

Electromagnetic Simulation of Antennas Installed Inside Automobiles

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→ The increasing use of electronics and wireless technologies in today's automobile has increased the challenge of meeting electromagnetic compatibility (EMC) performance standards. Even if all the vehicle's subsystems are individually validated, the interactions between them may adversely affect the electromagnetic behavior of the complete system and, in the worst case, even cause case safety issues. A new generation of simulation tools makes it possible to evaluate EMC performance of a vehicle from the chip level all the way up to the complete vehicle. Simulation can evaluate EMC performance in the early stages of the design process to prevent occurrence of late-stage problems that can increase development time and cost – and possibly lead to customer dissatisfaction or even injuries – if they are not identified prior to product launch.

EMC Design Challenges

Automotive technology innovations, such as digital FM radio broadcasting, remote keyless entry, tire pressure monitoring systems, global positioning systems (GPSs), satellite digital audio radio service, Bluetooth[®] and Wi-Fi[®], have increased the challenges of vehicle antenna design. At the same time, the continuous increase in clock speeds and the higher density and more complex structure of today's integrated circuits, printed circuit boards (PCBs) and connectors mean that many components can act as an antenna that transmits signals to other components that happen to be in the area. The potential for electromagnetic interference is increasing due to an increased number of embedded control units (ECUs), higher onboard diagnostic II (OBD-II) data rates, increased number of controller area network (CAN) lines, etc.

"Insatiable demand for fuel efficiency and better driving dynamics together with vehicle manufacturer's focus on making cars safe, fun, comfortable and luxurious have greatly increased electronics and software content in cars," said Krishnaswami Rajagopalan, industry analyst Frost & Sullivan's global project manager, Chassis, Safety & Driver Assistance Systems group. "While electronics has increased efficiency and passenger comfort, it has also exposed consumers to higher risk of accidents, and exposed vehicle manufacturers to painful recalls costing millions of dollars. It has also caused an inordinate blow to the trust that countless consumers have bestowed on the car maker."

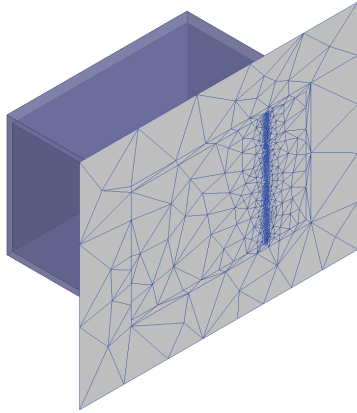


Figure 1. Test case from the Applied Computational Electromagnetics Society

Benefits of Simulation

The electromagnetic behavior of the entire vehicle can be tested only when the first complete prototype is available. Problem resolution at this phase of the process is expensive and time consuming. Furthermore, the complexity of today's electronics and the huge number of possible product configurations that companies offer makes it impossible to fully test most automobile models.

A new generation of simulation tools makes it possible to predict and correct in advance the major things that can go wrong with the electronics. For example, simulation can identify electromagnetic interference (EMI) that is emitted by high-speed electronics components; it can also determine the effect of that radiation on vehicle subsystems. Unlike physical testing, simulation makes it possible to simultaneously consider the effects of potentially conflicting design requirements, such as keeping electronics cool while avoiding unintended emissions.

This paper shows how ANSYS® HFSS™ 3-D full wave electromagnetic field simulation software can compute the electrical behavior of high-frequency and high-speed components. With HFSS, engineers can extract parasitic parameters including S, Y and Z, visualize 3-D electromagnetic near-field and far-field behavior, and generate full-wave SPICE models to evaluate signal quality issues, such as transmission path losses, reflection loss due to impedance mismatches, parasitic coupling and radiation. Most engineers begin by correlating simple models with physical measurements. Figure 1 shows a typical test case from the Applied Computational Electromagnetics Society (ACES), and Figure 2 shows the correlation between simulation results and physical testing.

