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Simulation of Internal Electromagnetic Interference for Vehicular Antenna Performance Evaluation

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***Abstract*—Due to the increasing number of infotainment and safety functions in vehicles, the need for reliable communication link is becoming very critical. A key consideration in providing a reliable link is the antenna performance, which is conventionally evaluated by its efficiency and ability to provide the required coverage upon integration in vehicles. However, modern vehicles are equipped with many electronic devices that emit electromagnetic interference (EMI), which can become the main bottleneck of vehicular antenna performance. In this work, a simulation framework is provided to study the impact of EMI on vehicular antenna performance. Specifically, full-wave car simulations of the coupling of EMI into antennas at the GSM900 band is presented as a case study to demonstrate the important need to address EMI issues in vehicular antenna design and implementation.**

***Index Terms*—vehicular antenna, performance evaluation, electromagnetic interference**

I. INTRODUCTION

Antenna systems on cars today support a variety of applications, including satellite positioning (e.g., GPS), vehicle-to-vehicle (V2V) communications for vehicular safety (e.g., IEEE802.11p), and cellular communications for ubiquitous connectivity (e.g., HSPA, LTE). These applications involve significantly different usage scenarios, which lead to different antenna design requirements. To fulfill the requirements and reduce the need for prototyping, computer simulations have been instrumental in vehicular antenna design and evaluation. For convenience and proof-of-concept, many vehicular antennas are designed, simulated and measured on a large ground plane instead of full integration on a realistic car platform, e.g., [1], [2]. The significant influence of the car body on antenna performance has also been explored [3]. Furthermore, to optimize the antenna placement and configurations for the usage scenario, the performance of candidate antennas can be predicted in "Virtual Drive" [4], involving end-to-end system simulation considering all components in the communication link, including realistic models of the antennas and the propagation environment.

In this context, existing work on vehicular antennas focuses on the fulfilling requirements relating to antenna properties and their interaction with the channel. However, an emerging challenge in the automotive industry is increasingly complex electromagnetic environment inside the vehicle. Due to increased functionality in the vehicles, the number of electronic control units (ECUs) has increased drastically. As a result, both the number and length of cables connecting the ECUs have increased. These cables and the ECUs create electromagnetic interferences (EMIs) inside the vehicle, which if go unchecked can couple into antennas and significantly degrade the performance of critical systems [5]. The modeling and simulation of EMIs in vehicles has been a topic of interest [6]-[8], and the ECUs used in vehicles are required to comply with relevant electromagnetic compatibility (EMC) standards [9]. However, EMC requirements and evaluation methods are constantly evolving to keep up with new systems and functionalities. The ability to accurately predict the actual EMIs and their impacts on system performance in a simulation environment is crucial to ensure minimal mutual disturbances.

In this paper, a simulation framework based on antenna simulations is proposed for evaluating the EMIs received by vehicular antennas. A real life scenario is studied using this framework, where an ECU identified as a strong EMI source at the GSM900 band is represented by an antenna, and the interference power coupled into another antenna placed at different locations around the car is simulated using a simplified car model. The actual received power from the EMI source is also measured in an experiment involving a real vehicle. Preliminary results reveal that the relative level of the EMI power measured at different receiving antennas show good agreement with the corresponding simulation results, despite the use of simplified EMI source and car models in simulation. Moreover, the simulated channels provide different frequency-selective responses for the different receiving antenna locations, indicating a significant effect of multipath propagation on the received power. These initial results show promising potential of using full-wave antenna simulations to model and evaluate the impact of EMI, as well as to facilitate antenna optimization and robust antenna design.

II. SIMULATION AND MEASUREMENT SETUPS

A. Simulation Setup

The antenna simulations were performed using the time-domain solver in the CST Microwave Studio software. The car model chosen for the simulation was Volvo XC60 (with sun-roof), since an ECU in the vehicle had been found to emit a

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narrowband EMI within the GSM900 band. The original CAD model from the car manufacturer came with many fine details irrelevant to the electromagnetic environment of the main car body at around 900 MHz (e.g., interior decorations, sealing, wielded nuts), and these were removed to reduce the mesh size. A three-dimensional (3D) perspective of the rear section of the simulated car model is shown in Fig. 1.

