A distributed wearable EM field recorder for RF exposure assessment in real environments

De Clercq H[1], Thielens A[2], Lecoutere J[1], Agneessens S[2], Rogier H[2], Joseph W[2], Puers R[1]

[1] ESAT-MICAS, KULeuven, Leuven, Belgium

[2] Information Technology, Ghent University, Ghent, Belgium

Abstract

The wireless market has been growing at a tremendous speed and an ever-increasing number of radio-frequency systems are carried around by people. Therefore, the World Health Organization has indicated the need for an RF exposure assessment to describe the public electromagnetic environment. Current portable RF dosimeters suffer from a lack of wearability due to their size and rigidity. Moreover, they experience low signal reliability due to shadowing of the body. This paper introduces a personal distributed exposimeter, developed with off-the-shelf components. The system contains ten wearable nodes. Each node comprises RF transceivers that measure the received signal strength in the mobile communication and Wi-Fi channels. Two different topologies to acquire the radiation power are discussed.

Keywords: Dosimetry, Radio frequency exposure, wearable electronics, textile antennas.

Introduction

The capability to wirelessly transmit information over large distances using electromagnetic radiation revolutionized the field of communication in the early twentieth century. While radio waves were originally used for maritime and military purposes, today they lend their invisible presence to almost all aspects of communication ranging from cellular and cordless phones, radio and television broadcasting to wireless internet-based communication. They are utilized in detection and localization (e.g. radar), heating (e.g. microwave oven), navigation systems (e.g. GPS), healthcare (MRI systems), remotes (e.g. garage door openers) etc. In effect, radio waves are a part of modern life and we are exposed to them continuously. Therefore, the World Health Organization has indicated the need for an RF exposure assessment to describe the public electromagnetic environment. Until now, studies on their short and long term biological effects have not been able to make any definitive causal link between RF exposure and any adverse effects. However, the increasing use of cell phones and wireless internet makes it empirical to investigate the potential of long term exposure leading to physiological effects in human beings. Currently, an increasing number of studies that aim at quantifying this exposure have been carried out [1-5]. An individual's personal exposure is typically measured using commercially available personal exposimeters (PEMs). However, PEMs suffer from a lack of wearability due to their size and rigidity. Moreover, they experience low signal reliability due to shadowing of the human body [6]. Another problem is that these devices have a significant crosstalk, being the power that is emitted in a certain band and registered in another, which perturbs the data recorded by PEMs [7]. A possible approach to reduce these uncertainties is the use of multiple antennas distributed on the body. To this aim, a personal, distributed exposimeter (PDE), containing multiple antennas placed on the human body, has been proposed in previous work [8]. The prototype is able to accurately measure the incident electric field using an optimized placement of the antennas on the body and a careful calibration in an anechoic chamber using human phantoms. A further novelty of this dosimeter is the use of textile antennas, which have a comparable performance to their rigid counter-parts, while ensuring optimal comfort [9]. This paper will focus on two topologies, to acquire the frequency of radiation and its power using of-the-shelf components. Figure 1 depicts a block-level schematic of the PDE.

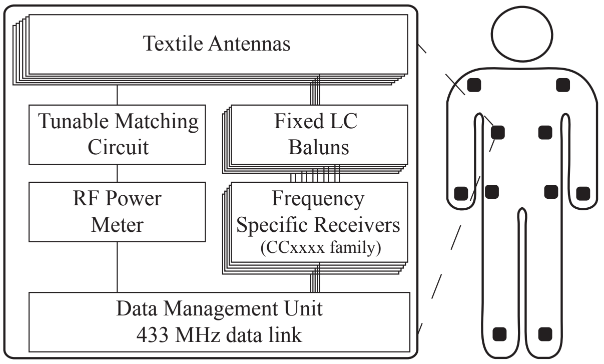

Fig. 1: A block-level schematic of the PDE

Materials and Methods

The frequency bands corresponding to mobile communication and WiFi are sources of radiation to which exposure is incessant for large durations of the day. Additionally, during mobile uplink and WiFi based exposure, the source of radiation is quite close to the subject. These arguments identify mobile phone communication, DECT communication and WiFi as the most relevant sources to be investigated [10]. The following frequency bands are therefore earmarked for the purpose of design:

