Benefits of Full Time-Domain EMI Measurements for Large Fixed Installation

Marc Pous[1], Marco Azpúrua[1] and Ferran Silva[1]
[1] Grup de Compatibilitat Electromagnètica (GCEM), Departament d'Enginyeria Electrònica (DEE)
Universitat Politècnica de Catalunya (UPC)
Barcelona, Spain
email: marc.pous@upc.edu

Abstract— **It is difficult to properly evaluate the electromagnetic disturbances generated by large fixed installations because of, i.e., the background noise, unsteady emissions and transient interferences. Those challenging EMC issues have been recently studied in European research projects on improved test methods in industrial environments. In order to overcome traditional *in-situ* EMI measurement troubles, a novel time-domain methodology is proposed and used in a real fixed installation with large machinery. Firstly, a comparison between the developed measurement system, using an oscilloscope, and an EMI receiver is done in some test-cases for validation purposes. After verifying the accuracy of the measurements, we proceed with the measurement campaign applying the full time-domain methodology. The main benefits of employing the time-domain system are emphasised through the results. It was observed that the some remarkable advantages of the time-domain approach are: triggering by disturbance events, extremely reduce the capturing time, identify on real time the worst emissions modes of the EUT, avoid changes at the background noise and perform simultaneous multichannel synchronous measurements.**

Keywords—time-domain measurements; fixed installations; in-situ meaurements; conducted, radiated, background noise

I. INTRODUCTION

Within the framework of a European research project [1] novel measurement methodologies have been developed. The goal is to perform reliable *in-situ* electromagnetic interferences (EMI) measurements. It is well known that carrying out radiated and conducted EMI measurements is challenging in large fixed installations scenarios [2-4]. In comparison with the tests conducted in an electromagnetic compatibility (EMC) test laboratory, *in-situ* measurements have a common and meaningful problematic related to the inherent uncontrolled environment conditions.

In particular, the lack of a line stabilization impedance network (LISN) in *in-situ* conducted emissions assessments causes that the noise generated by other equipment connected to the same power network is not filtered from the EMI generated by the equipment under evaluation. Hence, uncontrolled and discontinuous interferences are present at the power supply measured cable increasing uncertainty of the results.

The procedure to distinguish the emissions produced by the equipment under test (EUT) and the ambient noise described at CISPR 16-2-5 technical report consists, basically, into capturing the interferences when the EUT is switched off (or in standby) and then turning on the EUT and repeat the measurements. It is considered that the differences on the spectrum are due to the emissions of the EUT. However this procedure is obtaining the data at different moments and the results can be affected by the variations of the background noise. Nevertheless, these fluctuations can be caused by a discontinuous interference generated by other loads connected to the same power or communication network.

Another problem is that large machinery measured in fixed installations has many different functional modes producing numerous interferences. It shall be considered that a large fixed installation can have many engines, electronics, etc. that work following a long procedure for which it has been designed for. For instance, at the real installation presented in this paper, the noisiest engines were active only during few seconds within a long functioning cycle that last several minutes. Hence, if frequency sweep based or stepped scan based EMI measuring apparatus are employed, the required overall measurement time would be extremely long to measure properly all the frequency range. In addition to the time-constrain that we have mentioned, we must also add that if we use the detectors defined at the EMC standards such as the quasi-peak or the average detectors this trouble is even worst. For example, if we perform a conducted EMI measurement with the average detector from 150 kHz to 30 MHz for it can take around 10 minutes to complete a frequency sweep which is a waste of time if we consider that the worst interference is generated only during few seconds. Hence, if we employ conventional frequency sweep instrumentation, the emissions produced by the EUT will be constantly changing and the results obtained along the spectrum will correspond to different measured situations.

Fortunately, current capabilities of hardware and previously studies demonstrate that it is feasible and reliable to perform time-domain measurements instead of frequency sweeps to obtain the spectral information of the interference [5-7]. Therefore, in this paper a measurement system based on time-domain captures is employed to overcome these main difficulties that recurrently appear when *in-situ* measurements are carried out. Moreover, other benefits that time-domain

978-1-5090-1416-3/16/$31.00 ©2016 IEEE

measurements offer will be highlighted and explained at the following sections.

II. METHODOLOGY

In this section the key aspects of the full-time-domain EMI measurement system and the main benefits of using it are explained.

A. *Overview of the Full-Time domain measurement system*

The full-time-domain (Full-TDEMI) EMI measurement system employed for the *in-situ* measurements have been developed and extensively used in recent years by GCEM-UPC [8-12]. This measurement system is based on a time-domain acquisition followed by a post-processing stage which allows obtaining equivalent results than conventional EMI test receiver.

