



## **Modeling of Conductive and Radiated Electromagnetic Disturbances -Special Application to Cable Harness Interference**

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Through the Center for Automotive Systems Technologies and Testing, Luleå University of Technology aims to first of all support automotive winter testing in Northern Sweden. This means to support the local automotive test entrepreneurs and through them their customers: the car manufacturers and their suppliers. To succeed in this task, the center relies on the university's areas of leading research and most importantly on the cooperation between those areas.

### **Background**

Ensuring automotive electromagnetic compatibility (EMC) is dominated by experimental activity. However, the advent of electric and hybrid vehicles and the increasingly wide range of systems and frequencies which are used in vehicles, are expected to make automotive EMC an increasingly troublesome burden to vehicle manufacturers in the future. It is considered that the adoption of numerical modeling techniques will provide the most cost effective approach for future automotive EMC engineering.

The use of numerical modeling techniques became possible by the introduction of high speed computers in the early 60s and the use of numerical modeling within electronic design started at the same time. There are currently a number of different methods to model electromagnetic effects in electronic systems. For example the finite difference method (FDM), the finite element method (FEM), and the Method of Moments (MoM). These methods offers solutions to special classes of problems but for combined electric and electromagnetic modeling the partial element equivalent circuit (PEEC) method is the most suitable. This method was originally developed at IBM for inductance calculations but is now used for complete electric and electromagnetic modeling. The advantage with the method is the systematic development of equivalent circuits which offers a good insight in the physics of the original problem and a deep understanding of the interaction mechanisms (conduction and radiation).

To solve electromagnetic (EM) problems for modern cars several types of modeling techniques has to be used. To understand the complexity of the task, consider the schematic description in Fig. 1. This figure separate automotive EM modeling based on:

- geometrical level (IC, component, and system) and
- simulation domain (circuit or field),

and indicate the suitable modeling approach. Familiar to most electronic engineers is the circuit simulation of electric and electronic functionality at component level by using SPICE-like solvers (Equivalent Circuits). From this figure, it is clear that the PEEC method is the link between circuit simulation (electronic functionality) and field simulation (electromagnetic effects). This is a result from the equivalent circuit description utilized in the method.

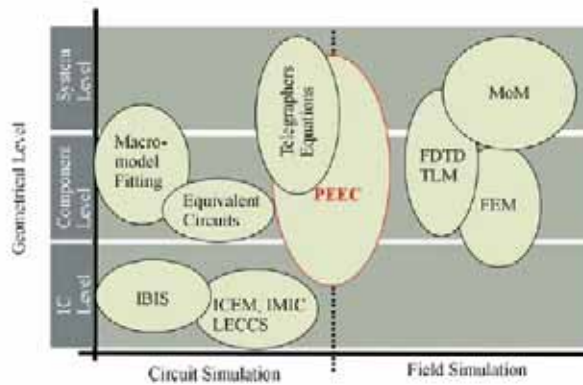


Figure 1. Mapping of current EM simulation methodologies [1] and their usage.

### Objective

Since the PEEC method is a circuit based technique in which electromagnetic effects are naturally incorporated, the method is very suitable for certain classes of problems. For example, the study of cable harnesses layout and the electromagnetic interference effects on these. This is a problem which is often encountered by the automotive industry and is very well suited for modeling using the PEEC method. Therefore, a project detailing a method for systematic model development for cable harnesses layout with conducted and radiated electromagnetic effects is proposed with the following main objectives.

1. Develop the PEEC method for combined electric and electromagnetic (EM) modeling of cable harnesses in an automotive environment.
2. Detail a systematic approach for the generation of electric and electromagnetic models for cable harnesses considering the layout for use within EMC and EMI studies. Demonstration includes time- and frequency- domain analysis of multi-conductor cables in a realistic automotive environment.
3. Transfer of knowledge and application of recent research efforts within electrical interconnects and packaging modeling to the automotive industry.

### Approach

The goal is to extend the PEEC method to enable efficient treatment of specific EMI/EMC problems encountered by the automotive industry. Typical application areas are within early stage EMC studies, signal integrity analysis, and antenna/communication design and layout.

#### **Example. Harness to antenna coupling**

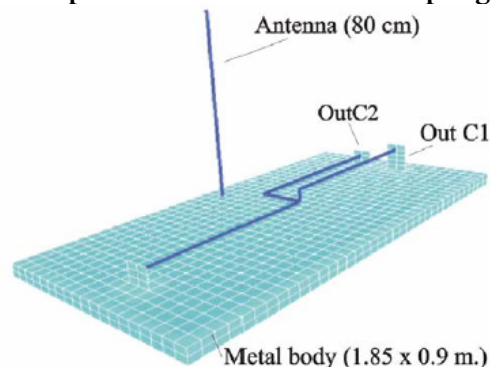


Figure 2. Example of geometry studied in [6] by using a hybrid EM solver.

To show the potential of the PEEC approach and the relation to other work, an example detailing the coupling between a cable harness and an antenna is given. The problem was studied in [6] by using a hybrid method combining a finite-difference code and transmission line code. **This is clearly not necessary since PEEC can handle both electric components (R, L, C, V, I, T) and conductive and radiated coupling in the same solver without problems.** In [6], the hybrid approach was verified against measurements for a simple structure, shown in Fig. 1, for which the transmission coefficient between one cable and the antenna was compared. The same tests were repeated using the current PEEC solver [7] and the results are shown in Fig. 3 (b) compared to the results presented in [6] in Fig. 3 (a) with very good agreement. Since all the geometrical details of the structure were not given, the resonance is shifted in the comparison between the results.

