Broadband Measurement of Spread Spectrum Signals

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Abstract— Starting from an analysis of the limitations due the process implemented to calibrate broadband field probes, the paper illustrates an experimental procedure that allows the use of these instruments for an estimation of digitally modulated electromagnetic field, thanks to an extended pre-calibration process. The process permits to identify probes that guarantee a measurement error within desired bounds. In presence of known and controlled signals, it offers a possibility to correct the measurement by use of a pre-characterised offset.

I. INTRODUCTION

The identification of reliable procedures for the measurement of modulated electromagnetic fields assumes a growing interest for a correct assessment of citizens exposure to radio transmitters emissions. On the other hand, last generation radio services make use of more and more complex modulations, that may preclude or limit the use of the standard procedures implemented for electromagnetic compatibility radiated measurements.

This paper concentrates the analysis on the application of broadband field probes for the measurement of spread spectrum digital signals. In the recent years, spread spectrum transmissions were widely exploited for any kind of wireless application, from broadcasting, to cellular and networking services. Digital Audio Broadcasting (DAB), Digital Radio Mondiale (DRM) and Digital Video Broadcasting (DVB) make use of Orthogonal Frequency-Division Multiplexing (OFDM). Third Generation Mobile Networks make use of (Wideband) Code Division Multiple Access ((W)-CDMA), while the next generation (Long Term Evolution - LTE) is moving towards OFDM. Personal, Local and Metropolitan Wireless Networks (WPAN, WLAN and WMAN) make use of Direct Sequence Spread Spectrum (DSSS) and OFDM, while Frequency Hopping Spread Spectrum (FHSS) is exploited by former WLAN standards and Bluetooth. Among all these applications, W-CDMA, DSSS and OFDM based systems are the ones characterized by higher radiated powers. Consequently, an electromagnetic field exposure assessment in presence of such services could be required in many circumstances.

The presence of additional measuring uncertainties due to the effect of a modulation was already demonstrated in literature [1], [2]. In particular, it was shown that diode detectors may overestimate digital signals implemented for W-CDMA communications [3], [4]. Nevertheless, many international standards take into consideration the use of field probes as a first means for an initial assessment of human exposure [5].

Recently, an experimental procedure for an accurate estimate of the additional measurement error due to the use of field probes in presence of a complex modulation, has been introduced [6]. Starting from the obtained results, this paper describes a method for a selection of the most suitable probe and analyzes the possibility to set up a compensation process.

II. FIELD MEASUREMENTS BY FIELD PROBES

Electromagnetic field measurements are typically performed by means of broadband probes to characterize the electromagnetic noise over wide portions of the frequency spectrum. The acquisition is realized by means of a detector, that can be constructed either by use of diodes or temperature sensors [7]. Temperature or bolometric detectors are characterized by a linear response over a large dynamic range, but their cost grows exponentially as the desired sensitivity decreases. On the other hand, diode detectors exhibit a better sensitivity for much cheaper prices, but, making use of non linear devices, offer limit dynamic ranges.

Independently from the choice of the detector, to construct a direct relationship between the incident field and the detector output, a calibration process is used. The calibration is performed by exposing the probe at increasing field levels, in a certain dynamic range and at pre-determined frequencies The look-up table consequently defined allows the use of the probe over large dynamic ranges, independently on the detector input/output relationship. Probes are solely calibrated in presence of Continuous Wave (CW) signals, but the process works also for modulated signals with narrow dynamic, like the ones implement for analogue transmissions. On the other hand, the measurement of a modulated electromagnetic field is possibly affected by errors, especially when the dynamic of the detector is limited and the modulation is a wide-band digital one [4], [6]. This error has been referred in [6] as Modulation Additional Error (MAE). In this paper it will be addressed in the same way. In [6] the MAE is calculated as the ratio E_{mod}/E_{CW} , where E_{mod} is the field value indicated by the probe in presence of the digital modulation, and E_{CW} is the field value indicated by the probe in presence of the CW signal, for a constant RMS value of the radiated signal.

