# Numerical Analysis of the Electromagnetic Interference of a WAVE Inter-Vehicle Communication System on Vehicle Electronics

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*Abstract*— **Inter-vehicle communication systems present an increasing popularity due to their critical, for public safety, as much as attractive and convenient applications. This technological tendency could potentially become hazardous for automotive electronics. The radiated immunity of automotive electronics in electromagnetic fields caused by inter-vehicle communication systems described by the IEEE 802.11p WAVE standard or its equivalents is studied in this paper. The electric field produced in critical points of the interior of a vehicle is estimated by means of full wave Finite Difference Time Domain method simulations. In each simulation, the vehicle-to-vehicle or vehicle-to-infrastructure communication according to the characteristics of the IEEE WAVE standard is assumed.**

***Keywords-EMC; Inter-vehicle communications; Vehicle electronics***

## I. INTRODUCTION

Inter-vehicle communications have gained great attention over the past decade [1], [2]. As a successor of the wireless LANs, they gave rise to a significant number of projects, running worldwide and aiming at the development of effective networks [3]. An IEEE standard of the 802.11 family, IEEE 802.11p, is at hand as the IEEE equivalent to other already developed ones for the same cause. They all define a system architecture that provides wireless access to vehicular environment and are known as WAVE standards [4]. WAVE technology defines how vehicle-to-vehicle (V2V) communication and vehicle-to-infrastructure (V2I) communication can be realized. Applications such as information exchange about heavy traffic conditions in a specific road between neighbouring vehicles or between the members of a vehicle fleet, e.g. taxis or buses, (V2V public-safety application) and map download for a GPS device (V2I private application) are indicative of the new technology's possibilities (Fig. 1) [5], [6].

Therefore, after the spread of mobile phones, bluetooth and WiFis, inter-vehicle communication is another invasion of wireless technology in the automotive world. The central frequency of the system is located around 5.9 GHz whereas the transmitted power seems to be quite high for this frequency [5]. It is expected that such an innovation will affect the immunity to electromagnetic fields of automotive electronics. However, most studies performed so far on inter-vehicle communications mainly concern critical communication subjects such as coverage, collisions, messaging type etc [5]-[8]. EMI immunity of automotive electronics to radiation from inter-vehicle communication systems is equivalently important to other EMC issues (ignition noise, conducted immunity, electrostatic discharge etc.) that automotive industry had to study and overcome [9]-[12].

A computational estimation of the electric field intensity level caused in the interior of a vehicle only by antennas that

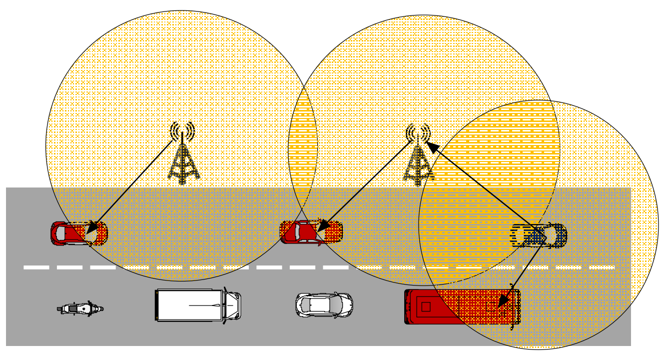

Figure 1. Example of inter-vehicle communication coverage.

radiate with the characteristics of WAVE IEEE 802.11p standard is performed in this paper. Full wave simulations are performed by means of the well known Finite Difference Time Domain (FDTD) method. Appropriate computational models are created based on vehicle solid models. In an effort to better simulate realistic conditions, various cases with different antenna positions are studied, as described in section III. The electric field computation is performed in critical points in the interior of the vehicle according to the existence of sensitive electronic devices or the possible human presence (section IV).

