Microwave Vision: From RF Safety to Medical Imaging

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***Abstract*—This article gives an overview of the activities of the company Microwave Vision, formerly Satimo, oriented to health-related applications. The existing products in terms of Specific Absorption Rate (SAR) measurement and RF safety are described in detail. The progress of the development of a new imaging modality for breast pathology detection using microwaves is shortly reported.**

***Index Terms*—antenna, propagation, measurement, microwave imaging, medical imaging**

I. Introduction

Nowadays, we experience a fast evolution of the society, based on technological progress and societal trends, that tend to connect people and applications with more and more wireless and telecommunication devices. This is a fundamental evolution that won't stop in the next years and decades. In order to accompany the installation and the use of a very fast increasing number of radiating devices, regulations have been put in place progressively. Specific devices, also called RF safety devices, aimed at measuring this new electromagnetic environment in which we are living daily, have been developed: systems to measure the Specific Absorption Rate (SAR) of mobile phones in the market, exposimeters that monitor the field levels for workers or in the streets of the towns, etc. The frequency spectrum that is used for the different telecommunication systems is also becoming larger and larger, while the protocols of communication are becoming more and more complex. In the coming years for instance, the 5G protocol will be progressively implemented worldwide with frequencies up to 110 GHz and bandwidths close to 200 MHz that can be aggregated up to 1 GHz. In order to cover this large variety of applications, exposimeters have to become frequency-selective, adaptive, having variable sensitivities, etc. The denser and denser network of radiating devices implies also the use of specific simulation software that can reach the required spatial resolution, which can't be achieved only by using exposimeters with measurement points at limited number of locations.

Electromagnetic waves, beside telecommunications and information transfer, can also be used in medical applications. This is a relatively recent evolution that started in the late 80's / early 90's, with the first experiments of hyperthermia, using microwave emission to heat the zone where a tumor was developing. There were several difficulties at that epoch, but since then the technology has evolved significantly in terms of efficacy and precision, thanks, among others, to improved simulation tools. Breast cancer is a main concern nowadays and activities involving non-ionizing microwaves (in contrary to X-rays) for detection of breast pathologies have also emerged since about 10 to 15 years, involving numerous scientific teams around the world. The goal is the detection and localization of tumors inside the breast, using electromagnetic waves and advanced algorithms for image reconstruction.

The company Microwave Vision, formerly Satimo, was founded 30 years ago and started its activities in the field of antenna measurement systems. In 2007, the company decided to extend its product portfolio to environmental and RF safety testing, including SAR measurement systems and exposimeters. Some years ago, an R&D action in the medical domain has also been initiated, thus transposing the technology of multi-sensor systems for ultra-fast antenna measurement [1] to microwave medical scanners. In this article, the Microwave Vision activities in the RF safety and in the medical domain are presented in detail.

II. SAR Measurements

Each commercial mobile device should comply with ElectroMagnetic Field (EMF) exposure limits, as specified by the regulatory authorities (SAR values). SAR is defined as the power absorbed by a unit mass of human body, and is measured in Watts/Kg. In 1998, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) issued guidelines to limit electromagnetic field (EMF) exposure [2]. In 2001, the European committee for electrotechnical standardization (CENELEC) published protocols for SAR measurements between 300 MHz and 3 GHz for handheld devices (EN 50360 and EN 50361). In addition, today there are two major standards for SAR measurements: The International Electrotechnical Commission (IEC) 62232, and the IEEE 1528 standards [3]-[4].

A. SAR measurement solution at MVG

Microwave Vision Group (MVG) started working on SAR measurement equipment in the early 2000s. A complete measurement system was then developed [5] fully compliant with the actual standards. The system has been updated ever since, following the standards evolution, such that a reliable and up-to-date system for certification and R&D purposes all over the world is assured.

SAR measurements are quite complex and time-consuming. MVG has put a lot of effort on reducing this time, as it can be a critical parameter in the development process of new mobile devices. The so far developed techniques employ, either different algorithms to reduce the 2D and 3D scanning time while maintaining the uncertainty levels within the standard limits [6], or an innovative very fast multi-probe method for SAR estimation [7].

