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Component-Level Characterization for Vehicle-Level Electromagnetic Simulations

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ABSTRACT

With the proliferation of high-speed electronics and wireless devices in today's automobiles, full-vehicle electromagnetic simulations are becoming an important part of the automotive design process. Full-vehicle simulations require complete and accurate models for the various electronic components found in the vehicle. Although automotive electronic components are currently subjected to a variety of electromagnetic measurements designed to ensure electromagnetic compatibility, existing measurement procedures do not yield sufficient information about the electromagnetic behavior of components to be useful in full-vehicle simulations. This paper outlines a set of tests designed to characterize automotive components as electromagnetic sources. Source models derived from these tests can be used in vehicle-level electromagnetic simulations. These simulations can then be used to help determine the best design and placement of wireless devices and other electronic components in the vehicle. They can also be used to identify potential electromagnetic compatibility problems and/or predict the outcome of full-vehicle electromagnetic compatibility tests. The proposed tests characterize components as four source types: conducted sources, electric-field sources, magnetic-field sources, and radiated field sources. High-, mid- and low-impedance load tests are proposed to derive Thevenin equivalent conducted sources. Hybrid TEM cell measurements are proposed to derive electric- and magnetic-field source models. Floor-mounted semi-anechoic chamber measurements are proposed to derive radiated field source models.

INTRODUCTION

Today's automobiles are highly complex electronic systems. As illustrated in Fig. 1, a wide variety of automotive functions and features are electronically controlled. Automobiles rely on electronic subsystems in order to meet performance, safety, and fuel economy requirements. Cars and trucks on the road today have dozens of microprocessor-controlled systems, and with each new model year, the number of processors in the average vehicle rises.

Packing a large number of electronic systems into a small volume presents many opportunities for electromagnetic interference (EMI) problems. It is important that automobile manufacturers take the necessary steps to ensure that the electronic systems are capable of functioning without error in the presence of noise generated by sources both internal and external to the vehicle.

