

ON-BOARD COMPACT SYSTEM FOR FULL TIME-DOMAIN ELECTROMAGNETIC INTERFERENCE MEASUREMENTS

M. A. Azpúrua ⁽¹⁾, M. Pous ⁽¹⁾, and F. Silva ⁽¹⁾

⁽¹⁾ Grup de Compatibilitat Electromagnètica. Universitat Politècnica de Catalunya, Spain

ABSTRACT

This paper presents a compact system for the measurement of electromagnetic interferences in the time domain. The measurement system is based on a USB oscilloscope, used as digitizer, and specific software for signal processing and spectral estimation. The measurement system is suitable for both conducted and radiated electromagnetic emissions up to 200 MHz. Its accuracy, precision and dynamic range are sufficient for the intended application. It is particularly suitable for measuring transient disturbances due to its triggering capabilities. Its relative low weight and cost makes it a valuable tool for investigating on-board the indirect effects of lightning strikes as disturbances coupled to cables and antennas inside launch vehicles, aircrafts, and unmanned aerial vehicles.

1. INTRODUCTION

Nowadays, the control systems of the aircrafts rely on electronics. Therefore, the electromagnetic compatibility has become essential for assuring the safety and reliability of manned and unmanned aerial vehicles. In that sense, previous research has identified three main types of electromagnetic disturbance that affect aircrafts: a) the man-made High-Intensity Radiated Fields (10 kHz - 40 GHz) [1], b) the non-nuclear electromagnetic pulse weapons (0-100 MHz) and c) the indirect effects of lightning strikes (0-50 MHz) [2].

In particular, some of the distinctive characteristics of lightnings as sources of EMI are: a) the interaction of lightning with airborne vehicles is mainly caused by the aircraft or the launch vehicle itself, making it even more difficult to anticipate, b) given the impulsive and transient behaviour of lightning it has a broadband EMI signature that cannot be measured using the standard frequency sweep/stepped scan approach c), Lightning damage to airborne electronics is generally minimal, but it could be catastrophic for the launcher and payload electronic [3].

In order to improve the immunity of aircrafts to the aforementioned indirect effects of lightning strikes it is necessary to measure the interference coupled to cables and antennas placed inside the fuselage under real conditions. Hence, a compact and light weight measurement system for electromagnetic interference (EMI) capable of measuring properly transient disturbances is required.

Recently, specific implementations of Time-Domain EMI (TDEMI) measurement systems for conducted and radiated emissions measurements, with the emphasis in the evaluation of the impact of transient disturbances have been presented [4]. Those oscilloscope based TDEMI measurement systems do not require an intermediate frequency stage, therefore they will be further referred as Full-TDEMI measurement systems.

Currently, the improved capabilities of Full-TDEMI measurement systems and the advantages derived from measuring in the time-domain [5] make it feasible to implement a compact setup for on-board assessment of EMI with remarkable capabilities for performing: Mixed (Time/Frequency) domain analysis, signal decomposition [6], statistical evaluation of the EMI [7] and its impact on the degradation of communication systems [8], [9].

In that sense, this paper is intended to present an on-board compact system for electromagnetic interference measurements and experimental results that support suggested applications.

2. MEASUREMENT REQUIREMENTS

A specific EMI measurement system suitable for on-board measurements of the indirect effects of lightning strikes shall be able to:

- Measure simultaneously and synchronously electric and magnetic fields and induced currents and voltages.
- Provide a full spectrum measurement result, and not just monitoring selected frequencies.
- Comply with the usually restrictive volume and mass budget, therefore it shall be as compact and light weighted as possible.
- Be used to anticipate the degradation caused by the EMI in the on-board communication systems.

In this regard, time-domain measurement techniques seem to be the more straightforward alternative to satisfy the abovementioned requirements because:

- It takes advantage of the multichannel feature of oscilloscopes.
- It can be used to estimate the EMI spectrum in the whole measurement bandwidth using the Short-Time Fourier Transform and derived methods.
- USB oscilloscopes are relatively small, consume little power and are light-weighted.

- The measured EMI in the time-domain contains all the information required to predict accurately the degradation suffered by digital communication systems by means of the Amplitude Probability Distribution (APD) detector.