Figure 1 shows a block diagram of the measurement system, indicating that the measurement can be done either with an antenna, a current clamp, a voltage probe, etc. The time-domain data is acquired by a general purpose oscilloscope and the post-processing is carried out with a standard laptop. The amplitude spectrum of the EMI is computed using the Short-Time Fourier Transform and non-parametric spectral estimation methods. More details can be found at [8-12].

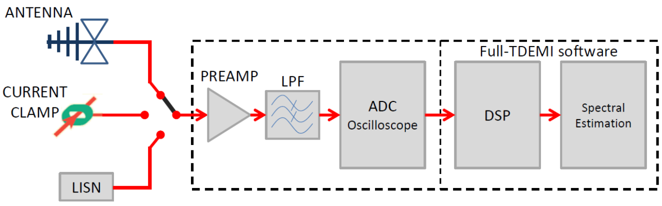

Fig. 1. Full TDEMI measurement system block diagram

Regarding the equipment and the software used to conduct the measurements at the fixed installation shown in this paper two different hardware have been used. To obtain the measurement for conducted emissions according to CISPR 16 standards, a Picoscope 5444B has been used for the acquisition stage. The conducted measurement system is limited to 200 MHz, the maximum sampling rate is 1 GSample/s and the total storage memory is 512 MSamples. Moreover, for conducted disturbances measurements, a multiline voltage probe has been constructed according to CISPR 16-2-1 specifications in order to measure the EMI at several lines of the EUT simultaneously. Fig. 2 shows an *in-situ* measurement using the multiline voltage probe which it is connected to the EUT and then to the oscilloscope.

Likewise, for radiated emission tests up to one gigahertz, an oscilloscope Tektronix model DPO5104B has been used. In this case the oscilloscope is connected to a biconical or to a log-periodic antenna depending on the frequency range.

B. *Main benefits of the Full-TDEMI measuring system for in-situ measurements*

- Reduction of the effective measurement time: Comparing Full-TDEMI measurements with traditional frequency sweep methodologies with regards to the effective measurement time; the time-domain based systems are able to obtain the full spectrum information in milliseconds instead of several minutes.

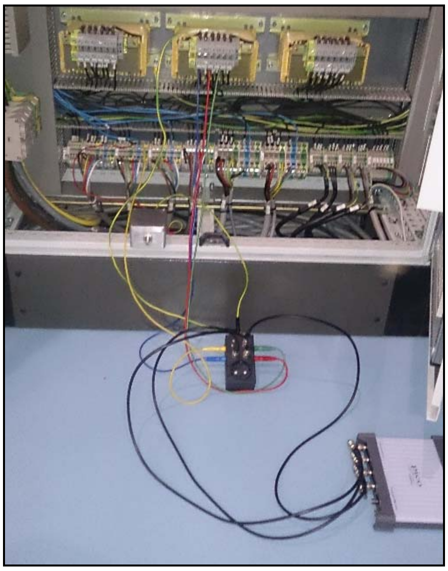

Fig. 2. In-situ example measurement for conducted emissions employing the time-domain methodology and the multi-channel in-situ voltage probe.

  Therefore, capturing data at this speed reduce the possibility of changes in the EUT functional mode. As it has been mentioned at the introduction, in large installations the EUT could have many functional modes lasting only few seconds, and it is really challenging to measure the full spectrum mode in each functional mode. Additionally, reducing the capturing time to a practical instantaneous capture of some milliseconds, the uncertainty contribution due to the changes in the background noise during the observation time can be reduced. Escaping from continuous changes at the emissions produced by other equipment connected to the power supply or either intermittent transmitters. Finally, the reduction of the capturing time is an opportunity for the industry to perform more controls and measurements to the fixed installations due to the cost reduction.

- Full spectrum real-time measurements: Another advantage that time-domain methodologies offers to the end users is that it is possible to obtain both the spectral and time domain information in a real-time. This means that the user can view the entire spectrum and the time domain signal several times per second (depending on the hardware and software employed). This is an important advantage compared with the frequency sweep instrumentation as we have several benefits. Firstly, it is easy to identify the worst cases as the spectrum is refreshing constantly, moreover as we are using time-domain instrumentation, we have several trigger functionalities available. Therefore it is possible and simple to measure, for instance, transient events like the disturbances that appear when we are switching ON or OFF. Moreover, it is important to mention that capturing transient phenomena employing frequency sweep instrumentation is near to impossible.