A typical MVG SAR bench is shown in Fig. 1. It consists of a 6-axes robotic arm which controls the probe movement inside the SAR phantoms and assures precise E-field measurement. The mobile phone device is placed below the SAR liquid containers, using precise positioning systems. The mobile device is controlled by an RF signal emulator which forces the mobile device to emit at maximum power at the desired frequency and technology (2G, 3G, LTE, etc.). The SAR liquids used in the phantoms have selected properties, such that the human body tissue is realistically simulated at the specific frequency band of interest. The measurement setup is fully automated and remotely controlled using the OPENSAR software. The measurement equipment can provide certified measurements from 30 MHz up to 6 GHz.

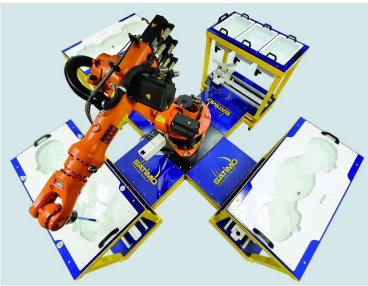


Fig. 1. MVG's SAR measurement system

III. RF SAFETY EQUIPMENT

While SAR measurements provide certified and precise evaluation of a mobile telecommunication device in terms of EMF exposure, public concern according to several EU studies is more focused on the effects of exposure due to base station antennas (BTS) [8]. In order to propose a simpler procedure to evaluate the EMF exposure, ICNIRP and the World Health Organization (WHO) have defined reference levels for human exposure in Volts/meter deduced from basic restriction levels of SAR values [2],[9].

MVG has been involved in several research projects since 2003 regarding the EMF exposure along with the major stakeholders in this domain (mobile phone manufacturers, service providers, public regulatory bodies, research organizations, and the academia) [10]. From this rich collaborative research experience, MVG has developed over the years, several state-of-the-art EMF exposure measurement equipment [11].

A. *MVG exposimeters*

Exposimeters (or dosimeters) are portable devices, capable to carry out precise isotropic E-field measurements. There are two types of exposimeters.

The EME Guard family is destined for professionals working in close proximity of radiating elements (base stations, broadcast centers, radars, etc.). It provides precise broadband (from 27 MHz up to 40 GHz) E-field exposure levels and alerts the user if the exposure exceeds the thresholds defined by the standardized limits [2], [9].

The EME Spy family is designed to provide frequency-selective E-field measurements with excellent isotropy, according to the IEC protocols and ICNIRP guidelines. These devices are used by local authorities, service providers, research organizations, and regulatory bodies. These exposimeters cover the widely deployed wireless communications bands over the 80MHz – 6 GHz range (from FM, TV broadcast bands to 2G, 3G, LTE, Wi-Fi frequency bands). An android app is designed especially for the purpose of real-time frequency-selective exposure measurements with GPS localization [11].

The EME Spy exposimeters are based on a fixed filter RF chain architecture, with RF switches which choose a given frequency band to measure. If the frequency band changes from one country to another, the hardware has to be modified in order to measure the correct band. A short-term solution to this problem is to design specific exposimeter devices intended for use in target areas where the frequency spectrum usage is known. Hence, MVG has developed two versions of exposimeters intended for the European and North American market.

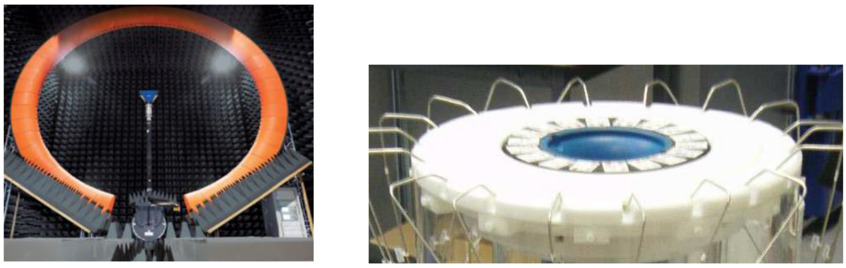
For a long term solution for global coverage, a proof of concept solution has been developed under the collaborative research project Lexnet [12]. The idea is to use a wideband homodyne receiver with programmable local oscillator and baseband filters, in order to adapt to any frequency and bandwidth in the band [80 MHz-6 GHz].

B. *EMF monitoring stations*

MVG has developed two types of fixed EMF exposure monitoring stations.

