EMC/EMI simulations for Automotive Industry using a Time Domain approach based on Finite Integration Technique

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Abstract: *In this paper EMC/EMI simulations of an electrically large automotive application are performed using the code CST MICROWAVE STUDIO® (CST MWS). CST MWS is a well-known software package which is based on the Finite Integration Technique and provides different simulation methods for 3D EM analysis. It is ideal for such applications since the geometry can be easily imported and modified using the powerful user interface. The Time Domain solver in CST MWS exploits the accurate and robust PERFECT BOUNDARY APPROXIMATION (PBA)® and THIN SHEET TECHNIQUE (TST)™. It takes advantage of the linear scaling of memory with increasing number of mesh cells and allows the broadband simulation of AM/FM, GSM and GPS antennas. Other advantages include time domain simultaneous excitation of multiple sources for mutual coupling analysis and near- and far-field calculations in the time and frequency domains.*

1. Introduction

The number of antennas and sensors in automotive applications are increasing nowadays so it is therefore necessary to ensure satisfactory communications performance of the on-board devices. Possible EMC threats associated with on-board devices for automotive applications are an essential part of the design process and have to be addressed before prototypes can be manufactured. Electromagnetic simulations of entire vehicles are now feasible due to the efficient memory scaling of the CST MWS [1] Time Domain solver. The vehicle simulations were carried out using the Finite Integration Technique (FIT) method [2], a full-wave 3D field modelling technique. FIT can be formulated as a time domain technique, which is well suited to obtaining the wideband results needed for EMC simulations. In this application, the band of interest was defined up to 2.5GHz. Furthermore, the time domain formulation allows the use of different time signals according to the type of EMC/EMI test undertaken, such as radiation/immunity, ESD or EMP. The simulations were performed on a BMW vehicle (Fig. 1), imported in STL format, including on-glass AM/FM antenna, as well as a GPS patch antenna on the roof.

Figure 1: Geometry of imported car and supported CAD import formats

2. Numerical Modelling Theory

The implementation of FIT method generates exact algebraic analogues to Maxwell's equations that guarantee physical properties of computed fields and lead to a unique solution. Maxwell's equations and the related material equations are transformed from the continuous domain into a discrete space by allocating electric voltages on the edges of a grid G and magnetic voltages on the edges of a dual grid $\widetilde{G}$. The allocation of the voltage and flux components on the grid can be seen in Fig. 2. The discrete equivalent of Maxwell's equations, the so-called Maxwell's Grid Equations are shown in Eqs.(1)-(4). This description is still an exact representation and does not contain any approximation errors.

$$\mathbf{C}\widehat{\mathbf{e}} = -\frac{d}{dt}\widehat{\widehat{\mathbf{b}}} \qquad \widetilde{\mathbf{C}}\widehat{\mathbf{h}} = \frac{d}{dt}\widehat{\widehat{\mathbf{d}}} + \widehat{\widehat{\mathbf{j}}} \quad (1,2) \qquad \mathbf{S}\widehat{\widehat{\mathbf{b}}} = 0 \qquad \widetilde{\mathbf{S}}\widehat{\widehat{\mathbf{d}}} = \mathbf{q} \quad (3,4)$$

In these equations $\widehat{\mathbf{e}}$ and $\widehat{\mathbf{h}}$ denote the electric voltages between grid points and the magnetic voltages between dual grid points, respectively. The symbols $\widehat{\widehat{\mathbf{d}}}$, $\widehat{\widehat{\mathbf{b}}}$ and $\widehat{\widehat{\mathbf{j}}}$ are fluxes over grid or dual grid faces. Due to the consistent transformation analytical properties of the fields are maintained resulting in corresponding discrete topological operators on the staggered grid duplet. The topology matrices $\mathbf{C}$, $\widetilde{\mathbf{C}}$, $\mathbf{S}$ and $\widetilde{\mathbf{S}}$ correspond to the curl- and the divoperators. The tilde indicates that the operator belongs to the dual grid. The discrete analogue of the coupling between voltages and fluxes is represented by the material matrices $\mathbf{M}_{\varepsilon}$, $\mathbf{M}_{\mu^{-1}}$ and $\mathbf{M}_{\kappa}$.

