Human Exposure Assessment in Indoor Environments Using A 60 GHz Personal Exposure Meter

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SHORT ABSTRACT

This paper presents the first mm-wave personal exposure meter (mm-PEM) to assess human exposure to the 5th generation of mobile networks (5G) in indoor environments. The mm-PEM consists of 9 elements of an antenna array and is calibrated on a skin-equivalent phantom in a reverberation chamber at 60 GHz. The designed mm-PEM has a response of 1.043 (0.17 dB) at 60 GHz which is very close to the desired response of a PEM i.e. 1 (0 dB). The mm-PEM measured an incident power density of 41 mW.m^{-2} at 60 GHz for an input power of 1 mW in the empty chamber.

INTRODUCTION

The rapid progress in 60-GHz wireless technologies and the availability of the 5th generation of mobile networks (5G) in the near future [1] has raised concerns regarding the potential adverse health effects of mm-waves on human body. The absorption of mm-waves is limited to skin tissues [1]. Therefore, the incident power density (IPD) is studied as a dosimetric quantity. The safety limits of IPD are 1 mW.cm^{-2} and 5 mW.cm^{-2} averaged over 20 cm^{2} of the exposed area for general public and occupational exposure, respectively [2]. Human exposure to radiofrequency (RF) electromagnetic fields is usually measured by Personal Exposimeters (PEMs) [3, 4]. These are portable devices worn on body allowing for continuous measurement of the electric fields strength in several frequency bands for which protocols have been developed [5]. PEMs are calibrated in free space while used on body. In other words, the measured values are compromised by the presence of the human body and thus have large measurement uncertainties [6]. In order to reduce this measurement uncertainty, personal distributed exposimeters (PDE) with multiple antennas can be used for single [7] and multi telecommunication bands [8].

Research shows that people spend more than 80% of their times indoors [9]. This could increase human exposure the electromagnetic fields. The total power in an indoor environment consists of specular and diffuse multipath components. The former and the latter are due to the reflections from large surfaces and presence of objects in a room, respectively. The DMC can contribute up to 95% to the total power density in an indoor environment [10].

The novelties of this research are as follows: 1) For the first time, design and calibration of a mm-wave personal exposure meter (mm-PEM) for RF exposure assessment in indoor environments. 2) on-phantom calibration of the mm-PEM in a reverberation chamber (RC) at 60 GHz. 3) To determine the measurement uncertainty of the proposed mm-PEM including 9 antenna elements.

MATERIALS AND METHODS

The goal is to determine the measurement uncertainty of the designed mm-PEM in diffuse indoor environments. The mm-PEM consisting of 9 antennas is calibrated in an RC at 60 GHz with a bandwidth of 1 GHz. The experimental setup is shown in Figure 1.