The FlashRad EMF monitoring solution is based on broadband EMF measurements from 700 MHz up to 11 GHz. It can monitor dense EMF environments (military bases, radar sites, airports, dense urban areas, smart cities) [11]. Several models, each adapted to different environments, having different frequency bands, sensitivity level, and dynamic range requirements, are developed. Several fixed FlashRad monitoring stations can be deployed on a target site to ensure the EMF safety regulations over that area with all the measurements from the different sensors collected at a central command center controlled by a dedicated software. The different sensors can be connected using 3G / LTE modems, or by means of a network of Ethernet cables.

For in situ spot measurements with frequency selectivity according to different standard protocols, MVG has



(a) (b)

Fig. 2. (a) StarGate vertical measurement arch (b) Medical Imaging horizontal measurement arch

developed a mobile monitoring solution called INSITE Free. It is based on wideband isotropic probes (covering 100 KHz up to 6 GHz bands), a spectrum analyzer, a tripod, a RF switch with amplifier, and a dedicated software. This device is used by regulatory bodies, public authorities, service providers, research organizations, etc. to carry out certified in-situ EMF measurements. This device can be adapted to follow a given protocol for a given frequency band, application, and scenario (for example, the French National Agency of Radiofrequencies (*ANFR*) protocol v3).

C. *EMF Visual software*

Each measurement provides a precise value of the EMF exposure at a given location. A finite number of measurement points can be used to estimate the EMF exposure over a given area (or a given population). MVG has developed the EMF Visual simulation tool [11], a reliable software for EMF exposure evaluation, with the capability to generate exposure maps showing the variation of the E-field level over a target area, while taking into account multiple radiating elements and the impact of the surrounding 3D environment. The major users are the service providers, regulatory and certifications bodies. The software can be used in several scenarios, e.g. *i)* to estimate the exposure levels before installing a new radiating element in a given environment, *ii)* to evaluate the exposure levels around already installed radiating elements, *iii)* to designate safe zones for workers around the radiating elements, according the specific guidelines for a given case.

The user can generate a custom 3D environment with detailed characteristics (permittivity, building types, floor type, placement of radiating elements, frequency, gain, power, tilt, etc.). The software contains an extensive database with the majority of radiating elements used for wireless broadcast or telecommunications.

With the evolution of the society towards a denser wireless environment (smart cities), reliable software tools are needed. EMF Visual provides a very attractive solution. The ultimate goal is to couple the simulations with measurements, in order to improve the precision level and have calibrated results with high confidence levels.

IV. MICROWAVE BREAST IMAGING

In this section, an overview of MVG's ongoing Research & Development (R&D) activity in the medical imaging domain is presented. The medical device under development is a microwave imaging system, aimed at detecting malignant breast lesions [13].

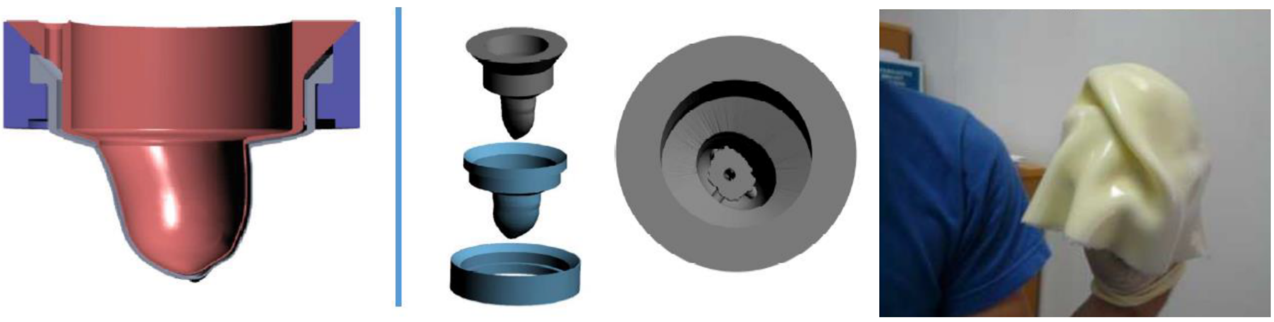
A. *MultiStatic Radar Imaging System*

For this application, the well-established MVG technology for fast antenna measurement, using multiple sensors in a vertical arch configuration, has been transposed to a horizontal arch of sensors, as illustrated in Fig.2. In addition, vertical translation of the horizontal arch has been enabled, such that 3D multi-static short-range radar imaging is possible. The sensors are in contact with a recipient that hosts a coupling liquid with electromagnetic (EM) properties appropriately selected such that the EM wave penetration in the breast is maximized. A breast phantom is immersed in the coupling liquid and imaged.

