# Analysis of Vector E-field Sensor Array for Real-Time SAR Assessment

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# Analysis of Vector E-field Sensor Array for Real-Time SAR Assessment

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***Abstract*—A novel Specific Absorption Rate (SAR) measurement approach using a finite but electrically large array of vector field sensors embedded in a phantom is introduced and analyzed. In particular, the cross-polarization rejection of the array and mutual coupling between probes are investigated.**

***Index Terms*—SAR measurement, Vector E-Field Sensor, Probe Correction, Diffraction, Back Propagation, PWS Theory, Array Decoupling .**

## I. Introduction

Specific Absorption Rate (SAR) is a quantity commonly used to characterize human exposure to electromagnetic fields in the radiofrequency range. It provides a measure of the rate of dissipated energy per unit mass within the exposed body. Traditionally, SAR measurement for a mobile wireless device under test (DUT) is carried out by means of a volumetric scan of the square modulus of the electric field in a mannequin / phantom exposed to the radiation of the DUT. Standard-based approaches [1, 2] require the use of a robot to perform the scan, what is generally recognized as time-consuming. To overcome this limitation, faster techniques have been developed. Those techniques have become particularly attractive in order to face the dramatically increasing number of tests needed to assess the peak spatial-average SAR of modern communication devices across all covered bands, modulations and intended use cases. A particular class of faster methods exploiting vector E-field, through implementation of phase retrieval methods or using electro optical probes, have been proposed and shown to yield accurate results on a number of studied test cases [3-5].

Recently, a new technology of this class capable of real-time SAR assessment has been introduced [6, 7]. This technology uses a novel type of probe-array [8] immersed in a sealed Specific Anthropomorphic Mannequin (SAM) or flat body phantom filled with broadband tissue-simulating material complying with IEC requirements [1, 2]. The array allows assessing the amplitude and phase of the Cartesian E-field components over a rectangular and uniform grid inside the phantom. Efficient use of the plane-wave spectrum theory is made to propagate the field measured over the scanned surface within the whole volume of the phantom [9].

After a brief introduction of this specific array, cross-polarization rejection and probe mutual coupling performances are evaluated using numerical modeling and presented.

## II. Probe Array Technology Overview

The studied probe-array consists of a grid of dual-polarized monopoles made for capturing two orthogonal E-field components tangential to the measurement surface (Fig. 1).

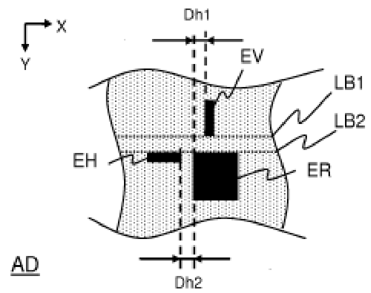


Figure 1. Typical dual-polarized sensor arrangement (metal in black; substrate in grey) [8].

The sensors are arranged in linear array modules connected to perpendicular printed circuit boards (PCB) supporting embedded signal transmission lines (Fig. 2).

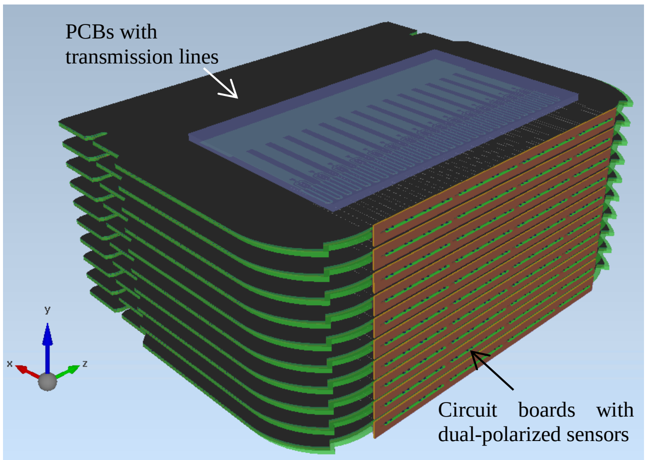


Figure 2. Probe-array example made of ten linear array modules.