- Multichannel synchronous measurements: This feature is available because the instrumentation used for time domain acquisition has multiple input channels instead of the unique channel, as happens with EMI receivers. Therefore, for conducted emissions the multichannel Full-TDEMI allows to perform simultaneous measurements at the different lines of the power supply, which is particularly useful for *in-situ* measurements. The main benefits are the combined testing time reduction and also to avoid differences caused by influence of the background noise. These multichannel measurements can be performed with the aid of a multiline voltage probe, as shown in Fig. 2.

- Versatility of the measurement system: The Full-TDEMI system can be USB powered and it has sufficient autonomy to be used in conjunction with a standard laptop. Therefore, this is a grateful advantage for *in-situ* measurements where it is difficult to power the measuring equipment. Many times a long cable has to be placed in order to power the measurement instruments and other times the instruments are connected to the same mains from where EMI is being measured causing additional errors.

- Time-domain data available: Finally, it is important to highlight that having available the time domain data is a great advantage compared with the limited information provided by traditional EMC measurements using the EMI receiver. Previous research has demonstrated the time domain data of the EMI can be used to predict the bit-error-rate of digital communication systems [13].

III. RESULTS

Some of the results produced by measuring the real scenario of the large fixed installation are shown to illustrate the advantages of the time-domain measurement system. In the following sections you will find a description of the measured scenario, some validation results comparing the time-domain data with standard EMI receiver measurements and finally the results that highlight the main benefits of using the time-domain measurement system instead of the traditional frequency sweep instrumentation.

A. Measured scenario

A complex scenario was measured in accordance with the requirements of the customer. The large fixed installation is an automatic storage and retrieval system composed by various large machinery including engines, elevators, shuttles, etc. running a complex working cycle.

B. Validation

Several comparisons were made for conducted and radiated disturbance measurements to determine if the time-domain approach provided coherent results when compared with an EMI test receiver, which is taken as the standard reference. Following some comparison results of a conducted measurement test case are shown in Fig. 3.

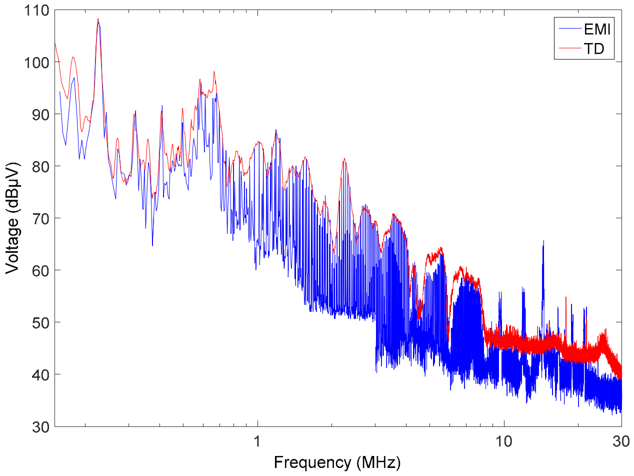

Fig. 3. Conducted EMI peak measurement comparision between time-domain methodology and a conventional EMI test receiver

From the Fig. 3, it is important to highlight that with the time-domain system a dynamic range up to 70 dB can be reached. This is important because dynamic range is one of the main concerns when oscilloscopes are employed instead of EMI receivers.

Regarding the comparison between the results obtained with the EMI receiver and the ones reached with the Full-TDEMI approach, there is and evident similarity between both results. Moreover, an objective validation method was applied to quantify the agreement of the measurement in terms of the EMI amplitude spectrum. The Feature Selective Validation (FSV) method, which is described into IEEE standard 1597.1 has been used with the limit-line consideration improvement [14] to compare the results. This limit-line criterion weights the influence of the points according to their relevance in terms of their proximity to a certain limit-line, which is an interesting capability from an EMC point of view. The limit line used for this purpose is the one defined for industrial environments (Class A limit). The results provided by the FSV method are shown below in Table I.

TABLE I. FSV VALIDATION RESULTS

Indicator	***Result***	
Amplitude Difference Measure (ADM)	0.193	Very Good agreement
Feature Difference Measure (FDM)	0.6	
Global Difference Measure (GDM)	0.66	

Hence, the conclusion of the comparison with the FSV is that the agreement is very good. This similarity is very good in terms of shape and excellent considering the amplitudes.

