The Efficient EM Modelling of Electrically Large Structures

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Introduction

There is an increasing need to solve larger and larger computational EM problems, which is leading to longer simulation times requiring larger computational requirements. An example of this is installed antenna performance, whereby the user models the fine geometric features of the antenna structure in a potentially large and geometrically complex computational volume.

This paper discusses two advanced features; in the TLM (see reference [1]) based 3D EM simulation tool MicroStripes, which enable RF designers to model electrically large structures efficiently; octree meshing and compact models.

Octree Meshing

It is often necessary to solve for electrically large structures while, at the same time, ensuring the geometrically small but electrically important features are also accurately represented. This could result in very large meshes, which could lead to unsolvable problems on standard PC platforms. While the cost of 64-bit systems is reducing, and can now be applicable for desktop PC, the fundamental issue of potentially inefficient computational meshes is not addressed.

With TLM, this problem was tackled by implementing a multi-grid scheme on a Cartesian based grid technology [2]. Figure 1, shows a simple schematic of a representative geometry where the grey areas need extra grid refinement [3]. In a basic Cartesian grid, the resulting mesh would have fine cells extending from the geometry to the boundaries of the computational volume. This results in many additional cells, of high spatial resolution, in areas where such fine grid is not required.

With the implementation of the Octree multi-grid scheme in TLM, it becomes possible to recombine (or lump) the small cells in areas where they are not required to make larger cells. Figure 2 shows a schematic for the resulting lumped mesh from the example in Figure 1 [3]. The automated octree scheme lumps not only the cells outside the geometry region, but also the area in-between the two finely gridded regions. In addition, the automated octree scheme also allows cells within materials to be lumped together, by calculating the wavelength of the highest frequency of interest within the material. This will be beneficial to problems with high dielectric permittivity or complex geometries, where very fine meshes are required.

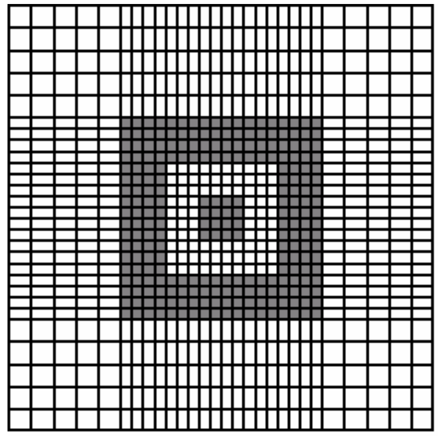

Figure 1 Basic Cartesian grid

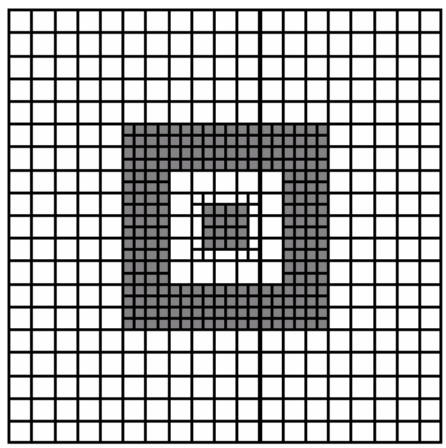

Figure 2 Octree multi grid mesh

One of the key features of the octree scheme is the ability to automatically lump the cells. Without auto-lumping, the number of cells is a cubic function of the reciprocal of the cell size, i.e. the number of cells per meter. If the cell size is halved to improve the resolution of the fine detail, then the number of cells in this volume will increase by a factor of 8. If the cell size in this region is kept on halving, the cells there will quickly come to dominate the total cell count, which will become too big. However, with the auto-lumping the smallest cells only exist around the edges of objects and in a thin layer over curved or sloping surfaces. This means that the cell count will be at worst quadratic in the reciprocal of the smallest cell size. In the rest of the paper, 'octree meshing' will be referred to octree meshing with auto-lumping feature switched on.

The octree meshing scheme was applied to a series test models, which clearly showed the improvement in computational efficiency of the simulation. The antenna shown in figure 3, consists of a perfectly conducting metallic horn body and double ridge structure [3]. Inside the horn, there is a pyramidal dielectric rod (ε_r= 2.2 and σ= 2S/m) loading the structure. The double ridge and pyramid forces a finer mesh due to their complex shape and permittivity.

Two different simulations were performed on the horn antenna structure; firstly for a standard Cartesian mesh without lumping, and then with automatic octree lumping. In the basic model, the maximum cell size was 10 mm and the minimum 2.4 mm. When lumping was employed, the maximum cell size for lumping was set to 20 mm, 10% of a wavelength at the maximum frequency of 1.5 GHz.