Optimizing ECU Placement

Let's consider a more practical example of evaluating GPS reception in various areas of the vehicle to determine the best placement for the ECU. The GPS telematics ECU receives the signal broadcast by satellites at L1 frequency (1.575 GHz), calculates the actual position of the vehicle, and sends this information through the cellular data network. A transient solver with a right-hand circularly polarized (RHCP) 1.575 GHz incident plane wave flowing normally from above toward the vehicle surface is used to simulate the GPS signal. The electrical field can be visualized anywhere in time, showing reflections due to the vehicle's structures that will cause multipath as well as attenuation and phase shift.

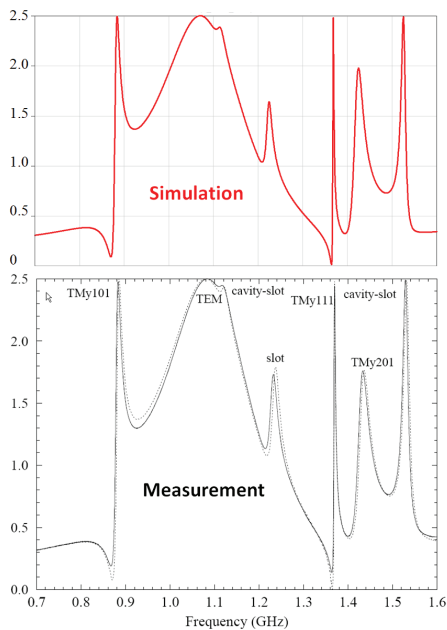


Figure 2: Simulation results match physical measurements.

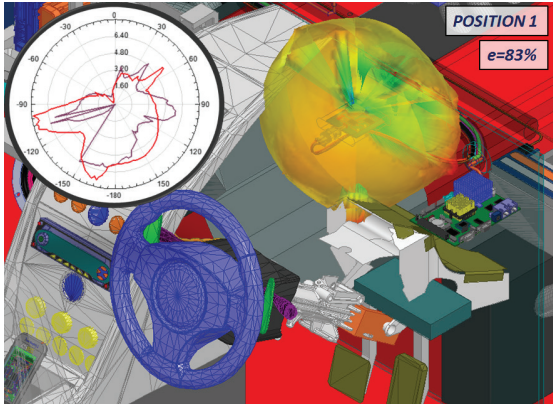


Figure 3. Model and 3-D polar plot and radiation pattern for location 1

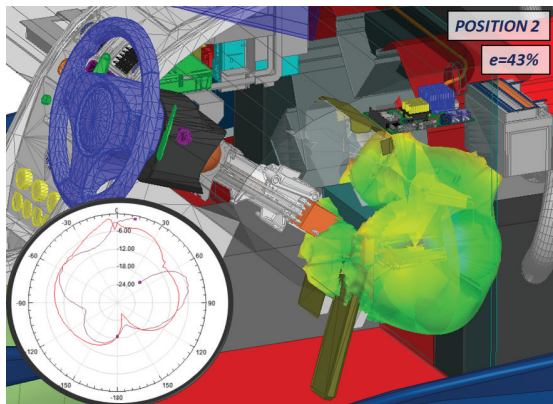


Figure 4. Model (left) and 3-D polar plot and radiation pattern for location 2

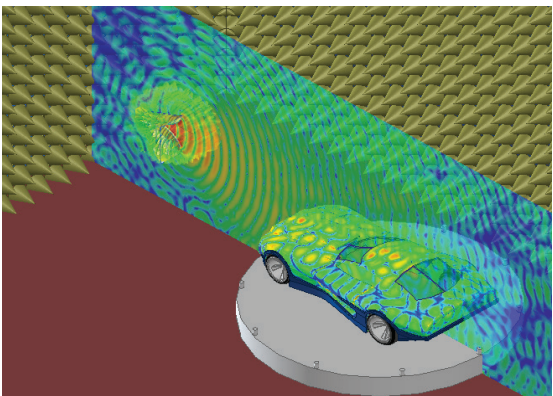


Figure 5. Full 3-D FEM model showing cross sectional electrical field distribution in air region at 1 GHz

The GPS signal is received at numerous incident angles. Transient analysis for numerous waves becomes very time consuming. An alternative is to simulate radiation efficiency by having the GPS antenna of the ECU transmit an L1 signal instead of receiving it. Radiation efficiency is the ratio of the radiated power to the acceptor power. Radiated power is the amount of time-averaged power in watts exiting a radiating antenna structured through a radiation boundary, in this case the lateral walls of an airbox that surrounds the vehicle in the HFSS model. The radiation efficiency method can provide fast results in the frequency domain that indicate the best candidates for GPS placement inside the vehicle. The near-field 3-D polar plot and radiation plots in Figures 3 and 4 show that radiation efficiency e is 83 percent in position 1 and only 43 percent in position 2.

