wall. The cavity is filled with dielectrics of relative permittivity 4.4 and tangent loss 0.02. Source and observation ports are located at (1, 2) and (9.5, 3), respectively (unit: cm). This structure is referred as case 1 in the following discussion.

An important step of hybrid method is to determine the PMC interface planes between blocks. The application of cavity model to block 1 and block 3 inherently requires that the two interface planes between block 1 and block 2 and between block 3 and block 2 should be a little bit far away from aperture so that fringing field arising from aperture discontinuity is negligible. Fig.3 shows the effect of different positions of interface planes for case 1 using the hybrid method. The segment length is selected to be 3 cm, 4 cm and 6 cm, respectively. This means the separation of the boundary interface from the aperture is 0.5 cm, 1.0 cm and 2.0 cm respectively. It can be seen that for low frequencies, these three interface locations have resulted in almost same mutual impedance between port 1 and 2. However, for higher frequencies than 3 GHz, obvious differences among them resulted. To make sure the accuracy of the following simulations, the length of the segment 2 is selected to be 6 cm.

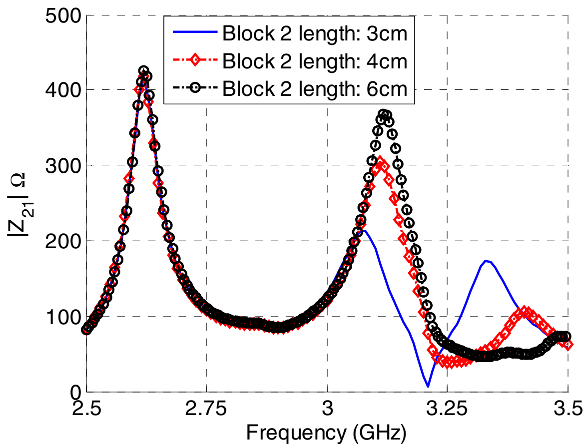


Figure 3 Result comparison from hybrid method with different location of interface planes

Fig. 4 compares the mutual impedance between source and observation ports for case 1 using the hybrid method and full wave solver, HFSS. Table 1 provides feature selective validation (FSV), the quantitative evaluation of the agreement. It shows very good agreement has been achieved between these two methods.

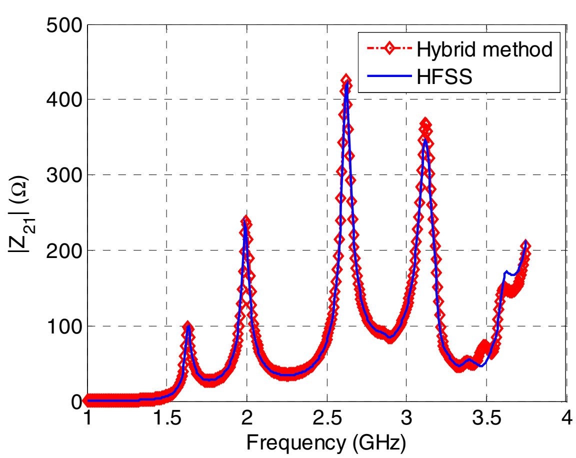


Figure 4 Comparison of the mutual impedance using the hybrid method and HFSS for case 1

Table 1 Feature Selective Validation (FSV) numbers for case 1

GDM	0.10357(very good)
ADM	0.05632(excellent)
FDM	0.07618(excellent)

For case 2, the aperture size is reduced from 2cm to 1cm while keeping other parameters the same as case 1. Again the good agreement was demonstrated by either the curves in Fig. 5 or the FSV numbers in table 2.

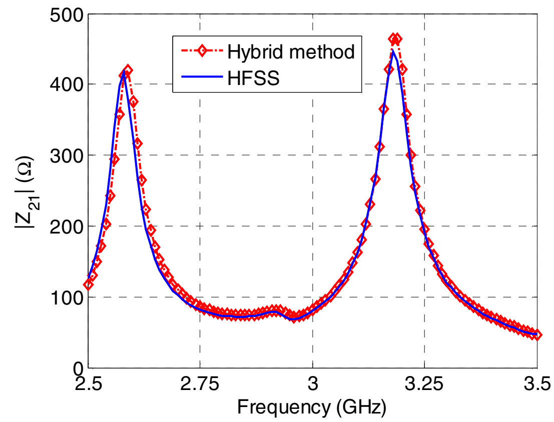


Figure 5 Result comparison from hybrid method and HFSS for case 2

Table 2 Feature Selective Validation (FSV) numbers for case 2

GDM	0.18488(very good)
ADM	0.11615(very good)
FDM	0.13991(very good)

Let's reduce the enclosure height from 2cm to 1cm. This is the case 3 studied. Fig. 6 gives the comparison of the hybrid method and HFSS for the mutual impedance. The results of these two approaches, thirdly, match very well. The FSV in Table 3 also proves the accuracy of the hybrid method.

