SIMULATION MODEL OF RADIATED EMISSIONS USED IN AUTOMOTIVE MEASUREMENTS

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This paper proposes a Feko simulation model of the radiated emissions test setup used in the automotive component measurements performed in the frequency range of 0.01 MHz – 30 MHz. The study investigates first the ground plane resonance issues with the anechoic chambers metallic floor within 10 MHz – 30 MHz. A multilayer ferrite ground plane is introduced in the simulation model; therefore the simulation geometry and results reproducibility are much improved. The paper details afterward the radiated emissions simulation results from two parallel wires excited by a 4.8 kHz pulse signal source. The Feko simulation results are compared and validated with the experimental data.

Keywords: electromagnetic compatibility, radio frequency interference, radiated emissions, CISPR 25, anechoic chamber, antenna factor, radio frequency reflections, multilayer floor, ferrite tiles

1. Introduction

The automotive electronics technology is continuously growing; therefore, it requires special attention on electromagnetic interferences due to conducted signals and externally radiating cable harnesses.

Today’s challenge is to protect the vehicles onboard radio reception and meet the legal standardization which is unified by European electromagnetic compatibility and rest of world committees. The electromagnetic compatibility standardization is aligned to protect the onboard radio receivers which have been released and published to be used as a reference test method ensuring the repeatability of the measurements. CISPR 25 requirements include test methodology, apparatuses used and applied limits to conducted and radiated emissions levels. This standard has been adopted by all Original Equipment Manufacturers and all the electronics companies that must develop the hardware with this standardization in mind. The radiated and conducted emissions tests are performed in shielded rooms named “anechoic chambers”, where the electronics and related harnesses are represented by the CISPR 25 test setup layout. The main interest is represented by the studies and research capabilities to validate and calibrate the anechoic chambers via simulation software. As multiple test houses share different calibration results, some test setup layouts and configurations have

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been adopted to meet the calibrated data. However, it is very difficult to characterize all of the chamber`s parameters, therefore a radiated emissions Feko simulation model is developed with the scope of work is to identify the required anechoic chamber characteristics and test setup calibration. One of the today's issues is the reproducibility problems when making radiated emissions measurements of automotive, components in the frequency range 10 MHz - 30 MHz. The problems are caused by resonances that are introduced by the test setup chamber floor [7] [9].

When a periodic signal is propagated through the wire harnesses it creates electromagnetic interferences, either conducted through the cables and/or through the air where the cable wires behave as a dipole antenna. The radiation phenomena from the conductive wires are difficult to anticipate and predict. Almost all components and car manufacturers have introduced this activity as a part of the development process. Due to this interest, this paperwork proposes a Feko simulation model for the radiated emissions generated by the periodic signals propagated through parallel wires. The presented Feko simulation model is developed with respect to the CISPR 25 automotive test setup requirements.

2. Radiated emissions test setup and the equivalent simulation model

As per CISPR 25, radiated emissions are measured in the radio frequency screened rooms, with the walls covered by radio frequency absorber materials. The main role of the screened room is to prevent unwanted signal to propagate through and to minimize the electromagnetic wave reflections at the impact with the metallic chamber floor. In the centre of the screened room is placed the cooper test bench electrically connected to the metallic ground floor. The copper test bench is placed on the conductive floor, both electrically connected via 9 copper straps. The whole bench test setup creates a microstrip structure. In the Feko simulation model, the chamber walls are not considered, because the wires geometry model is electrically long compared with the chamber dimensions. In the middle of the test bench there are placed the two parallel wires with 1.7 m in length and at 0.01 m parallel with the bench edge. The wires are placed 0.05 m above the copper ground plane on insulation with low permittivity e.g. air ($\varepsilon r \leq 1.4$). For the purpose of this study, both termination-ends of the parallel wires are terminated with a 50 Ω impedances. One end termination is supplied by a continuous sine wave modulated in frequency with the frequency varied from 0.01 MHz to 30 MHz. The monopole antenna, used to receive the electromagnetic energy, is placed in a vertical orientation at 1 m away from the wire centre. The monopole antenna transmits the measured signal to a radio frequency receiver through a double shielded coaxial cable. The coaxial cable is passing through the screened room. Both double shield coaxial cable and receiver provide a matched

50 Ω impedance. The height of the counterpoise of the rod antenna is in the same plane with the bench and bonded to the ground plane.

