Risk-based EMC System Analysis Platform of Automotive Environments

Vasiliki Gkatsi
University of Twente
Enschede, The Netherlands
vasso.gkatsi@utwente.nl

Robert Vogt-Ardatjew
University of Twente
Enschede, The Netherlands
r.a.vogtardatjew@utwente.nl

Frank Leferink
University of Twente, Enschede
Thales Nederland, Hengelo
The Netherlands
frank.leferink@utwente.nl

***Abstract*—Constantly on-going changes in new technologies applied in modern vehicles introduce many challenges in the automotive electromagnetic compatibility engineering. So far, the currently implemented EMC requirements and methods present sufficient performance. However, they do not illustrate thoroughly an actual automotive environment. They tend to focus on the EMC validation of each system individually without always considering other possible influential factors and co-existing systems. Aim of this paper is to introduce an EMC system investigation platform using a simplified model that demonstrates an automotive environment in order to point out the importance and scale of significance of various parameters. In this paper, the structure of the introduced three-point model is first described and explained. Then, experiments are presented in order to point out the influence of selected macro-parameters. Finally, suggestions for further extension of the model through Monte Carlo simulations are proposed with a brief presentation of a modelling procedure.**

***Keywords*— automotive, model, electromagnetic compatibility, large complex systems, risk-based EMC**

I. Introduction

Over the years, automotive EMC engineering has been facing rapid changes due to the constantly increasing technological developments. The wide range applications and the complexity of new technologies into the automotive introduce many challenges [1]. Already existing EMC requirements aim to characterize the vehicle performance [2] in order for the system to be validated [3]. Moreover, regulations concentrated on functional safety issues such as [4] along with new standards on managing risks [5] introduce further approaches in the automotive. Currently, EMC testing focuses on immunity measurements on the component [6] and vehicle [7] level along with vehicle emissions testing as described in [8] and [9]. Measurements on vehicles are conducted on various sites as anechoic chambers (ACs) [10] and reverberation chambers (RCs) [11]. Although these presently implemented test sites/methods still produce sufficiently usable results, they do not fully replicate an actual automotive environment [12]. According to the EMC Directive [13], all electronic equipment shall remain operational in its intended environment. Such environments, outside of laboratory conditions are extremely complicated to calculate or even define. There are numerous parameters regarding environmental elements, communications, interactions and relations among systems, e.g. vehicle to vehicle (V2V) or vehicle to everything (V2X). Each system is individually evaluated with fixed settings as for example specific number of frequency sweeps, specific resolution bandwidths, fixed distances, etc. [2]. Therefore, the system-under-test (SUT) is isolated from other possibly influential factors that might change its behavior once placed in its intended environment. Although the fixed setting do indirectly address the intended environment, e.g. by adapting the emission levels to the system skyline [9], they are often too generalized.

A single vehicle can be characterized as a large and complex system. These large and complex systems require a [14] risk-based EMC approach [15]. Many models focus on detailed analyses and finding precise solutions [16]. They may not however be entirely applicable [17] in the real-life environment due to its randomness caused by many uncontrollable variations. Oppositely, a more simplified and macro-scaled model might come closer to an accurate and realistic solution. Additionally, a tool commonly used in a system-level risk-based EMC, incorporating the interactions between its elements is the source-victim matrix. This matrix aims to track and assess possible sources and victims in a given environment. It has also been applied in naval ships with great success [18]. A model built upon the source-victim matrix concept and incorporating macro-scaled parameters is presented and discussed in this paper.

In Section II, a conceptual model is introduced as a tool for the improved system EMC analysis and investigation. The model aims to narrow down the complexity existing in the automotive environment via three points placed in it. It accounts for two source types and one victim, as in source-victim matrix framework, along with their intermediate relations. In Section III, an example experiment using a simple source-victim structure is performed to point out how various macro-parameters can influence significantly the risk of electromagnetic interference (EMI). In the same section, the experiment results are briefly discussed. In Section IV, a modelling procedure is proposed for further simulation applications based on existing literature. Additionally, it suggests further implementation of the presented modelling procedure via Monte Carlo simulations using a link budget approach in order to investigate and evaluate the various parameters with greater efficiency. Lastly, Section V concludes the paper.

