Module-Level Characterization for Vehicle-Level Emissions Modeling (Invited)

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***Abstract* - Automotive components are subjected to a variety of electromagnetic compatibility tests before they are ever installed on a vehicle, and yet the correlation between component-level EMC test results and vehicle-level EMC performance is generally poor. As automobiles become more reliant on electronic systems to ensure the reliable operation of the vehicle and the safety of its occupants, full-vehicle electromagnetic simulations are becoming an increasingly important part of the automotive design process. These simulations require accurate models for the various electronic modules found in the vehicle. CISPR 25 measurements do not yield sufficient information to be useful in full-vehicle simulations. New test procedures are required to characterize automotive modules as electromagnetic sources. Source models derived from these tests can then be used in vehicle-level electromagnetic simulations for the purpose of determining the optimum design and placement of electronic modules and wiring harnesses in the vehicle.**

I. Introduction

In order to help ensure that a vehicle will not have problems with electromagnetic interference, extensive electromagnetic compatibility (EMC) testing of each model is performed as the vehicle and its components are being developed. Over the past 20 years, a number of EMC test standards for automotive components have evolved. The most widely referenced standard for unintentional conducted and radiated emissions from vehicles is CISPR 25 (IEC, 2002) [1].The CISPR 25 standard covers frequencies from 150 kHz to 1 GHz and includes an in-vehicle test procedure as well as bench-top tests.

For the in-vehicle test, the test receiver is connected to an antenna mounted on the vehicle. This antenna is an existing radio antenna when measurements are made at frequencies within the radio receiver bandwidth. Out-of-band testing is done with a monopole antenna mounted in the same location. Each electronic system being evaluated is powered on and operated while monitoring the voltage induced at the antenna terminals. If the voltage exceeds the limit specified in the standard, the system under evaluation is non-compliant.

Bench-top tests are done on a 0.9-meter tall table with a metal top located in a shielded room as illustrated in Fig. 1. The bench top is bonded to the wall or floor of the shielded room and the equipment under test (EUT) is placed on the table. Both the EUT and its wiring harness are insulated from the bench top by a 5-cm thick sheet of dielectric material. The EUT is powered through an artificial network that provides a stable well-defined power bus impedance at the measurement frequencies. Another box attached to the wiring harness emulates the sensors, actuators and communication devices needed to operate the EUT.

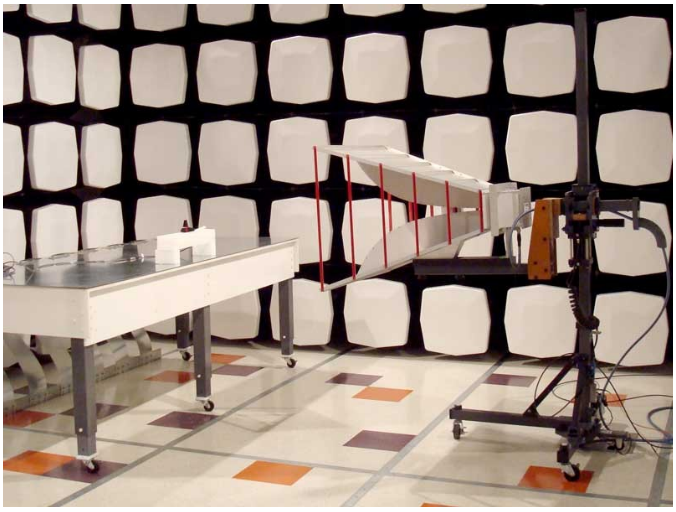

Fig. 1. CISPR 25 radiated emissions test configuration.

CISPR 25 describes four bench-top tests, two that measure conducted emissions from the EUT and two that measure radiated emissions. The EMC test plan for a particular product may call for all or a subset of these tests to be performed.

II. Conducted Emissions Testing

CISPR 25 describes two conducted emissions tests, a *voltage method* (Section 6.2) and a *current probe method* (Section 6.3). The voltage method employs an artificial network to measure the voltage across a 50-ohm termination to the chassis ground. Many important details are left to the discretion of the person or company conducting the test, so it is difficult to get good agreement between measurements made in different labs. However, even if this measurement could be made accurately and was repeatable, it would not fully characterize the component as a source of conducted emissions. Very few automotive components have signals or power terminating in 50-ohm loads. In fact, many automotive load impedances are reactive (capacitances or inductances) at the frequencies of interest. Even a very accurate measurement of the voltage dropped across a 50-ohm termination cannot provide a reliable estimate of what the voltage dropped across another load impedance would be.