Fig. 1. Radiated emissions. Experimental test setup and Feko simulation model geometry

The electromagnetic field is received by the monopole antenna and transmitted via the 50 Ω double shield coaxial cable to the spectrum analyzer. The antenna port provides a high impedance through a 10-pF capacitor. The spectrum analyzer is set up to the appropriate detector bandwidth to achieve the discrete harmonics for the test case when the 2 wires are supplied by the 4.8 kHz trapezoidal train pulse. The CISPR 25 test setup used for the experimental data is detailed in figure 1.

3. Chamber floor characteristics and simulation model setup

Modern screen rooms, used for the radiated emissions and radiated immunity testing, are usually characterized by two main important features: to provide a shielded enclosure in order to avoid the external radio broadcasting source to propagate inside the setup environment and to achieve low electromagnetic reflexions. In the proposed Feko simulation model, the external radio broadcasting source is not considered, and the circuitry is electrically short, in the 0.01 – 30 MHz frequency domain. Therefore, the chamber walls are not considered as they don’t have a negative impact on the results. However, the test bench is electrically connected to the ground floor via 9 ground straps. The simulation model results demonstrate how important the electrical parameters of the ground floor are for a valid technical solution to achieve accurate and reproducible results. Therefore, to create a reflection-less chamber floor it is required to understand how to send a signal down a transmission line and not have it reflect back. Since the shell of the floor is metal, the transmission line model will have a shorted circuit at its termination. Since no energy is dissipated in the metallic wall, short circuit load, all of the signals sent down the transmission line will be reflected back [3].

To avoid electromagnetic wave reflections phenomena, the ferrite tiles are introduced as an additional layer on the chamber floor. The role of the additional ferrite layer is to change the impedance around wave characteristic impedance. In the 0.1 - 100 MHz frequency domain the ferrite tiles are used to attenuate the reflected wave by -15 dB to up to -25 dB. Since the studied test setup model introduces resonances within 10 MHz – 30 MHz the ferrite properties in this frequency interval will suffice.

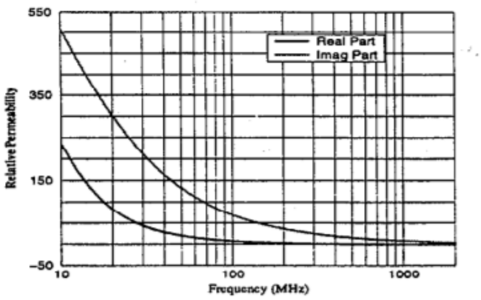


Fig. 2. Ferrite tiles relative permeability

This attenuation is defined by the ferrite tiles electrical properties, size and air gaps between them. The ferrite material properties are selected from the literature and material datasheet and detailed in figure 2 [6] [7] [8].

The chamber floor is defined as a planar multilayer substrate characterized by three-layered materials with a specific thickness. In the Feko simulation model, the chamber floor is defined by a perfect electric conductor layer, air dielectric layer, and the ferrite tiles layer. The perfect electric conductor as a metal layer and air electrical properties are automatically defined in the software interface.

The electromagnetic radiated field propagated from the wires is received by the monopole antenna model. The monopole antenna geometry is defined as 1 m vertical copper wire and connected electrically to the counterpoise at 1 m away from the middle of the harness wires. The Feko numerical simulated data is represented by the voltage read on the 10 pF capacitor monopole antenna port. The voltage represented on the antenna port is transformed into an electric field after the antenna factor is included and where the electromagnetic field is defined as:

$$dB\mu V/m\ (E_i) = dB\mu V\ (E_i) + AF_{dB} \quad (1)$$

where E_i is the incident electric field received by the monopole antenna and AF is the antenna factor. The antenna factor results are within constant 2 dB level as per antenna datasheet. The simulated results are presented in figure 3 [12].

