A Novel Technology for Fast and Accurate Specific Absorption Rate Measurement

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ABSTRACT: Standard Specific Absorption Rate (SAR) measurement methods are highly time consuming. Compliance test lead times for mobile wireless devices are incompatible with current needs in the industry and become a growing pain with the emergence of 4G communications. This paper introduces a new technology designed for solving this problem and providing instantaneous and accurate peak spatial-average SAR evaluation.

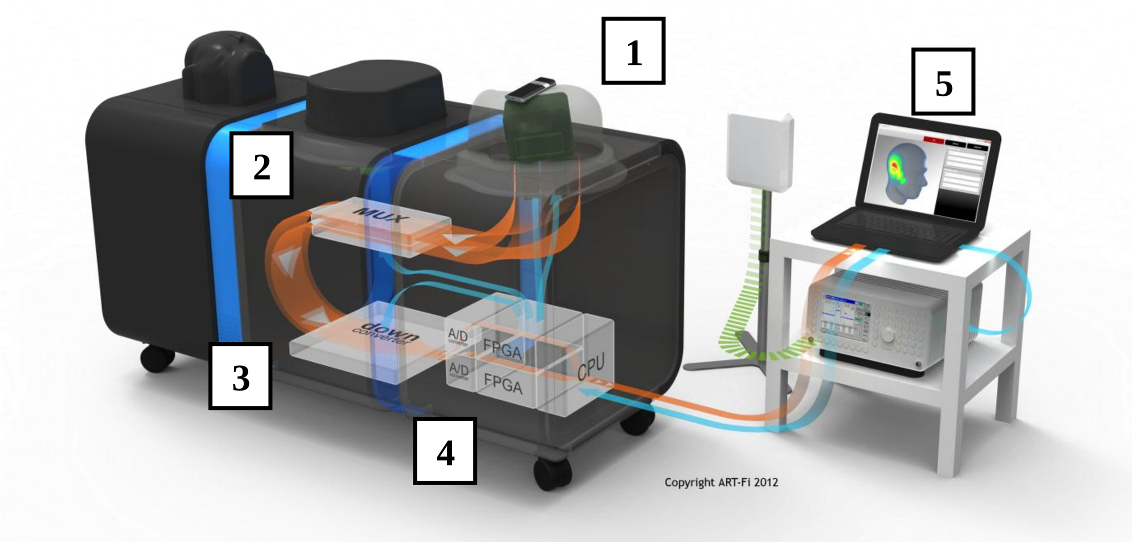
INTRODUCTION

Mobile phones, tablets, USB dongle transmitters as well as any device radiating radiofrequency (RF) waves in the close proximity to the human head or body have to conform to local market regulations regarding electromagnetic field exposure. As recommended by the World Health Organization (WHO), a significant number of countries have adopted international exposure guidelines [1], [2] to provide protection against adverse health effects from RF fields. Those guidelines set exposure limits in terms of Specific Absorption Rate (SAR). International standards [3]-[5] define procedures to assess this quantity.
In this context, SAR measurement has become a key step in the type approval process for wireless products. However, the increasing complexity of communicating devices, integrating always more bands and technologies, as well as the multiplicity of intended use conditions make it a very heavy duty on the industry to execute compliance testing procedures. In particular, the number of usable frequency bands and communication modes for 4G LTE (Long Term Evolution) result in a dramatic rise of SAR test times. For a smartphone covering e.g. two LTE bands, compliance evaluation typically requires a hundred of head and body SAR tests taking about 60 hours (8 working days) with a traditional SAR system. In total, when including GSM, UMTS, WLAN and other communication modes/bands, the application of type approval procedures can easily end up in 5 weeks testing with two 8-hour shifts per day.

Standard measurement methods are based on a point-by-point probing of the square modulus of the E-field at several hundreds of points in a biological tissue-simulating medium. The complete scan is performed thanks to a robot moving a diode-detected probe. Mechanical displacement is the main source of time consumption. A number of faster approaches have been introduced, proposing to reduce the number of measured points or limit to a surface scan of the E-field amplitude, e.g. [6]-[8]. A majority of those techniques rely on approximations and a priori modelling of the field propagation in the tissue, which results in a decreased accuracy and reliability of the SAR evaluation [9].
To overcome this drawback, another class of faster methods exploiting vector E-field through implementation of phase retrieval methods or using electro optical probes has also been introduced [10], [11]. Despite some attempts to make arrays of vector probes, no publication identified to date reported a technology suitable for the fabrication of an array with a size being sufficient to avoid the use of a robot. Recently, the authors patented a novel type of RF probe-array [12] adapted for manufacturing larger grid arrangements. Using this technology together with an innovative phase measurement technique [13], ART-MAN, a complete system capable of full 3-D SAR assessment in a few seconds was derived [14]. This paper gives an overview of the proposed system and technology.

