EVALUATION OF EM VEHICLE ENVIRONMENT MEASUREMENT METHODS FOR RISK-BASED EMC ANALYSIS

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ABSTRACT

Due to the increasingly implemented electronic devices in modern applications, the electromagnetic environments become more and more complex. Therefore, there is need for such environments to be evaluated, so that potential electromagnetic compatibility issues can be identified and solved. So far, standardized methods have been using conventional measuring techniques such as e.g., superheterodyne receivers, oscilloscopes, etc. These types of devices depict the output data measured over frequency or time, determining the electromagnetic behavior of a system under test in a single domain. Although they are suitable for laboratory tests, a proper description of the real intended electromagnetic environment, where the device would be placed, requires a more careful analysis, especially in order to implement the risk-based EMC approach. Experiments performed in a vibrating intrinsic reverberation chamber representing an example harsh environment, using four different measuring methods show the receiving capabilities of each for better understanding on how an electromagnetic environment could be characterized.

1. INTRODUCTION

The increasing number of electronic components and devices with broad emission spectra, in various types of electrically large and often reverberant structures such as car chassis, aircraft, spacecraft, etc., creates a complex electromagnetic environment (EME) concluding to a potential increase of electromagnetic interference (EMI) issues. Therefore, the interest in the characterization of these types of EMEs increases rapidly to minimize the risk of EMI and assure electromagnetic compatibility (EMC) within [1].

Standards exist on assessing the performance of electronic components and subsystems installed on a platform regarding its EM characteristics in terms of immunity and emissions as e.g. [2] applied in the automotive, and [3] applied in space systems. Such measurements are performed in specific test sites as e.g., anechoic chambers (ACs) and reverberation chambers (RCs) [4]. This type of testing aims at characterizing the operational performance of a sub-system under fixed, standardized conditions represented by a fixed set of rules, such as single-frequency illumination, performed in a certain laboratory environment, with high repeatability and reproducibility. Although these standards are implemented today with success [5], they do not replicate the intended real dynamic, complex environment conditions very well [6]. Oppositely, new approaches suggest evaluation methods focused on risk-based EMC [7] that incorporate and predict the effects caused by the EME, and their effects on EMC. The environment of a platform can be difficult to define or even characterize since there are numerous predictable as well as unpredictable parameters that could influence the behavior of that system [8]. The rapid technological developments and applications of new wireless technologies at the interior as well as exterior of platforms as e.g., sensors, Wi-Fi, GPS, 4G and 5G, as well as increased switching frequencies of modern electronics, increase subsequently the application of on-board electronic components and devices [9]. This results in complex environments and thus requires investigation towards real environments and a more conclusive environmental characterization so that potential threats resulting to unstable operation can be avoided.

The internal environment of a platform can be described as a semi-enclosed metallic cavity loaded with numerous electronic devices. Methods have attempted to characterize the EM environment of an enclosure based on spatial, time and frequency parameters. Such a complete environment description is useful to avoid any unwanted EMI issues as well as to design more robust systems. Common techniques apply spectrum analyzers (SA) [10], oscilloscopes [11] and field probes [12] to obtain information about the EM environment. Regarding spatial effects, an approach using the random-walk technique for specifically measuring the EM environment in reverberant spaces has been implemented in [13]. These measuring methods give field magnitude values either in the time or frequency domain. Each measuring method, though, offers different type of information depending on its operation and available settings.

In this paper, an overview of measuring methods in the frequency as well as in the time domain is given. It addresses the advantages as well as disadvantages of each in terms of identifying and assessing potential crucial sources of an EME inside or/and outside a platform such as a vehicle. The paper aims to analyze and do an overall comparison between the use of a typical spectrum analyzer, an oscilloscope, an E-field probe, and a real time spectrum analyzer (RTSA). For the measuring techniques to be investigated, a series of measurements inside a vibrating intrinsic reverberation chamber (VIRC) using a comb generator and amplitude modulation (AM) to alter the spatial, temporal, and frequency properties of the EME, are performed.

2. MEASURING TECHNIQUES

The measuring techniques differ in operation as well as in application. Each of the four methods investigated in this paper offers different type of data about an EME. They usually incorporate parameters such as time, space, frequency, and amplitude, which can address an EME [14]. In this section, a brief description of the techniques is made.