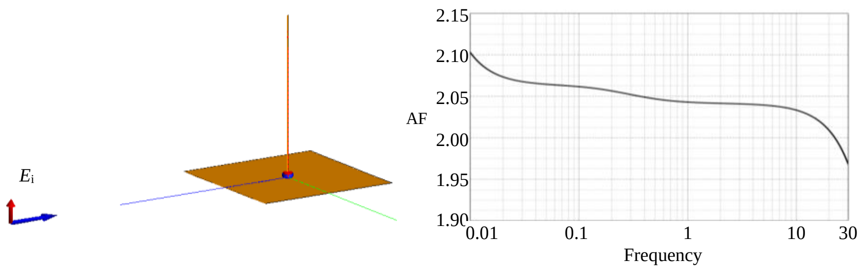


Fig. 3. Monopole antenna model and antenna factor simulation

The antenna port voltage results and measured at the receiver end is desired to relate to the incident electric field. This is calculated with the antenna factor, which is defined as the ratio of the incident electric field at the surface of the measurement antenna to the received voltage at the antenna terminals. Therefore the antenna factor (AF) is expressed via the simple ratio as per equation (2) [1] [5].

$$AF = E_{incident} / V_{received} \tag{2}$$

After the Feko geometry is established, all the input parameters, source, and load ports are introduced in the simulation software. The simulation model is analyzed in the 0.01 – 30 MHz frequency range. The output request is the voltage as simulated on the monopole antenna port.

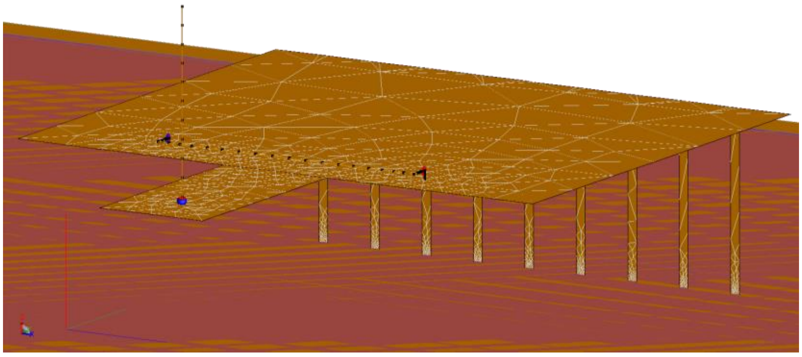


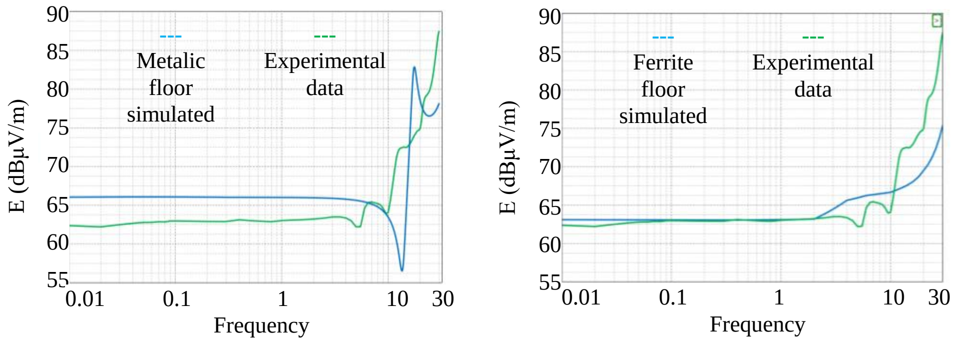
Fig. 4. Feko simulation model geometry and mesh discretization

The mesh is discretized in triangle finite elements for the 2D surfaces and 1D segments for the conductive wires and the monopole antenna. A mesh refinement is defined around the cables and the monopole antenna counterpoise as depicted by the figure 4. The Feko simulation model is, therefore, an open-ended microstrip. It is solved with the Method of Moments (MoM), which is a frequency domain solving problem that calculates the currents on the geometry model hence created. The continuous frequency range is synthesized by solution at a single frequency. The total runtime depends on the number of frequencies defined within 0.01 – 30 MHz with 200 kHz steps linearly spaced discrete points.

The numerical method uses a surface mesh to represent the geometry, including also dielectric and ferrite materials. In the simulation model geometry, the solution of the ferrite was changed to a volume discretization method, which uses a volumetric mesh. The total compile effort is depending by the mesh size and by the multilayer ferrite floor seize therefore this model is solved on 8 CPU cores solver and it takes up to 1 hour to compile. Without the ferrite tiles, the numerical effort is much smaller, but it was added in line with the test chamber floor parameters and specifications, due to its importance on the accuracy of the results and to achieve the experimental data correlations. The simulated results are computed with the formula (1) and (2) and then compared with the experimental data.