## II. Inter-vehicle Communication System

The concept of the inter-vehicle communication system lays in the exchange of information between moving vehicles or between vehicles and infrastructure in order to achieve high levels of security, comfort and efficiency. The overall procedure is automated by means of the entities that compose the WAVE system and that guarantee a successful communication. Specifically, each vehicle is equipped with a computing platform which is functionally independent of the vehicle processors and controllers (processors and microcontrollers dedicated to specific tasks performed in the vehicle such as fuel injection and emission control, braking etc.). This is responsible for running the WAVE protocols and supporting applications. It is connected to the vehicle's main communication system, CAN (Controller Area Network), or another appropriate system (LIN, Flex Ray) in order to acquire the required information. This computing platform is also considered a transceiver, that is a transmitter and receiver, since it is also connected to antenna (or antennas depending on the system) that transmits and receives messages. The communication channel that concludes the overall system is actually the surrounding vehicular environment (urban, rural area) and affects the link and coverage quality. In this WAVE operation, the driver does not interfere but as the final receiver of the information and the one that exploits it.

From the EMC point of view, a inter-vehicle communication system is another burden to the electromagnetic environment of the vehicle as it is created by other on board wireless devices (mobile phones, WiFis), off board electromagnetic sources (antenna stations, transmission lines) and the vehicle operation itself (ignition, inductive loads). Such an environment is at least suspicious for the immunity of vehicle electronic systems. The latter must be guaranteed by appropriate EMC tests (measurements and/or simulations).

Isolating the WAVE communication system, the normal operation of a vehicle's electronics may be affected by the signal of its own WAVE antenna and by the signals from similar antennas of the neighbouring vehicles or antenna stations. Therefore, among the various parameters of the IEEE 802.11p WAVE standard that define the communication system (table I), the transmitted power, the frequency range of the signals and the antennas relative locations are of interest for a core EMC test simulation.

TABLE I Parameters of 802.11p WAVE Standard

| Parameter | Value |
|---|---|
| Bit rate | 3-27Mbps |
| Range | < 1000m |
| Transmitted Power | 2W EIRP |
| Bandwindth | 20 MHz |
| Spectrum | 30 MHz |
| Frequency | 5.86 – 5.92 GHz |

## III. Numerical Model

For the EMC analysis of a WAVE communication system, it is assumed that no other electromagnetic interference exists. A vehicle equipped with a WAVE communication system is considered. The system's antenna is a simple monopole vertically polarized with respect to the ground and transmits at according to the IEEE 802.11p standard, that is with a power of 1W EIRP (equivalent isotropic radiated power) and central frequency of 5.9 GHz respectively.

Two case studies are examined. In the first one, the antenna is placed at the interior of the vehicle while in the second case the antenna is placed outside the vehicle (mounted on the vehicle's body). The former constitutes the worse scenario for the interaction of electromagnetic fields with the electronics of the first vehicle. In each case the antennas transmit the same overall power. Fig. 2 illustrates the model (in solid form) that is used for the simulations together with the two positions of the antenna

The numerical simulation of the two problems can provide very useful results and conclusions concerning the electric field levels in the interior of a vehicle due to WAVE communication and the possible interferences to automotive electronic systems. Obviously, such a task requires a great deal of computational resources due to the electrically large nature of the problems. For the numerical analysis of these difficult cases, the Finite Difference Time Domain (FDTD) method is selected [13].

The FDTD method is one of the most popular algorithms for the analysis of various electromagnetic field problems including EMC ones [14], [15]. In contrary to other popular computational approaches, like FEM or Method of Moments, it does not require the solution of an equation system (fully explicit). This is its great advantage since for large scale problems the solution of a system of equations would be very difficult. On the other hand, FDTD simulations are performed

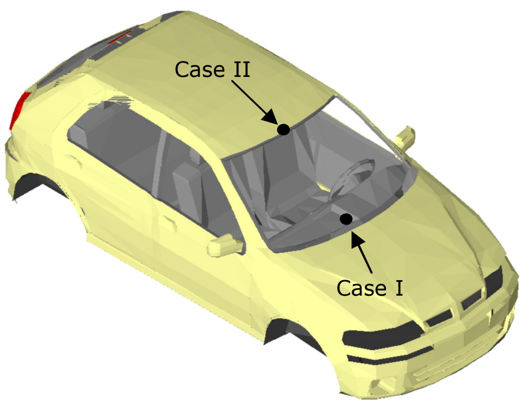


Figure 2. Vehicle model and locations of the antenna.

in the time domain which allows the modelling of a variety of stimulations and the inference in a wide frequency band out of a single program execution. Apparently, the FDTD method provides a very effective handling of large scale numerical problems requiring high computational cost.