2.1. Spectrum Analyzer & Real-time Spectrum Analyzer

The superheterodyne receiver such as EMI receiver and SA is the mostly implemented type of device when it comes to EMC testing as it offers numerous benefits [15]. Utilizing frequency sweeps, it can give magnitude information about the individual frequency components of the environment in a wide spectrum considerably fast. This operation allows the device to scan the pre-selected frequency span and depict immediately the response. It can, therefore, offer a high resolution of independent frequencies. However, for low resolution bandwidth (RBW) which provides the highest frequency resolution with highest sensitivity, the sweep times (SWT) are relatively long excluding the ability of capturing transient effects. Additionally, an SA features zero-span analysis, which is a useful tool when it comes to investigating discrete frequencies over time, but at a price of narrowing down the spectrum to a single component.

On the other hand, an RTSA offers some additional advantages compared to a conventional SA [16]. An RTSA is structured as a traditional SA, but it captures and digitizes the down converted signal in the time domain translating it via the fast Fourier transform (FFT) into the frequency domain [17] within a broader frequency band than a traditional SA. This function offers a high sampling rate which allows tracking transient effects similarly to an oscilloscope but typically only within a dozen-megahertz bandwidth, resulting in the capability to generate spectrograms [17]. In case the analysed frequency band is broader than its instantaneous bandwidth, it still performs sweeps significantly faster than an SA. Although it has typically narrower bandwidth than an oscilloscope, it can give a good estimation of the EME as will be shown in Section 4.

2.2. Oscilloscope

Oscilloscope is a device which can perform broadband measurements in the time domain considerably fast. Due to the very high sampling rate, it can capture rare transient effects [18] with ease and produce useful and accurate spectrograms as shown in [19]. Since they directly sample the received voltage wave, phase information is also stored. However, considering the large amount of directly-sampled data, they quickly run into memory issues, disallowing a continuous operation, and triggered bursts are used instead. In order to express the measured data in terms of a spectrogram, an FFT is performed over the whole, large frequency band. Additionally, oscilloscopes are generally multi-channel compared to the single-channel SAs and RTSAs, which allows them to measure in different points in space or polarizations simultaneously. However, due to a limited resolution of the analog-to-digital converters (ADC), typically 8 bit, they have lower sensitivity and hence dynamic range. Also, since oscilloscopes utilize direct sampling, the upper frequency range is limited by the ADC according to the Nyquist theorem.

2.3. E-field probe

E-field probes are mostly used in EMC for calibration, validation, detecting and controlling the generated fields in the various test sites [2]. However, they can also be used for investigating and understanding an EME. These devices sample the field in the time domain and can offer a continuous broadband field magnitude measurement result. However, since only the envelope is sampled, FFT cannot be performed, and hence they are not able to distinguish the individual spectral components compared to the previously mentioned methods. However, this also alleviates the memory issues of an oscilloscope, and the data can be stored continuously with high sampling rate. The state-of-the-art models are built based on log-amps [20] and thus can have a high dynamic range and sampling rate, and they can provide three-axis information about the orthogonal E-field values. Moreover, they can capture transient effects with ease similarly to an oscilloscope and an RTSA.

3. MEASUREMENT SETUP

To observe and understand the mechanisms of each measuring technique, experiments were conducted in a VIRC. The dimensions of the VIRC are 150 cm x 120 cm x 100 cm. Two log-periodic antennas were placed inside the chamber, one acting as a transmitter (Tx) and the second one as a receiver (Rx). The Tx antenna was connected to a signal generator, which was further linked to a frequency multiplier, effectively working together as a comb generator producing a rich spectrum. The Rx antenna was connected to one of the four available receiving devices (SA, RTSA, oscilloscope, E-field probe) at a time. The measuring setup can be seen in Fig. 1. The aim of these measurements was to modify the spatial, temporal and frequency parameters to observe how the different receivers can capture the continuously changing field.