4. Experimental data and simulated results

The simulation results show strong electromagnetic reflexions phenomena starting with 10 MHz up to 30 MHz when a metallic floor is used as detailed in figure 5 (a). In section 3 of this paper, the radiated emissions test chamber floor was characterized by a planar multilayer substrate defined by ferrite tiles, air as a dielectric and the metal layer.



(a) (b)

Fig. 5. Radiated emissions for the 1dBm CW signal source. Experimental data and simulated results. Multilayer ferrite floor results improvement

As a result of the proposed technical solution, the experimental and simulation data show now a good correlation and gap analysis within 10 MHz – 30 MHz is up to maximum 6 dB margin, as detailed in figure 5 (b). Compared with figure 5(a) the resonance around 10 MHz – 30 MHz is mitigated, and the simulation model results greatly improved [9] [10] [11]. Therefore, it is demonstrated that the implemented solution with the multilayer ferrite chamber floor, the simulation model provides reproducible results when they are compared with the experimental data. The purpose of the achieved results, as detailed in figure 5 (b), is that the proposed Feko simulation model can be used as a generic simulation model for the radiated emissions from wire harnesses supplied by any time domain signal source characteristics. Therefore, the same Feko simulation model geometry is adapted for the radiated emissions produced by 2 parallel wires when they are supplied by a trapezoidal train voltage signal. The simulation results are compared with the experimental data. The trapezoidal train pulse is characterized by the 10 V amplitude with a frequency of 4.8 kHz and 0.25 ns and 2.5 μs raise fall time. The figure 6 details the radiated emissions spectrum from a trapezoidal pulse train source with very fast 0.25 ns rise / fall time. As a result of the simulation, it is obvious that the radiated emissions harmonics are identified as multiple frequencies of the trapezoidal pulse repetition frequency.

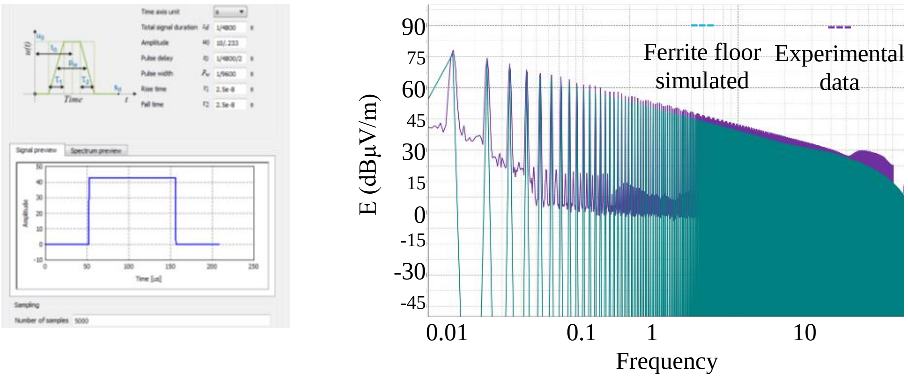


Fig. 6. Radiated emissions for the 0.25 ns raise fall time signal. Experimental data and simulated results

The spectrum decreases by - 20 dB / decade [1] [2] [4]. In figure 7 the spectral bounds are now becoming clear that the high-frequency content of a trapezoidal pulse train is mainly due to the rise/fall time of the pulse. Pulses having small rise/fall times will have larger high-frequency spectral content than will pulse having larger rise/fall times. Thus, in order to reduce the high-frequency spectrum of a noise source, a solution is to reduce the rise/fall times pulse characteristics.

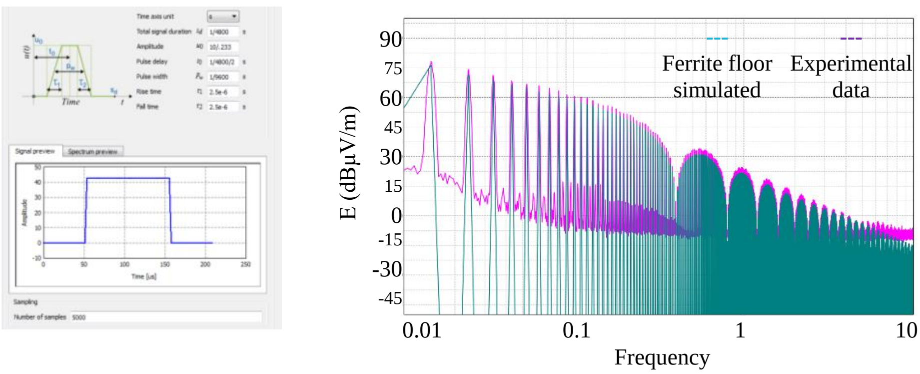


Fig. 7. Radiated emissions for the 2.5µs raise fall time signal. Experimental data and simulated results