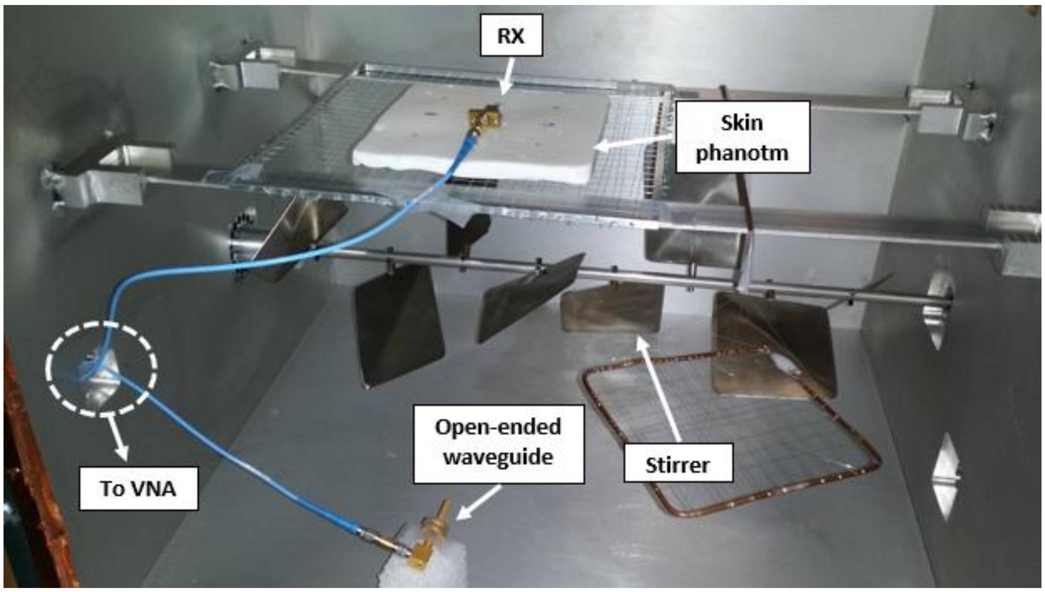

Figure 1. The proposed experimental setup inside the reverberation chamber for on-body calibration of the mm-PEM.

The dimensions of the RC are 0.58×0.592×0.595 m^3. The antenna used for this study is a microstrip four-patch antenna array (Rx) [11]. The surface of the phantom is divided into 9 symmetric locations (i) with a distance of 4 cm. First, the Rx is placed at every location i and the scattering (S-) parameters are measured for every position of the Rx on the phantom and for 100 positions of the stirrer. Second, the measurements are repeated for the Rx far from the phantom at the same locations i. This is to emulate free space conditions for the RX when the RC is loaded with the phantom. The IPD (S_i) for the Rx at every location i is obtained as:

$$S_i = \frac{Q_i P_t \lambda}{2\pi V} \tag{1}$$

Where Q_i is the quality factor of the RC for the Rx at location i, P_t is the transmitted power, λ is the wavelength and V is the volume of the RC. The Q-factor of the RC is calculated from the S-parameters [12].

The response R of the mm-PEM is determined as the ratio of the received power P_r on the Rx placed on the phantom and the Rx in the loaded RC (Rx far from the phantom):

$$R = \frac{P_{r,phantom}}{P_{r,no-phantom}} \quad (2)$$

RESULTS

Figure 2 illustrates the measured response of the mm-PEM averaged over 100 positions of the stirrer for 9 individual antennas on the phantom and the spatial average over 9 locations (antennas) on the phantom. Using a single antenna results in either underestimation (0.6 or -2.21 dB) or over estimation (1.4 or 1.46 dB) of the incident fields inside the RC. Using the average over 9 antennas the mm-PEM has an R of 1.043 (0.18 dB) at 60 GHz. This is an excellent agreement with the ideal value of R that is 1 (0 dB) for a PEM on body. Using less than 3 antennas leads to an overestimation of the IPD up to a factor of 1.25 to 1.4. Increasing the number of antennas up to 9 decreases the response to the values close to 1 as discussed above. Using 9 antennas the mm-PEM has an R of 0.85 (-0.66 dB) to 1.13 (0.55 dB) in the range of 59.5 to 60.5 GHz.