II. Model Structure

In this section the wide-ranging model is described and explained. The model consists of three individual points set in space. Each point illustrates a different feature that could exist in the automotive environment. In the following subsections the different points and their relations are discussed.

A. *First point*

The first point in this model illustrates the victim in a source – victim matrix. It is individually measured at the appropriate EMC test sites according to EMC standards [19]. Since the point acts as a victim, it is evaluated via immunity values. EMC regulations regarding immunity provide procedures with fixed test setups and settings. Parameters like measuring positions, distances, equipment used, etc. are

This project has received funding from the European Union's EU Framework Program for Research and Innovation Horizon 2020 under Grant Agreement No. 812790.

exactly settled. Therefore, a system is entirely evaluated via these fixed values. These type of measurements produce easy, quick and cost-effective results. Sufficient performance that does not exceed the particular levels according to the regulations sets the system appropriate for further application towards real conditions. As this way is implemented today with great efficiency, this technique of assessment isolates the systems from potential variability of the environmental and systems' parameters. The fixed conditions that the measurements are conducted in commonly include further investigations of potential variability of the involved parameters.

B. *Second point*

In order for additional parameters, which might influence the behaviour of the structure, to be included, a second point is added in the existing structure. The second point portrays any potential known sources. This extra point is also measured according to EMC standards. A point acting as one or more sources can be described via emission values as stated in the according regulations [2]. Therefore, it also represents a well-known and EMC standard-based unity.

With the addition of the second point, the structure changes. The difference with the application of an extra point is that the structure becomes more complicated and a relation appears between these two points unlike the single-point structure. In this case, parameters such as distance, coupling paths, etc. between the two points require a different approach of evaluation. V2V relations is a basic example of such a structure. Two vehicles communicating and co-existing together create a classical source-victim link.

Parameters between these systems are numerous and often very difficult to define. Many modelling approaches, e.g. numerical full wave simulations, tend to create in-detail replicas of structures in order to find the exact solutions of them. However, this way of implementation cannot always be applicable in real conditions as a real-life environment is presumably unknown, and hence unpredictable. Therefore in-depth and precise analyses towards a detailed model of a structure might not efficiently conclude to accurate results in terms of understanding its behaviour. In contrast, a more general investigation concentrating on macro-scaled parameters might result in a more effective, robust, as well as time- and cost- efficient analysis. This approach is further discussed in Section III and IV.

C. *Third point*

The two-point structure considers only the known sources but does not consider any unknown activity as for example a changing number of vehicles co-existing. The model is complete with the inclusion of a third and final point in the structure (Fig. 1). In contrast to the other two individual points, the last one is not evaluated through EMC tests. It represents any potential sources that exist in the same environment but their parameters are too unpredictable to be accurately described and implemented like the second point. These sources can thus be characterized only by estimated emission values and simplified coupling path to the victim. In Fig. 1, the schematic of the entire 3-point structure that consists of the known and unknown sources along with the victim is depicted.

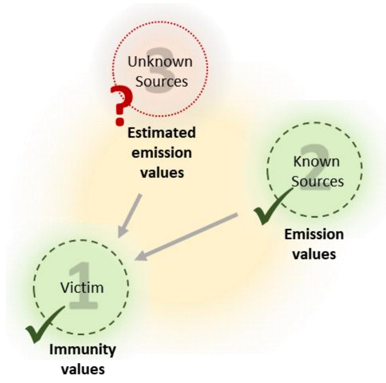

Fig. 1. Schematic of the three-point model

With the inclusion of the final point the whole structure of the model is finalized. Instead of neglecting this unknown factor, this model incorporates it. A simple example of the three-point system is the case of one vehicle (acting as the first point) co-existing with other vehicles or a base station nearby (acting as the second point) in the same environment. The third point in this case could be an unpredicted event like a lightning strike. The model also contributes as a tool for detecting potential crucial and influential parameters that can cause EMC issues. An overall application of the model is presented in the next section with some experiments of a simple setup.