Also regarding the data displayed at Fig. 3, from 10 MHz till 30 MHz frequency band, differences can be appreciated between the EMI receiver and the TD system. These differences are attributable to the capturing time, which is longer when the frequency sweep method is applied. The measuring time needed for the EMI receiver is around 5 minutes to obtain the peak measurement; consequently the noise produced by the other equipment connected to the power supply network is not stable. On the other hand, the instantaneous measurement of the full-TDEMI methodology allows more control in terms of the changes in the background noise.

According to the great similitude observed at the results shown and other measured cases, we decided to continue with the measurements using only the time-domain methodology due to the benefits commented at the previous sections.

C. Time-domain results

The fixed installation is measured using the methodology described in section II. Next, some representative results are used to illustrate the advantages.

The first set of measurements presented was obtained when conducted emissions measurements were carried out. As it has been discussed previously, the different functional modes of the large installation generate different type of interferences. In Fig. 4 and Fig. 5 the results in time domain and frequency domain shows as the huge differences that appear when the different components of the installation connected to the same power supply are working. The tools available at the software allow the user to see in real time the changes of the full spectrum making it easy to identify the cases with strongest emissions. From the comparison of the spectrum measured at two different functional modes, differences of more than 40 dB are observed in the EMI. In Fig. 4, the results are obtained when some rollers of the fixed installation start to move. Otherwise, Fig. 5 shows the results in time and frequency domain when an elevator was activated.

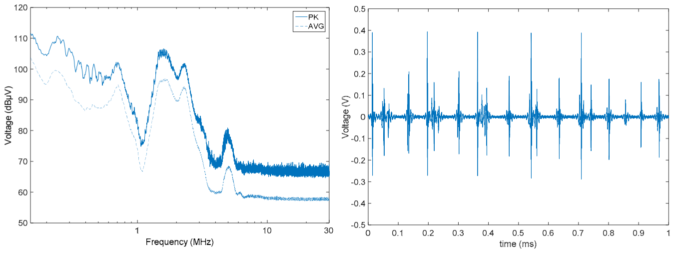

Fig. 4. Results in frequency domain with the peak and average detector and the time domain data when the rollers were measured.

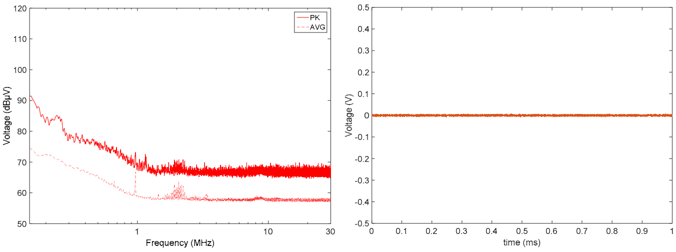

Fig. 5. Results in frequency domain with the peak and average detector and the time domain data when the elevator was measured.

It is really important to highlight that the movement of the rollers only last 5 s in the entire machinery cycle of several minutes. Therefore, if a traditional frequency sweep approach were used it would have been extremely unlikely to measure this worst case emissions. Probably, these worst case emissions have been omitted due to the short duration of the rollers cycle. Moreover, if an EMC expert has estimated beforehand that the worst test case should correspond to the elevator disturbances, a wrong assessment of the EMC would have been produced.

Then, in order to demonstrate other capabilities of the time-domain *in-situ* measurements, Fig. 6 shows the results obtained with the time-domain system in another location of the fixed installation. The results were obtained employing synchronous measurements from the three-phase EUT power supply. In Fig. 6, the results of the peak and average detector EMI measurements are presented. With an instantaneous measurement we were able to capture not only the highest emission level of the fixed installation, but also the average measurements. This is a step forward if we think in terms of ensuring that we are sure of getting the highest disturbances of the EUT and also in terms of time-reduction to have the full frequency range response of the three lines with both detectors. To illustrate this statement we have also conducted a measurement with a traditional EMI receiver.

In this case, only the peak detector was employed as it is the fastest alternative to sweep the spectrum. Compared with the time domain measurement, where the full peak and average spectrum are obtained for the three lines using only a 100 ms measurement, it was required to spend more than 20 minutes to obtain an almost equivalent results using the peak detector and measurement with the EMI receiver. Although frequency sweeps were repeated continuously over more than 20 minutes with the *maxhold* function, it was not sufficient to record the full spectrum interferences generated by the EUT. Due to the time restrictions it was not possible to perform the average measurement on this facility.

