

Capacitance of a 3D Interconnect in a VLSI circuit

Description

In recent years, the electrical characterization of 3D interconnects in VLSI has become increasingly important. This trend can be attributed primarily to the increase of interconnect layers and clock speed of modern days VLSI. A prime characterization of the interconnects is the extraction of the capacitance matrix of 3D structures.

In this validation example, an interconnect, consisting of six conductors embedded in a seven dielectric layers, is considered. As indicated in Figure 1, four of the six conductors cross over two 90 degrees bends.

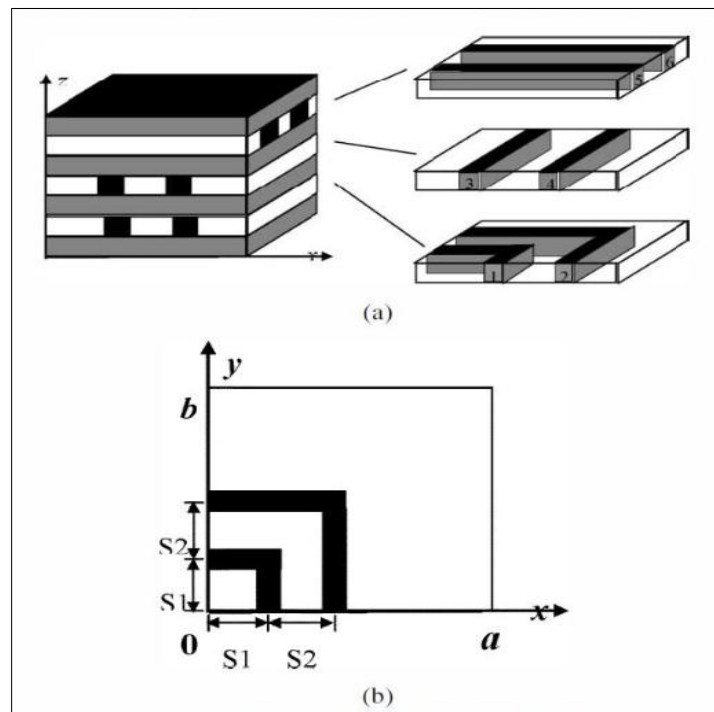


Figure 1: Six conductors embedded in a set of seven dielectric layers

Each straight conductor has a length of 13mm. The cross-section of all conductors is 1mm × 1mm. As shown in Figure 1, the piecewise lengths of the bent conductors are $a = b = 13\text{mm}$, and $S1 = 3.5\text{mm}$, $S2 = 3\text{mm}$. The relative permittivity of the dielectric layers are, from the bottom, $\epsilon_{r1} = 2$, $\epsilon_{r2} = 3$, $\epsilon_{r3} = 3$, $\epsilon_{r4} = 4$, $\epsilon_{r5} = 4$, $\epsilon_{r6} = 5$, $\epsilon_{r7} = 5$. The thickness of each layer is 1mm, except the third layer from the bottom. It has a thickness of 2mm. The total height of the structure is 8mm. The air around the structure must be also included in the model.

In the published article, both the domain-decomposition method (DDM) and Ansoft's Maxwell Spice Link were used to extract the capacitance matrix of the considered interconnect. We wish to validate the results of EMS against the published data [1].