III. Model Application

In real life applications the environment presents unpredictability and continuous changeability. Therefore, detailed system representations might not be entirely effective once they become a part of the even bigger system, the environment, in terms of evaluating possible changes and errors such as failure of a received signal or unwanted EMI. Combining a large number of detailed models might cause a strong under- or overestimation of the actual coupling. Oppositely, when the investigation tool focuses mainly on more macro-scaled parameters, system variations might be more easily managed, since according to the law of large numbers, a number of local variations tend to eventually average out in the big picture. Working with expected values and deviations is often more accurate and practical [20]. The implementation of the previous presented three-point model via experiments of a simple case in a multipath environment, as seen in Fig. 2, is demonstrated in this section. This example could be considered as a simple case of a victim car (represented as a metallic box) illuminated by a nearby base station (represented by the monopole antenna) in a multipath urban environment.

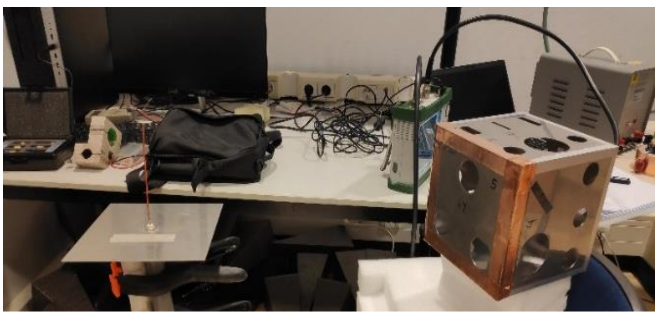

Fig. 2. Setup where the box is at an angle

A. Measurement procedure

The scope of the model application is to illustrate each systems' behaviour and to additionally investigate possible in-between relations concentrated on various macro-parameters. Through this process the most influential parameters that could possibly cause EMC problems could be easier and faster identified. The demonstration is taking place through a simple setup consisting of a 15 cm monopole antenna on a 20 cm x 20 cm ground plane acting as a source and a 15 cm monopole antenna inside a 20 cm x 20 cm x 20 cm metallic box with various circular and rectangular apertures acting as the victim [21] (Fig. 2). The test setup was placed in a room with multiple metallic objects. The environment presented thus multiple reflections [22] and acted as a multipath medium. The two structures were both connected to the Anritsu MS2712E spectrum analyzer with tracking generator and the measurements were conducted in the frequency range of 600 MHz to 4 GHz.

Multiple iterations of three experiments were performed changing one parameter at a time in order to investigate the variation of the results. For all the experiments, the equipment as well as the location of the measurements remained the same. At first, the two structures were placed at a distance of around 0.7 m (Distance 1). For the same positioning of the setup (Angle 1), two measurements were performed 5 minutes apart. The received values of two repetitions of this measurement can be seen in Fig. 3.