As for now, the system has been only experimentally tested, using phantoms that simulate the real breast. These phantoms have been manufactured considering the state-of-art knowledge in terms of dielectric properties (DPs) of the breast tissues in the frequency range of interest.

B. *Experimental Breast Phantoms*

The breast phantom repository, as published by the



(a) (b) (c)

Fig. 3. 3D printed molds for ACR2 breast (UWCEM Phantom Repository) (a) View 1, (b) View 2, (c) Oil-In-Gelatin skin of 2mm thickness

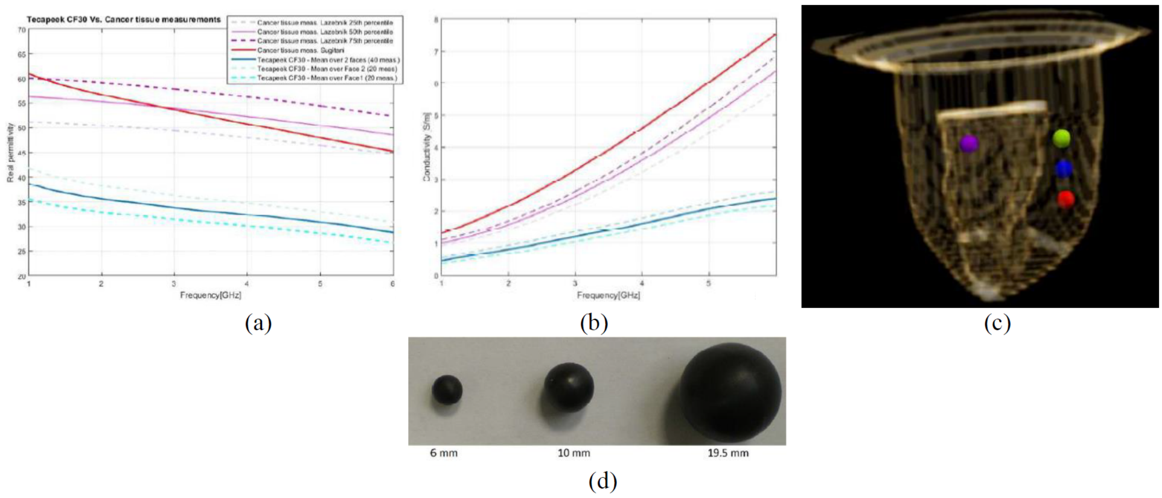


Fig. 4. (a) Real permittivity of Tecapeek CF30 Vs Cancer, (b) Conductivity of Tecapeek CF30 Vs Cancer (c) Indicative test positions of the 'tumor' in the ACR2 breast phantom, (d) Tecapeek CF30 spherical targets, simulating the tumor

University of Wisconsin [14] has been used to define MRI-based realistic breast geometries. Using this input, three molds and an upper supporting ring have been 3D printed for each breast phantom, as illustrated in Figs.3(a) and (b). From the inside outwards:

- a mold with contour resulting from the segmentation of the fibroglandular tissue on the input MRI image, after the minimal required simplification such that a single printable mold is defined
- a mold having the shape of the external breast contour
- a second mold with the same shape (i.e. external breast contour) but slightly dilated, such that a 2mm radial distance exists between corresponding points on the external surface of the two molds.

The purpose of the third mold is to use it only for molding a breast skin layer of 2mm. The Oil-In-Gelatin (OiG) recipe for breast skin [15] has been applied and an example of the resulting skin phantom after unmolding is given in Fig.3(c). The OiG skin is further fit to the external surface of the breast contour mold and used for the imaging tests.

Both the fibroglandular tissue and external breast contour mold are filled with liquids having DPs similar to the ones of the fibroglandular and fatty tissue correspondingly, as specified in [16],[17]. We have been inspired by the liquid recipes published in [18], with slight adjustments in order to avoid gelification for given Triton-X/Water proportions of interest.