3. THE MEASUREMENT SYSTEM

The on-board compact system for Full-TDEMI measurements is based on a USB oscilloscope with the following main specifications: 4 channels, 200 MHz of analog bandwidth, 1 GS/s as the maximum sampling rate, a flexible resolution of 8 to 16 bits and a buffer memory of 512 MS. With regards to other relevant specifications, the size it is contained in the 190 x 170 x 40 mm volume, it consumes 1.5 A at 5 V of d.c. power and it weighs approximately 0.5 kg.

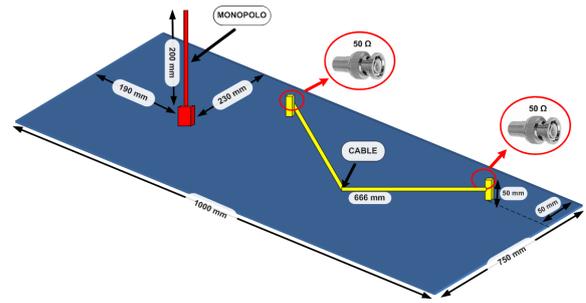
This measurement system is able to measure simultaneously the indirect effect of a lightning strike in terms of the voltages, currents and/or electromagnetic fields depending on the type of probe/antenna used for monitoring. Its triggering capabilities allow to synchronize the acquisitions with the instant of occurrence of a certain event defined by the leading or the trailing edge of a pulsed EMI. Then the time-domain data is transferred to a computer that runs a specific software intended to perform the signal processing (windowing, filtering, equalization, decimation, spectral estimation, correction, and escalation) required to present the results in the frequency-domain according to the standards for emissions measurement.

4. EXPERIMENTAL SETUP

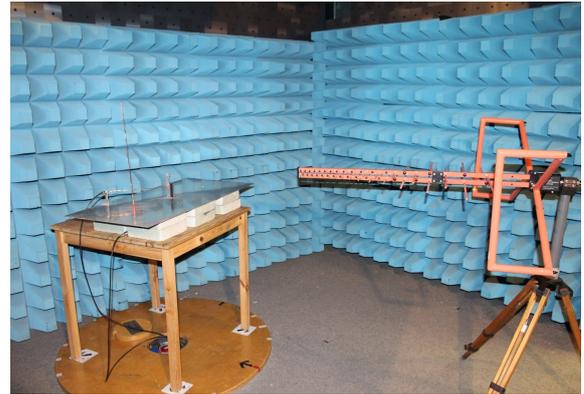
This experiment is intended to verify the suitability of the compact Full-TDEMI measurement system for the on-board assessment of the indirect effects of lightning strikes in aircrafts.

This experiment consisted in using the compact Full-TDEMI measurement system for measuring the voltage induced in a monopole antenna and in an unshielded cable placed over the same ground plane. The ground plane represents the fuselage of the aircraft.

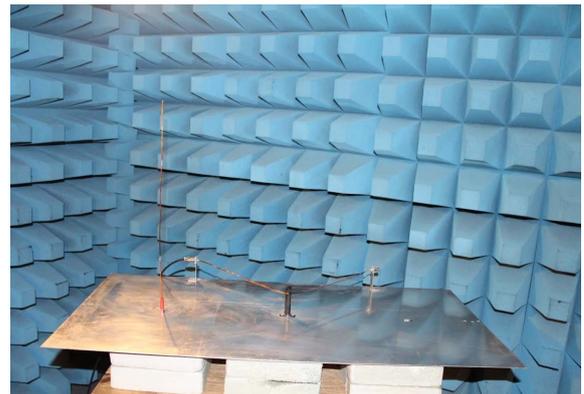
The source of the disturbance was an arbitrary waveform generator Agilent 81160A. The coupled disturbance voltage was measured simultaneously in the 10 MHz – 200 MHz frequency range using two oscilloscope channels. Measurements were performed inside a fully anechoic room (FAR). The disturbance field was radiated using a Schaffner CBL6143 bilog antenna in horizontal polarization placed at a 1 m distance from the antenna. Fig. 1 shows the previously described test setup.



a) Diagram of the fuselage emulating setup.



b) Test setup. Side view.



c) Test setup. Front view.

Figure 1. The experimental test setup.