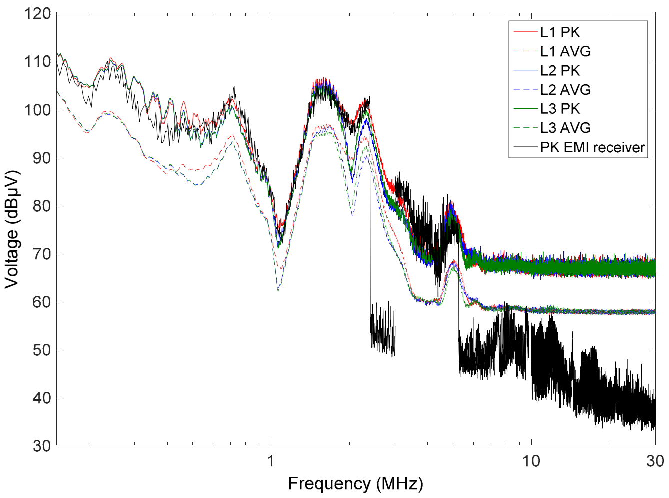

Fig. 6. Conducted peak and average EMI measurements for every line of the mains port of a three-phase EUT employing the full time-domain methodology and a peak measurement of one line using the EMI receiver.

From the results observed in Fig. 6, between 2 MHz and 3 MHz there is not significant data when the EMI receiver is used. In this frequency band, the emissions generated by the EUT are not captured as the frequency sweep is not synchronized with the occurrence of the interference in any of the multiple sweeps performed during the 20 minutes of measurement. In the rest of the EMI frequency spectrum the fitting of the TD method results and the EMI receiver are excellent in terms of amplitude and shape.

Next some results of the radiated emissions are also shown to demonstrate that measuring with the oscilloscope is also feasible for radiated emissions tests. As it has been mentioned before, ambient noise is one of the main concerns of *in-situ* measurements. From the results given by Fig. 7, the ambient noise of the FM radio broadcasting service and other transmitting signals close to 200 MHz are easily identified. However, broadband interferences are detectable around 50 MHz and they are clearly attributable to the EUT when it is switched on.

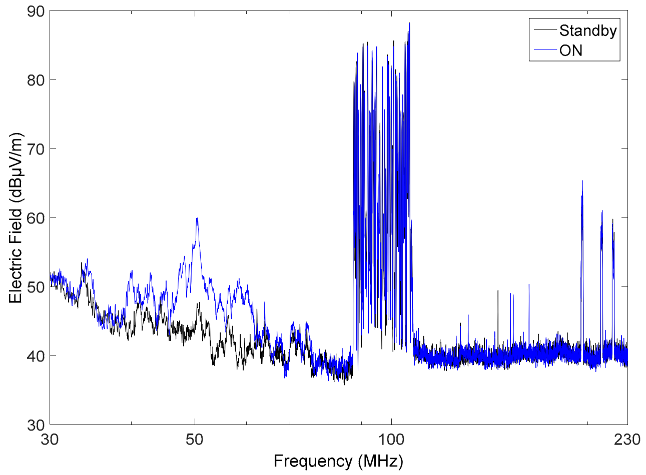

Fig. 7. Radiated peak measurements employing the full time-domain measurement system for an EUT when it was at standby and switched on.

In this case, the main advantage of using the time-domain methodology is that we are able to perform instantaneous measurements, avoiding changes at the background noise that introduce confusion to the EMC assessment. As we have the capability to analyse the full spectrum with instantaneous time domain captures we can identify the emissions produced by all the functional modes of the EUT and be immediately aware of the changes at the spectrum. Otherwise, using traditional slow frequency sweep instrumentation we can miss interferences that last few seconds and also misunderstand changes at the background noise confusing it with emissions of the EUT.

IV. DISCUSSION AND CONCLUSIONS

With the aim to improve the measurement of the disturbances at large fixed installations, the full time-domain methodology has been developed and validated with a measurement campaign. The results shown in this paper conclude that the main troubles of *in-situ* measurements can be partially solved by using a time-domain approach. Moreover, through the different comparisons done, it has been shown that it is also possible to obtain as good results in terms of accuracy as with an EMI receiver.

Regarding the main benefits observed, the time-domain methodology aids the test technician to overcome challenges such as the changes of background noise, evaluate accurately all the EUT functional modes (even the short lasting ones) and reduce significantly the effective measurement time. As has been shown along this paper, one key aspect is the multiple channel synchronous measurements capability, this allow us to carry out conducted disturbances measurements at three-phase power supply lines employing the multiline voltage probe. Furthermore, multiple channel synchronous measurements open many possibilities that are particularly interesting for *in-situ* measurements, including advance triggering capabilities and measurements post-processing for ambient noise cancellation. Finally, it is essential to highlight that with the time-domain measurements the spectrum data is available in terms of the amplitude and the phase. Therefore, it is possibly to use this data to predict if the noise generated by the EUT is degrading the performance of any digital communication system, since it has been shown that peak, quasi-peak or average measurements are not sufficient to estimate directly the degradation suffered by digital communication systems.