For both source characteristics, detailed in figure 6 and figure 7, the simulation results show a very good correlation. However, within 5 – 10 MHz is illustrated a marginal gap within 6 dB margin. This gap is recorded in the calibrated simulated model results represented by the figure 5 (b).

5. Conclusions

The presented paper proposes a Feko simulation model of the radiated emissions from 2 parallel wires within 0.01 – 30 MHz frequency range. The issues with radio frequency reflections introduced by the metallic ground chamber floor have been identified through the simulation data as a strong resonance of the simulated electromagnetic wave when hits the ground floor metallic surface as represented in figure 5 (a). The simulation model proposes as a study case the multi-layered ground floor with ferrite tiles included. The simulation resonance and electromagnetic wave reflections are solved with the ferrite geometry and electric parameters introduced in the simulation software. The simulation results are compared with the experimental data and validated with maximum 6 dB gap as the worst case within 10 – 30 MHz as represented in figure 5 (b). The simulation model presents further the radiation emissions results from two the parallel wires when they are sourced by the 4.8 kHz pulse characterized by 10 V amplitude with 0.25 ns and 2.5 μs rise/fall time as represented in the figures 8 and 9. The simulation results are compared with the experimental data. The gap in the results identified around 5 – 10 MHz are originated to be caused by the ground floor electrical parameter and size tolerances. Further research could be conducted in order to achieve better correlations with experimental data. Therefore, the number of the ground straps connected to the ground floor and ferrite electrical properties and air gaps could be further investigated. Therefore, the simulation model could be used for further radiation emissions simulation and research for any electrical circuitry that operates with narrowband signals propagated through wire harnesses.

R E F E R E N C E S

[1]. *Clayton R. Paul*, „Introduction to Electromagnetic Compatibility” Second Edition, 2006 by John Wiley & Sons, Hoboken, New Jersey.

[2]. *Henry W. Ott*, „Electromagnetic Compatibility Engineering” 2009 by John Wiley & Sons

[3]. *Hortopan, G.*, „Principii şi tehnici de Compatibilitate Electromagnetică”, Ed. Tehnică, Bucureşti, 2005.

[4]. *Dieter Schwarzbeck,* The EMI-Receiver according to CISPR 16-1-1

[5]. CISPR 25, Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers"

[6]. *Alex Goldman,* Handbook of Modern Ferromagnetic Materials, Springer Science & Business Media, 31 May 1999 - Technology & Engineering - 646 pages, ISBN 0412146614, 9780412146619

[7]. *S. M. J. Razavi, M. Khalaj-Amirhosseini, and A. Cheldavi,* Minimum Usage of Ferrite Tiles In Anechoic Chambers, Progress In Electromagnetics Research B, Vol. 19, 367- 383, 2010

[8]. *K. Shimada and K. Ishizuka, M. Tokuda*, A Study of RF Absorber for Anechoic Chambers Used in the Frequency Range for Power Line Communication System, Progress in Electromagnetics Research Symposium 2006, Cambridge, USA, March 26-29

[9]. *Dr Luke Turnbull*, THE GROUNDPLANE RESONANCE – Problems with Radiated Emissions Measurements Below 30 MHz, Automotive EMC Conference 2007

[10]. *M. Iordache, L. Mandache, D. Niculae*, Analiza asistată de calculator a senzitivităţilor şi toleranţelor circuitelor analogice, Editura Matrix ROM, Bucureşti, 2010, ISBN: 978 – 973 – 755 – 583 - 0 (376 pag.).

[11]. *F. Lafon; R. Dupendant, J. Davalan*, “Invesigation on dispersions between CISPR25 chambers for radiated emissions below 100 MHz”.

[12]. *** Model 3301B Active Rod & Field Antenna User Manual