This structure has been designed to operate from 0.69 to 6GHz and limit the impact on the tangential field components at the locations of the sensors in this frequency range. Extensive use of Finite Difference Time Domain (FDTD) 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.

## III. NUMERICAL SIMULATION MODEL

In order to analyze mutual coupling and cross-polarization rejection of the array, the numerical model illustrated in Fig. 3 is considered. A single linear probe-array with 15 dual-polarized sensors is immersed in homogeneous tissue-simulating material. This array is a close representation of a physical probe module integrated in the measurement system described in [6, 7]. In order to enable straightforward broadband simulation from 0.69 - 6GHz, the relative permittivity and loss tangent of the tissue model are respectively set to 40 and 0.4. Those values typically lie within less than 20% of the values required by international standards [1, 2]. The sensors are located at 15mm distance from the air-tissue interface.

Using the FDTD code EMPIRE from IMST GmbH, this structure is illuminated with a plane-wave progressing in the *x* direction with either *y* or *z* polarization. So as to reduce the computational volume and preserve the polarization of incident excitation, boundary conditions are alternatively set up as perfect electric conductors (PEC) in one direction and perfect magnetic conductors (PMC) in the other direction. A distance of 50mm of the array to the boundaries was found to yield accurate results. The size of the model is about 133 million cells with a minimum step of 0.0175mm. Time is discretized with a step of 7.94e-14s and simulation is stopped after 30dB energy decay. Time-domain voltages obtained at the probe outputs are then recorded.

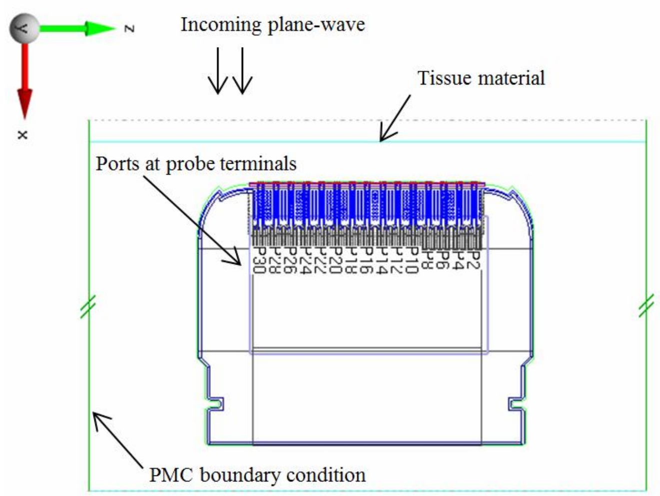


Figure 3. Simulation set-up for analyzing polarization purity of the sensors.

Using the same model, another simulation setup is defined by replacing plane-wave excitation by Gaussian pulse stimulation of one of the ports of the probes. A second linear array module is added in parallel to the first one at a center-to-center distance of 7mm (Fig. 4). Such a configuration allows deriving a figure of coupling between the probes by analyzing S-parameters.

## IV. SIMULATION RESULTS

Fig. 4 illustrates the sensors numbering for two linear array modules. Sensors designed for receiving *z*-polarization are identified with an even number between 2 and 30 for the first linear array. Sensors designed for receiving *y*-polarization are identified with an odd number between 1 and 29. Numbering for the second array module goes from 31 to 60. Fig. 5 represents the response of one linear sensor array exposed to *y* and *z*-polarized plane-waves as a function of frequency and sensor number. Those results respectively show a cross-polarization rejection of more than 45dB in *y*-polarization and 35dB in *z*-polarization over the 0.69 – 6GHz range.