Since one of the main characteristics of the FDTD method is the discretization of space by means of two staggered meshes of hexahedral cells, the vehicle models are discretized by a mesh generator. In order to assure the consistency of the simulation, the size of each cell must be of the order of $\lambda/10$, where $\lambda$ is the smallest wavelength of interest and corresponds to the largest frequency of interest. Having an operating frequency of 5.9 GHz, $\lambda$ is approximately equal to 50.8mm in air, which means that the maximum cell size must be of the order of 5mm. Therefore, the overall mesh, taking into account the air surrounding the vehicles consists of 386×730×294 hexahedral cells. The size of each cell is 5mm×5mm×5mm. For the repetitive procedure of each problem 12000 time steps were selected, discretization in the frequency domain. It is also noted that the computational mesh is terminated by the Liao absorbing boundary conditions.

Fig. 3 depicts the basic simulation model that was used in both cases as discretized by the FDTD method. Each vehicle is a simplified model without any details inside. The overall simulation time and required memory was approximately 8 hours and 2.3 GB of RAM in a computer with 2x Intel XEON$^{TM}$ W5580 CPUs and 48GB of RAM

## IV. NUMERICAL RESULTS

As it was mentioned in the previous section, two simulation problems are developed. In the first one (case I) the transmitting antenna is placed approximately in the middle of the vehicle's front panel (at a distance of 1.01 m from the right edge). In the second one (case II) the transmitting antenna is placed at the same distance from the right edge but on top of the vehicle as shown in Fig. 2. Both antennas are vertically polarized with respect to the ground plane.

Two groups of results are extracted from each simulation. The first group of results contains electric field distribution on a cross section of the vehicle along its main axis and on the plane of the antenna. Figs. 3 and 4 present the values of the normalized electric field (in dB) on this cross section ($x$ = 1.01 m) for cases I and II respectively. The second group of results contains the electric field distribution along two lines that cross the vehicle. Figure 5 depicts the levels of the electric field intensity (in dB) along a horizontal line ($x$ = 1.01 m, $z$ = 0.62 m) for the two cases examined. The black curves correspond to the directly computed values, while the red ones are acquired after performing an averaging procedure, which removes the small-scale fading characteristics. In both cases, transmitted power equal to 1 W has been assumed. Similar results for the electric field intensity (in dB) along a horizontal line ($y$ = 1.2m, $z$ = 0.62 m) are depicted in Fig. 6.

The specific planes and lines were selected because they are considered as locations where critical for the operation of the vehicle electronic components are placed. For example, along the lines of Fig. 5 and in the front part of the vehicle the engine control unit (ECU) may be found. On the other hand,

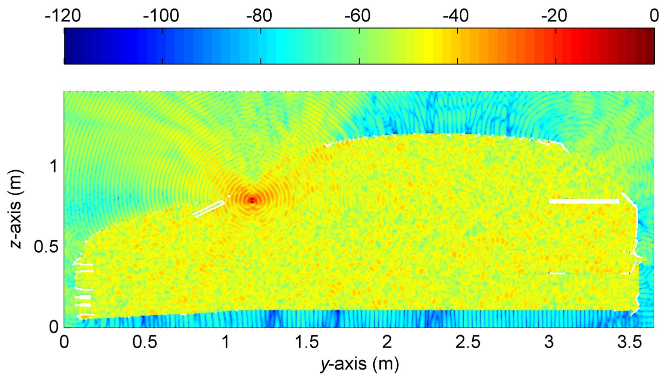


Figure 3. Normalized electric field distribution (in dB) on the cross section $x$ = 1.01 m for case I.