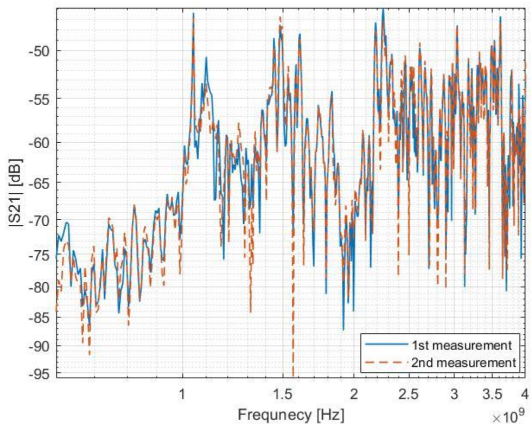

Fig. 3. |S21| values using the same setup but measured at different times

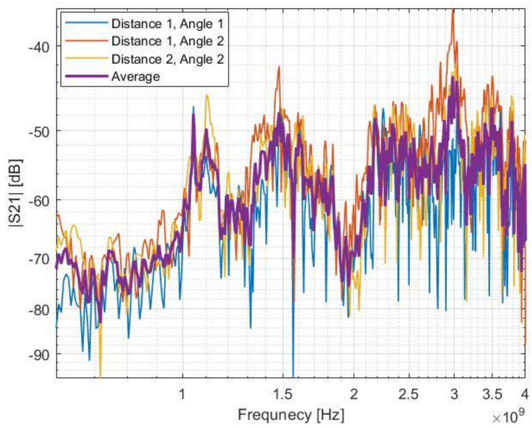

Fig. 4. |S21| values in three cases using different settings in each case

In a follow-up experiment, the box was slightly rotated by a random angle (Angle 2). Only one parameter of the setup was purposely changed. In the third and final experiment, the angle of the box remained the same as in the second experiment, while the distance between the monopole antenna and the box was increased to around 0.9 m (Distance 2). A comparison of the raw results of the three experiments can be seen in Fig. 4.

B. Result Discussion

The particular setup could easily represent many cases in the automotive. For example, the case of a base station communicating with a vehicle in an urban environment or the interaction between an antenna and a component inside a vehicle. Here, the setup is used in order to observe the influence of some macro-parameters to the output values. A setup as the one in Fig. 2 features numerous parameters, such as gains of the antennas, shielding of the box, distance between the two structures, angles of incidence, coupling paths, field distributions inside the box, receiver settings, etc. Each parameter causes a certain modification at the received values.

As seen in Fig. 3 the results of two iterations performed with a difference of some minutes present a small dissimilarity for each frequency despite the fixed settings. Their difference is calculated and depicted in Fig. 5. From the results it can be easily understood that the setup is highly susceptible to its around environment. As it can be observed, the two measurements present high deviations up to almost 25 dB. As mentioned, the two iterations were taken in the same conditions without purposely changing anything in the setup. Since the settings of the setup remained stable, this behavior of the changing output values can be assessed as the third point of the introduced model in Section II. The box acting as the victim (first point) as well as the monopole antenna acting as a source (second point) are elements with certain describable behaviors. In this case, the emission and reception characteristics did not change. The resulting deviations can therefore be assumed to belong to either an unknown source (third point) or be an effect of an unpredictable change of the coupling path.

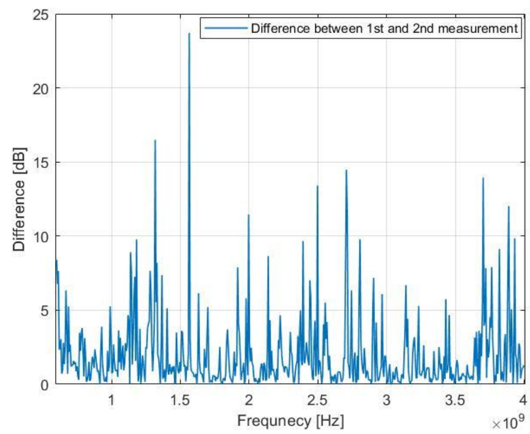

Fig. 5. Calculated difference between the source and the victim using the same setup but measured at different times

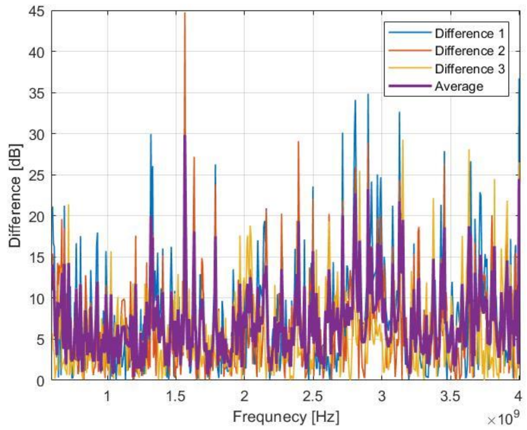

Fig. 6. Calculated difference between the source and the victim in three cases using different settings in each case

In Fig. 4, it can be observed that the graphs present high differences between each other. These differences are quantified in Fig. 6. With just a slight change of one parameter, such as the angle or the distance, the results present noticeable differences compared to the results of the first experiment. As mentioned before, differences between absolute values, in terms of precise models or in this case – measurement, can often be very high. Often a small alteration within the environment can lead to significant changes. Such differences can here be attributed to an entirely different coupling path due to the multipath environment and radiation pattern of the box. On the other hand, comparing the individual measurement results to the averaged trace leads to smaller error, as shown also in Fig. 6. The averaged trace is an experimental representation of an expected result from using a macro-model. As described in Section IV, the usage of such macro models is both simpler, more robust, and leads to statistically smaller errors.