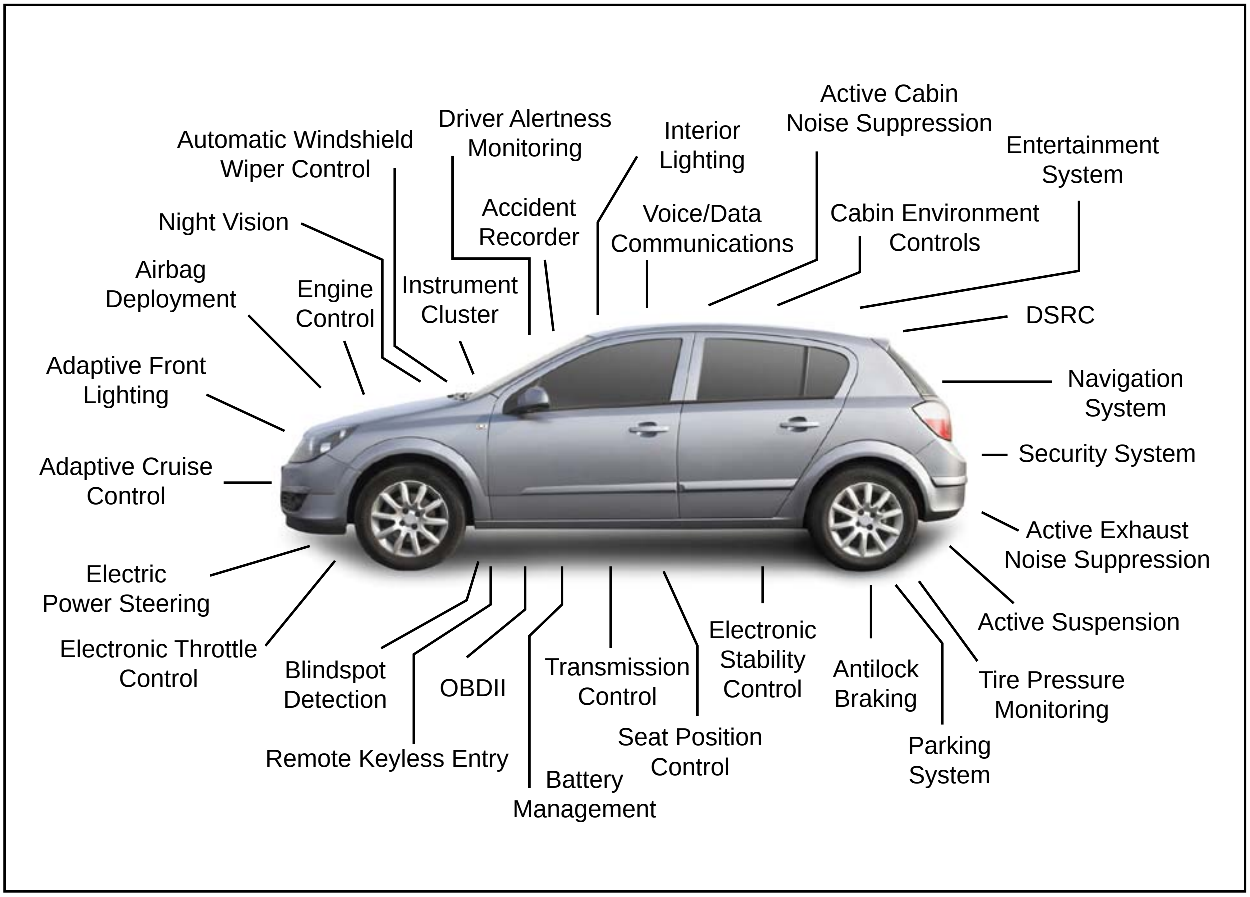

Fig 1. Examples of electronic systems in modern automobiles.

Automotive electronics are currently subjected to a wide range of tests designed to ensure that they are electromagnetically compatible with their intended environment. Component-level electromagnetic compatibility (EMC) tests include measurements designed to evaluate the conducted and radiated emissions from the component as well as the susceptibility of the component to electromagnetic fields and conducted noise on the power and signal wires.

EMC testing is also performed at the vehicle level. Vehicles are subjected to EM fields, conducted noise on wiring harnesses, and electrostatic discharge while operating under normal driving conditions in order to try to ensure that EMC problems will not adversely affect vehicle safety or reliability.

While component-level EMC testing is an essential step in ensuring that vehicle-level performance is satisfactory, it is not uncommon to encounter EMC problems during vehicle-level EMC testing that were not observed during component-level testing. This is partially due to the fact that the operation of a system depends on interactions between components that cannot be modeled or anticipated during the evaluation of the component.

One of the best ways to anticipate system-level EMC problems is to use computer modeling tools to simulate the operation of the system in the presence of various interfering sources. System-level EMC modeling is widely used to help build electronic products that meet EMC requirements without the need to build, test and redesign several prototypes.

Unfortunately, system-level EMC modeling in the automotive industry is severely hampered by a lack of component-level information. Existing component-level EMC tests generally test the performance of a component in a contrived system environment. They do not attempt to characterize the electromagnetic source properties of the component itself and do not generate data that can be used to model the components in a system-level EMC simulation.

The following sections briefly discuss some of the limitations of existing component-level conducted and radiated emissions tests and propose alternative tests that would provide information about a component that could be used in system-level EMC simulations.

CURRENT TEST PRACTICES

Procedures for measuring the unintentional conducted and radiated emissions from automotive components are outlined in the CISPR 25 standard [1]. This standard describes a procedure for measuring the “radiated” emissions from an automotive component, by placing the component on a metal table in an absorber-lined shielded enclosure (ALSE). The component is attached to a wiring harness and the emissions are measured by an antenna located 1 meter from the harness center, as illustrated in Fig. 2.