Firstly, the accuracy of the compact Full-TDEMI measurement system was verified using a synthesized multi-tone test signal with 5 MHz tone spacing. This multi-tone test signal was applied into the radiating bilog antenna. Then the voltage coupled to the monopole and to the cable was measured using the compact full-TDEMI measurement system and an EMI test receiver. As shown in Fig. 2 and Fig. 3, both methods provide approximately the same results for the amplitude and the frequency of the tones. For the measurement of the amplitude of the prominent peaks, the difference between both measurement methods was ± 1.28 dB in the worst case.

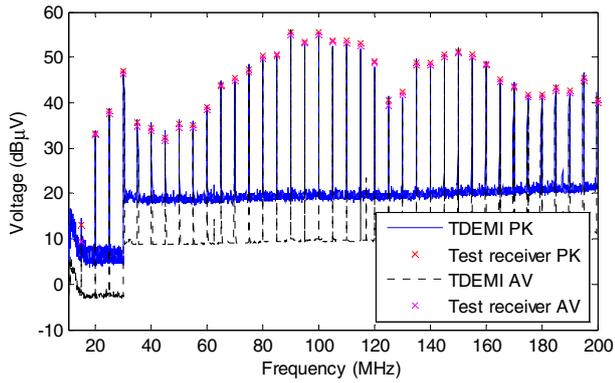


Figure 2. Voltage coupled to the antenna due to the indirect application of a radiated multi-tone test signal.

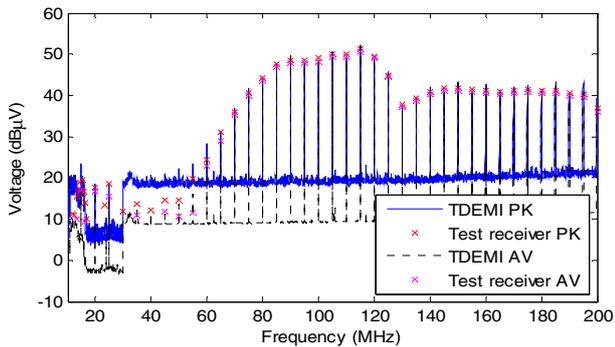


Figure 3. Voltage coupled to the cable due to the indirect application of a radiated multi-tone test signal.

In the next stage of this experiment, a surge pulse with the rise and fall times specified by the “RS105, radiated susceptibility, transient electromagnetic field MIL-STD-461E” standard was generated using the arbitrary waveform generator Agilent 81160A. Then, this surge pulse was applied to the input of the radiating antenna. The disturbance voltages induced in the monopole antenna and in the cable were measured using the compact Full-TDEMI measurement system and the results are shown in Fig. 4.

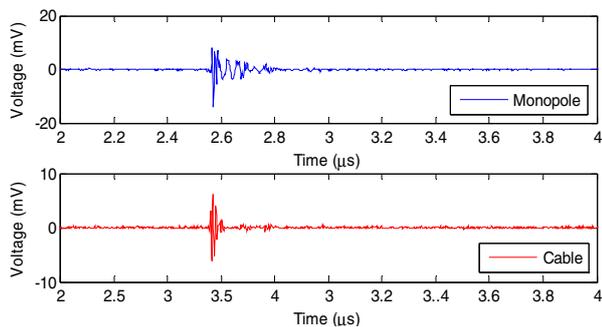


Figure 4. EMI measurement in the time-domain

This transient EMI is clearly a broadband disturbance that occupies almost the whole measured spectrum during its occurrence, as shown in Fig. 5. An EMI test receiver would have been unable to measure properly such disturbance since it is a one-time event.

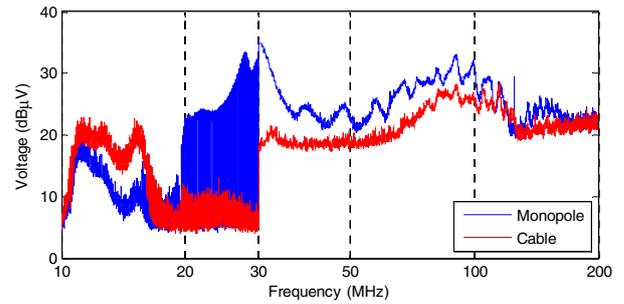


Figure 5. EMI measurement in the frequency-domain

From Figure 5 it is important to notice the change in the resolution bandwidth (RBW) used for presenting the results in the frequency domain. Below 30 MHz, a 9 kHz RBW was used (CISPR band B) while for the 30 MHz – 200 MHz frequency band a 120 kHz RBW was used (CISPR band C). Since the direct measurement results are in the time-domain, practically any required RBW can be selected for the EMI spectral estimation by configuring the appropriate windowing parameters in the Short Time Fourier Transform.