IV. Proposed Modelling Procedure

Creation of a detailed full three-point model representing this setup, as also mentioned previously, would need extreme effort. The analysis of factors such as number and shapes of the box apertures, radiation patterns of the box, angles of incidence, channel variations, etc. is very time consuming and perhaps unnecessary. All these parameters, are complicated and difficult to define in detail. Alternatively, since the exact solutions are presumed to be unknown, macro-parameters can be of significant help. It is commonly acknowledged that the state-of-the-art description of a multipath environment is statistical [22]. A deterministic approach is considered to be impossible due to the very high unpredictability and sensitivity to any change introduced to the environment. Probability distribution functions (PDFs) of the possible solutions are defined according to models such as [23]. An example Rayleigh PDF describing the E-field in a strongly multipath environment is shown in Fig. 7. Instead of focusing on the exact individual possible field solutions, usage of statistics such as the mean value and standard deviation are much more practical. Following this concept, the metallic box can be represented as an unintentional radiator [23]. The random apertures and slots placed on the its sides produce an unpredictable and complex radiation pattern [21]. There have been already some approaches on estimating the directivity of radiating devices via deterministic models [24] as well as via statistical models in [25]. Since the exact calculation of such a factor is an extremely difficult attempt, there is need for the use of various distributions. According to [24] the directivity of the unintentional radiation patterns could be obtained through a chi squared distribution with two degrees of freedom, thus an exponential distribution, shown in Fig. 8.

In this work, we aim to create a MATLAB simulation platform to analyse the risk of EMI using the three-point model as described in Section II. Aim of this modelling procedure is to incorporate multiple macro-parameters modularly following the link-budget approach [26]. The link analysis connects a transmitted (input) value, such as the total radiated powers (TRP) of the known sources, to the field coupled onto the victim. The analysis is performed from the perspective of the victim, the first point of the model, and referred to its ability to withstand the incoming field emitted by the other two points, in order to estimate the risk of EMI. Firstly, according to the risk-based EMC approach, all of the known and unknown sources present in the environment are listed and characterized by their TRP. It is important to notice that they can operate at various frequencies, with various time-behaviors, and even their numbers can be a variable. Then, the possible coupling paths with the victim are defined according to the corresponding environment, whether it is free space or a multipath urban area. The coupling paths also incorporate all the obstacles that could modify the magnitude of the propagating EM wave such as distance and shielding effects. In case an emission is known to be present but it is difficult to estimate its behavior, it is modelled within the premises of the third point. A typical example is the manmade noise or unpredictable effects such as a lightning strike. It is crucial to mention once again that although all of the individual models are taken from the existing literature, their input parameters are defined statistically. Therefore, even a simple case of a line of sight link using Friis' formula is modelled using a PDF due to the assumed distribution of e.g. distances. Once the whole three-point model is established, a Monte Carlo simulation is performed. A MATLAB script performs multiple iterations of all the interactions, at all frequencies, choosing a different value from the presumed PDFs of each parameter. Eventually, a histogram combining all the results, field strength at the victim is created, and a corresponding PDF can be fitted to it.

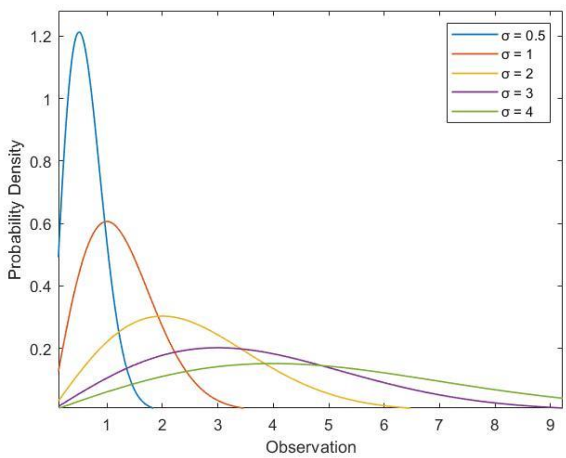

Fig. 7. Rayleigh Distribution for different mode values (σ)