By taking advantage of the two symmetrical planes, only a quarter of the geometry was solved. The calculated return for the standard and octree meshed simulations are shown in figure 4. It can be seen that the results obtained show very little difference in the response across the frequency band of interest. Closer analysis shows that across the majority of the band, the variation is within ± 0.2 dB of the reference.

Table 1, shows the improvement in computational time and resource by applying the lumping scheme. As can be seen, having applied lumping to the model, the automatic octree meshing showed a reduction in cell count of approximately 93 % over the reference. This reduction in the cell count has resulted in a reduction of 94% and 91% on the computation time and required memory respectively, when compared to the basic multi-grid scheme. This significant reduction in required memory suggests that more geometrically complex models could be solved on standard PC platforms.

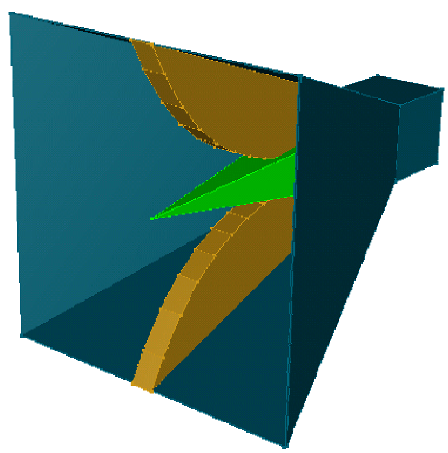

Figure 3 Horn antenna used in Octree meshing tests

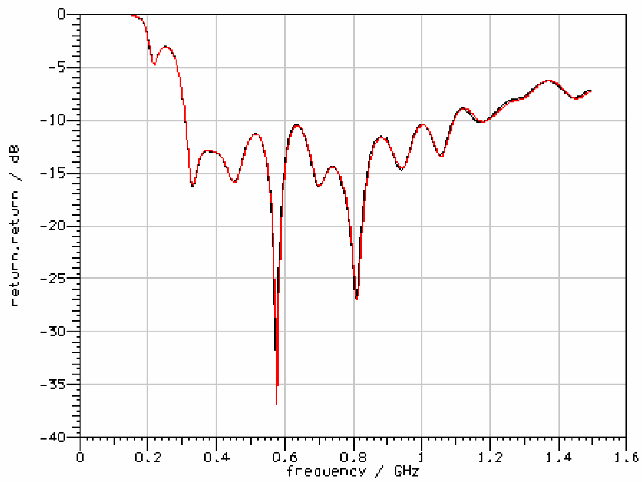

Figure 4 Return losses for the horn antenna with and without auto lumpling scheme applied

Table 1 Comparison of number of cells and solve times between standard and auto lumping meshing

	No. of cells in background grid (k)	No. of cells in solver model (k)	Computation time (mins)	Required Memory (MB)
No Lumping	4346.5	4326.3	152	421.3
Automatic Lumping	4346.5	304.6	9	38.8

Compact Sub Cell Model

It is often the case for time domain volumetric solutions that small features, such as wires, slots and thin films must be finely meshed to fully capture their EM behaviour [4]. This introduces a small mesh size, which has an impact on the overall computational time required for a simulation. It is because the simulation time also depended on the smallest cell size, which determines the length of the time step; hence the number of time steps for the whole simulation. The size of the time step can not be reduced by applying octree meshing. However, enhancements to the TLM solver allow those fine features to be solved within a single cell through the introduction of compact equivalent circuits, which correctly capture EM behaviour without compromising accuracy. This delivers a huge advantage as it increases solution speed and reduces the model size.

Sub cell models currently available in TLM include: thin slots, wires (including multi wire bundles), small aperture arrays (air vents), thin films and metal-backed ferrite tiles.

To illustrate the benefits of this feature, two examples are presented for the slot and wire compact models.

For the slot, consider a metallic screen of 500 mm by 300 mm that has been punctured by a 2 mm wide rectangular slot, as shown in Figure 5. The metallic screen was illuminated by a plane wave from the back. A monitor point, used to view the E and H field was allocated in the front of the centre of the screen. The frequency domain solution obtained from the compact model and the full mesh model are given in figure 6 and show good agreement. It is worth noting that the compact model was solved within 2 minutes and required 3 Mbytes of memory, while the full model required over 3 hours of CPU and 30 Mbytes of memory and need two planes of symmetry. The compact model also allows the slot space to be filled with lossy dielectric or magnetic material to simulate the presence of a shielding gasket.