It has been demonstrated that, in presence of continuous transmissions [4], [8], the MAE takes the form of an overestimation that increases with the field value; the output increment does not depend only on the signal intensity, but varies, depending on the typology of signal modulation. Moreover, some results obtained by these authors, that will be presented in future publications, demonstrate that discontinuous signals can produce an underestimation.

As a consequence, the use of field probes for the assessment of human exposure to last generation digital radio services, may produce unreliable results.

III. MAE CHARACTERIZATION

Since the MAE depends on modulation characteristics and time variations, it is not clearly possible to compensate it for measurements of uncontrolled transmissions. On the other hand, if the modulation is known and it is possible to exclude the presence of void signals, the MAE can be partially balanced, thanks to an extension of the calibration.

To this purpose, the MAE must be experimentally

measured, exposing the probe to known signals, with increasing field intensity. Since digital signals are characterized by high dynamics, ranging up to 20 dB or more, a specific measurement procedure that allows the generation of fields with the same effective value used for the standard CW calibration, must be introduced. This means that the generated field must exhibit a peak level at least X dB more than the corresponding CW level, where X is the maximum Cumulative Distribution Function (CDF) value of the considered modulation.

The proposed procedure is applied in referenced environments, generating and measuring electromagnetic fields in a fully anechoic chamber. The experimental setup is described in Fig. 1 and is based on the use of a vector signal generator amplified by means of a linear power amplifier. Thanks to the use of a dual directional coupler, the generated signal is monitored by means of a spectrum analyzer combined with a vector digital signal analyser. The main component of the transmitted signal is guided by RF cables into the chamber, to the transmitting antenna; both direct and reflected waves are monitored by use of a second dual directional coupler connected to a dual-channel RF power meter. As a transmitting antenna a standard gain horn is used. Standard gain horns are preferred to other typologies of broadband antennas, to guarantee the flatness of the spectrum over the modulation bandwidth. Moreover, a standard horn antenna offers a satisfactory field uniformity, also in its Fresnel region. Thanks to this uniformity, the probe under test can be placed in vicinity of the radiating antenna, allowing an exposition to field of much higher intensity. This is allowed by the fact that probe antennas are either placed within a cube with side less than 5 cm, or disposed symmetrically on the border of a dumpy cylinder with radius less than 5 cm, height less than 1.5 cm.

The setup was tested in two anechoic chambers, making use of the same instruments: an Agilent Technologies, model number E4438C as signal generator, an Agilent Technologies,

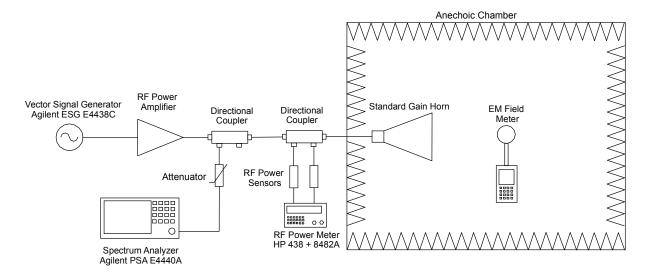


Fig. 1 Experimental set-up used to evaluate the performance of field probes

model number PSA E4440A as spectrum and signal analyser, an HP 436A combined with 8482B/8482A heads as an RF power meter.

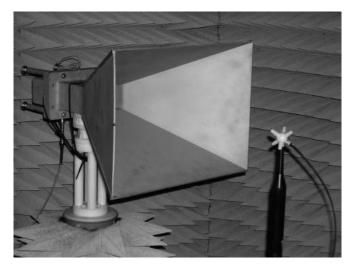


Fig. 2 Example of the set-up in the LACE anechoic chamber



Fig. 3 Installation phase in the INRIM anechoic chamber

The former chamber is located in the Antennas and Electromagnetic Compatibility Laboratory of Politecnico di Torino – LACE (see Fig.2 for reference), the latter is located at the Italian National Metrological Institute – INRIM (see Fig.3 for reference). The LACE chamber is a room with walls (including floor) shielded by means of absorbing material (pyramids 20 cm height) with an available volume of approximately 4m x 2m x 2m. In this chamber it is possible to generate electromagnetic fields up to 30 V/m for frequencies ranging from about 900 MHz to about 3 GHz. The INRIM chamber is a room with walls (including the pavement)

shielded by means of absorbing material (pyramids one meter height) with an available volume of approximately 8m x 4m x 4m. In this chamber it is possible to generate electromagnetic fields up to 35 V/m for frequencies ranging from about 450 MHz to about 4 GHz.