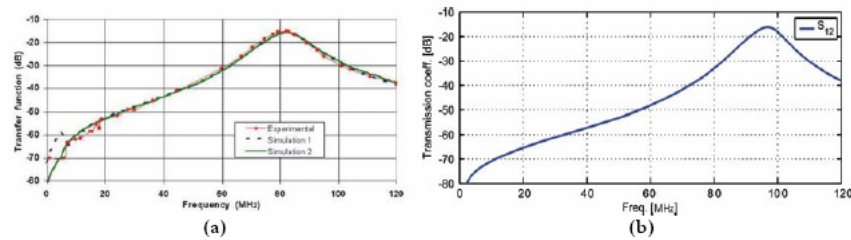


Figure 3. Transmission coefficient from input of cable 1 (C1) to antenna load (50 Ω). Results from hybrid method detailed in [1] in (a) and using the current PEEC code (b).

Now, by using the developed PEEC code, the same problem can be studied in the time domain. This is an extremely important feature of PEEC based modeling and allows signal integrity problems within the structure to be studied in parallel to EMC/EMI (in the frequency domain). An example is shown in Fig. 4 where the top of the antenna is subjected to a fast (~ ns) current transient and the induced cable voltages are calculated and shown in Fig. 4 (b). The ringing seen in the time domain waveform has a period of ~10 ns which correspond to a resonance frequency of ~100 MHz which was previously seen in the frequency domain results, Fig. 3 (b), reflecting the geometrical layout of the body-antenna-cable-system.

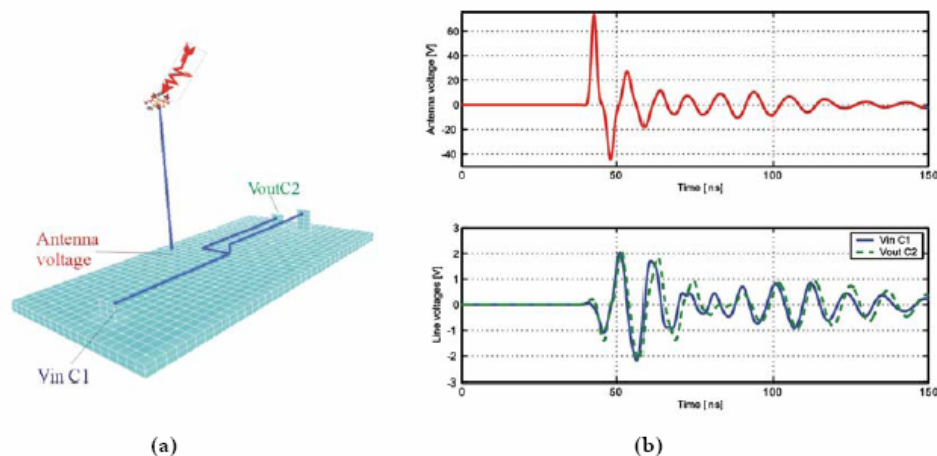


Figure 4. Time-domain simulation of antenna and harness voltages (b) when antenna top is struck by a fast current transient (a).

## **Project plan**

The project requires the PEEC methodology to be extended to apply to the characteristics of automotive EMI and EMC problems. To enable practical modeling the following main areas need to be considered:

1. The treatment of geometrical data (CAD-files). For an EM simulation, all geometrical details of the body (chassis) have to be considered. This is not a research problem as much as a time problem since manufacturers CAD-files are too much detailed for realistic EM modeling. This issue is best treated by focusing on one, or possibly two, specific chassis in the early stage of the project. From these CAD-files, the PEEC model geometrical input is created by using intermediate software similar to Gridgen [2] and GiD [3].
2. The calculation of partial elements. The basis in the PEEC method is the partial elements which represent the magnetic and electric field coupling effects in a system. The partial elements are calculated from the geometrical layout of a structure and the importance of high accuracy and the speed of the calculations cannot be disregarded. This is a well known issue within EM modeling and can be treated by carefully applied meshing and calculation routines.
3. Equivalent circuit descriptions. In order to obtain useful results, the electronic function of additional components needs to be incorporated in the PEEC solver. For example, the schematics (circuit layout) for electronic control units (ECUs) and other active/passive components. This can be done by using the correct circuit representation, by MNA stamps [4], for simple components or by black-box representations for more complex components. Another possibility to model both EM interactions and the complex functionality of control systems is to generate a reduced order model of the PEEC model (EM modeling) and import this as a sub-circuit in for example SPICE (electronics modeling). The choice depends on the complexity of the electronics network/ECUs.
4. Signal transmission in complex multi-conductor cables. To efficiently model signal transmission in cable harnesses, the theory of multi-conductor transmission lines is an efficient approach. This 2.5-dimensional approach considers the cables to have homogeneous cross-section for all the length resulting in very efficient computational techniques. However, the cables are allowed to be constructed from an arbitrary number of signal conductors surrounded by homogeneous dielectric materials in various layers. Recent work [5] serves as a good starting point for this sub-task.

The presented main areas are considered to be suitable for the treatment of one PhD student during a four year period. The current level of knowledge and the suite of tools that are developed gives the project a fast start and results can be expected during the first year.

## **References**

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