

# HFSS Shell Element

## Modeling Layered Structures with Shell Elements

### Introduction

In general, it is common approach to apply a sheet impedance boundary condition in place of thin layers to simplify the meshing requirements to accurately capture the strongly decaying electric fields inside the thin layered structures.

Two typical cases exist where a simple sheet impedance boundary condition accurately replaces the thin layer(s): the electromagnetic field decays rapidly to zero inside the thin layer due to high conductivity or the electromagnetic field does not change greatly along the normal direction of the thin layer. However, when the skin depth of the layer is approximately equal or smaller than the thickness of the layer, the electromagnetic field will change considerably along the normal direction of the layer, but it will not do so rapidly enough to decay to zero inside the layer. In this case, the simple sheet impedance boundary condition is not applicable. ANSYS HFSS now allows the accurate simulation of these thin layers using Shell Elements without the need to densely mesh these layers.

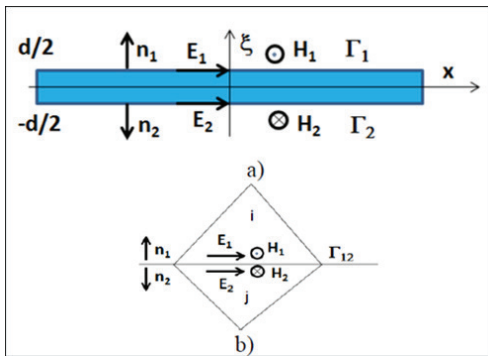


Figure 1. a) A layer to be replaced by an equivalent sheet boundary condition and b) two adjacent finite element tetrahedra on  $\Gamma_{12}$ .

### Mathematical Model

The goal is to set up an internal sheet boundary condition, which is equivalent to a layer (thin or thick) as demonstrated in Fig. 1.

The field relationship between the two sides of the layer can be written as:

$$\begin{bmatrix} \mathbf{n} \times \mathbf{H}_{t1} \\ \mathbf{n} \times \mathbf{H}_{t2} \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix} \begin{bmatrix} \mathbf{n} \times \mathbf{n} \times \mathbf{E}_{t1} \\ \mathbf{n} \times \mathbf{n} \times \mathbf{E}_{t2} \end{bmatrix}$$

where the frequency dependent Y matrix characterizes the layer(s). It can be given in closed analytical form, e.g. by using a transmission line model of the layer ([1 -3]) or in numerical form by linking to a FEM unit cell model of the layer [4]. The latter is the aim of this paper. Since the relationship is known between the two sides of the layer, the 3D layer can be excluded from the computational domain by shrinking the thickness to zero and doubling the essential variables on  $\Gamma_{12}$ . This results in two regular Neumann boundary conditions on the two sides of  $\Gamma_{12}$ :

$$\begin{aligned} \int_{\Gamma_1} \mathbf{E}_1^* \cdot (\mathbf{n}_1 \times \nu, cur / \mathbf{E}_1) d\Gamma &= \\ -j\omega\mu_0 \int_{\Gamma_1} (\mathbf{E}_1^* \cdot (\mathbf{n}_1 \times (y_{11}\mathbf{n}_1 \times \mathbf{E}_1) + (y_{12}\mathbf{n}_1 \times \mathbf{E}_2))) d\Gamma & \\ \int_{\Gamma_2} \mathbf{E}_2^* \cdot (\mathbf{n}_2 \times \nu, cur / \mathbf{E}_2) d\Gamma &= \\ -j\omega\mu_0 \int_{\Gamma_2} (\mathbf{E}_2^* \cdot (\mathbf{n}_2 \times (y_{22}\mathbf{n}_2 \times \mathbf{E}_2) + (y_{21}\mathbf{n}_2 \times \mathbf{E}_1))) d\Gamma & \end{aligned}$$

where  $\mathbf{E}^*$  denotes weighting functions in the FEM Galerkin method. In this approach, a shell element is similar to an outer impedance boundary condition. The coupling between the two sides is implemented via the terms with  $y_{12}$  and  $y_{21}$  by doubling degrees of freedoms of  $\mathbf{E}$  on the surface. It also follows, when assembling the  $i$ -th tetrahedron, no coupling terms are included from the  $j$ -th tetrahedron except the  $y_{12}$  term and similarly for the  $j$ -th tetrahedron.

Note that the method is also valid for thick layers. For this case, the thickness cannot be removed but the interior does not need to be meshed. Additionally, the surface mesh of the two sides does not need to be conformal.

The method is applicable both for layers with high conductivity and dielectric layers. For dielectric layers, the accuracy depends on the incident angle of the field. This dependence is much less when using layers with high conductivity.

