

### High-resolution near-field measurements accounting for antenna/body coupling around 60 GHz

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## Abstract

We report on a novel method of near-field pattern measurement at the surface of the human body model taking into account the antenna/body coupling at 60 GHz. The proposed technique allows for high-spatial-resolution and fast field pattern measurements. Numerical and experimental distributions of a 4-elements patch antenna array and a conical horn antenna are compared. Results demonstrated a very good similarity between simulated and measured distributions of the power densities. This technique can be successfully applied to near-field exposure assessment of wireless devices in emerging scenarios.

# 1 Introduction

Conventional near-field measurements are performed using antenna scanning systems [1, 2]. However, this requires long acquisition time, large separation distance between the antenna under test and field probe for interferences mitigation, and suffers from low spatial resolution and relatively high uncertainty. IR thermography allows for remote high-spatial-resolution (sub-mm) fast (typically several sec) field pattern measurements, not achievable using standard probes (e.g., monopole or dipole, which typically won't measure details smaller than a wavelength). In addition, the complex field topography in the reactive near-field including evanescent component are measurable thanks to its non-perturbating nature. Finally, this technique is broadband and entirely covers the upper part of the microwave spectrum.

A methodology of tangential electric field visualization using an absorption screen of carbon loaded polymers and IR camera was implemented in [3] at 2.45 GHz and in [4] at 12-16 GHz. However, when an antenna is located in the vicinity of scatter, such as human body, complex interactions occur leading to modification of the field distributions impinging on the body surface compared to the free-space radiation [5]. Therefore, for accurate measurements of the absorbed power density (APD), it is crucial to perform measurements under conditions where the wireless device under test is perturbed in the same way as by the presence of the human body in realistic use case scenarios.

In this paper, we present a novel method of near-field pattern measurement at the surface of the human body model taking into account the antenna/body interactions. For the first time, measurements of APD are performed under conditions where the wireless device under test is perturbed in the same way as by the presence of the human body. To this end, we used a high-resolution IR camera and a novel planar solid skin-equivalent model emulating the same reflection coefficient as the one at the air/skin interface. The proposed system allows for high-spatial-resolution and fast field pattern measurements. Numerical and experimental distributions of APD are compared for a 4-elements patch antenna array and conical horn antenna at 60 GHz.

# 2 Materials and methods

The experimental set-up is represented in Figure 1. A continuous-wave signal is generated by a high-power mmW generator. The power and frequency are controlled by a programmable power supply. The signal is transmitted to the antenna under test through a set of WR-15 rectangular waveguides. The measured input power of the antenna under test (AUT) equals to 3.83 W. An IR camera is used to record the heating pattern dynamics on the surface of the phantom. The camera is located above the phantom, on the opposite side of the AUT, at a distance *d*. The phantom is designed in a way that the power density distributions at both interfaces are almost identical (minimum correlation between the two sides is 99 % [6, eq 3.40]).



Figure 1. Experimental set-up

Due to the shallow penetration depth at mmW into soft tissues (approximately 0.5 mm at 60 GHz), the electromagnetic power absorption in the human body is mainly limited to skin [7, 8]. As a consequence, a homogenous skin-equivalent layer is used as a model. For accurate characterization of antenna/body interactions, the total reflection coefficient at air/phantom interface should approach the one at the air/skin interface. In addition, the transmission through the phantom should be as high as possible so the field can be visualized on the top side of the phantom.

At the same time, the losses in the phantom should be maximized to ensure sufficient temperature rise and therefore the signal to noise ratio of the recorded heat profiles. Furthermore, the field distributions at both phantom interfaces should be as close as possible. To this end, we fabricated a 2.5 mm thick solid phantom using PDMS (lossy dielectric composite) and carbon black poweder. The fabrication process is described in detail in [9]. The complex dielectric permittivity of the carbon-PDMS phantom (CPDMS) is measured at 60 GHz using the free-space transmission method as described in [9] and found to be equal to  $\varepsilon_{\rm r} = 11.64 - 2.91$ j.

We used a two-by-two patch antenna array (2  $\times$  2 PAA) matched to 50  $\Omega$  at 60 GHz [10] and a V-band (50-75 GHz) linearly polarized conical horn antenna.

## **3** Results

To compare the simulated and measured distributions of APD, the following correlation coefficient (r) was employed [6, eq 3.40]:

$$r = \frac{\sum_{m} \sum_{n} (X_{mn} - \bar{X}) (Y_{mn} - \bar{Y})}{\sqrt{\sum_{m} \sum_{n} (X_{mn} - \bar{X})^2 \sum_{m} \sum_{n} (Y_{mn} - \bar{Y})^2}},$$
(1)

where *X* and *Y* are the distributions to compare and  $\overline{X}$  and  $\overline{Y}$  are the mean values of *X* and *Y*, respectively.

The computed and measured absorbed power density are shown in Figure 2 for several antenna/phantom separation distances d. The results demonstrate a very good similarity between simulated and measured power densities for  $2 \times 2$  PAA (correlation ranging from 98.3% to 98.7%) (Table 1) (Figure 2 first and second rows, respectively). Slight discrepancy between simulations and measurements for the conical antenna, with a more complex pattern, is attributed to the thermal diffusion during the temperature recording (correlation ranging from 86.3% to 97.8%) (Table 1) (Figure 2 third and fourth rows, respectively). This discrepancy can be mitigated by shortening the exposure duration.

#### Table 1. Correlation coefficient



**Figure 2.** Absorbed power density:  $2 \times 2$  PAA at d = 6 and 11.5 mm (1<sup>st</sup> and 2<sup>nd</sup> rows, respectively), conical horn antenna at d = 3 and 5.5 mm (3<sup>rd</sup> and 4<sup>th</sup> rows, respectively): (a) simulation; (b) measurement.

# 4 Conclusion

We reported a novel technique for near-field pattern measurement on the surface of the human body model taking into account the antenna/body coupling. For the first time, measurements of APD at 60 GHz are performed under conditions where the wireless device under test is perturbed in the same way as by the presence of the human body in realistic use case scenarios. The proposed measurement system consists of a highresolution IR camera, a novel skin-equivalent model emulating the same reflection coefficient as the one at the air/skin interface, and a signal generator. It allows for high-spatial-resolution and fast field pattern measurements.

Numerical and experimental distributions of the APD are compared for a 4-elements patch antenna array and linearly polarized conical horn antenna. Results demonstrate a very good similarity between simulated and measured APD for  $2 \times 2$  PAA and conical horn antenna (correlation up to 98.7 % and 97.8, respectively). This highlights a promising potential of this technique for fast remote high-resolution near-field exposure assessment.

# **5** Acknowledgements

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