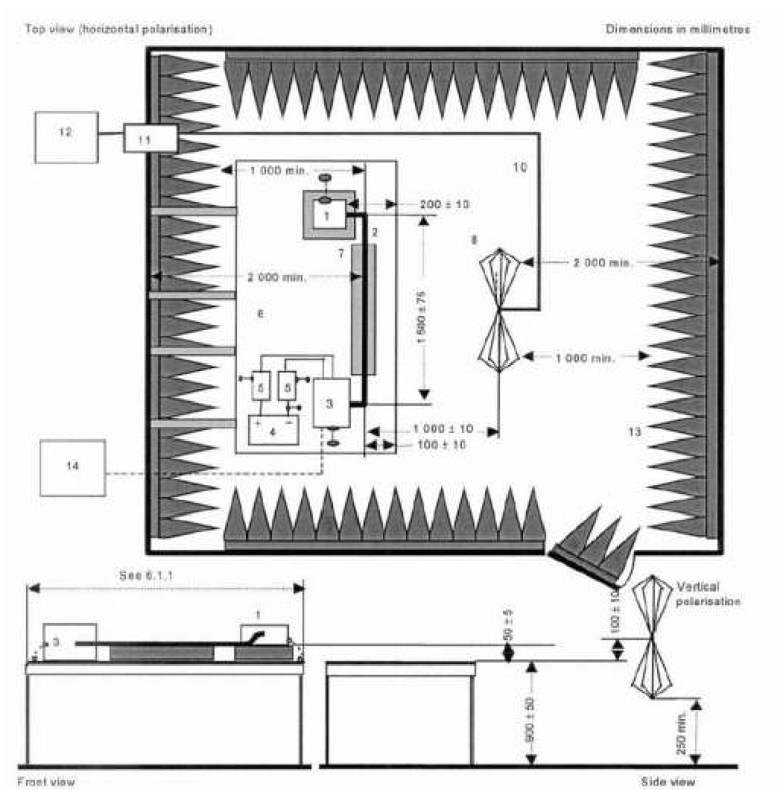

Fig. 2. CISPR 25 radiated emissions test set-up [1].

The premise of the test is that components most likely to be the source of a radiated emissions problem in a vehicle are likely to generate a stronger field (as measured by the receiving antenna) in this configuration. Although it is possible to point to several problems with the procedure, it has basically served the automotive industry well for many years.

The CISPR 25 radiated emissions test results are basically a measure of the relative “goodness” or “badness” of different electronic components. The tests do not provide information useful for system-level EMC modeling, because they do not characterize the component as a source of radiated emissions. Noise measured by the receiving antenna is generally dominated by the electric field coupling from the wiring harness. The noise on the harness could have been conductively coupled directly to the wires in the harness through the component-harness connector. Harness currents could also have been induced by the electric or magnetic near-fields of the component. It is also possible for the antenna to pick up fields emanating directly from the component without coupling to the harness first.

Each of these behaviors corresponds to a unique coupling mechanism that would result in different system-level interactions. Without knowing the source characteristics of the component, it is not possible to accurately represent it in a system-level EMC simulation.

There are only 4 mechanisms by which electromagnetic energy can be coupled from a component to the rest of the system. They are:

- Conducted coupling
- Electric-field (capacitive) coupling
- Magnetic-field (inductive) coupling
- Radiated coupling

To represent a component in a system-level EMC simulation, we must be able to model the component as a source of noise coupled by each of these mechanisms independently.

CONDUCTED COUPLING

Most electrical engineers are familiar with how to represent a source of conducted electric energy. Given an unknown linear independent source with just 2 terminals, it is possible to fully characterize that source by either its Thevenin or Norton equivalent. A simple test to determine the parameters of the equivalent source is to measure the open circuit voltage and the short circuit current at the source terminals. Armed with that measurement data, it is possible to replace the unknown source with its equivalent circuit model in any system simulation with full confidence that the source model will interact with the rest of the system in the same way that the original unknown source would have.