### Assigning Shell Element

Depending on the type of layer (metal or dielectric) that is being modeled, the assignment for Shell Elements differs.

#### 1. For thin or thick metal layers:

Shell Elements for modeling thin or thick metal layers can be accessed from the Finite Conductivity Boundary dialog. To assign a Finite Conductivity boundary: Select a surface on which to assign the boundary and click **HFSS>Boundaries>Assign>Finite Conductivity** to bring up the Finite Conductivity Boundary dialog box. To assign the Shell Element Boundary select **Two sided**, as shown in Fig. 2.

#### 2. For thin or thick dielectric layers:

Shell Elements for modeling thin or thick dielectric layers can be accessed from the Layered Impedance Boundary dialog. To assign a Layered Impedance boundary: Select a surface on which to assign the boundary and click **HFSS> Boundaries>Assign>Layered Impedance** to bring up the Layered Impedance Boundary dialog box, as shown in Fig. 3. To assign the shell element click Next. In the next window, select **Two sided**, enable **Shell Element**, and enter the layer thickness and layer material, as shown in Fig. 3.

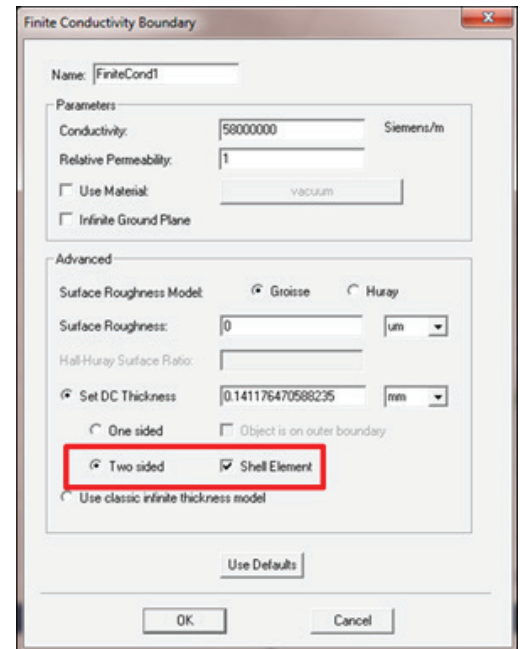


Figure 2. Assigning Shell Element Boundary in HFSS for thin or thick metal layers

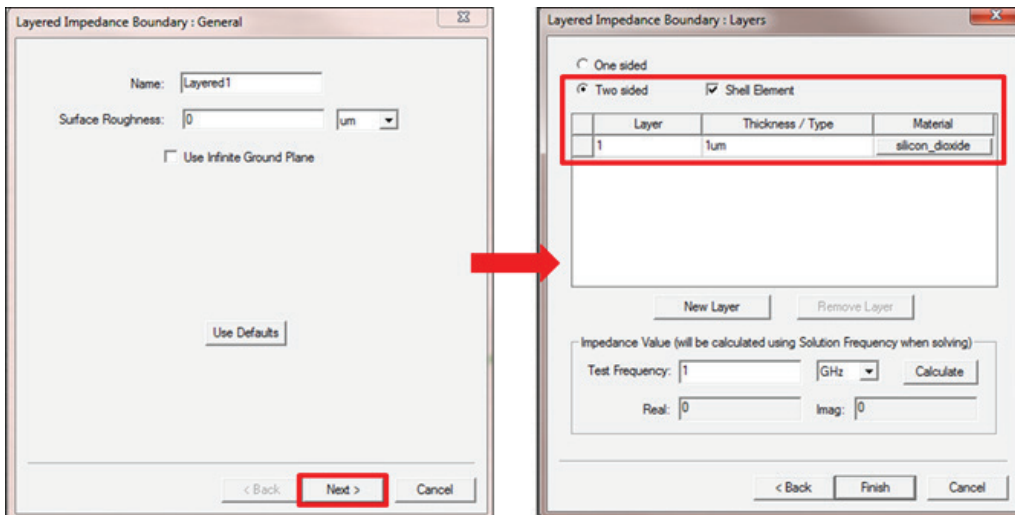


Figure 3. Assigning Shell Element Boundary in HFSS for thin or thick dielectric layers

The following features are not currently supported when using shell elements:

- Fast sweep
- Scattered field formulation
- Sensitivity
- Eigen solver
- Transient solver
- IE solver

In this app note, we will consider modeling of thin metal layers only. To show the effectiveness of the Shell Element boundary, the shielding efficiency of a 4 um thick metal layer ( $\sigma = 5.0 \times 10^7$  S/m) consisting of 32 layers, each of which is 0.125 um thick, will be studied using a very fine discretized 3D FEM solution and compared to a simulation utilizing the new Shell Element boundary condition.