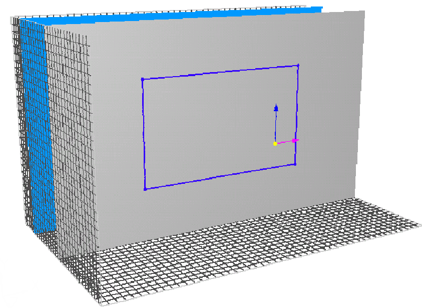

Figure 5 Slot on a metal plate driven by a plane wave from behind

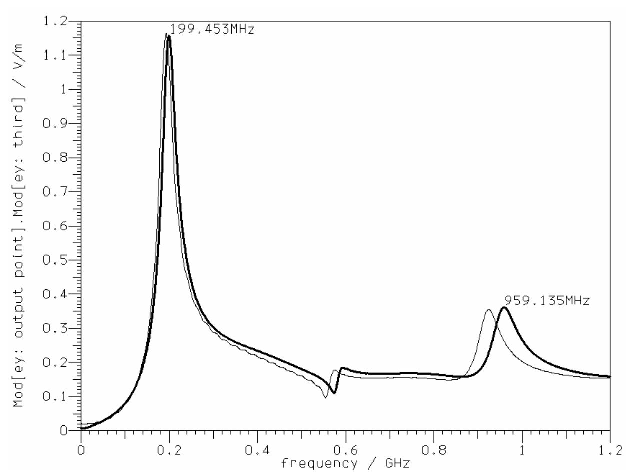

Figure 6 E-field comparison at a monitor point in front of the slot using two different models

Figure 7 shows a dipole meandered antenna embedded on a metallic wheel, with diameter of 460 mm. The antenna resonating at around 868 MHz and 916 MHz, was installed for monitoring the tire pressure. The antenna has the maximum dimension of 50.4 mm, and the wire thickness of 0.1 mm representing the dipole circuit. Using the compact wire model and octree meshing enabled the whole simulation to be completed within 35 minutes, and required merely 45 MB of memory.

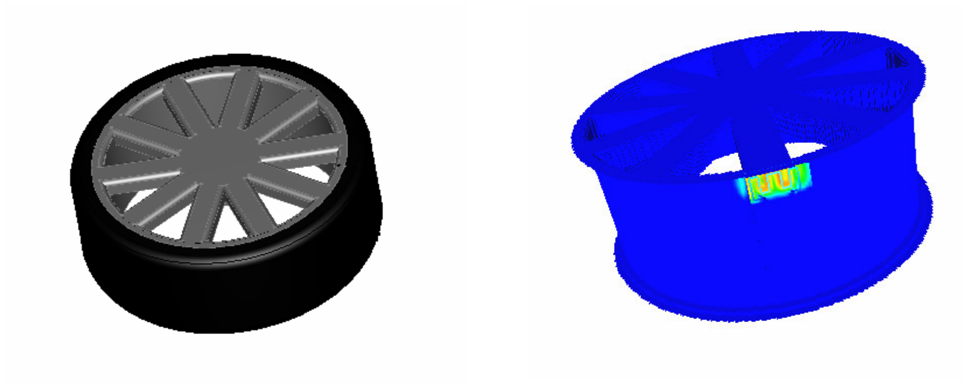

Figure 7 Embedded antenna in wheel and simulated surface current distribution

Application Examples

The following application examples illustrate the efficient modelling of electrical large structures through the use of octree meshing and compact models.

Figure 8 shows an aircraft of 26m x 26m x 8m, which has been imported as a hollow object into MicroStripes 7. The aircraft is surrounded with free space of 10m in each direction, giving a total computational volume of about 59250 m^3. The structure was illuminated by an off-axis plane wave with maximum frequency of 100 MHz. From figure 8, showing the surface current distribution, we notice that a very fine mesh has been applied to capture the detail of the aircraft surface. However, by using the automatic octree lumping, the total cell count is only 3.6 million, which has a saving of 99.3% compared to the graded mesh of 529 million cells before lumping. The octree scheme ensures that the lumping is mainly performed inside the aircraft and in the free space, while keeping fine mesh on the metal surface of the aircraft. The simulation was completed within 17 hours on a Dual 1.99 GHz AMD Opteron, using only 609 MB of memory.