To conclude, in the near future time-domain EMI measurements are likely to become the standard approach for *in-situ* industrial assessments due to the benefits it offers in comparison with traditional frequency sweep instrumentation.

ACKNOWLEDGMENT

This work was supported in part by the EURAMET IND60 EMC research project (the EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union) and by the Spanish “Ministerio de Economía y Competitividad,” under project TEC2013- 48414-C3-3-R.

REFERENCES

[1] EMPR JRP IND60 Improved EMC test methods in industrial environments. (http://www.emc-industry.com/)

[2] J. Catrysse, F. Vanhee, J. Knockaert, I. Hendrickx and V. Beauvois, "In situ testing of large machines: Alternative methods for conducted emission measurements," *Electromagnetic Compatibility, 2008. EMC 2008. IEEE International Symposium on*, Detroit, MI, 2008, pp. 1-6.

[3] A. Tacchini, "Radiated emission testing: In-situ measurements on large machines," *Electromagnetic Compatibility (APEMC), 2010 Asia-Pacific Symposium on,* Beijing, 2010, pp. 1610-1613.

[4] Z. H. Lu, J. B. Liu and P. G. Liu, "A Novel Method of Ambient Interferences Suppressing for In Situ Electromagnetic Radiated Emission Test," *in IEEE Transactions on Electromagnetic Compatibility,* vol. 54, no. 6, pp. 1205-1215, Dec. 2012.

[5] S. Braun, T. Donauer and P. Russer, "A Real-Time Time-Domain EMI Measurement System for Full-Compliance Measurements According to CISPR 16-1-1," *Electromagnetic Compatibility, IEEE Transactions on,* vol. 50, no. 2, pp. 259-267, May 2008

[6] C. Keller and K. Feser, "Fast Emission Measurement in Time Domain," *Electromagnetic Compatibility, IEEE Transactions on,* vol. 49, no. 4, pp. 816-824, 2007.

[7] F. Krug and P. Russer, "The Time-domain Electromagnetic Interference Measurement System," *Electromagnetic Compatibility, IEEE Transactions on,* vol. 45, no. 2, pp. 330-338, May 2003.

[8] M. A. Azpurua, M. Pous, S. Cakir, M. Cetinta and F. Silva, "Improving time-domain EMI measurements through digital signal processing," *in IEEE Electromagnetic Compatibility Magazine*, vol. 4, no. 2, pp. 82-91, 2nd Quarter 2015.

[9] M. A. Azpurua, M. Pous and F. Silva, "A measurement system for radiated transient electromagnetic interference based on general purpose instruments," *Electromagnetic Compatibility (EMC), 2015 IEEE International Symposium on,* Dresden, 2015, pp. 1189-1194.

[10] G. Costa, M. Pous, A. Atienza and F. Silva, "Time-Domain Electromagnetic Interference Measurement System for intermittent disturbances," *Electromagnetic Compatibility (EMC Europe), 2014 International Symposium on*, Gothenburg, 2014, pp. 833-837.

[11] M. A. Azpurua; M. Pous; F. Silva, "Decomposition of Electromagnetic Interferences in the Time-Domain," *in IEEE Transactions on Electromagnetic Compatibility* , vol.PP, no.99, pp.1-8

[12] M. A. Azpurua, M. Pous and F. Silva, "On the Statistical Properties of the Peak Detection for Time-Domain EMI Measurements," *in IEEE Transactions on Electromagnetic Compatibility*, vol. 57, no. 6, pp. 1374-1381, Dec. 2015.

[13] M. Pous, M. A. Azpurua and F. Silva, "Measurement and Evaluation Techniques to Estimate the Degradation Produced by the Radiated Transients Interference to the GSM System," *in IEEE Transactions on Electromagnetic Compatibility*, vol. 57, no. 6, pp. 1382-1390, Dec. 2015.

[14] R. Jauregui, M. Pous and F. Silva, "Use of reference limits in the Feature Selective Validation (FSV) method," *Electromagnetic Compatibility (EMC Europe), 2014 International Symposium on*, Gothenburg, 2014, pp. 1031-1036.