Simulating Full-Vehicle EMC Standards

There are several automotive standards designed to reduce the probability of EMI through laboratory testing. One of the most important standards is ISO 11451-2, which is intended to determine the immunity of vehicles to electrical disturbances from off-vehicle radiation sources. An antenna radiates a vehicle in an anechoic chamber while electronic subsystems are operated to ensure that their performance is not affected. The prototype and equipment required to perform this test is very expensive, and the test takes long periods of time, limiting the number of times that it can be performed during the development cycle.

The greatest challenge in simulating this test is the large computational domain required to model the air region. The hybrid finite element/boundary integral method (FEBI) helps to overcome this challenge by using the boundary integral — a method-of-moments (MoM) solution for Sommerfeld's radiation condition — as the interface boundary for the finite element solution. This eliminates the need to model the air region while providing an exact mathematical calculation of the far-field radiation condition. This technique can be used to perform full-vehicle simulation including complex geometries and dielectric materials without having to simulate the air regions, resulting in accurate simulation with less computing resources.

Figure 5 shows the electric field distribution and antenna radiation far-field pattern at 1 GHz for a complete vehicle simulation according to ISO 11451-2 using the conventional finite element method (FEM) approach. The air region was modeled for the entire room including the absorber elements on the side walls. For this particular simulation, 89 percent of the total number of elements was used to model air. The model was solved using the domain decomposition method (DDM) on a high-performance computing platform with 12 nodes in 310 minutes with 75 GB of random-access memory (RAM).

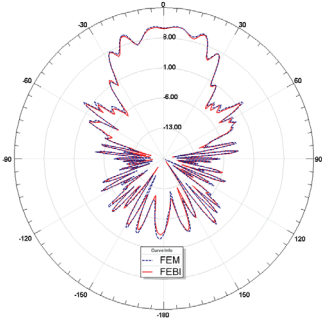


Figure 6. Electrical field distribution plot for entire domain calculated by FEM and FEBI

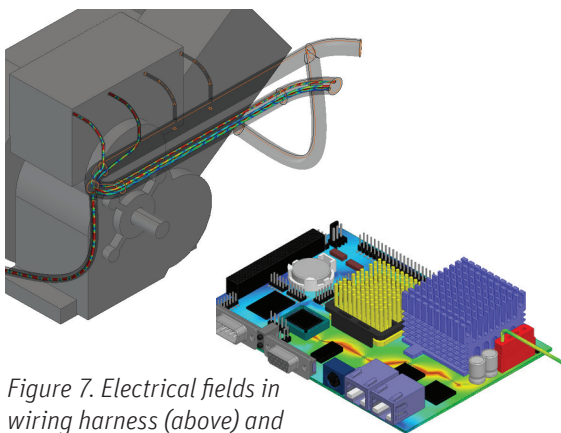


Figure 7. Electrical fields in wiring harness (above) and attachment to PCB (below)

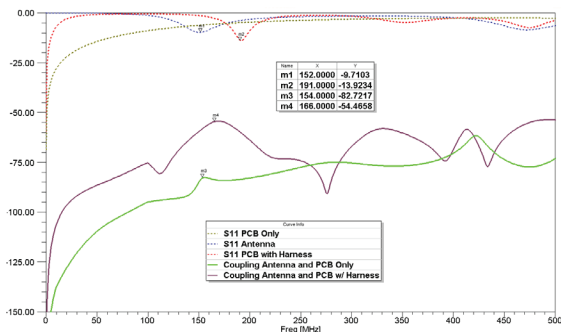


Figure 8. S-matrix with PCB only and PCB with wiring harness

The same test was simulated using the FEBI method. The big air box that comprises most of the model when using FEM was replaced with two much smaller conformal air boxes whose outer surfaces are very close to the antenna and vehicle. The absorber elements were replaced with the integral equation (IE) boundary, which yields the same results. The electric field distribution plot is shown for the entire domain in Figure 6 for both FEM and FEBI. The antenna far-field patterns for the two different methods are nearly identical, indicating that FEBI is essentially equal to FEM in accuracy. Yet, FEBI required only 28 minutes of solution time and 6.8 GB of RAM on the same 12-node HPC platform. So both solution time and computational effort were reduced by a factor of 10 by using FEBI.