5. DISCUSSION

This experiment was an approximation of a real scenario intended to exercise the implemented compact TDEMI measurement system to quantify disturbances induced as indirect effects of a lightning strike.

In that sense, the test method RS-105 from MIL-STD-461E was used to perform the described experiment as a proof of concept for the feasibility and convenience of using a Full-TDEMI for the on-board evaluation of lightning induced transient. However, other test methods and their waveforms, such as those described in the section 22 of the standard RTCA-DO-160G “Environmental Conditions and Test Procedures for Airborne Equipment” are also compatible with Full-TDEMI measurement systems.

6. CONCLUSION

The current USB oscilloscope technology complemented by specific measurement processing software allowed to implement a reliable and feasible Full Time Domain Electromagnetic Interference measurement system capable of being used for monitoring the electromagnetic fields on-board aerospace vehicles. The accuracy, the precision and the dynamic range of the on-board Full-TDEMI measurement system are sufficient for the required applications and have been verified for the measurement of both continuous wave and pulsed emissions. This compact TDEMI measurement technology is especially suitable for monitoring the indirect effects of a lightning strike on launch vehicles, aircrafts, and UAV because its acquisitions can be triggered by the transient disturbances coupled into cables and antennas inside the fuselage.

ACKNOWLEDGMENT

This work was supported by the Spanish “Ministerio de Economía y Competitividad,” under project TEC2013-48414-C3-3-R.

REFERENCES

- [1] G. A. Rasek, E. Pascual-Gil, A. Schroder, I. Junqua, R. Guidi, C. A. Kreller, H.-D. Bruns, and S. E. Loos, “HIRF Transfer Functions of a Fuselage Model: Measurements and Simulations,” *IEEE Trans. Electromagn. Compat.*, vol. 56, no. 2, pp. 311–319, 2014.
- [2] M. Aprà, M. D'Amore, K. Gigliotti, M. Sabrina Sarto, and V. Volpi, “Lightning Indirect Effects Certification of a Transport Aircraft by Numerical Simulation,” *IEEE Trans. Electromagn. Compat.*, vol. 50, no. 3, pp. 513–523, 2008.
- [3] M. A. Uman and V. A. Rakov, “The interaction of lightning with airborne vehicles,” *Progress in Aerospace Sciences*, vol. 39, no. 1. pp. 61–81, 2003.
- [4] M. A. Azpúrua, M. Pous, and F. Silva, “A Measurement System for Radiated Transient Electromagnetic Interference Based on General Purpose Instruments,” in *Electromagnetic Compatibility (EMC EUROPE), International Symposium on*, 2015.
- [5] M. A. Azpúrua, M. Pous, and F. Silva, “Improving Time-Domain EMI measurements through Digital Signal Processing,” *Electromagn. Compat. Mag.*, vol. 4, no. 2, pp. 66–74, 2015.
- [6] M. A. Azpúrua, M. Pous, and F. Silva, “Decomposition of Electromagnetic Interferences in the Time-Domain,” *IEEE Trans. Electromagn. Compat.*, (early access), 2016.
- [7] M. A. Azpúrua, M. Pous, and F. Silva, “On the Statistical Properties of the Peak Detection for Time-Domain EMI Measurements,” *Electromagnetic Compatibility, IEEE Transactions on*, vol. 57(6), pp. 1374 - 1381, 2015.
- [8] M. Pous and F. Silva, “Full-Spectrum APD Measurement of Transient Interferences in Time Domain,” *Electromagnetic Compatibility, IEEE Transactions on*, vol. 56, no. 6. pp. 1352–1360, 2014.
- [9] M. Pous, M. A. Azpúrua, and F. Silva, “Measurement and Evaluation Techniques to Estimate the Degradation Produced by the Radiated Transients Interference to the GSM System,” *Electromagnetic Compatibility, IEEE Transactions on*, vol. 57(6), pp. 1382 - 1390, 2015.