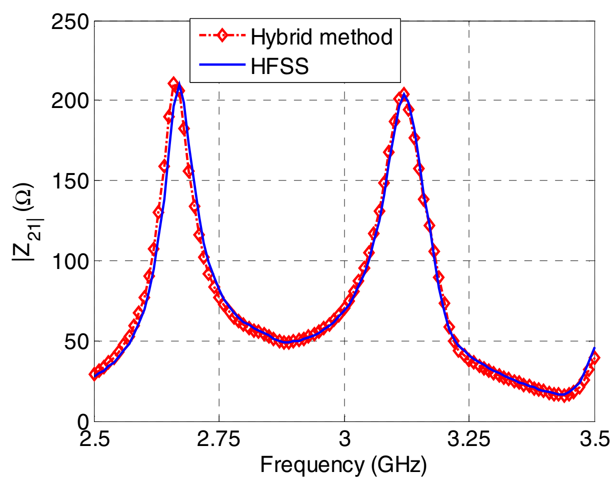


Figure 6 Comparison of mutual impedance using the hybrid method and HFSS for case 3

Table 3 Feature Selective Validation (FSV) numbers for case 3

GDM	0.17337(very good)
ADM	0.09519(excellent)
FDM	0.13784(very good)

Fig. 7 shows the impact of the boundary port size on the accuracy of the hybrid method. It can be seen that the boundary ports with 2 mm dimension can achieve more agreeable results than the boundary ports of 0.3 mm comparing to the HFSS simulation. This can be explained as that larger port size acts more or less as a pulse basis function in the method of moments for an integral equation, while the shorter port size as a point matching procedure. Larger boundary ports make better field continuities along the boundaries.

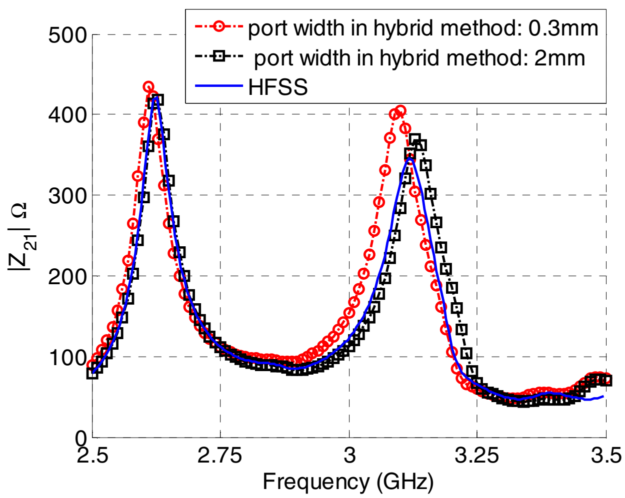


Figure 7 Result comparison from hybrid method with different dimension of auxiliary ports

IV. CONCLUSION

Hybrid finite element method and cavity model with segmentation method is proposed to predict RFI in a enclosure with an aperture on the top wall. While the cavity model provides an efficient way to describe fields distributions in regular cavities, full wave finite element method is flexible and accurate for complicated, irregular geometric structures. By carefully implementation of the hybrid method, complicated enclosure structures can be efficiently analyzed in an automatic approach. Effectiveness of the hybrid method is validated by comparing with full wave simulation, which is appropriate to solve RFI issue inside complex shape enclosure.

REFERENCES

[1] Clayton R. Paul, Introduction to Electromagnetic Compatibility. Wiley-Interscience, 2 edition January , 2006.

[2] T. Okishi, Y. Uehara, and T. Takeuchi, “The segmentation method-an approach to the analysis of microwave planar circuit,” IEEE Trans. Microwave Theory and Techniques., vol. 24, pp. 662-668, October 1976.

[3] G. T. Lei, R. W. Techentin, P. R. Hayes, D. J. Schwab, and B. K. Gilbert, “Wave mode solution to the ground/power plane noise problem,” IEEE Trans. Instru. Meas., vol. 44, pp. 300-303, April 1995.

[4] G. T. Lei, R. W. Techentin, and B. K. Gilbert, “High-frequency characterization of power/ground plane noise problem,” IEEE Trans. Microwave Theory and Techniques., vol. 47, pp. 562-569, May 1999.

[5] W. Wallyn, D. D. Zutter, “Modeling the shielding effectiveness and resonance of metallic enclosure loaded with PCBs,” 2001 IEEE international symposium on Electromagnetic Compatibility, vol. 2, pp.13-17, August 2001.

[6] W. Cui, J. Fan, Y. Ren, H. Shi, J. L. Drewniak, and R.E. Dubroff, “DC power bus noise isolation with power plane segmentation,” IEEE Transaction on Electromagnetic Compatibility, vol. 45, pp. 436-443, May 2003.

[7] G. Feng, G. Selli, K. Chand, M. Lai, L. Xue, and J. L. Drewniak, “Analysis of noise coupling result from overlapping power areas with power delivery networks,” IEEE Int. Symp. Electromagnetic Compatibility, Portland, Oregon, Aug. 2006

[8] Y. Ji, and T. H. Hubing, “On the modeling of a gapped power bus structure using a hybrid FEM/MOM approach,” IEEE Transactions on Electromagnetic Compatibility, vol. 44, pp. 566-569, November 2002.

[9] X. D. Cai, G. L. Costache, R. Laroussi, and R. Crawhall, “Numerical extraction of partial inductance of package reference (power/ground)planes ,” IEEE Int. Symp. Electromagnetic Compatibility, pp.12-15, 1995.

[10] X. Ye, D. M. Hockanson, M. Li., Y. Ren, W. Cui, J. L. Drewniak, and R. E. Dubroff, “EMI mitigation with multilayer power-bus stacks and via stitching of reference planes,” IEEE Transaction on Electromagnetic Compatibility, vol. 43, No. 4, November 2001.