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The current probe method in CISPR 25 calls for common-mode current measurements to be made on “the control/signal leads as a single cable or in sub-groups as is compatible with the physical size of the current probe” (see Figs. 2 and 3). Cables are routed over a metal plane and a current probe is positioned at various places along the wire(s) to measure the common-mode current flowing on them. Generally speaking, this common-mode current will be a function of many parameters including the cable routing and the common-mode impedance of the cable termination at both ends. The standard does not strictly specify these parameters, which again makes it difficult to get the same results when measurements are made in different labs. More significantly however, a single measurement of the common-mode current on a wire in the test configuration provides no information that can be used to characterize the component when it is installed in the vehicle.

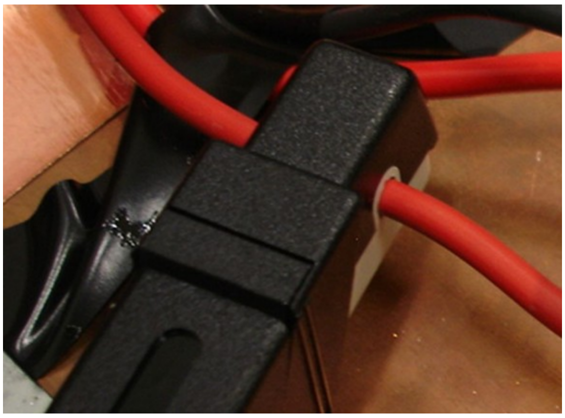

Fig. 2. Current probe measuring an individual wire in a harness.

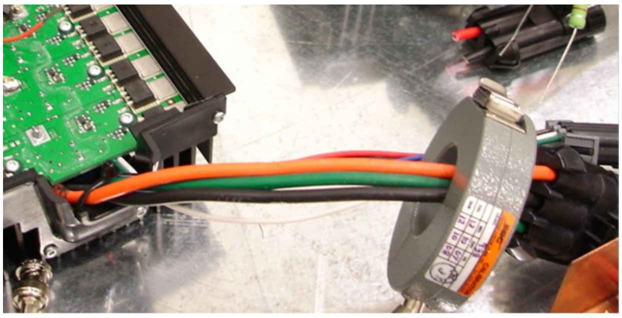

Fig. 3. Current probe measuring a sub-group of wires in a harness.

If the signal or power current flowing on the wire is returning on another conductor that does not pass through the current probe, the probe picks up this differential-mode current in addition to any common-mode current. To the extent that this measurement detects differential-mode current, it could be used to characterize the source if the termination impedance and voltage across the termination were also known. To the extent that the measurement detects true common-mode current, it is a better indicator of potential radiated emissions than conducted emissions.

In order to truly characterize a source of conducted emissions, it is necessary to determine both an open-circuit voltage and a source impedance. This cannot be done by making a single measurement across a known load resistance. However, in theory, voltage measurements across three known loads would be sufficient. Such a measurement procedure is described in [2] using a 1/50/500 ohm load technique. However, the procedure in [2] is susceptible to small measurement errors that can cause the resulting source model to be inaccurate, especially when the source impedance is reactive.

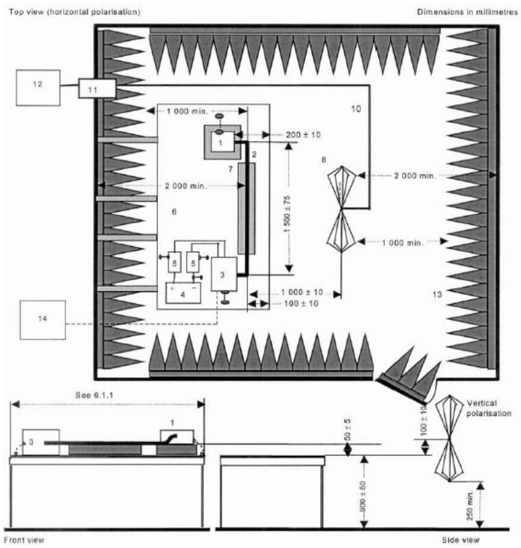

Fig. 4. CISPR 25 ALSE radiated emissions test environment [1].

