Accurate Measurement of RF Exposure from Emerging Wireless Communication Systems

Thierry Letertre, Vikass Monebhurrun and Zeno Toffano
1Department of Telecommunications, SUPELEC, 3 rue Joliot-Curie, 91192 Gif sur Yvette Cedex, France
2Department of Electromagnetics, DRE-L2S, SUPELEC, 3 rue Joliot-Curie, 91192 Gif sur Yvette Cedex, France

E-mail: thierry.lettertre@supelec.fr, vikass.monebhurrun@supelec.fr and zeno.toffano@supelec.fr

Abstract. Isotropic broadband probes or spectrum analyzers (SAs) may be used for the measurement of rapidly varying electromagnetic fields generated by emerging wireless communication systems. In this paper this problematic is investigated by comparing the responses measured by two different isotropic broadband probes typically used to perform electric field (E-field) evaluations. The broadband probes are submitted to signals with variable duty cycles (DC) and crest factors (CF) either with or without Orthogonal Frequency Division Multiplexing (OFDM) modulation but with the same root-mean-square (RMS) power. The two probes do not provide accurate enough results for deterministic signals such as Worldwide Interoperability for Microwave Access (WIMAX) or Long Term Evolution (LTE) as well as for non-deterministic signals such as Wireless Fidelity (WiFi). The legacy measurement protocols should be adapted to cope for the emerging wireless communication technologies based on the OFDM modulation scheme. This is not easily achieved except when the statistics of the RF emission are well known. In this case the measurement errors are shown to be systematic and a correction factor or calibration can be applied to obtain a good approximation of the total RMS power.

1. Introduction
With the proliferation of wireless communication systems, there is an ever-increasing public concern regarding human exposure to RF fields. Furthermore, in order to avoid potential electromagnetic interference among wireless communication devices, there is also a need to control the electromagnetic emissions. Herein the in-situ measurement of the electric fields (E-fields) emitted by current or future wireless communication systems is investigated. An isotropic broadband probe or a spectrum analyzer (SA) may be used for the in-situ RF exposure evaluation [1]. The legacy measurement protocols are well adapted for the E-field evaluations of regular or predictable systems such as the 2g and the 3g wireless communication systems that occupy a frequency bandwidth of up to 5MHz with a relatively small variation of the signal envelope. Indeed such signal characteristics are compatible with currently used isotropic broadband E-field measurement systems. However the measurement protocols prove to be inadequate for signals with high CF that are emitted by emerging wireless communication systems based on the OFDM modulation scheme such as WiFi, WIMAX and LTE systems. Several recent works have addressed the issue of the E-field measurements of complex digital signals using measurement instruments that are typically calibrated using continuous wave...
(CW) signals [2]. The effect of the digital modulations on the measurements of the specific absorption rate (SAR) is discussed in [3] whereas the in-situ measurements using personal exposimeters are discussed in [4]. The influence of the calibration parameters on the in-situ measurements using either selective or non-selective equipment is discussed in [5]. The influence of the digital modulation schemes (e.g. Phase Shift Keying (PSK), Quadrature Amplitude Modulation (QAM), and OFDM) on the E-field measurements is further discussed in [6].

In emerging wireless communication systems, the CF, also referred to as the peak to average power ratio (PAPR), is a key parameter that must be taken into account because of its non-negligible impact on the E-field evaluations [7-8]. WIMAX and LTE signals are rather difficult to measure accurately because of the rapid variations of their temporal shape. Typically two types of measurement errors have been identified. The first error which is a deterministic one is due to the “burst” and/or due to the duty cycle (DC) of the signal thereby producing a strong power variation over a relatively short time (within the frame time) relative to its average value (typically a few ms). This affects the average power measurements since most SAs and isotropic broadband probes cannot take into account instantaneously the emitted power because of the frame duration which is shorter than the rise time of the detector. The second error which is non-deterministic is inherent to the use of the OFDM modulation scheme in association with the Orthogonal Frequency Division Multiple Access (OFDMA) technique. The superposition of several modulated subcarriers over a wide bandwidth results in relatively high and variable PAPR values (ranging from 10dB to 20dB).

To account for these two errors, a calibration of the measurement system using complex test signals becomes a prerequisite.

2. Test bench and protocol descriptions

The experimental setup is shown in Figure 1. Two isotropic broadband probes, labelled A and B, are submitted to four different signal configurations emitted with the same carrier frequency:

- a) Pure sinusoidal or CW signal, with or without pulsed mode,
- b) Single-carrier modulated signal,
- c) Non-modulated multi-tone signal with variable number of CW sub-carriers,
- d) WIMAX or LTE standard compliant signal where the number of OFDM symbols of the User Data sub-frame is chosen to achieve a given DC target value.

The signals are synthetized using a vector signal generator (Agilent ESG 4438C with the “Signal Studio” software ©Agilent Technologies). Prior to the radiated mode measurements using the isotropic broadband probes, and in aim to minimize the errors, a SA is first used in the conducted mode to verify that the output RMS power of the signal generator is unchanged whatever the waveform chosen. An attenuator is used to reduce the power measured by the SA and compensation is also allowed for the additional cable loss. The embedded complementary cumulative distribution function (CCDF) command of the SA is applied to measure the PAPR or CF values of the emitted waveform. The working frequency \( f = 2.45\)GHz is arbitrarily selected to ensure compatibility with the measurement equipment. The distance \( d \) \((d > \lambda \approx 12.3\)cm\) and the RMS output power \(P_{\text{RMS}} = +20\)dBm\) of the signal generator are fixed to ensure a sufficient level of the E-field for the two isotropic broadband probes without reaching the saturation level for the radiated mode measurements.