IV. USE OF MAE TO ENHANCE MEASUREMENT RESULTS

Once measured, the MAE offers a direct and simple evaluation of the overestimation or underestimation produced by the probe, as a function of field amplitude. This value can be consequently used to compensate the probe output, to avoid the additional errors due to the presence of digitally modulated field.

To show and demonstrate an example of application, a probe was selected with the following characteristics: application bandwidth from 300 kHz to 6 GHz, nominal CW dynamic range from 0.5 V/m to 300 V/m. The probe makes use of diode detectors and have three orthogonal antennas, for RMS isotropic measurements. Fig. 4 shows the MAE, as a function of field amplitude, for three different kinds of digital modulations: a W-CDMA test signal, with 64 channels, bandwidth 3.84 MHz, a Direct Sequence Spread Spectrum (DSSS) signal, with bandwidth 10 MHz, frames duration 5 ms, full filled frames, and an OFDM signal, with bandwidth 20 MHz, frames duration 5 ms, full filled frames. It is shown that the MAE varies with the modulation, and consequently it is necessary to identify different compensation values for different typologies of signal.

Fig. 5 shows the MAE, as a function of field amplitude, for an OFDM signal, with bandwidth 20 MHz, frames duration 5 ms, frames progressively voided. It can be observed that, with a frame filled down to one half, the MAE is slightly stable, and a unique value can be adopted for measurement compensations.

The reported results demonstrate the possibility to adopt a compensation procedure, by pre-characterizing the additional measurement error due to the modulation. The compensation can be applied easily, but requires the construction of several look-up tables, for any kind of modulated signal. Moreover, since it depends on the time variations of the signal, it is clearly applicable, only when the signal is known or can be controlled at the source.

V. CONCLUSION

The paper introduces the possibility to adopt an extended pre-characterization process, to compensate the inadequacy of broadband field probes for the measurement of broadband spread spectrum digital signals. The procedure has not general validity, but provides a useful help, when the monitored signal has known modulation characteristics. Further researches are still carried out, and results will be presented in future publications.

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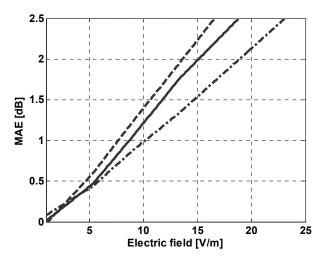


Fig. 4 Compensation factor MAE [dB] as a function of the electric field; continuous line: W-CDMA modulation, 3.84 MHz bandwidth, 64 channels; dash-dotted line: DSSS modulation, 10 MHz bandwidth, frame duration 5 ms; dashed line: OFDM modulation, 20 MHz bandwidth, frame duration 5 ms.

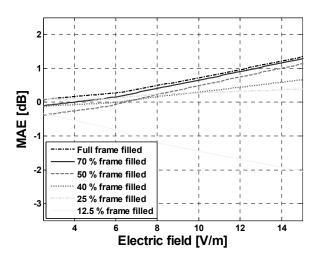


Fig. 5 Compensation factor MAE [dB] as a function of the electric field for an OFDM modulation, 20 MHz bandwidth, frame duration 5 ms; dark dash-dotted line: filled frame;

continuous line: frame filled for 70 %; dashed line: frame filled for 50 %; dotted line: frame filled for 40 %; light dash dotted line: frame filled for 25%; light continuous line: frame filled for 12.5 %.

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