CHARACTERIZATION OF COMPLEX 2D SURFACE OBJECTS USING THE 3D TRANSMISSION LINE MATRIX (TLM) METHOD WITH A HIGH-RESOLUTION MESH

Petr Lorenz and Peter Russer

Technische Universität München, Institute for High-Frequency Engineering, Arcisstr. 21, 80333 München, Germany
Email: lorenz@tum.de, russer@tum.de

Abstract

The three-dimensional electromagnetic modeling of two-dimensional curved structures with the Transmission Line Matrix (TLM) method is investigated. The category of problems we address is the characterization of objects that may be approximated by thin sheets, e.g., surfaces of metallic objects with high conductivity.

1 Introduction

The 3D Transmission Line Matrix (TLM) method has been originally developed in a structured Cartesian mesh [1], [2], [3]. The formulation of the TLM algorithm in structured Cartesian mesh is the easiest one and the implementation is straightforward. However, the lack of conformity of the Cartesian mesh to the boundaries of complex curved objects has been soon recognized.

Many researchers have tried to improve the conformity of the mesh to the boundaries of the objects by using graded, conformal, unstructured triangular and tetrahedral meshes [4]. However, all of these approaches increase the complexity of the TLM computation. Higher memory requirements, mesh queries and additional specialized techniques increase the complexity of the TLM algorithm and computational time. Another very important aspect is the possibility of parallelization of the TLM solver. Structured solvers are much easier to be parallelized then unstructured solvers. In general, properly designed structured solvers are also always faster and more robust than properly designed unstructured solvers.

Obviously, the main arguments why to use unstructured solvers is the conformity of the mesh to the object and easier mesh generation than for a structured solver. On the other hand, if we are able to approximate complex curved geometries within a high-resolution structured Cartesian mesh, i.e., a mesh where the spatial resolution is much higher than the curvature of the object, the computed solution will converge to the solution computed with an unstructured mesh. A study on the influence of the stepped (staircase) boundaries has been done for the finite-difference time-domain method in [5].

Since TLM in the formulation of Symmetrical Condensed Node (SCN) [1] (and all the other condensed nodes) has both the electric field components and the magnetic field components defined at the same discrete spatial coordinate, it is easy to introduce boundary conditions in the face of the TLM cell. Lossy surface boundaries may be modeled easily by specifying the reflection coefficient on the link-lines interfaces of the TLM cell [2]. We may use the surfaces available from the TLM mesh to approximate the curved two-dimensional objects. If the structured mesh has a sufficient resolution, the curvature of the objects is well approximated.

To demonstrate the described technique we give examples of the characterization of rectangular cavity resonator and compare the results with analytical results. In the examples we use a regular structured Cartesian mesh with a high-resolution. The objects are discretized within this mesh. Due to the relative ease of parallelization, we use the Grid environment [6] and solve the examples in a High-Throughput Transmission Line Matrix (HT-TLM) system [7].

2 High Resolution Mesh

In this section the *High Resolution Mesh* (HRM) is introduced and a discretization procedure is outlined. The usage of HRM in the TLM method for 2D surface objects is also described.

2.1 Definition

We define the High Resolution Mesh (HRM) as a mesh where the spatial discretization step Δl ($l \in \{x, y, z\}$) is sufficiently small compared to the curvature of the boundaries of the objects. Consequently, the temporal time step Δt is also reduced. We assume that Δt satisfies the stability criterion.

A rule of thumb for the TLM method (this rule is also valid for other volumetric methods like FDTD or FIT) is to choose $\Delta l \leq \frac{\lambda_{min}}{10}$, where λ_{min} is the shortest wavelength present in the simulation. However, if a geometrical object exhibits fast changes in the spatial domain, the spatial discretization step Δl has to be much below the above given limit.

The sufficiency condition on Δl should be chosen such that the objects under investigation are characterized with sufficient accuracy in the desired frequency range. This paper deals with experimental investigations of the size of Δl. An example of HRM is shown in Fig. 1.