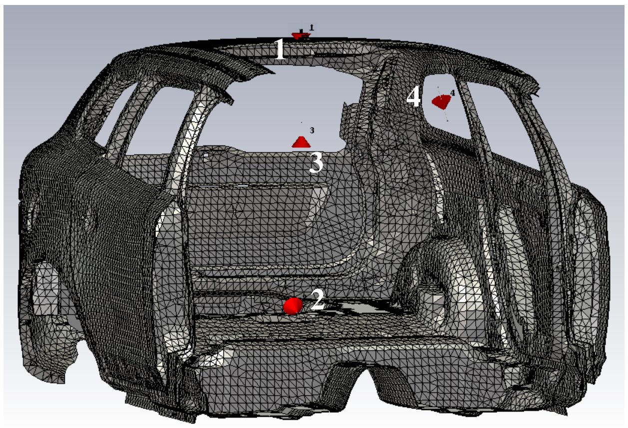

Fig. 1. 3D view of the simulated car model (rear part) shown together with the positions of all the antennas used in this study.

For simplicity, the EMI-emitting ECU mounted at position 2 was modeled as a horizontal dipole antenna at 8 cm above the floor (see Fig. 1). The impact of the EMI source was evaluated for three receiving antenna configurations (see Fig. 1): 1) a typical shark-fin antenna (e.g., [2]) at position 1 on the roof ("on roof top"), 2) a vertical dipole antenna at position 3 ("above rear seat"), mimicking a mobile phone antenna held at the ear level above the middle of the rear seat, and 3) a dipole antenna at position 4 ("on quarter glass"), which was placed in the middle of the left quarter glass location with a 15 degree tilt angle, in a similar location as the DVB-T antenna in some Volvo XC60 cars. The radius of the dipole antennas was 1 mm and all antennas were tuned for a reflection coefficient of less than -8 dB at 913 MHz, which corresponds to the frequency of the narrowband EMI source. The simulation was performed at the center frequency 913 MHz and approximately 122 million mesh cells were generated by CST. The simulation was run on an Intel core i7 CPU 3 GHz with 32 GB of installed RAM. The total simulation time for the three receiving antenna positions was approximately 55 hours.

B. *Experimental Setup*

A measurement campaign was performed on a real Volvo XC60, which is equivalent to the simulated car model, except that it is full equipped with regular car seats, wall panels, dash board, etc. The measurement was performed in an anechoic room. A photo of the car in the measurement room as well as the positions of two receiving antennas is shown in Fig. 2.

To obtain the EMI received at the different positions, the ECU that produces the strong interference was powered up and a spectrum analyzer (Agilent Technologies N9010A EXA) was connected to each of the antennas in sequence. The resolution bandwidth was 120 kHz and the video bandwidth was 100 Hz. The sweep time was 30 seconds with 1001 measurement points. The measured frequency span was 730-960 MHz.

A careful scan of the electromagnetic environment was made to ensure that the received interference power at 913 MHz came from the ECU. Figure 3 shows the received EMI power spectrum for antenna position 3 (above the rear seat). A distinct peak can be seen at 913 MHz, which was caused by the ECU. At the same time, it is apparent from the graph that there are other EMI peaks as well in the measured band. A separate measurement was performed to identify that if these interferences were also caused by the same ECU. It was found that even when the ECU was switched off, the other interferences remained whereas the peak at 913 MHz disappeared. Therefore it can be concluded that there are several ECUs inside the vehicle that are causing interferences and the one creating the highest interference is the one chosen for this investigation.

Fig. 2. The Volvo XC60 and the positions of two receiving antennas used in the measurement.

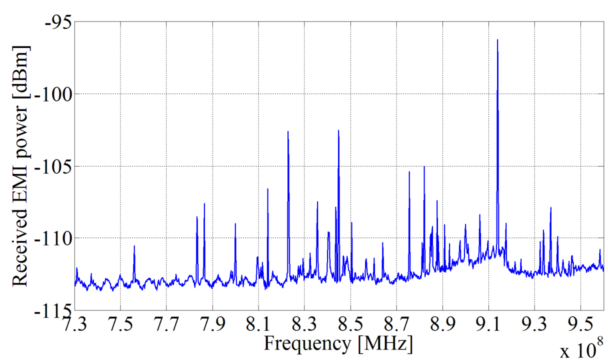

Fig. 3. Measured EMI power spectrum for antenna position 3 (above the rear seat).

III. RESULTS AND DISCUSSIONS

The simulated coupling coefficient between the EMI source (dipole at position 2) with each of the three receiving (Rx) antennas at 913 MHz are listed in Table I. The results show that the highest EMI was experienced by the antenna at position 3 above the rear seat, followed by the antenna at position 4 on the rear quarter glass window and then the roof top antenna at position 1. This trend can be attributed to separation-distance dependent propagation loss as well as the shielding of the roof top antenna by the metal roof. Moreover, even though the antenna at position 3 was closest to the EMI source, it was vertically placed and hence had a pattern null near the line-of-sight (LOS) path from the EMI source. Nevertheless, the multipath (reverberation) environment in the car ensured that it coupled efficiently to the EMI source. On the other hand, the antenna at position 4 has higher pattern gain in the LOS direction to the EMI source as compared to the antenna at position 3, but it was farther away.