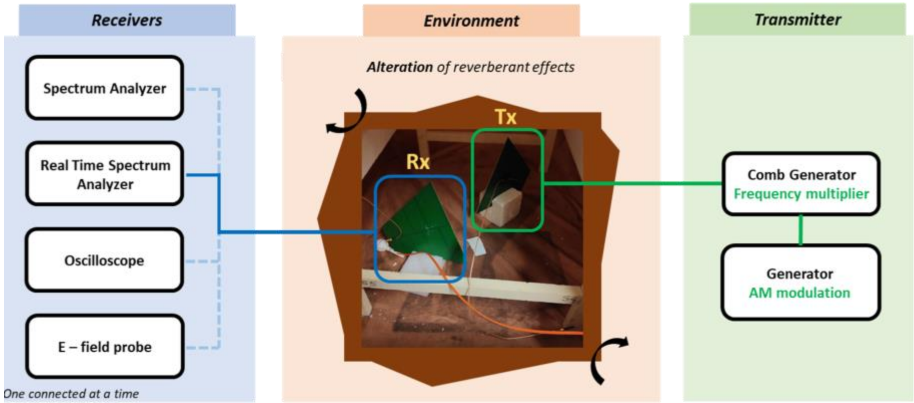

Figure 1. Schematic of the measurement setup

The vibrating walls of the VIRC caused an alteration of the amplitude of the field inside the chamber representing a harsh, reverberant environment. The changing boundary conditions due to the moving walls also count for spatial alteration as they correspond statistically to volume sampling [21]. Additionally, amplitude modulation (AM) was set at the signal generator to disrupt the initial CW and create various amplitude signals. Each measuring device was used independently at different times.

Experiments were conducted to understand the receiving properties of these measuring techniques so that their results can further be used to characterize an EME. All implemented devices are portable and can be used in larger systems as e.g., cars, rooms, etc. The software interface for both the SA and RTSA was the same and both devices were set at the same settings.

4. RESULTS & DISCUSSION

4.1. Raw Data

In this section, the results of the different methods are presented along with discussion on some of their characteristics. Firstly, the differences between the operation of an SA and an RTSA can be seen in Fig. 2 and Fig. 3, respectively. The two figures show the amplitude of the raw received signals of each device as a function of time as well as frequency. The frequency range is 750 MHz to 850 MHz while the measuring time is equal to 1 min. (24 sweeps) for the SA and 10 sec. (343 sweeps) for the RTSA. The different measurement times are depicted here to emphasize on the great difference of the sampling rates between the two devices. Even though, the measurement time of the SA is longer, its sweeping operation excludes a great amount of information compared to the RTSA as seen from the figures. The RTSA can capture the generated signals with great resolution, while the SA loses a lot of information due to its sweeping operation. The graphs look like spectrograms as they incorporate time as well as frequency values. However, these spectrograms are generated within a narrow frequency range. Spectrograms of wide frequency range can be usually achieved with expensive equipment or devices of very high sampling rates such as oscilloscopes [19]. Here, the spectrograms offer a good depiction of the EME even though they have a relative narrow frequency range. Additionally, the spectrograms here are helpful in comparing the responses of the two methods with both time and frequency parameters.

In the time domain, the response of the environment can be depicted via the use of oscilloscopes as well as E-field probes. In Fig. 4, the raw results of an oscilloscope are shown over 5 sec. in the frequency range of 750 MHz to 850 MHz, again via a spectrogram. As it is observed, the oscilloscope offers indeed, a great amount of data in a short time due to its very high sampling rate. Therefore, it captures the EME with a much higher resolution compared to the SA and RTSA. However, between each data recording there is a certain time delay which interrupts the continuity of the output values with respect to time. Therefore, some information is lost during the measurement. However, due to the great sampling rate as well operation capabilities, the oscilloscope can produce spectrograms with great efficiency. Due to its high resolution and broadband spectrum, it can depict the EME in much detail. Finally, as already mentioned, its multi-channel characteristic can cover a range of spatial information. In contrast to the previously mentioned methods, an E-field probe can show the total field variations over the three spatial axes (x, y, z) as seen in Fig. 5 for a measurement of 5 sec.