The current CISPR 25 conducted emissions tests measure a voltage across a known load resistance (50 ohms) OR common-mode currents on a wire or wire bundle with an unknown termination impedance. Neither of these tests characterizes the source with sufficient detail to represent that source in a system-level EMC simulation.

For a source with unknown source amplitude and unknown source impedance, at least 2 measurements are required to fully characterize the source. Therefore, in order to obtain meaningful data for system-level simulations, each terminal pair of interest must be measured twice. Open-circuit and short-circuit measurements are not practical at high frequencies, therefore it is better to make one low-resistance measurement and one high-resistance measurement. The low-resistance measurement should be made across a resistor that has just enough resistance to ensure that it is not overwhelmed by inductive reactance at the frequencies of interest. For many automotive components a resistance of 1 - 10 ohms in a low-inductance test fixture is sufficient for measurements over a broad range of frequencies. The high-resistance measurement should employ a resistor with a value just low enough to ensure that it is not bypassed by the parasitic capacitance in the test fixture. In many situations, a resistance of 300 – 500 ohms is appropriate.

Since the sources being characterized may have complex source impedances, it is important to measure both the magnitude and phase of the voltage and current delivered to the low- and high-impedance test loads. This is often not a practical alternative when measuring real systems, so additional measurements are required. The additional measurement may employ a mid-value load impedance (e.g. 50 ohms) or a reactive load impedance (e.g. a capacitance) [2].

Many important automotive sources are non-linear and will exhibit different source properties when tested under extreme loads, so it is important to ensure that the source operates normally during all tests. For EMC testing, it is usually possible to vary the load at the frequencies of interest without affecting the fundamental operation of the source. This is the basic function of the line impedance stabilization network (LISN) described in CISPR 25.

ELECTRIC-FIELD COUPLING

Electric-field coupling can be a much more difficult property to characterize, because a simple equivalent source model does not exist. However, recent research has shown that electric-field coupling measurements made in a TEM cell can be used to characterize electrically small components and generate relatively simple models that can be used in system-level EMC simulations [3].

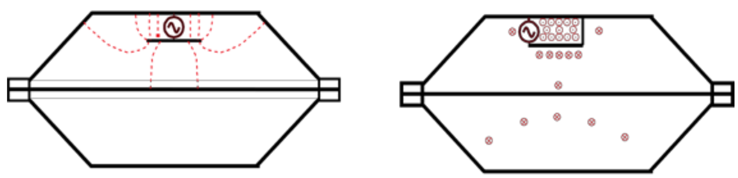

Fig. 3. Electric- and magnetic-field coupling to a TEM cell.

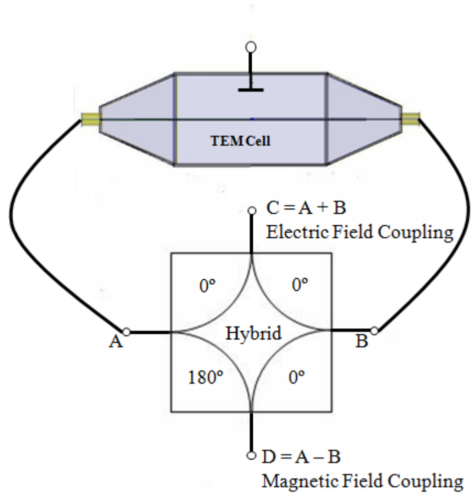

Fig. 4. Hybrid TEM cell measurement.

The electric and magnetic fields of components mounted in the wall of TEM cell couple to the septum, as illustrated in Fig. 3. A hybrid coupler attached to both ends of the TEM cell can be used to separate the electric field contribution from the magnetic field contribution, as indicated in Fig. 4.