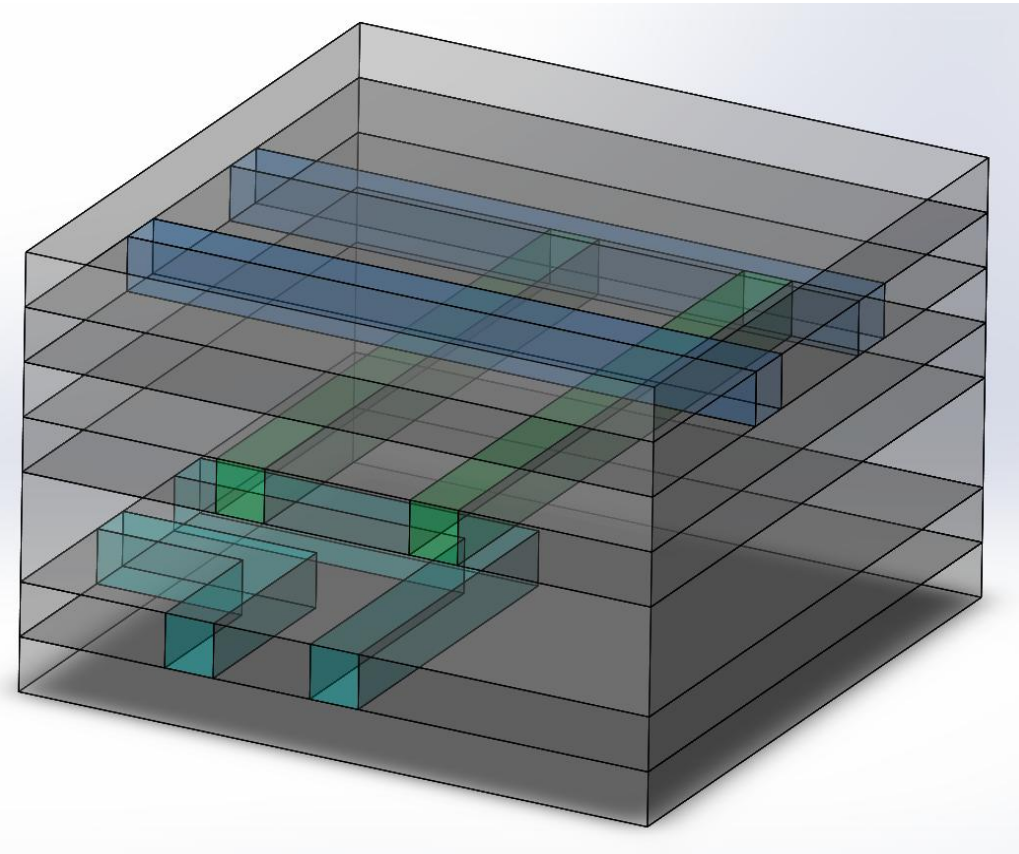


Figure 2: Solid model of the seven layers interconnect

The study

The Electrostatic module of EMS is used to compute the capacitance matrix of the 3D multilayered-interconnect structure at hand. After creating the Electrostatic study, or the design scenario, in EMS, three important steps shall always be followed. That is, apply the proper material for all solid bodies, apply the necessary boundary conditions, or the so called Loads/Restraints in EMS, and mesh the entire model.

Materials

In the Electrostatic analysis of EMS, the only required material property is the relative permittivity, which is shown in Table 1 for the seven insulators and the surrounding air.

Component/Body	Material Name	Relative Permittivity
Air	Air	1.0
Dielectric 1	e2	2.0
Dielectric 2	e3	3.0
Dielectric 3	e3	3.0
Dielectric 4	e4	4.0
Dielectric 5	e4	4.0
Dielectric 6	e5	5.0
Dielectric 7	e5	5.0

Table 1: Relative permittivity of the seven insulators and the surrounding air

The application of materials is straight forward. Just right-click on the component icon and apply the material.

Loads/Restraints

Loads and restraints are necessary to define the electric and magnetic environment of the model. The results of analysis directly depend on the specified loads and restraints. Loads and restraints are applied to geometric entities as features that are fully associative to geometry and automatically adjusted to geometric changes.

In this study a grounded conductor is applied on the top and bottom faces of the seventh and the first dielectric layers, respectively. The conductors are indexed, i.e. numbered, using the so called floating conductors in EMS.

Meshing

Meshing is a very crucial step in the design analysis. EMS estimates a global element size for the model taking into consideration its volume, surface area, and other geometric details. The size of the generated mesh (number of nodes and elements) depends on the geometry and dimensions of the model, element size, mesh tolerance, and mesh control. In the early stages of design analysis where approximate results may suffice, you can specify a larger element size for a faster solution. For a more accurate solution, a smaller element size may be required.

In this particular benchmark, the meshing is rather straightforward since the geometry does entail small regions and gaps. Thus, the global element size is set to 2 mm with a mesh tolerance of 0.1 mm. To achieve a good accuracy without increasing the total number of mesh elements, it is recommended to apply a mesh control to the regions where a large variation is expected. Two locals mesh control of 0.5 mm and 0.25 mm are applied to the six conductors and to dielectric layers, respectively. Figure 3 shows the resulting mesh.