For simulating tumors, we have used spherical inclusions of a minimal diameter D=6mm, consisting of the solid material Tecapeek CF30 [19]. Cubic samples of this material with sufficient volume have been measured using the Keysight High Temperature coaxial probe 8570E. The

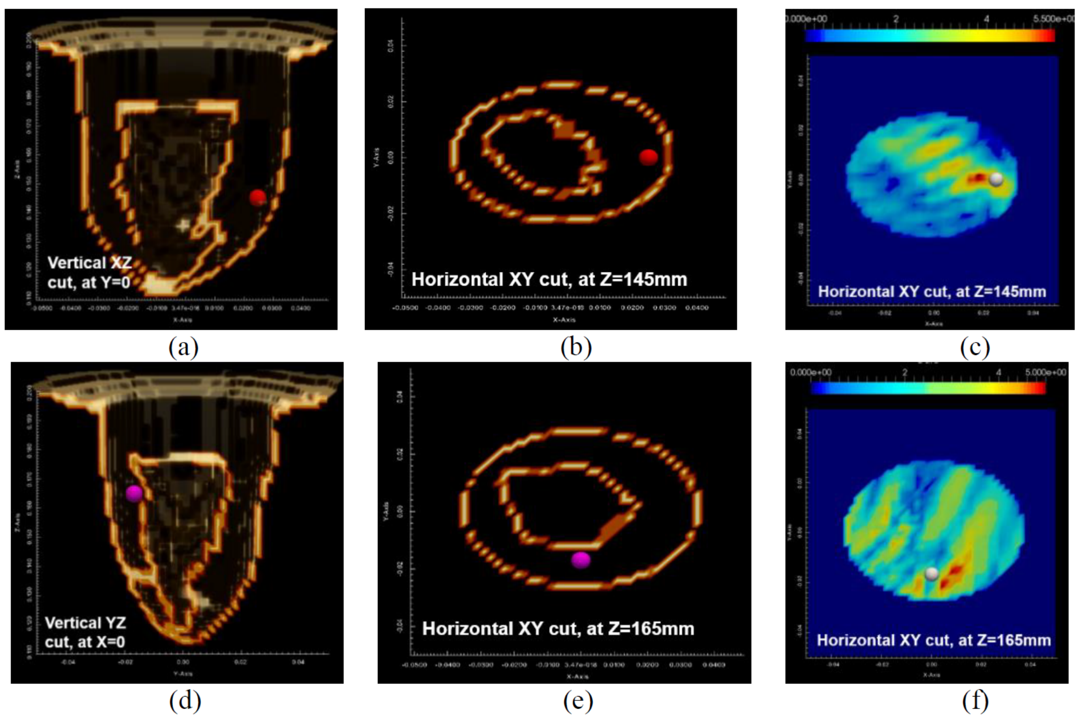


Fig. 5. Imaging test 1: (a) Ref. geometry vertical slice, (b) Ref. geometry horizontal slice, (c) Imaging result horizontal slice, Imaging test 2: (d) Ref. geometry vertical slice, (e) Ref. geometry horizontal slice, (f) Imaging result horizontal slice,

measured real permittivity and conductivity of Tecapeek CF30 are shown in Fig.4(a) and (b), in comparison with the cancerous tissue DPs, as specified by Lazebnik et al.[16] and Sugitani et al. [17]. The DPs of Tecapeek CF30 underestimate the cancerous tissue DPs. Several indicative test positions of such a 'tumor' inclusion of D=6mm placed in the fatty tissue, but at close proximity to a voluminous fibro gland, are illustrated in Fig. 4(c) using multi-color spheres.

C. *Imaging Results*

Achieved imaging results for the experimental configuration of Fig.4(c) are shown in Fig.5 for two target test positions. The images have been formed using multi-static radar processing algorithms [20],[21],[22], after appropriate calibration of the mutual coupling and strong clutter mitigation.

The imaging results shown in Figs.5(c) and (f) are 2D slices of the full 3D breast volume, taken at the *a priori* known vertical target position. The color scale indicates the confidence level for anomaly (i.e. tumor) detection at the given location, with a maximum level of 6 for the specific algorithm parameterization. These are just preliminary results illustrating the potential of our imaging system for detection of small inclusions with limited dielectric contrast against clutter.

We are progressively increasing the complexity of our experimental test scenarios, in order to render them more realistic and better guide the continuing development of our system (hardware and software). We are ultimately aiming at working with real breast data.

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