Electric-field coupling to the two ends of the septum is in-phase, and magnetic-field coupling to the two ends is 180 degrees out of phase. Therefore the sum of the signals to each end is a voltage proportional to the electric-field coupling. The difference in the signals at each end is a voltage proportional to the magnetic-field coupling.

The sum of the two signals can be used to calculate an "electric moment," which is a number that can be used to characterize a component as a source of electric-field energy in a system-level simulation [4]. The electric moment is essentially the product of the effective voltage behind an electric-field and the capacitive reactance associated with the coupling of this voltage to distant objects. The electric moment has units of amperes and is typically obtained by dividing the measured voltage by half the TEM cell characteristic impedance and applying a unitless correction factor that depends on the dimensions of the TEM cell. This approach has been used to model the electric-field coupling from integrated circuits and heatsinks, but it can also be applied to model automotive components as sources of electric field coupled noise.

Of course electric-field coupling is a complex phenomenon that cannot be fully characterized by a single number. Nevertheless, an electric moment obtained by making a TEM cell measurement can do a reasonably good job of representing a component's potential to be an effective electric-field coupling source. Since EMC simulations are often designed to determine what might happen in a worst-case scenario, electric moment based source models are well suited to the task.

MAGNETIC-FIELD COUPLING

A "magnetic moment" can be derived from a hybrid TEM cell measurement in much the same way as electric moments are obtained [5]. Magnetic moments are essentially measures of the effective net loop currents in a component times an inductive reactance. The inductive reactance is due to a mutual inductance between the component's effective loop and an electrically large loop with a specified location. Since magnetic-field coupling is sensitive to the orientation of the source relative to the object it couples, it is necessary to measure at least two orthogonal orientations of the component in a TEM cell to determine the maximum magnetic moment.

RADIATED COUPLING

For EMC modeling, analysis and troubleshooting, it is very important to distinguish between radiated coupling and near-field coupling. Grounding and shielding solutions to near electric and magnetic field coupling problems are very different from grounding and shielding solutions to radiated field problems. Radiated coupling cannot occur between two objects that are close to each other relative to a wavelength. Electric and magnetic field coupling cannot occur between two objects that are far from each other relative to a wavelength. The easiest way to evaluate the radiated coupling from a component is to place that component (isolated from all attached wires and metal) in a well defined environment and measure the radiated emissions.

Simpler environments are better for getting results that can be used in system-level simulations. An anechoic environment is perhaps the simplest of all radiated emissions test environments, but anechoic chambers do not provide an easy way to isolate a component from the equipment and wires necessary to make it function properly. A semi-anechoic environment provides a metal wall (or floor) to separate the component from everything else.

Radiated emissions measurements can be made with the component mounted in the metal plane of a semi-anechoic environment. The component should be rotated and/or the antenna position scanned to determine the orientation that results in the maximum radiated emissions.

System-level models can then replace the component with simple sources that produce essentially the same radiation pattern. Often these will be electric or magnetic dipole sources. In fact, it is often possible to develop one source that effectively models both the near and far field coupling for a worst-case analysis.

It should only be necessary to perform radiated emissions tests on components at frequencies where the size of the component is a significant fraction of a wavelength. At lower frequencies, the component itself is unlikely to produce significant radiated emissions. Ultimately the radiated emissions due to an electrically small component will be the result of conducted or near-field coupling to larger objects that act as antennas.

Wiring harnesses should never be part of a component-level radiated emissions test. The wiring harness is more effectively modeled as part of the system-level simulation. The way that the harness interacts with the rest of the system cannot be characterized independently. After characterizing the components, component models can be used to determine what voltages and currents are induced on a given harness in a given system.

CONCLUSIONS

System-level EMC simulations require models for each of the components in the system. Four test procedures capable of characterizing automotive components for system-level emissions simulations have been outlined. Test procedures employing low/high-impedance artificial networks, hybrid TEM cells, and true radiated emissions measurements are capable of providing all of the component-level information required for system-level EM emissions simulations.

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