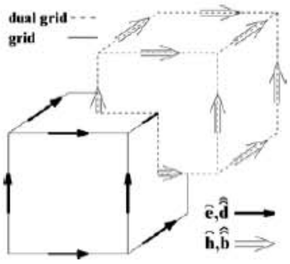

Figure 2: Allocation of voltage and flux components in the mesh.

$$\hat{\hat{\mathbf{d}}} = \mathbf{M}_{\varepsilon}\hat{\mathbf{e}} \quad (5) \qquad \hat{\mathbf{h}} = \mathbf{M}_{\mu^{-1}}\hat{\hat{\mathbf{b}}} \quad (6) \qquad \hat{\hat{\mathbf{j}}} = \mathbf{M}_{\kappa}\hat{\mathbf{e}} + \hat{\hat{\mathbf{j}}}_{\mathbf{A}} \quad (7)$$

These matrices have diagonal form and contain the unavoidable approximations of any numerical procedure. The boundary of the calculation domain is assumed to be ideal electric, ideal magnetic or 'open'. In the case of an open boundary, a perfectly matched layer (PML) is additionally wrapped around the structure to absorb incident waves at the boundary. The discretization of the time derivative can be formulated as an explicit algorithm, the so-called leap-frog algorithm. The calculation of each further time step only requires one matrix-vector multiplication, which makes the method very memory efficient. For the loss less case, the scheme is described in Eqs.(8) and (9). FIT in time domain is therewith a generalization of the FDTD method.

$$\hat{\mathbf{h}}^{(m+1)} = \hat{\mathbf{h}}^{(m)} - \Delta t\mathbf{M}_{\mu^{-1}}\mathbf{C}\hat{\mathbf{e}}^{(m+1/2)} \quad (8) \qquad \hat{\mathbf{e}}^{(m+3/2)} = \hat{\mathbf{e}}^{(m+1/2)} + \Delta t\mathbf{M}_{\varepsilon}^{-1}\left(\widetilde{\mathbf{C}}\hat{\mathbf{h}}^{(m+1)} - \hat{\hat{\mathbf{j}}}^{(m+1)}\right) \quad (9)$$

The excitation signal for the time domain calculation can be fed in the structure on any desired path of edges in the normal grid. This path is referred to as discrete port which represents discrete impedance combined with a feeding current source. At the excited port the input and output signals are calculated from the current, voltage and impedance of the port, which are known from the electric and magnetic field components. To calculate the S-Parameters in a wide range of frequencies a broadband input signal is chosen. In Fig. 3 typical excitation signals are shown: on the left a Gaussian pulse for broadband S-parameter calculation, on the right an electromagnetic pulse (EMP) used e.g. for lightning simulations. All input and output signals resulting from the time domain simulation are transformed into the frequency domain by application of a Discrete Fourier Transform (DFT) algorithm. Finally, the S-Parameters are obtained as the ratio of the frequency domain representations of the direct incident and inverse wave components.

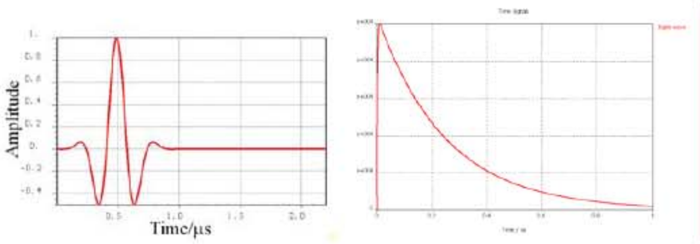

Figure 3: Time dependent broadband input signal and a typical EMP signal.

1. Vehicle modelling

A variety of CAD formats may be used to import the structure into CST MWS. Fig. 4 shows the various types of antennas that can be simulated with CST MWS demonstrating the versatility of the PBA and the TST features for the correct modelling of small features such as thin-wire on-glass antennas and relatively thin power cables.

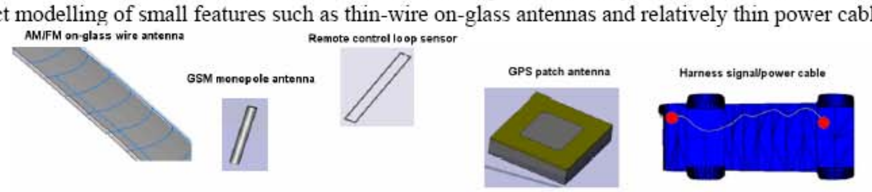

Figure 4: Typical antenna structures and placements (AM/FM, GPS) and power cable setup (DC).