TABLE I. SIMULATED COUPLING COEFFICIENTS AT 913 MHZ

Rx antenna position	Coupling coefficient [dB]	
1 (On roof top)	S_{12}	-33.8
3 (Above rear seat)	S_{32}	-27.5
4 (On quarter glass)	S_{42}	-30.0

To verify the simulation results, EMI measurements were performed with a real Volvo XC60 car for a similar setup as the simulation, but using the real EMI source (an ECU that was active during the measurement) instead of a dipole antenna. Calibration was performed to acquire the received powers at the antenna ports. The measurement results are shown in Table II. From the table we can see that the highest EMI power was received by the antenna at position 3 and the lowest by the antenna at position 1. Therefore, the measured results in Table II show similar trends as the simulated results in Table I.

TABLE II. MEASURED RECEIVED EMI POWER AT 913 MHZ

Rx antenna position	Received EMI power [dBm]
1 (On roof top)	-103.7
3 (Above rear seat)	-96.3
4 (On quarter glass)	-98.5

To compare the measured EMI power (Table II) with the simulated coupling coefficients (Table I) more explicitly, the difference in the received power between any two of the three positions was calculated and summarized in Table III. For the coupling results, this meant the difference in the coupling coefficients (in dB) between any two cases.

TABLE III. RELATIVE MEASURED AND SIMULATED EMI AT 913 MHZ

Compared Rx antennas	Difference in simulated coupling [dB]	Difference in measured power [dB]
3 vs 1	6.3	7.4
4 vs. 1	3.8	5.2
3 vs. 4	2.5	2.2

It can be seen in Table III that generally there is good agreement between the simulated and measured results (i.e., discrepancies of up to 1.4 dB only). The small discrepancies could be due to several factors: Firstly, the measurements were done in a fully equipped car, whereas the simulated car model was simplified, as previously described in Section II-A. For example, apart from omitting non-metallic structures, some metallic structures that could have significant impact on the propagation environment within the car were also neglected (e.g., the metal frames in the car seats). Secondly, the ECU was modeled as a horizontal dipole and there is a possibility that the ECU did not radiate like a dipole antenna, despite being an electrically compact structure. Thirdly, there were other common sources of experimental error including antenna feed cable influence and measurement tolerances in the equipment and the positioning of antennas.

To gain further insight into the results, the frequency responses of the simulated coupling coefficients are shown in Fig. 4. To facilitate fair comparison, we focus on a smaller range of frequencies (±25 MHz) around 913 MHz, where the reflection coefficients of the three receiving antennas are below −8 dB. This helps to ensure that the reflection coefficients will have insignificant impact on the observed coupling behavior. The graph shows a stable trend in the vicinity of 913 MHz. However, S_{42} undergoes a fading dip at around 937 MHz. Moreover, it can be seen that the trend of the coupling coefficients starts to change at frequencies above 930 MHz, e.g., S_{12} becomes stronger than S_{42} just above 930 MHz. This changing trend over frequency confirmed that the multipath environment in the car strongly influenced the received EMI power. In other words, if the EMI power is emitted by a different ECU at another frequency (or frequency range for wideband EMI), then the received EMI power can exhibit a significantly different trend.

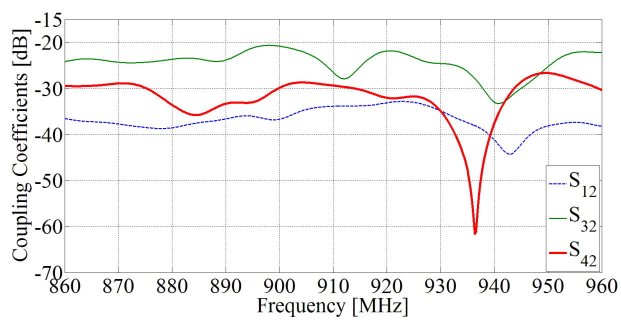

Fig. 4. Simulated channels (coupling coefficients) for the transmitting dipole (modeling EMI source) and different receiving antenna configurations.

IV. CONCLUSION

The ability to reproduce the interior EMI environment in cars and to evaluate its impact on antenna system performance is becoming increasingly important for the car industry. In this work, we provide a simulation framework for studying the impact of EMI on vehicular antenna performance based on a real-life example involving an in-car EMI source at 913 MHz. The coupling coefficients between the EMI source and three receiving antennas were simulated, and it was found that the simulation was able to accurately predict the difference in the measured EMI power at these receiving antennas in a real car. Possible future work includes a study on the expected impact of the measured level of EMI power on the throughput performance of LTE [10].

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