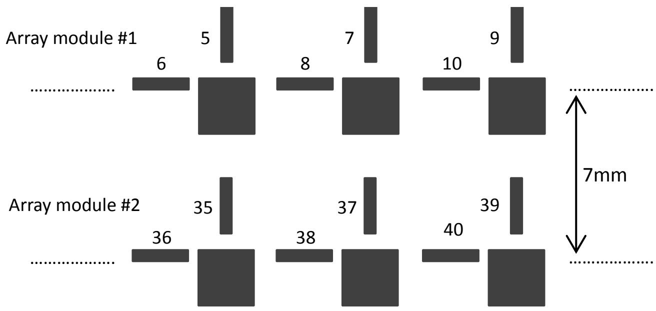


Figure 4. Numbering of sensors in the configuration with two linear array modules. In the center of each module: sensor #7 and sensor #37.

It can be noticed that the lower frequency of operation of the array is limited by the measurement of the *z*-polarization. More specifically, the physical proximity of the sensors to the transmission lines board oriented along *z* results in a drop of sensitivity of the *z*-component at the lower edge of the frequency range.

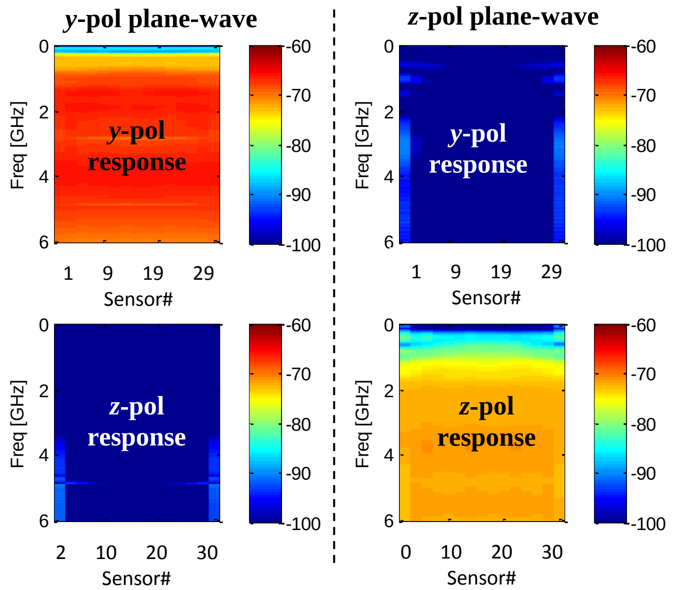


Figure 5. Linear sensor response in dBV for plane-wave illumination (1V/m) as a function of sensor number and frequency in GHz.

Fig. 6 provides a selection of S-parameters obtained at the probe outputs when probe 7 (at the center of the first linear array) is excited. The simulated setup includes two linear array modules. A decoupling greater than 20dB is observed from DC to 6GHz. The highest coupling level is represented and obtained for sensor 8 which is collocated with sensor 7 and perpendicular to it. The strongest board-to-board coupling remains below 35dB and is obtained for sensor 37, being the closest to sensor 7 and in the same polarization.

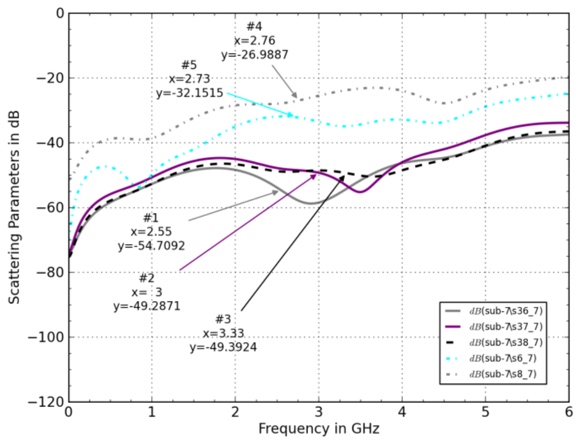


Figure 6. S-parameters for two linear array modules with probe 7 excited.

## V. CONCLUSIONS

A new sensor array technology designed for measuring radiofrequency vector E-field in biological tissue-simulating material was introduced. Based on FDTD modeling of a number of array elements, cross-polarization rejection better than 35dB and decoupling between sensors larger than 20dB were demonstrated. Work will be continued to deliver a complete analysis of the array performances based on numerical simulations and experimental assessment.

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