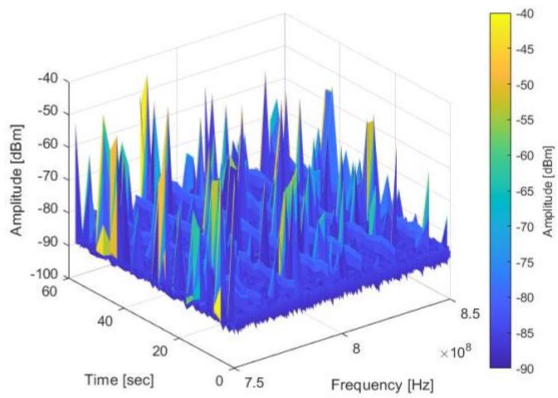

Figure 2. Spectrogram of 24 sweeps (1 min.) of an SA in the frequency range of 750 MHz to 850 MHz.

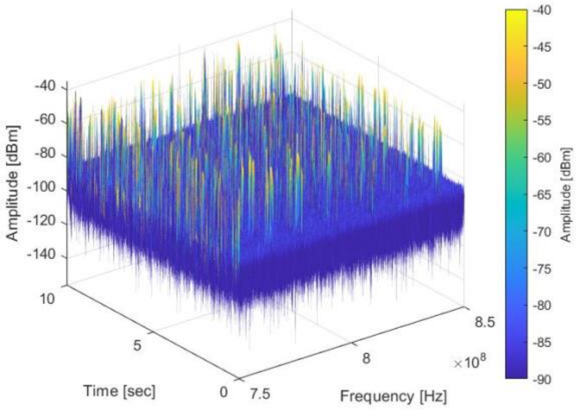

Figure 3. Spectrogram of 343 sweeps (10 sec.) of an RTSA in the frequency range of 750 MHz to 850 MHz.

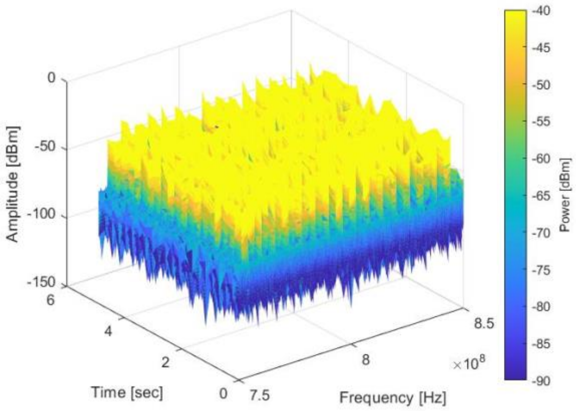

Figure 4. Spectrogram of 22 recordings (5 sec.) of an oscilloscope in the frequency range of 750 MHz to 850 MHz.

Its broadband spectrum offers great information over time and space but does not distinguish the individual frequency components. Additionally, it has a very high dynamic range as well as sampling rate and can easily capture the transient effects similarly to an oscilloscope.

4.2. Comparison

In this subsection a brief comparison between the measuring methods is made. As seen in the last subsection, the spectrograms for each measuring method already indicate the main differences between them. The sampling rates as well as other characteristics are shown. However, to observe and compare them more efficiently, a common graph is plotted in Fig. 6. Since the methods obtain the data either in the frequency or time domain, the figure shows the comparison in one of the two. This is achieved using the FFT. Therefore, the results from the oscilloscope have been transformed in the frequency domain. The graphs clearly show the main characteristics of each device as well as their in-between similarities and differences.

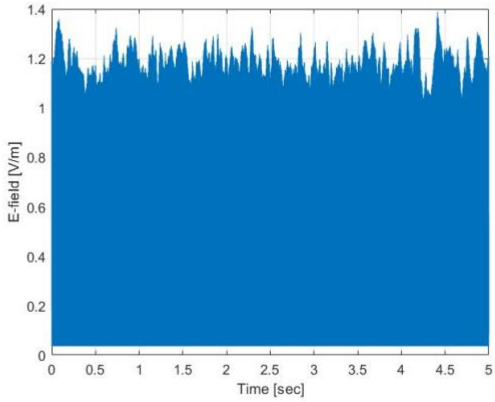

Figure 5. Total E-field values over the three axes (x, y, z) as function of time.