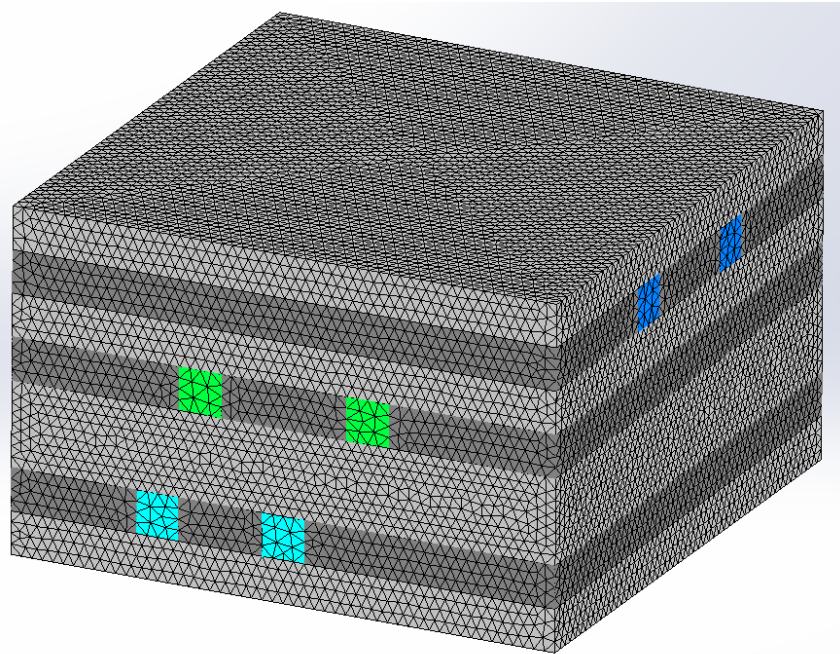


Figure 3: Mesh of the structure without the air region

Results

After a successful run, the Electrostatic module produces three result folders and a result table. The folders contain the electric field **E**, the electric displacement **D**, the potential distribution **V**, respectively. The results table contains the capacitance matrix. Furthermore, all of the results can be visualized in various formats such as fringe, vector, contour, section, line, and, clipping plots. The results can easily be zoomed-in, exported, and dissected.

For this particular benchmark, the capacitance matrix is compared against the reported results in [1]. As Table 2 indicates, the results of EMS match those reported by the authors of [1].

Cij (pF)	conductor-1	conductor-2	conductor-3	conductor-4	conductor-5	conductor-6
conductor-1	0.745	-0.158	-0.123	-6.515 e-03	-2.807 e-02	-4.566 e-03
conductor-2	-0.158	1.369	-0.210	-0.145	-3.278 e-02	-2.885 e-02
conductor-3	-0.123	-0.210	1.743	-0.172	-0.256	-0.262
conductor-4	-6.516 e-03	-0.145	-0.172	1.689	-0.265	-0.267
conductor-5	-2.807 e-02	-3.277 e-02	-0.256	-0.265	3.469	-5.154 e-02
conductor-6	-4.566 e-03	-2.885 e-02	-0.262	-0.267	-5.154 e-02	3.448

Table 2: Capacitance matrix (in pF) obtained by EMS

	C ₁₁	C ₂₂	C ₃₃	C ₄₄	C ₅₅	C ₆₆
DDM	0.680	1.29	1.57	1.52	2.54	2.54
Spice Link	0.669	1.29	1.60	1.54	2.53	2.53

Table 3: The self capacitance terms (in pF) as reported in [1]

Conclusion

This benchmark demonstrates the high accuracy achieved by the Electrostatic module of EMS compared to the published results. Hence, in addition of being fully integrated in SolidWorks and Inventor, EMS is also accurate and easy to use.

References

- [1] Zhenhai Zhu, Hao Ji, Wei Hong, "An Efficient Algorithm for the Parameter Extraction of 3-D Interconnect Structures in the VLSI Circuits: Domain-Decomposition Method," IEEE Transactions on Microwave Theory and Techniques, vol. 45, no. 8, August 1997, pp. 1179-1184.