Evaluating Immunity of ECU Modules

The FEBI approach can also be used to test the immunity of ECU modules. A PCB connected to an engine wiring harness is introduced into the simulation. The transmitted signal travels from a sensor, located at the bottom of the engine, to the PCB via a wiring harness. The wiring harness is routed from the PCB and around the engine, as shown in Figure 7. The wiring harness is attached to a red four-way connector. One of the four-way connector pins is soldered to a trace that begins at the top side of the PCB on the connector side and then goes through a via to the bottom side, where it is connected to the microcontroller.

To understand the role of the wiring harness, two simulations were performed with all of this geometry plus the car and source antenna. In the first simulation, three wiring harness cables were connected to the PCB. In a second simulation, the wiring harness was removed and a random CAN J1939 signal was applied directly into the connector on the PCB. The scattering matrix of the two simulations with and without wiring harnesses are shown in Figure 8. The results show a resonance on the PCB when it is connected to the wiring harness. The frequency of this resonance is a function of the cable length that is attached to the PCB. The results also show that the coupling between the source antenna and the PCB is increased by over 30 dB between 152 MHz and 191 MHz when the cable harness is attached to the PCB.

Determining EMC Impact on Components

The impact of EMC on automotive components must also be considered. The operation of the airbag and infotainment systems depends on microcontroller unit (MCU) speed. The operating speed of the MCU, in turn, depends upon the quality of the power that it receives. Poor PCB design can cause a 100+ mV drop and, in turn, reduce MCU performance by 40 MHz to 60 MHz, so the PCB must be designed to ensure performance of the MCU. Power integrity is a global issue involving chip, package and PCB design, so it cannot be properly addressed in the individual domains.

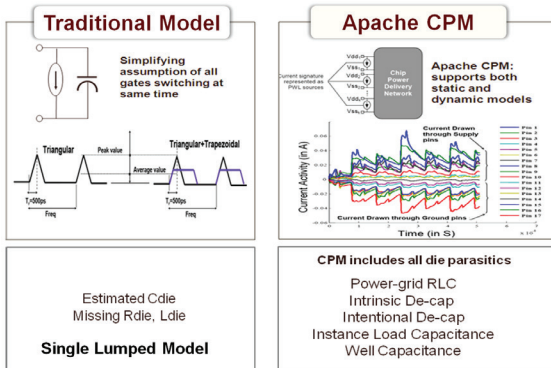


Figure 9. Increasing accuracy with Chip Power Model

Existing package design or selection methods rely on very rudimentary chip power estimations, such as total power, so PCB designers often have no information on transient characteristics of chip power consumption.

ANSYS recently acquired Apache Design tools for low-power design of integrated circuits, making it possible to use compact models such as the Chip Power Module (CPM™) in systems-level simulations. CPM is a compact SPICE-equivalent circuit model that captures the full-chip switching current signatures as well as the parasitic network of the chip power network. The chip power model can enable IC power-aware package selection design and, during the post-layout stage, can be used for IC package coverification as well as design and optimization of the PCB power delivery network.

Conclusion

The growing use of high-frequency components in today's automobiles is causing EMI to emerge as a potential problem at a time when the cost of delivering faulty products to customers has never been higher. Simulation makes it possible to examine radiation and evaluate its impact on the operation of subsystems within the vehicle. Simulation tools can be integrated with structural, thermal and fluid flow tools to simultaneously address the wide range of other issues that interact and often conflict with solving EMC problems. This approach makes it possible to consider in the early stages of the design process all of the potential electronics issues and to optimize the design with all of these factors taken into account before the first prototype.

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