The depicted amplitudes are the maximum received values over 10 sec. The response of the SA is similar to the response of the RTSA as expected. However, their two plots, show the great capabilities of the RTSA in terms of sampling as it captures a great number of samples in the same measuring time, and hence improve the estimation of the maximum. Oppositely, the SA misses multiple peaks due to the sweeping operation as discussed in the previous subsection. In the same graph the FFT data of the oscilloscope is to be seen. As expected, the oscilloscope shows great density in the peak capture of the signals, but it also has the highest noise floor of all the methods. Due to its high sampling rate, it can give a good overview of the occurred frequencies.

As seen, each method gives a different depiction of data according to settings, sampling rates, etc. Therefore, for different measurement procedures, different devices should be used depending on the needed output data. When it comes to evaluating an EME though, combination of more than one method could be used to acquire multiple information in both domains and be able to characterize it sufficiently. Such an investigation is set for further research applied in real cases.

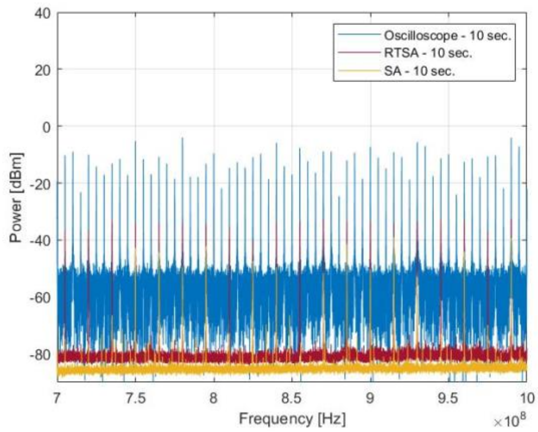

Figure 6. Comparison of the received data of three tested methods in the frequency domain.

5. CONCLUSION

Random signals are generated inside a VIRC to investigate the receiving capabilities of four usually applied measuring methods in EMC testing. Each method offers information either in the frequency, time or spatial domain. The devices variate in settings such as sampling rates, sensitivity, etc. as well as in operation. The superheterodyne receivers such as SA, as usually used in EMC testing (as EMI receivers), captures the data in the frequency domain quite efficiently. It offers the zero-span function for investigation of individual frequency components, but it has limitations due to the sweeping operation resulting to lost data. Similar to the SA, the RTSA depicts the data in the frequency domain but can capture greater amount of data for the same measuring time. However, due to the narrow bandwidth, it can produce spectrograms only within the instantaneous bandwidth. Outside of this bandwidth, they are still much faster than SAs due to the FFT performed in a bandwidth broader than the RBW of an SA. Oscilloscopes, on the other hand, produce spectrograms with ease due to the extremely high sampling rate and collection of data compared to the SA and RTSA. However, there is always an in-between delay while recording, which limits it from producing continuous measurements. Finally, the E-field probe captures and shows the data via broadband measurements and high sampling rates but does not offer any information on individual frequency components. As discussed in this paper, application of a method depends highly on the measuring procedure as well as the requested data. For characterizing an EME, use of more than one of these techniques could be helpful to utilize their complimentary aspects.

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7. REFERENCES

1. M. Terral, S. Patier, M. Lubineau, H. Schipper, and F. Leferink, "Characterisation of Inter-Cavities EMC Coupling in a Telecommunication Satellite", *ESA Workshop on Aerospace EMC (Aerospace EMC)*, Budapest, Hungary, May 20-22, 2019.

2. UNECE Reg10:2019, "Regulation No. 10 – Uniform provisions concerning the approval of vehicles with regard to electromagnetic compatibility", Add. 9, Rev. 6, 15/10/2019.

3. ISO 14302:2002, "Space systems – Electromagnetic compatibility requirements".

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

5. A. R. Ruddle, A. J. M. Martin, M. Emery, "Proposals for Change in Automotive EMC Standardization and Engineering Practices", *IEEE International Joint EMC/SI/PI and EMC Europe Symposium*, Raleigh, NC, USA, 26 July-13 Aug. 2021.