III. Radiated Emissions Testing

CISPR 25 describes two test procedures for measuring the radiated emissions from automotive components: an *ALSE method* and a *TEM cell method*. ALSE is an acronym for *absorber lines shielded environment* and generally describes a semi-anechoic chamber. ALSE tests are performed with the component placed on a 0.9-meter high bench as described in the introduction and illustrated in Fig. 4. The signals from a receiving antenna placed approximately 1-meter from the edge of the table are measured and compared to the limit.

Unfortunately, the standard does not specify all of the parameters necessary to ensure that a measurement made in one laboratory will correlate with a measurement made in any other laboratory. The exact size, shape and ground configuration of the table top can be extremely important in this measurement, as can the size and shape of the room (since there is no specific requirement for the site attenuation of the ALSE). Another problem with the procedure as defined is that it relies on the far-field antenna factor to translate measured voltages into field values; but the antennas are in the reactive near field at low frequencies and the Fraunhofer near field at high frequencies. Two antennas with the same far-field antenna factor can exhibit very different behaviour in the near field, so measurements made with different antennas are likely to yield different results.

Even if the test configuration variables could be standardized, the CISPR 25 radiated emission test could not be used to obtain information useful for developing component source models. The reason for this is that the procedure described in CISPR 25 measures the radiated emissions from the component-harness-table geometry and it is impossible to separate the contribution of the component from the contribution of the rest of the system. More often than not, peaks observed in the radiated emissions test are resonances associated with the harness and table that have nothing to do with the component parameters.

If we want to characterize the component, it is necessary to measure the radiated emission from the component only. This can be achieved by mounding the component in the floor of a semi-anechoic chamber and routing all harnesses and supporting equipment under the floor. Once the component has been fully characterized, the effect of the harness and other parts of the system can be determined by the system-level model.

IV. Field Coupling

The second radiated emissions test described in CISPR 25 is not actually a radiated emissions test at all; it is a measurement of the near-field coupling from a component to a TEM cell. There is no direct correlation between the near-field coupling to a TEM cell and far-field radiated emissions from a component; nevertheless many automotive radiated emissions problems result from the near-field coupling from electrically small automotive components to larger resonant-size objects such as wiring harnesses and the chassis/frame of the vehicle [3-5].

TEM cell measurements are only valid at frequencies where the dimensions of the component being modelled are small relative to a half-wavelength (allowing the component to fit inside the TEM cell). This turns out not to be a severe restriction because the electric and magnetic near-field coupling is most likely to dominate at these frequencies. At higher frequencies, the component is capable of radiating on its own, without needing to couple to nearby objects.

The CISPR 25 TEM cell test measures the voltage delivered to one end of the TEM cell. This voltage results from a combination of electric and magnetic field coupling to the cell. In order to separate the electric and magnetic field contributions, measurements can be made simultaneously at both ends of the TEM cell. The sum of the voltages is a signal that is proportional to the electric field coupling [4]. The difference in the voltages is a signal proportional to the magnetic field coupling. Using both these signals, it is possible to develop both an electric-field and magnetic-field source model that can be used in full-wave electromagnetic simulations [5].

V. Summary

Electromagnetic compatibility models at the vehicle-level require accurate source models to represent system components. Despite the large number of electromagnetic emissions tests that automotive components are typically subjected to, the information needed to characterize automotive components in vehicle-level models is not generally available. This paper has presented a basic outline for a set of measurements that could be used to completely characterize automotive component behaviour in vehicle-level simulations. These measurements are designed to determine parameters that model the component as a source of conducted emissions, electric-field coupled emissions, magnetic-field coupled emissions and radiated emissions.

These techniques have been successfully applied to a variety of printed circuit board structures as components in larger systems. The task of fully specifying and validating these procedures for automotive applications is still a work in progress.

References

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[2] H. Kwak, H. Ke and T. Hubing, “Measurement Methods to Characterize Conducted EMI Sources,” Proc. of the 7th International Workshop on EMC of Integrated Circuits - EMC Compo 2009, Toulouse, France, Nov. 2009.

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