The windscreen on-glass antenna highlights several significant features that are advantageous for such a simulation such as the ability to import curves of the antenna which can then be transformed into wires and be simulated with a finite radius in CST MWS, the thicken sheet feature to assign a thickness to an object imported as infinitely thin such as the windscreen

2. Results

Different test cases have been carried out. Fig. 5 shows an AM/FM on-glass wire antenna etched on the rear windscreen of the car as well as the horizontal component of the polar farfield pattern.

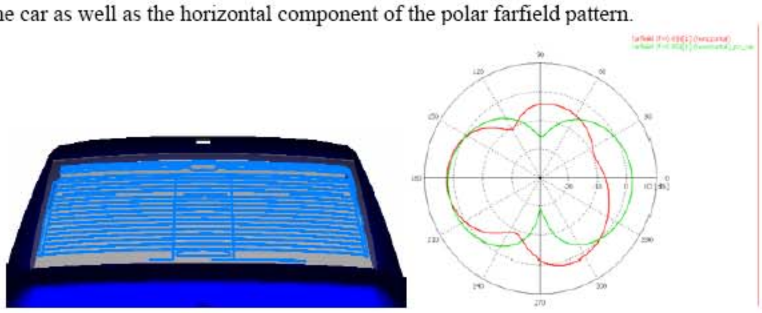

Figure 5: AM/FM on-glass wire antenna etched on the rear windscreen of the car and polar farfield patterns for the AM/FM on-glass wire antenna with and without car model present (green curves in the polar plots).

The effect of the car on the farfield patterns of GPS patch antenna is shown in Fig. 6, where the 3D and polar plots of the farfield are shown for the frequencies applicable to the antenna simulated (about 2.5GHz). The green polar curves are for the antenna simulations without the car present. The farfield calculation over lossy grounds enables the simulation of outdoor test ranges. Accurate calculation and visualization of 3D fields and surface currents useful for antenna and cable placement and results and geometry data may be easily exported for use in third party or in-house tools.

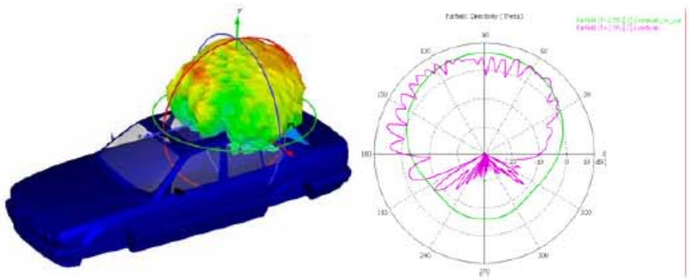

Figure 6: 3D and polar farfield patterns for the GPS patch antenna with and without car model present (green curves in the polar plots).

The antenna performance is affected negatively by the presence of the car and the dielectric windscreen – however, all antennas give a reasonable pattern coverage around the vehicle.

3. Conclusion

CST MICROWAVE STUDIO® is a unique tool which combines user-friendliness with a very powerful set of solvers. For the simulation of automotive antenna placement and EMC applications, CST MWS offers comprehensive CAD facilities to not only import structures but also to simplify and modify the model where necessary. This includes the ability to import wires which may either be treated as infinitely thin or finite radius wires. The Time Domain solver delivers, in addition to the Fourier-transformed frequency domain results, time varying probe data for either near- or far-field data. A multitude of frequency domain field data such as farfields, surface currents, etc. can be derived in one single simulation run. Automotive structures are usually electrically large can be easily handled due to the almost linear memory-mesh cell scaling characteristic of the CST MWS Time Domain solver. Different time signals may be applied to simulate of all kinds of EMC/EMI tests such as radiation/immunity, ESD or EMP.

[1] CST MICROWAVE STUDIO®, User Manual, www.cst.com

[2] T. Weiland: A Discretization Method for the Solution of Maxwell's Equations for Six-Component Fields. Electronics and Communication, (AEÜ), Vol. 31 (1977), p. 116.