6. K. Pliakostathis, M. Zanni, G. Trentadue, and H. Scholz, "Assessment of a Vehicle's Electromagnetic Emissions Under Dynamic Drive Conditions", *IEEE Transactions on Electromagnetic Compatibility*, vol. 62, issue: 6, pp.2411–2422, Dec. 2020.

7. F. Leferink, "Risk-based vs Rule-based Electromagnetic Compatibility in Large Installations", *IEEE 4th Global Electromagnetic Compatibility Conference (GEMCCON)*, Stellenbosch, South Africa, November 7-9, 2018.

8. V. Gkatsi, R. Vogt-Ardatjew, and F. Leferink, "Risk-based EMC System Analysis Platform of Automotive Environments", *IEEE International Joint EMC/SI/PI and EMC Europe Symposium*, Raleigh, NC, USA, 26 July-13 Aug. 2021.

9. A. R. Ruddle, and 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, Netherlands, August 27-30, 2018.

10. Z. Psenakova, D. Gombárska, and M. Smetana, "Electromagnetic Field Measurement inside the Car with Modern Embedded Wireless Technologies", *IEEE 21st International Conference on Computational Problems of Electrical Engineering (CPEE)*, (Online Conference), Poland, September 16-19, 2020.

11. M. Pous, M. Azpúrua, and F. Silva, "Benefits of Full Time-Domain EMI Measurements for Large Fixed Installation", *2016 International Symposium on Electromagnetic Compatibility - EMC EUROPE*, Wroclaw, Poland, September 5-9, 2016, pp. 514-519.

12. D. Gombarska, M. Smetana, and L. Janousek, "High-frequency Electromagnetic Field Measurement inside Personal Vehicle within Urban Environment", *12th International Conference on Measurement*, Smolenice, Slovakia, May 27-29, 2019.

13. G. B. Tait, and M. B. Slocum, "Random-Walk Technique for Measuring the Electromagnetic Environment in Electrically Large Reflective Spaces", *IEEE Transactions on Instrumentation*

and Measurement, vol. 60, no. 3, March 2011.

14. M. Das, R. Vogt-Ardatjew, B. van den Berg, and F. Leferink, "Time-efficient EMI Risk Evaluation Method in a Hospital Environment", *IEEE International Joint EMC/SI/PI and EMC Europe Symposium*, Raleigh, NC, USA, 26 July-13 Aug. 2021.
15. A. Al Adnani, J. Duplicy, L. Philips, "Spectrum analyzers today and tomorrow: part 1 towards filterbanks-enabled real-time spectrum analysis", *IEEE Instrumentation & Measurement Magazine*, Vol. 16, issue: 5, pp. 6 – 11, Oct. 2013.
16. W. Lv, C. Shen, F. Gui, Z. Tian, and D. Jiang, "Real-Time Spectrum Analyzer Based on All Phase FFT Spectrum Analysis", *Fourth International Conference on Digital Manufacturing & Automation*, Shinan, China, June 29-30, 2013.
17. A. Al Adnani, J. Duplicy, L. Philips, "Spectrum analyzers today and tomorrow: Part 2", *IEEE Instrumentation & Measurement Magazine*, Vol. 16, issue: 6, pp. 36 – 40, Dec. 2013.
18. M. A. Azpúrua, M. Pous, F. Silva, "On-board compact system for full time-domain electromagnetic interference measurements", *ESA Workshop on Aerospace EMC (Aerospace EMC)*, Valencia, Spain, 23-25 May 2016.
19. T. Hartman, R. Grootjans, N. Moonen, F. Leferink, "Time-Domain EMI Measurements using a Low Cost Digitizer to Optimize the Total Measurement Time for a Test Receiver", *International Symposium on Electromagnetic Compatibility - EMC EUROPE*, Rome, Italy, 23-25 Sept. 2020.
20. F. Leferink, "Fast, Broadband, and High-Dynamic Range 3-D Field Strength Probe", *IEEE Transactions on Electromagnetic Compatibility*, Vol. 55, issue: 6, pp 1015 - 1021, Dec. 2013.
21. R. Vogt-Ardatjew, "Electromagnetic fields in reverberant environments", Ph.D. thesis, University of Twente, Enschede, The Netherlands, 2017.