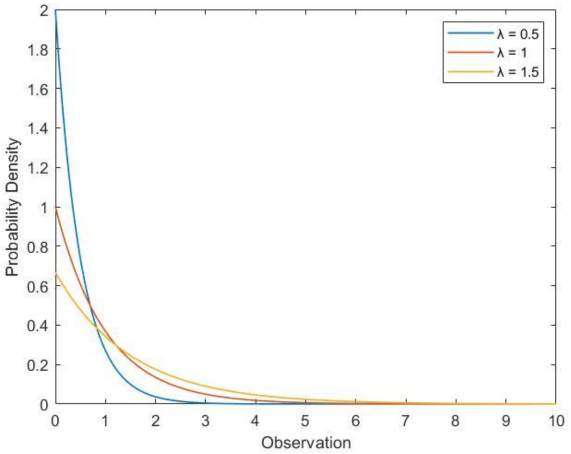

Fig. 8. Exponential Distribution for different mean values (1/λ)

Three important aspects of this method arise. Firstly, according to the law of large numbers, considering the high variabilities of the large number of macro-parameters, the output PDF is typically Gaussian. The majority of possible solutions will be found around one or two standard deviations from the mean value. Interestingly, the output PDF is typically not strongly sensitive to the even crudely presumed distributions of the input parameters. Secondly, the probability of EMI can be found directly from the PDF, and used to assess the risk by additionally combining it with the severity parameter. An analysis of the risk of a system to intentional EMI can also be found in [27]. Also, the reasonable and realistic worst-case scenarios can be estimated by looking at e.g. the 95th percentile to adopt further EMC measures if necessary. Lastly, the sensitivity of the input parameters on the result can be evaluated in order to find the sources of errors due to improper models or assumptions. The poorly performing models should be reevaluated. Since the whole script is modular, individual parts can be easily replaced.

V. Conclusion

Due to the always increasing technological developments, the automotive environment becomes more and more complex to illustrate and evaluate. Currently used EMC methods provide great assessment of the components and full vehicles, without though representing an actual automotive environment. A step towards risk-based EMC and the intended real automotive environment is presented in this paper. A model incorporating known but also unknown factors via a three-point structure is introduced. Furthermore, simple experiments of two systems (source-victim) are performed. Aim of these experiments is to point out how and in what scale can some parameters be more influential to the output values. Additionally, a broad discussion regarding the experiments takes place proposing macro-model applications. Finally, a modelling technique is introduced and proposed in order to be implemented in the future using Monte Carlo simulations. Modular incorporation and multiple iterations of various parameters aim to create a platform where each of them can be evaluated and investigated with great efficiency. Sufficient results from the simulations will conclude to point out the most influential parameters in any setup.

References

[1] A. R. Ruddle, A. J. M. Martin, "Adapting automotive EMC to meet the needs of the 21st century", IEEE Electromagnetic Compatibility Magazine, vol. 8, no. 3, pp. 75 - 85, October 2019.

[2] UNECE Reg10:2019, "Regulation No. 10 – Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility", Add. 9, Rev. 6, October 2019.

[3] 2007/46/EC, "Directive 2007/46/EC of The European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles", Off. J. EU, L 263, vol. 50, pp. 1–160, October 2007.

[4] ISO 26262:2018 series, "Road vehicles – Functional safety", 12 parts, 2018.

[5] IEEE 1848:2020, "IEEE Standard for Techniques and Measurement to Manage Functional Safety and Other Risks with Regards to Electromagnetic Disturbances", April 2021.

[6] ISO 11452 series, "Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy".

[7] ISO 11451 series, "Road vehicles – Vehicle test methods".

[8] CISPR 12: 2007+AMD1:2009, "Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers", 6th Ed., January 2009.

[9] CISPR 25:2016, "Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers", 4th Ed., October 2016.

[10] M. A. K. Wiles, "An overview of automotive EMC anechoic chambers", 10th International Conference on Electromagnetic Interference & Compatibility, November 2008.