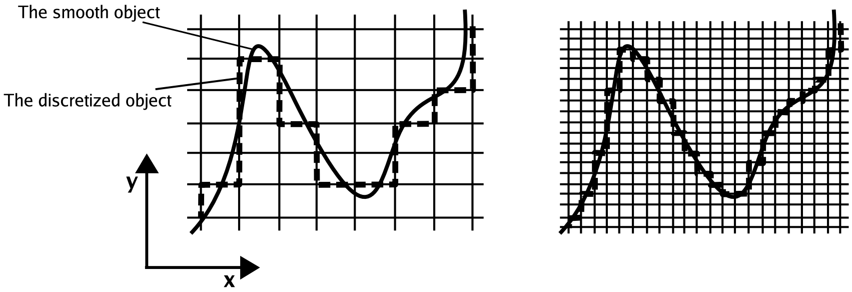

Figure 1: Definition of the High Resolution Mesh (HRM). Left – a standard mesh; right – the HRM.

2.2 Discretization procedure

The discretization procedure we are using here is an extension of the method described in [8]. For 2D surface object the discretization follows these steps:

1. create a model of the surface object,
2. define the mesh,
3. discretize the object using *ray shooting* technique,
4. extract the boundary from the volumetric object.

This method works for volumetric objects which exhibit a closed boundary. However, using boolean operations the method may be extended to discretize non-closed general 2D objects.

The ray shooting technique is depicted in Fig. 2. A ray with two constant spatial coordinates is examined for the intersections with the object under consideration. Since we know that the object has a closed boundary, i.e., it is a finite volume object, we identify the object in the prescribed mesh. Now the boundary of the discretized volumetric object may be easily extracted.

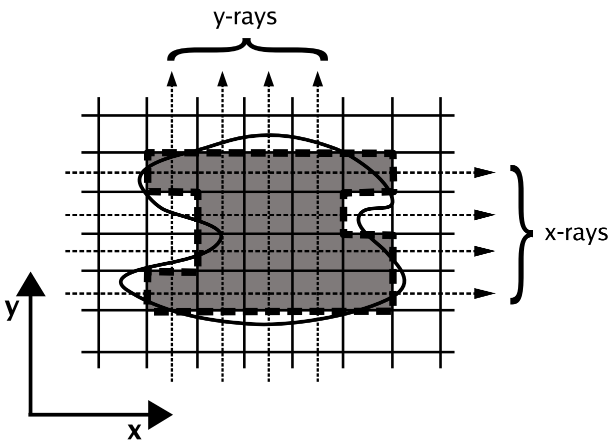

Figure 2: The ray shooting technique.

2.3 HRM in TLM for surface objects

In contrast to the Finite-Difference Time-Domain (FDTD) method, where the points of definition of the E- and H-filed components exhibit the leap-frog (more details may be found in [9]), in TLM the E- and H-field components are defined at the same discrete spatial coordinate [10]. Consequently, it is easy do introduce impedance boundary condition for surface objects, if the surface is defined using the surfaces of the TLM cells.

To increase further the efficiency, we may use a subgridding method like the octree-meshing described in [11]. This reduces the total number of cells significantly, but keeps the desired HRM around the curved boundaries.

3 Examples

All the examples have been computed using the open-source TLM simulation package YATPAC [12].

3.1 Rectangular cavity resonator

Recently, an off-grid perfect boundary conditions for the FDTD method have been published by Rickard and Nikolova [13], implementing an enhanced staircase approximations. We use the same rectangular resonator as in the above mentioned paper and compare the results obtained in the HRM.

The rectangular cavity resonator has dimensions $a = 10$ mm, $b = 20$ mm, $l = 30$ mm, with the l-th dimension located along the z axis. The resonator is rotated in the ϑ and φ directions and discretized using the HRM. The configuration of the simulation and the simulation times are summarized in Tab. 1. The calculated resonant frequencies and the relative error are summarized in Tab. 2. For the simulations computing nodes with Pentium4 3.0 GHz processors, 1GB 400 DDR memory, connected with 1-Gbit/s switched Ethernet network, have been used.