- 880 – 915 MHz: GSM900 uplink
- 925 – 960 MHz: GSM900 downlink
- 1710 – 1785 MHz: GSM1800 uplink
- 1805 – 1880 MHz: GSM1800 downlink
- 1880 – 1900 MHz: DECT
- 1920 – 1980 MHz: UMTS uplink
- 2110 – 2170 MHz: UMTS downlink
- 2400 – 2500 MHz: WIFI 2G

Frequency specific power receiver

Because the GSM900 and WIFI 2G channels are overlapping with ISM bands, commercially available RF transceivers can be used to detect power levels in these frequency ranges. The CC2500 and CC1101 transceivers (Texas Instruments) were selected. Such a frequency-specific receiver is designed for a narrow frequency band and reach high performance at the given frequency. Moreover, the selected transceivers have an in-built controllable frequency synthesizer, which together with a frequency mixer transfers the received signal through a narrow-band band-pass filter allowing power measurement at a really specific frequency of 100kHz. The disadvantage with this structure is that it also limits the width of possible receivable frequency band to about 100 MHz due to a very limited tuning range of the frequency synthesizer. Each channel therefore requires a unique receiver and a corresponding LC-balun matching circuit.

Tunable receiver

For the other bands, between 1700 and 2200 MHz, an RF power-meter with a tunable external matching circuit was developed. Such a power meter commonly includes a wide-band low-noise amplifier without a filter, thus measuring frequencies in a wide range. Specificity can be increased by an external matching circuit. The advantage is that the same receiver can be matched at several frequencies and that a single antenna can be employed to acquire a fairly large range of frequencies. The drawback of this topology is the poor specificity. This power receiver can only measure the total incident power for each band, rather then measuring at a very specific frequency. A common way to introduce electrical tunability to a matching circuit is to include a variable capacitor (varactor) to the design. Technically a traditional varactor comprises a reverse-based diode. A DC biasing voltage is applied to control the thickness of the depletion zone of the diode, thus changing the equivalent capacitance. The LT5534 power receiver (Linear Technology) was chosen for its high sensitivity down to *-63dBm* in the desired frequency band. Figure 2 shows simulation results for the S(1,2) parameter, the gain from the antenna to the power detector, for which the varactor is optimally tuned for 6 different frequencies.

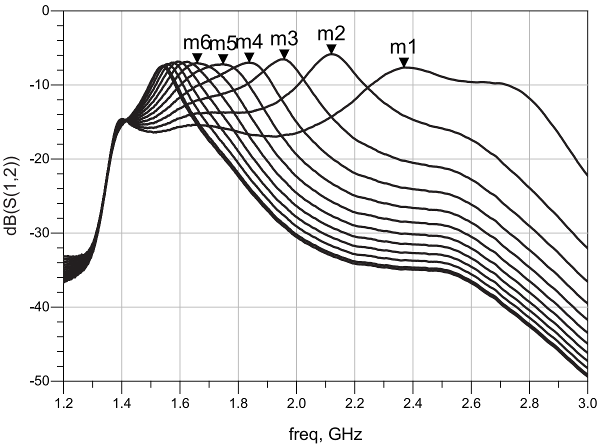

Fig. 2: Simulation results for gain and reflection from the antenna to the power detector for 6 different frequencies. M1: 2.369GHz, M2: 2.120GHz, M3: 1.958GHz, M4: 1.838GHz, M5: 1.748GHz, M6: 1.659GHz.

Results & Discussion

A first calibration of our preliminary personal distributed dosimeter has been performed in an anechoic chamber. Both free-space measurements, where the true incident power is measured, and measurements, using phantoms, are performed. The transmitting antenna is a dipole antenna emitting a sinusoidal wave at one frequency. The dipole can be rotated *360°* around an axis orthogonal to its axis of symmetry. Three different models have been used: one cylinder (height is *1.5m*, inner diameter is *0.24m*, mass is 10kg) filled with brain simulating liquid resulting in a phantom with the same mass as the VFM (77.2 kg), and two real human subjects with a BMI comparable to that of the VFM. The models are placed on a platform. The platform is in the far-field of the transmitter and the absorbing walls of the anechoic chamber ensure that there is only line of sight exposure. The platform can be rotated *360°*, so that a phantom or subject can be radiated in its transverse plane when standing in upright position. Free-space measurements are performed on the rotation axis of the platform. Figure 3a depicts the measurement results of a power sweep of the transmitter from *-20* to *10dBm*. Figure 3b shows the incident power level during a rotation from *-180°* to *180°*. Both measurements are performed at a fixed frequency of 900MHz.