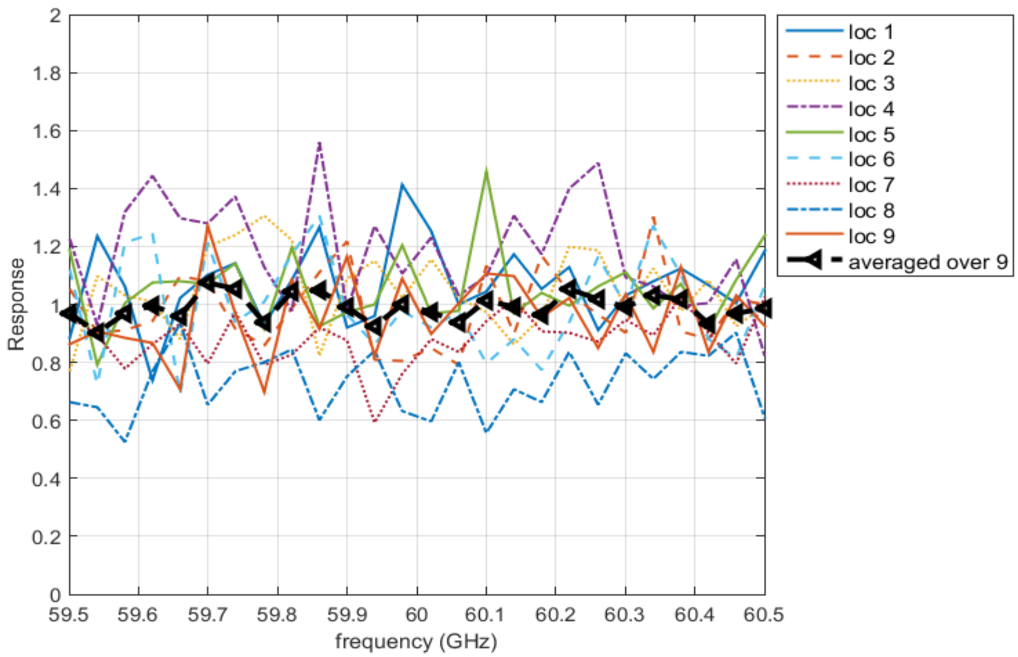

Figure 2. The response of the mm-PEM for 9 single antennas on symmetric locations on the phantom and for the average over 9 antennas.

Figure 3 shows the measured IPD for the antenna in the empty RC and on the skin-phantom in the range of 59.5 to 60.5 GHz. The measured IPD at 60 GHz for an input power of 1 mW are 40.9 $mW.m^{-2}$ and 12 $mW.m^{-2}$ for the antenna in the empty RC and on the phantom, respectively. The measured IPD in the empty RC is about 3.4 times higher than the measured IPD for the antenna on the phantom.

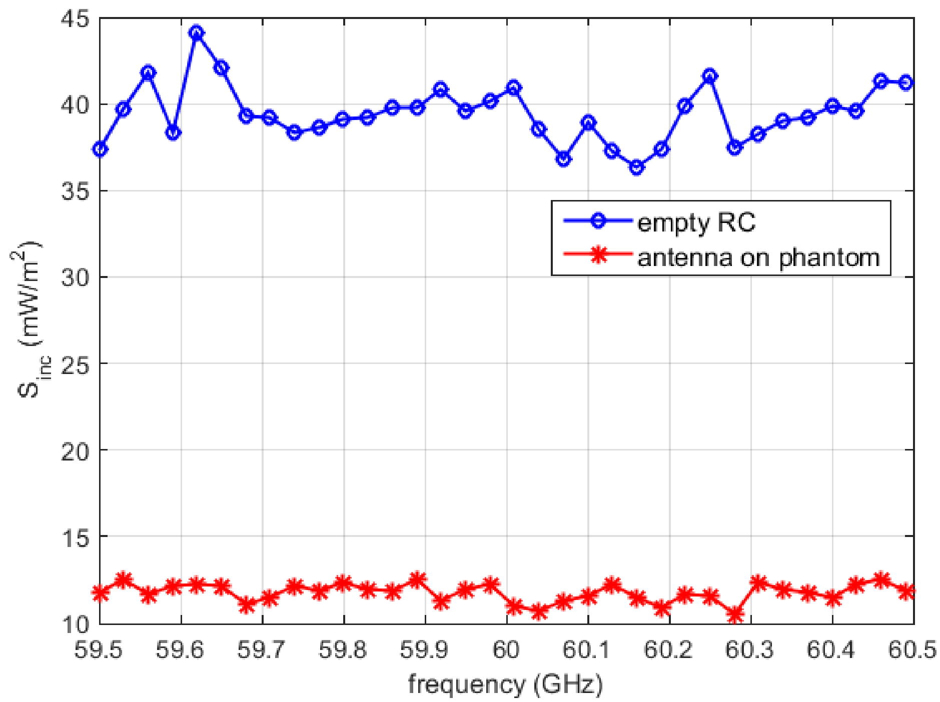

Figure 3. The measured incident power density in the empty RC versus for the antenna on the phantom.

CONCLUSIONS

A mm-PEM is designed and calibrated in a reverberation chamber in the range of 59.5 to 60.5 GHz. The mm-PEM will be used to measure personal exposure to 5G and wireless communication systems operating in the mm-wave band in indoor environments. We showed that using 9 antennas on a skin-equivalent phantom provides a response of 1.043 (0.17 dB) at 60 GHz which is very close to the desired response of a PEM i.e. 1 (0 dB). This means that the mm-PEM can measure the incident power densities in free space but in the presence of human body.

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