NEW SAR MEASUREMENT SYSTEM OVERVIEW

Fig. 1 shows an artist view of the ART-MAN system architecture. Orange lines represent measurement signals and blue lines, control signals.



Fig,1 : Artist view of the ART-MAN system architecture.

The top part of the system (1) is made of three standards-compliant phantoms [2]-[4] filled with a broadband tissue simulating material. The left and right phantoms are the two halves of the Specific Anthropomorphic Mannequin (SAM) designed for measuring devices used in close proximity to the ear. The central part is a flat phantom for SAR assessment of body-worn devices. 285 RF vector probes are immersed in the tissue simulant and embedded in each SAM side; 390 in the flat phantom. The instrumented mannequin assemblies as well as the complete ART-MAN system support wideband operation from 0.69 to 6GHz. The Device Under Test (DUT) can operate at any frequency within this range. A fast scanning of each array is ensured through probe-mounted RF switches and external multiplexers (2) allowing a full sweep in less than 30ms. Measured RF voltages are downconverted (4) to the 20 – 60MHz range using a superheterodyne receiver technique. Signals are then sampled and digital information is used by a real-time processing unit to execute a number of computations: (i) phase retrieval, (ii) application of calibration coefficients for obtaining E-field data from measured voltages; (ii) volumic field reconstruction based on inverse boundary-value techniques; (iii) standards compliant peak spatial-average 1g/10g SAR calculation. Processed data are streamed through a Gigabit Ethernet link to a PC. A dedicated software allows the user to control the ART-MAN system and visualize local as wells as averaged SAR instantaneously.

DETAILS OF THE TECHNOLOGY

RF Vector Probe Array

The probe-array consists of a grid of dual-polarized sensors made for capturing two orthogonal E-field components tangential to the measurement surface (Fig.2). The sensors are arranged in linear arrays (ABx in Fig.2) connected to perpendicular printed circuit boards with signal transmission lines (PTy in Fig.2). This structure has been designed to limit the impact on the tangential field components at the locations of the sensors. Extensive use of Finite Difference Time Domain simulation has been made to optimize the response of the probes to incident field excitation and decoupling between the sensors. The sensitivity which is below 1µW/g offers the possibility to measure the field at a distance of 15mm or more from the phantom inner surface. Placing the array at such a distance allows benefiting from the strong attenuation in the tissue-simulating material and mitigating the interaction between the array and DUT. Calibration of the probes is made by exposing the complete array immersed in a large phantom to known fields generated by reference antennas. Each reference antenna is measured at frequencies of interest and at positions facing sensors locations, in various orientations. Transfer functions of the probes are assessed by acquisition of complex transmission coefficients from the antenna to the probe output via a vector network analyzer.

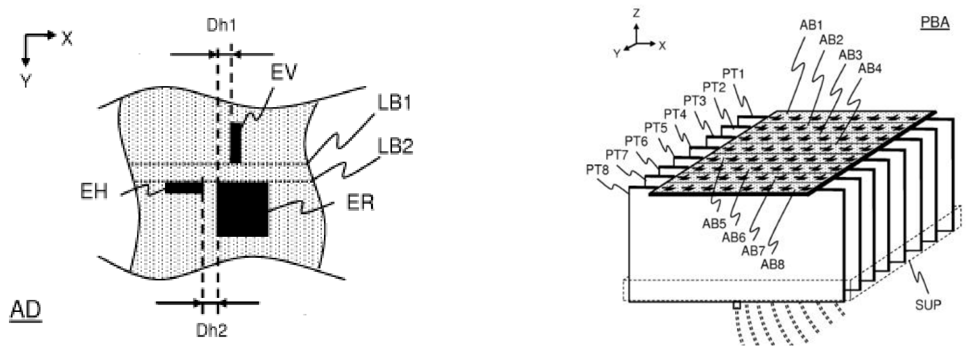


Fig.2 : Left: sketch of a dual-polarized sensor. Right: illustration of the probe-array structure. ABx, circuit boards with printed sensors; PTy, perpendicular boards containing transmission lines and RF switches. [12]

E-Field Phase Assessment

Assessing vector fields requires determining the phase relative to a reference. A reference is straightforwardly obtained when the antenna under test is cabled. However, in the case of standalone devices, cabling the DUT is not an option as the SAR has to be measured in real-life conditions. Moreover the phase has to be extracted from a comparison between complex modulated signals. The solution to this problem is described in [13]. The reference signal can be chosen as the output of one of the sensors. The location of this sensor basically remains unchanged and permanently monitored during the scan of the array.