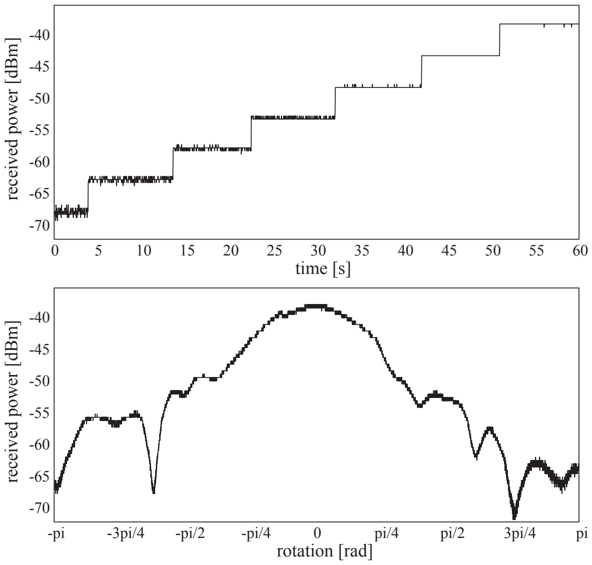

Fig. 3: (a) Power sweep measurement with a power sweep between -20 and 10dBm. (b) Power measurement during a rotation of the subject from -180 tot 180 degrees.

Conclusions

For the first time, a wireless personal distributed exposimeter has been designed. This PDE measures personal exposure to RF fields originating from WIFI and mobile communication networks. Two different topologies to measure the incident power in these frequency channels have been investigated. The PDE has been calibrated in an anechoic chamber and is ready to perform measurements in a real (sub)urban environment.

References

[1] Thomas S, Heinrich S, von Kries R, Radon K, “Exposure to radio-frequency electromagnetic fields and behavioural problems in Bavarian children and adolescents.” Eur J Epidem. 2010, 25(2), 135-41.

[2] Frei P, Mohler E, Neubauer G, Theis G, Burgi A, Frohlich J, Braun-Fahrlander C, Bolte J, Egger M, Roösli M, “Temporal and spatial variability of personal exposure to radiofrequency electromagnetic fields.” Environmental Research (109), 779-785, 2009.

[3] Knafl U, Lehmann H, Riederer M, “Electromagnetic field measurements using personal exposimeters.” Bioelectromagnetism 29, 160-162, 2008.

[4] Joseph W, Vermeern G, Verloock L, Heredia MM, Martens L, “Characterization of Personal RF Electromagnetic Field Exposure and Actual Absorption for the General Public.” Health Physics, 95(3), 317-330, 2008.

[5] Neubauer G, Cecil S, Giczi W, Petric B, Preiner P, Fröhlich J, Roösli M, “The association between exposure determined by radiofrequency personal exposimeters and human exposure: a simulation study.” Bioelectromagnetics 31, 535-545, 2010.

[6] Bolte JFB, Van der Zande G, Kamer J, “Calibration and uncertainties in personal exposure measurements of radiofrequency electromagnetic fields.” Bioelectromagnetics 32(8), 652-663, 2011.

[7] Thielens A, Agneessens S, Verloock L, Tanghe E, Rogier H, Martens L, Joseph W, “On-body calibration and processing for a combination of two radio frequency personal exposimeters”, Radiation Protection Dosimetry, submitted January 2014.

[8] Thielens A., De Clercq H, Agneessens S, Lecoutere J, Verloock L, Declerq F, Vermeeren G, Tanghe E, Rogier H, Puers R, Martens L, Joseph W, “Distributed on Person Exposimeters for Radio Frequency Exposure Assessment in Real Environments.” Bioelectromagnetics 34 (7): 563-567; 2013.

[9] Moro R, Agneessens S, Rogier H, Bozzi M, “Wearable textile antenna in substrate integrated waveguide technology”, Electronics Letters, 48 (16), 985-987, 2012.

[10] Bolte JF, Eikelboom T, “Personal radiofrequency electromagnetic field measurements in the Netherlands: Exposure level and variability for everyday activities, times of day and types of area”, Environ Int., 1 (48), 133-42, 2012.

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Author’s Address

Hans De Clercq
ESAT-MICAS, KULeuven, Leuven, Belgium
hans.declercq@esat.kuleuven.be
www.esat.kuleuven.be/micas