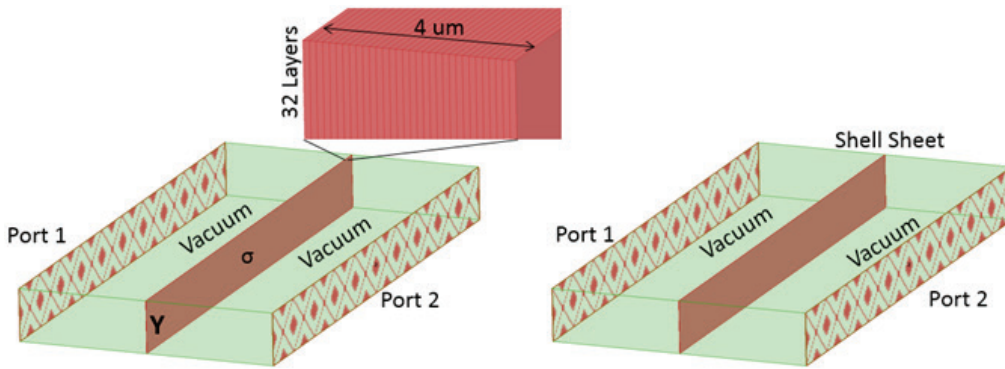


Figure 4. Unit Cell of a 4 um copper layer for Y matrix calculation and test case of a shielding sheet in parallel plate waveguide.

In this study, a parallel plate waveguide was used with a 4 um thick copper layer to calculate the Y matrix. The Y matrix was applied to a large sheet with shell elements in the middle of parallel plate waveguide, as shown in Fig. 4.

Table 1 shows the comparisons of modeling the thin metal layers considered in Fig. 4 using the Shell Element boundary condition and the very fine discretized 3D FEM solution. Clearly, solving the simulation utilizing Shell Elements requires less time and RAM compared to the simulation of the explicit model of the metal layers.

	Explicit model with 32 metal layers	Model with Shell Element
Time (Last Adaptive Pass)	0:01:25	0:00:08
Memory (GB)	2.33	0.0637

Table 1. Comparisons of Shell Element Boundary and Explicit Modeling results of Time and RAM taken for modeling the thin metal layers shown in Fig. 4.

## Summary

In summary, internal thin or thick conducting layers can be modeled accurately and efficiently using the Shell Element boundary condition introduced in ANSYS HFSS. The shell element option is applicable for all frequencies and can therefore be used for broadband simulations without the need to modify boundary options for various simulation frequencies. Several practical examples for this boundary condition include the study of shielding effects of a car chassis that is modeled with shell elements.

## References

- 1) T. Abboud, F. Béreux, "Thin Conducting Sheet (TCS) in non-destructive testing simulations: implementation in Code\_Carmel3D and validation," Compumag Budapest, PD2-16, Budapest, Hungary, 2013.
- 2) O. Biro, I. Bardi, K. Preis, W. Renhart and K. Richter, "A Finite Element Formulation for Eddy Current Carrying Ferromagnetic Thin Sheets," IEEE Transactions on Magnetics, Vol 33, No 2, March 1997.
- 3) W. Renhart, C. Magele, C. Tuerk, "Thin Layer Transition Matrix description applied to the Finite Element Method," IEEE Transactions on Magnetics, Vol 45, No 5, pp. 1618-1621, March 2009.
- 4) I. Bardi, M. Vogel and Z. Cendes, "Modeling Large Screens via Homogenization with the Finite Element Method", Microwave Symposium Digest, IEEE MTT-S International, pp. 1315 - 1318, 2006.

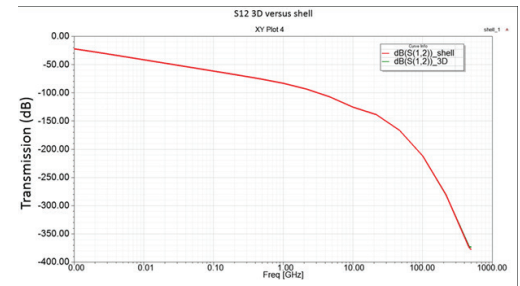


Figure 5. Shielding efficiency (Transmission (dB)) of waveguide shown in Fig. 4.



ANSYS, Inc.  
www.ansys.com  
ansysinfo@ansys.com  
866.267.9724

© 2016 ANSYS, Inc. All Rights Reserved.

MKT00000000