ϑ	φ	Δl	# Cells	t standalone	t distributed
0°	0°	1 mm	$28 \times 18 \times 38 = 19152$	1.43 min	-
45°	0°	1 mm	$40 \times 18 \times 40 = 28800$	2.03 min	-
45°	0°	0.5 mm	$76 \times 32 \times 76 = 184832$	9.72 min	-
45°	0°	0.25 mm	$156 \times 52 \times 156 \doteq 1.265 \times 10^6$	2.5 h	40.43 min; (2:3:1)
45°	45°	0.25 mm	$156 \times 148 \times 156 \doteq 3.4 \times 10^6$	6.5 h	1.82 h; (2:3:1)
45°	45°	0.125 mm	$300 \times 284 \times 284 \doteq 24.2 \times 10^6$	-	21.78 h; (7:1:1)

Table 1: Configuration of the rectangular cavity resonator. The distribution ratio in the distributed case is given in the brackets $(x : y : z)$.

ϑ	φ	Δl [mm]	f_{011}; δ[%]	f_{012}; δ[%]	f_{101}; δ[%]	f_{110}; δ[%]	f_{111}; δ[%]
0°	0°	1	9.0101; 0.027	12.493; 0.012	15.805; 0.029	16.756; 0.017	17.482; 0.034
45°	0°	1	8.8223; 2.057	12.228; 2.107	15.556; 1.547	16.5; 1.544	16.98; 2.9
45°	0°	0.5	8.9624; 0.5	12.45; 0.331	15.705; 0.604	16.72; 0.2322	17.44; 0.29
45°	0°	0.25	9.027; 0.215	12.537; 0.365	15.77; 0.192	16.829; 0.418	17.44; 0.29
45°	45°	0.25	8.973; 0.385	12.434; 0.4599	15.717; 0.528	16.668; 0.542	17.264; 1.28
45°	45°	0.125	9.0002; 0.082	12.479; 0.099	15.7811; 0.122	16.74; 0.108	17.44; 0.26

Table 2: Calculated resonant frequencies of the rectangular cavity resonator. All frequencies are given in GHz. Next to the resonant frequency is given the relative error.

4 Conclusion and Outlook

We have presented the characterization of 2D surface objects using the transmission line matrix (TLM) method. The objects are discretized with a high-resolution mesh (HRM) which enables sufficient approximation of the curvature of the objects and where the advantages of structured mesh are maintained.

It has been shown on an example of a rectangular cavity resonator that the resonance frequencies may be calculated with a relative error below 0.26 %.

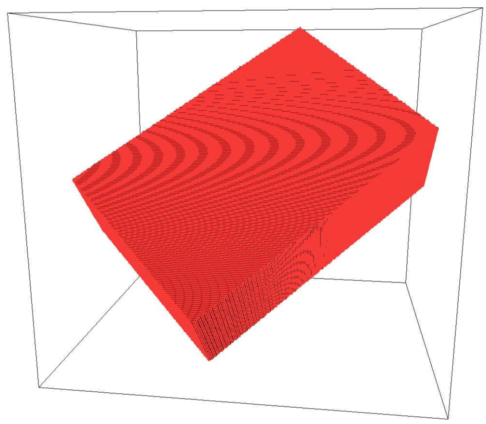

Figure 3: The rectangular cavity resonator discretized with HRM; $\vartheta = 45°$, $\varphi = 45°$, $\Delta l = 0.125$ mm.

The HRM approach results in a large number of TLM cells and large simulation times. However, with the speed of todays desktop computers it is possible to perform such simulations. For complex structures the Grid environment provides the required resources to solve these large problems. Using HRM and domain decomposition, the interfacing surfaces of the subdomains result also in a large number of cells. To keep the communication time at a minimum, special techniques for data handling need to be used, e.g., data compression. This will enable large-scale simulations in a highly geographically distributed environments.

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