[11] ISO 11452-11:2010, "Road vehicles — Component test methods for electrical disturbances from narrowband radiated electromagnetic energy — Part 11: Reverberation chamber",1st Ed., September 2010

[12] J. Lei, Y. Xu, T. Tian, R. Chen, M. Chen, J. Jia, "Challenges and opportunities on intelligent vehicle tests in anechoic chamber", 6th Asia-Pacific Conference on Antennas and Propagation (APCAP), October 2017

[13] "March 2018 Guide for the EMCD (Directive 2014 / 30 / EU)", March 2018, pp. 1–67.

[14] A. R. Ruddle, A. J. M. Martin, "The Need for a Risk-Based Systems Engineering Approach in Automotive EMC Engineering", International Symposium on Electromagnetic Compatibility (EMC Europe), Amsterdam, The Netherlands, August 2018.

[15] F. Leferink, "Risk-based vs Rule-based Electromagnetic Compatibility in Large Installations", IEEE 4th Global Electromagnetic Compatibility Conference (GEMCCON), November 2018.

[16] S. Frei, R. G. Jobava, D. Topchishvil, "Complex Approaches for the Calculation of EMC Problems of Large Systems", International Symposium on Electromagnetic Compatibility, August 2004.

[17] M. Bozzetti, C. Girard, A. Hoque, A. Marvin, J. P. Moreoau, J. P. Parmantier, M. S. Sarto, C. G. Spiliotopoulos, "HIRF Synthetic Environment: An innovative approach for HIRF design, analysis and certification of aircraft and rotorcraft", International Symposium on Electromagnetic Compatibility - EMC EUROPE, Rome, Italy, September 2012.

[18] F. Leferink, Jan-Kees van der Ven, H. Bergsma, B. van Leersum, "Risk Based EMC for Complex Systems", 32nd URSI GASS, Montreal, Cnada, August 2017.

[19] V. Rodriguez, "Automotive component EMC testing: CISPR 25, ISO 11452–2 and equivalent standards", IEEE Electromagnetic Compatibility Magazine, vol.1, no. 1, pp.83-90, July 2012.

[20] R. Vogt-Ardatjew, T. T. M. Palstra "Electromagnetic fields in reverberant environments", Ph.D. dissertation, University of Twente 2017.[Online].Available: https://ris.utwente.nl/ws/portalfiles/portal/18868825/Thesis_Vogt.pdf.

[21] D. Mandaris, T. T. M. Palstra, "High field strength electromagnetic field generation for radiated EMI measurements", Ph.D. dissertation, University of Twente 2020, [Online]. Available: research.utwente.nl

[22] R. Vogt-Ardatjew; U. Lundgren; S. Fernández Romero, F. Leferink, "On-Site Radiated Emissions Measurements in Semi reverberant

Environments”, IEEE Transactions on Electromagnetic Compatibility, vol.: 59, no. 3, June 2017.

[23] B. Menssen, D. Hamann, H. Garbe, “Predicting the maximum radiated electric field strength from unintentional radiators”, Asia-Pacific Symposium on Electromagnetic Compatibility (APEMC), May 2015.

[24] J. Hansen, Spherical Near-field Antenna Measurements. London: Peter Peregrinus Ltd., 1988.

[25] P. F. Wilson, D. A. Hill, and C. L. Holloway, “On Determining the Maximum Emissions From Electrically Large Sources”, IEEE Transactions on Electromagnetic Compatibility, vol. 44, no. 1, pp.79-86, February 2002.

[26] N. Ya’acob, J. Johari, M. Zolkapli, A. L. Yusof, S. S. Sarnin and N. F. Naim, “Link Budget Calculator System for Satellite Communication”, International Conference on Electrical, Electronics and System Engineering (ICEESE), Kanazawa, Japan, November 2017.

[27] Evgeni Genender, Heyno Garbe and Frank Sabath, “Probabilistic Risk Analysis Technique of Intentional Electromagnetic Interference at System Level”, IEEE Transactions on Electromagnetic Compatibility, vol. 56, no. 1, pp. 200 – 207, Feb. 2014.