In other words, the ART-MAN systematically measures two RF signals: (i) one out of the current sensor solicited for obtaining the field at a given location; (ii) and the other out of the reference sensor being constantly monitored during the array scan. The reference output is chosen to ensure a minimum signal-to-noise ratio. Reference probe must hence be dynamically allocated to adapt to the variety of SAR distributions. The two output voltages are digitized synchronously and discrete Fourier transforms are applied. After an appropriate integration time depending on modulation, the energy contained in the spectrum provides necessary information to precisely evaluate the RMS field value. Comparison between phases of the two complex spectra allows completing the vector field measurement.

3-D Field Distribution Evaluation through Inverse Boundary-Value Techniques

The surface equivalence principle states that the knowledge of two components of the vector E-field over a closed surface is sufficient to determine the three components of the electromagnetic field in the whole volume out of this surface. The system presented in this paper applies this principle by utilizing the tangential vector field data measured at the sensor locations to: (i) propagate and retro-propagate the E-field in the whole volume of the mannequins; (ii) retrieve the normal component using Gauss law (see e.g. eq. 4 of [15]). Various approaches and algorithms can be used for transforming the 2-D measurements in a 3-D distribution. Those approaches fall under the general class of “inverse boundary-value techniques” or “near-field to near-field transformations”. One possible approach particularly suitable for the flat phantom section is based on the expansion of the field in its plane-wave spectrum (PWS) [16]. By expressing the field in the plane of the sensors as a superposition of plane waves propagating in a variety of directions, well-known formulas can be applied to propagate and retro-propagate the PWS in the planes of interest for the SAR evaluation. An inverse transformation in those planes allows getting back to the spatial domain and reconstructing the E-field distribution at locations where no measurement was conducted.

Broadband Tissue Material

The use of tissue-simulating materials in traditional SAR measurement systems is often perceived as a burden. Being used in open air, fluids evaporate and dielectric characteristics deviate over time. Also, most of the materials proposed to date comply with standard requirements [3]-[5] over relatively narrow frequency ranges. The SAR system user is hence obliged to manipulate chemical products on a regular basis. Those issues were taken into account in the design of the presented approach. In the ART-MAN system, the mannequins are hermetically sealed, thereby preventing from evaporation. A consequent challenge was to develop a material complying with standard requirements in the wide frequency range of operation (0.69-6GHz) and demonstrating a high stability over time. A novel formulation was identified. Fig.3 represents the dielectric properties of the solution, measured with a 85070E dielectric probe kit from Agilent Technologies. The material complies with IEC requirements [3], [4].

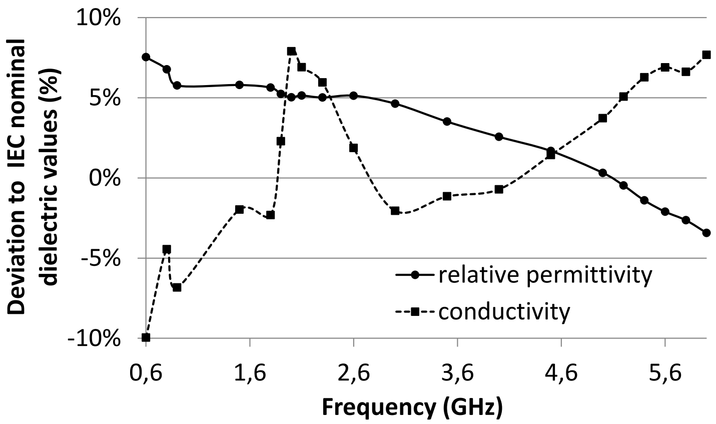


Fig.3 : Dielectric properties of ART-MAN broadband tissue at 25°C relatively to IEC nominal dielectric values.

CONCLUSION

The technology introduced in this paper offers an innovative approach to measure the peak spatial-average SAR of wireless devices in a matter of seconds, without a priori modelling of the field propagation. Based on RF techniques, broadband tissue and vector field assessment, the presented method addresses near-field human exposure evaluation from a completely different perspective compared to traditional robot-based amplitude scanning schemes. The spectrum analysis capability of the proposed system makes it a promising alternative for accurate SAR assessment of modern wireless terminals using complex communication modes and simultaneous multiple transmission.

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