

Vehicle-Level EMC Modeling for HEV/EV Applications

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ABSTRACT

Electromagnetic compatibility (EMC) is becoming more important in power converters and motor drives as seen in hybrid electric vehicles (HEV) to achieve higher reliability of the vehicle and its components. Electromagnetic interference (EMI) of the electronic components for a vehicle are evaluated and validated at a component-level test bench; however, it is sometimes observed that the EMI level of the components can be changed in a vehicle-level test due to differences in the vehicle's configuration (cable routing, connecting location etc.). In this presentation, a vehicle-level EMC simulation methodology is introduced to estimate radiated emissions from a vehicle. The comparison between the simulation and measurement results is also presented and discussed.

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INTRODUCTION

In the past few years the quantity of electronic components in automobiles has greatly increased. In order to guarantee flawless functionality of these electronic components, and to keep down the negative effects on external systems, electromagnetic compatibility (EMC) has become a significant topic and concern of the automotive industry. With the leap to hybrid electric vehicles (HEV) and electric vehicles (EV), EMC becomes even more crucial because high voltage components with faster switching speeds are used.

Automotive suppliers usually design and test their parts at the component level. However, the challenging issue with EMC is that components which pass all their EMC tests on a component level can still fail EMC testing at the vehicle level. The biggest problem is that usually the test on the vehicle is performed at a very late stage of product development. Resolving a problem at this stage of development is difficult, time consuming, and expensive. In order to avoid such problems, it is important for an automotive supplier to consider the vehicle level effects during the component's design phase.

In order to simulate EMC testing at the vehicle level, computer models provide a good opportunity. Chen [1] built a system level EMC model to study the noise distribution mechanisms for the

component embedded inside an engine block. Hubing [2] describes a general method to characterize the component level property for system level electromagnetic simulation. However, the noise propagation between the components and the vehicle antenna has not been well studied. This work describes a vehicle-level EMC simulation methodology to estimate radiated emissions from a vehicle. The approach is carried out by running a combination of an equivalent circuit and a 3D full-wave electromagnetic field simulation for a simplified vehicle structure including the essential inverter system components. The comparison between simulation and measurement results is presented and discussed for the AM band between 500 kHz to 2 MHz, in which we face real world issues.

The paper is organized as follows: Section II describes the general EMC design procedure and how this work fits in. The simulation methodology is introduced in section III and the measurements follow. Afterwards, conclusions are made.

VEHICLE LEVEL EMC MODELING

In this section, challenges of EMC design in the automotive industry are given. Methodology is presented to overcome these challenges. Measurements and results follow to show the simulation accuracy.



Challenges of EMC Design in the Automotive Industry

In the automotive industry, OEMs request that each electronic component meet component level EMC standards before product shipping to prevent potential EMC issues on vehicles. Figure 1 shows an example of a component level EMC test setup, which is prescribed in CISPR25 for automotive electronic components. In this test setup, radiated emissions from a component assembly including a device under test, loads, and a harness between them is measured by a monopole antenna and a log periodic antenna located at a prescribed distance from the copper table.

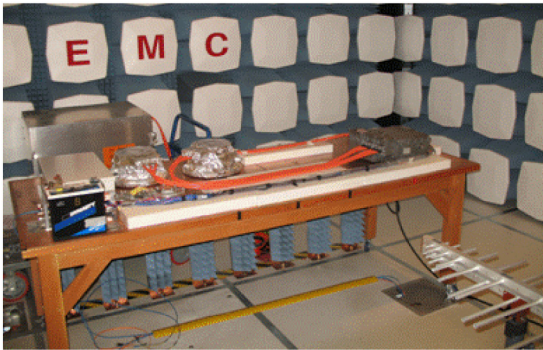


Figure 1. Component level EMC test setup for electrical components

OEMs develop a vehicle platform by assembling components from various suppliers. Vehicle level EMC tests are performed at this stage to make sure that the entire vehicle meets the final EMC standard. In this vehicle level test, auditory tests of AM/FM radio reception as well as antenna measurement tests are performed. Figure 2 shows an example of a vehicle level EMC test setup, which is prescribed in CISPR25 for automotive vehicles.



Figure 2. Vehicle level EMC test setup for a full vehicle

As shown above, the measurement conditions and evaluation methods of a component level EMC test can't imitate the real conditions of a vehicle level EMC test. The risk of having EMC issues increases at the vehicle prototype stage even though each component has passed its own requirements. If a vehicle level issue occurs, the supplier may be required to make design changes to solve the vehicle EMC issues. Increased costs and delayed shipments may occur for both parties. Electromagnetic noise analysis at the beginning of the design stage as shown in Figure 3 is effective for preventing such EMC issues. During the early design stage of both

the component and the vehicle, vehicle level simulation is performed to ensure good vehicle level performance to minimize EMC rework after vehicle prototyping. The most challenging point for the vehicle-level simulation is to cover a very high dynamic power range from kW, the inverter output, to mW, for electromagnetic radiation, with high accuracy. The 'Vehicle level simulation' tool is continuously refined to increase the accuracy of the prediction based on the previous generation of EMC data.

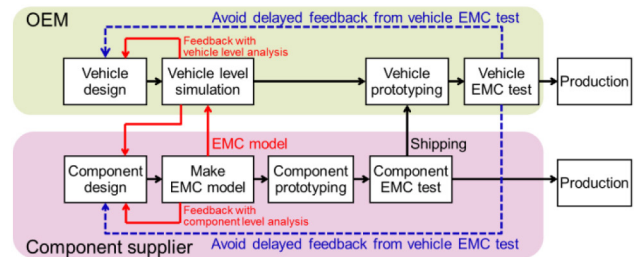


Figure 3. Proposal of product development process utilizing vehicle-level EMC simulation

Methodology

To develop a system level simulation methodology to calculate the radiated emissions from a vehicle, an electric vehicle with the main inverter system is studied. Major components of the inverter system include a power inverter, two motors, a high voltage battery, and a cable connected between each component. In this system, the battery supplies direct current (DC) power to the inverter, that converts DC to alternating current (AC) using pulse width modulation (PWM) switching to rotate the motor to provide the driving force. Due to the fast switching and high power, the inverter becomes the predominant contributing source of noise in an electric vehicle. To simulate this noise propagation, the components of the inverter system as well as the vehicle body and the antenna are modeled separately either by Simulation Program with Integrated Circuit Emphasis (SPICE) or by a 3D modeler.

The whole vehicle is modeled as a combination of these component models as shown in Figure 4. In order to handle the high dynamic range while maintaining accuracy, the simulation has been divided into three different analyses because the electromagnetic radiation is generated from the common-mode current. First, the conductor current (I_N) of inverter output is analyzed by the time domain circuit analysis. Second, the conversion factor (K_1) from the conductor current (I_N) to the common mode current (I_C) is analyzed by 3D electromagnetic analysis. Finally, the conversion factor (K_2) from the common mode current (I_C) to the antenna voltage (V_{ant}) is analyzed by 3D analysis. From the above three analyses, the antenna voltage (V_{ant}) is calculated by:

$$V_{ant} = I_C \times K_2 = I_N \times K_1 \times K_2 \quad (1)$$

With this analysis, the vehicle-level simulation was established and can be applied to the inverter development process to shorten the development time by preventing vehicle-level countermeasures.