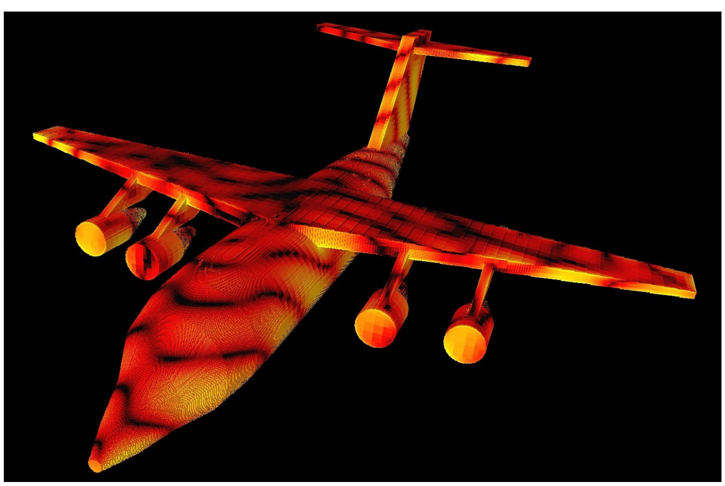

Figure 8 Surface current on the aircraft

Figure 9 shows a parabolic dish which is illuminated by a horn antenna, having a cut off frequency of 2.2 GHz. The dish is 2 m in diameter, and the horn is 1.38 m from the dish. By applying symmetry to the model, only a quarter of the geometry needs to be solved. The maximum dimension in the computation region is 2 m, which equal to 20 wavelengths at 3 GHz in free space. The background has a mesh with 18.8 million cells. The lumping scheme has reduced the total cell count by 40 %, to 11.4 million cells. Such cell reduction has allowed such a problem to be solved on a standard machine. Figure 10 shows the current distribution at 2.7 GHz. This simulation, from DC to 3 GHz was completed on a Dual Opteron 1.99 GHz, with total duration of 14 hours and 44 minutes, with required memory of 1.48 GB.

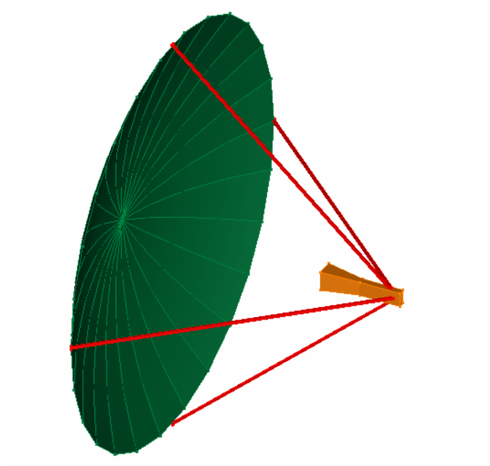

Figure 9 Parabolic dish antenna model in MicroStripes

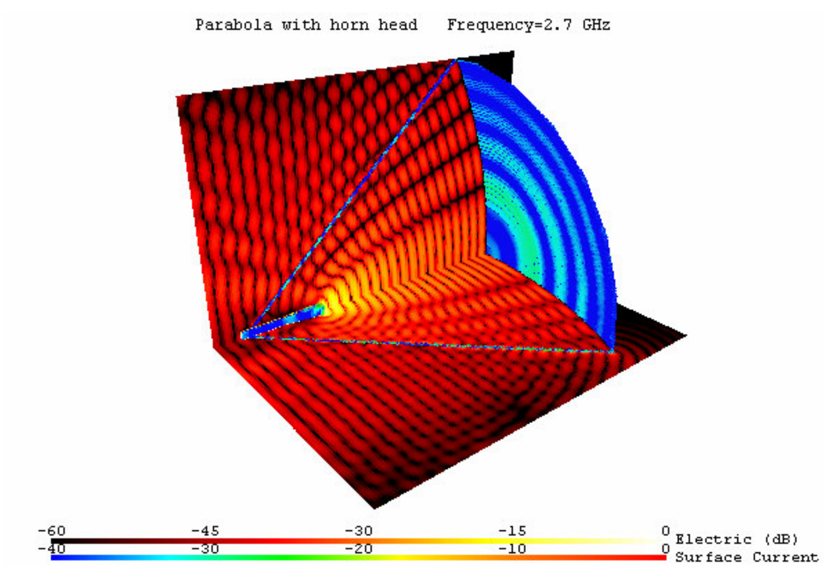

Figure 10 Current distribution (spectrum) & Electric field (hot scale) at 2.7 GHz

Conclusions

This paper has reviewed two of the key features within TLM, which benefit the modelling of electrically large problems. These allow significant reductions to be realized in the simulation times and memory requirements for complex models, without incurring a negative impact on the accuracy of result. The implementation of these features is now allowing electrically large and geometrically complex models to be much more efficiently solved on standard desktop PCs.

Acknowledgements

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