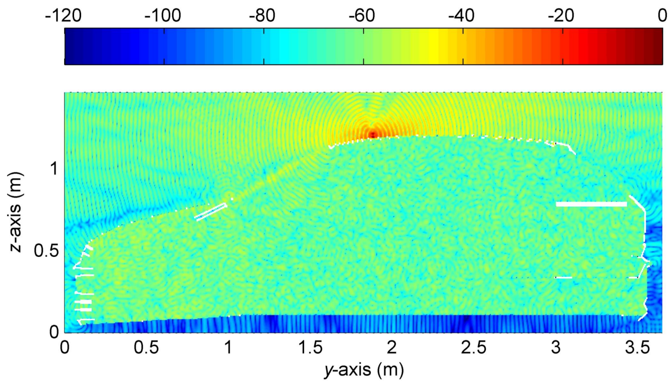


Figure 4. Normalized electric field distribution (in dB) on the cross section $x$ = 1.01 m for case II.

the line of electric field distribution of Fig. 6 coincides with the instrumentation area and the positions of various electronic control units that control the instrumentation, the ABS or other important systems.

## V. DISCUSSION

It is deduced from the results of Figs. 3-6 that in case II the electric field is about 15dB lower than in case I. This was expected since by the setup of the two simulations it was mentioned that case I corresponds to the worse scenario from the EMC point of view. Not only the antenna is placed inside the vehicle but it is also very close to critical electronic components and the electric field level in the selected areas or lines significantly increases. Therefore, such a placement should be avoided.

Vehicle electronic subassemblies (ESA) are subject to immunity reference limits to electromagnetic radiation. Nevertheless, a direct comparison cannot be made since most standards refer to low frequency radiation (< 2GHz) and only some extend to 5GHz (ISO 11452) [16], [17]. Comparing the maximum electric field intensity computed by case I (about 35dB) to the closest, in frequency, requirements for vehicle ESAs electromagnetic immunity tests, it is deduced that only the hardest limits (40-46dB [16]) are not invaded. On the other hand, in case II, no immunity problems are observed.

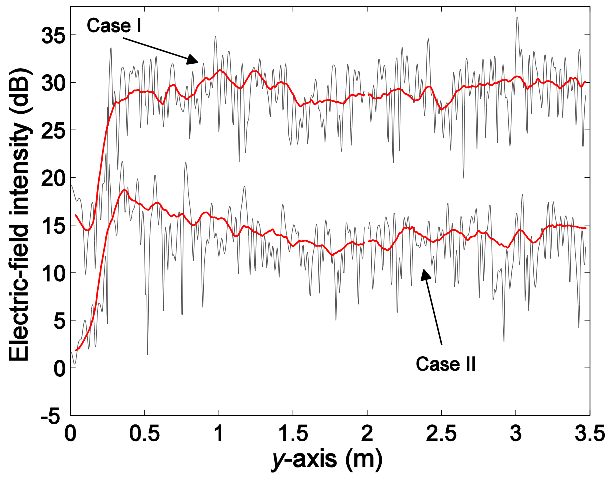


Figure 5. Electric field distribution (in dB) along the line x = 1.01 m, z = 0.62 m for both cases.

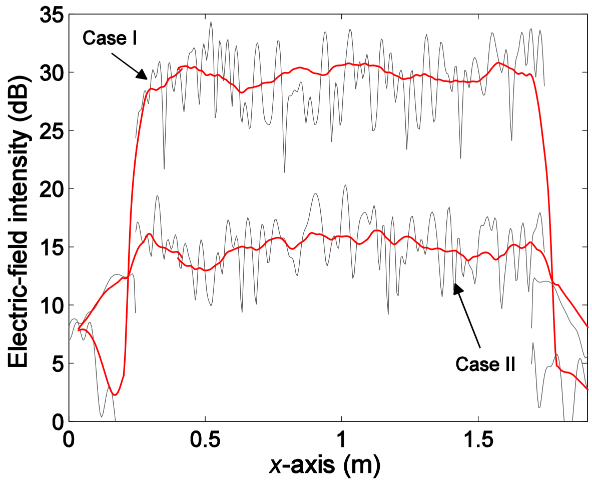


Figure 6. Electric field distribution (in dB) along the line y = 1.2 m, z = 0.62 m for both cases.

Therefore, antenna location may alter significantly electric field levels and it must be very carefully chosen.

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