![Figure 1](image_url)
3. Measurement results

Figure 2 shows the responses of Probes A and B for the cases of pulsed and WIMAX signals with variable DCs. The results show that the two isotropic broadband probes under test respond correctly to pulsed and CW (DC=1) signals. The E-field values measured by Probe A correspond to the peak value and they are independent of the temporal shape of the signal for pulse widths greater than 4ms. On the other hand the E-field values measured by Probe B correspond to the RMS value and they are linearly dependent on the temporal shape or the DC value of the signal.

![Figure 2. Comparison of the E-fields measured using Probes A and B for the cases of pulsed and WIMAX signals with variable DCs.](image)

When the two probes are submitted to WIMAX stimuli with the same DC as the previously considered pulsed signals (10% < DC < 50%), the measured E-fields are underestimated. The systematic errors are found to be linearly dependent on the square root of the DC value. They can therefore be corrected for the case of deterministic signals with known DC.

Figure 3(a) and (b) show the CCDF and Channel Power measurements of the two waveforms using the SA. The responses obtained by the SA using the default operating mode (e.g. Trace in “ClearWrite” mode) are highly perturbed by the temporal variations of the signal and by the DC value. Strube effects occur between the applied frequency sweep and the “burst” or frames period. Furthermore the measured power is underestimated when the signal bandwidth (from 1 to 20MHz for WIMAX or LTE) is greater than the resolution bandwidth (RBW) of the SA. Some SAs offer alternative measurement capabilities such as “ChPwr” (Channel Power) or CCDF calculus, which can circumvent the small value of the RBW as follows:

a) ChPwr mode: Measurement of the total average power in a specific or chosen channel bandwidth. The measurement is reliable for "broadband", “continuous” or constant DC signals (e.g. WCDMA).

b) CCDF mode: It provides information on how often the measured power is above a given value (typically the average value). A good estimation of the average value of the signal and the PAPR is obtained.

From Figures 3(a) and (b) it is observed that the errors are constant and can be easily adjusted by applying a correction factor.

![Figure 3. (a) CCDF (left) and (b) ChPwr (right) measurements of the pulsed and WIMAX waveforms using the SA.](image)
4. Conclusion

The E-field measurements using isotropic broadband probes show that such diode-detector based probes are not suitable for signals with relatively high power and time variations. A high value of the CF reduces the sensitivity and increases the uncertainty of the measurement. Furthermore the rise time of these detectors is not fast enough to cope with the rapid variations of modern wireless communication signals. The OFDM modulation scheme is not solely responsible for the measurement errors; the wide bandwidth of the useful frequency band is another cause. In order to accurately measure such signals, two approaches may be adopted:

1) Improve the detecting capabilities of isotropic broadband probes in order to render them compatible with the rapid temporal variations of the signals.

2) Apply a first correction factor in order to compensate for the CW-based calibration for the case of deterministic signals (such as WiMAX and LTE) and a second correction factor which takes into account the traffic statistics for non-deterministic signals (such as WiFi).

To compensate for the under-estimation of WIMAX signals due to the response time of the probes, the measured E-field values should be herein multiplied by correction factors $\alpha = 2.78$ and $\beta = 2.08$ for Probes A and B, respectively. Furthermore when using the SA for the in-situ measurements, the more reliable method consists in using the channel power mode, with a very long sweep time ($\gg$ frame duration) over the signal bandwidth, to obtain the RMS power. The peak power value may then be estimated by taking into account the PAPR or the CF. However an overestimated value will obtained for the case of QAM modulation. An alternative solution is to use the CCDF measurement mode of the SA when it is available.

5. References

[1] CENELEC 2008 Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations EN-50492

[2] IEEE 2005 Standard for Calibration of Electromagnetic Field Sensors and Probes, Excluding Antennas, from 9kHz to 40GHz IEEE Std 1309-2005

[3] Monebhurrun V 2010 Effect of time-averaging of pulsed radio-frequency signals on Specific Absorption Rate measurements IEEE Trans. On Electromagnetic Compatibility vol 52 no 1 pp 49-55

[4] Adamson D Bownds D, Fernandez A and Goodal E. 2010 The response of Electric Field probes to realistic RF environments IEEE MTT-S (Anaheim, CA, USA, May 2010)

[5] Sarolic A Roje V and Modlic B 2006 Measurement of electric field probe error for pulsed signals Proc. 2006 IEEE Intl Symposium on Electromagnetic Compatibility vol 2 pp 244-248 (Portland, OR, USA, August 2006)

[6] Letertre T, Monebhurrun V and Toffano Z 2011 Electromagnetic Field Measurements of Wimax Systems Using Isotropic Broadband Probes IMS 2011 (Baltimore, USA, June 2011)

[7] Wunder G and Paterson K 2004 Crest-factor analysis of carrier interferometry MC-CDMA and OFDM systems Proc. 2004 IEEE International Symposium on Information Theory (Chicago, ILL, USA, July 2004)

[8] Joseph W, Verloock L, Goeminne F, Vermeeren G and Martens L 2012 Assessment of RF exposure from emerging wireless communication technologies in different environments Health Physics 2012 vol 102 no 2 pp 161-172