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Specific Absorption Rate Measurement Method for Exposure Assessment and Conformity Evaluation of 2.45 GHz RF Wireless Power Transfer System

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Abstract – This article presents a new measurement method of evaluating the specific absorption rate (SAR) as part of human exposure assessment procedure for the radio-frequency wireless power transfer (RF WPT) system operating at 2.45 GHz. SAR distributions measured according to International Electrotechnical Commission standards were obtained and analyzed for the different locations of charging device with the respect to the flat elliptical phantom. RF exposure from the system under test was assessed by comparing the recorded peak 10 g average SAR values versus the ICNIRP general public restriction.

1. Introduction

Radio-frequency wireless power transfer (RF WPT) technology has recently been recognized as the most promising solution for the power supply of Internet of Things wireless devices and wireless sensors used for health care and lifestyle applications. Most of the related research efforts to date have been directed toward the system design and technological development of RF transmitters and receivers. However, there is currently a lack of reported results on human safety assessment and RF compliance testing of WPT systems being proposed for practical deployment. The purpose of this study is to establish a specific SAR measurement method as part of a conformity evaluation procedure for the RF WPT system to be used in various applications. According to international standards and ICNIRP guidelines [1, 2], SAR is utilized as the metric for assessing the human safety of wireless communication systems and electromagnetic (EM) radiation devices in the frequency range from 100 kHz to 6 GHz. In addition, incident EM field strengths are defined as the reference levels and evaluated versus the established national guideline values to complete the human safety assessment procedure. There is currently no international standard on the human exposure assessment of RF (or radiative) WPT devices. Because of differences in the application scenarios of WPT transmitters and receiver systems as compared to conventional wireless devices, the standard SAR evaluation method had to be modified. This work presents the SAR measurement method and an evaluation example of one RF WPT system operating at 2.45 GHz. A SAR measurement protocol has been proposed, and SAR distributions measured for the different operation scenarios of the RF WPT system are presented and analyzed.

2. SAR Measurement Setup

As is well known, the SAR value in the tissue equivalent medium is determined by the rate of the medium's temperature increase or by the E-field measurements (or calculations) according to the following formula:

$$SAR = \frac{\sigma E^2}{\rho} \tag{1}$$

where SAR is the specific absorption rate (W/kg), σ is the electrical conductivity of the tissue medium (s/m), E is the RMS value of E-field strength in the tissue medium (V/m), and ρ is the mass density of the tissue medium (kg/m^3).

In this work, SAR has been obtained by using the E-field strength measured in the tissue-equivalent liquid inside a phantom.

The evaluated system consists of the 16 $\times$ 16 element phased array retrodirective transmitter [3] and RF WPT receiver (client). The client sends an initial low-power (<8 mW) continuous wave "beacon" signal and rectifies the RF power unmodulated signal received from the transmitter operating at 15 W maximum output with 23 dBi array antenna gain [4]. The WPT client can be placed at both radiative near-field and far-field locations within the charging distance up to 10 m to the transmitter.

An elliptical flat phantom made according to International Electrotechnical Commission (IEC) 62209-2 for compliance testing of body-worn wireless devices as a part of the SPEAG DASY5 SAR measurement system has been used [5]. The SAR measurement method used in this work is compliant with the IEC standard. The phantom was filled with a tissue-equivalent liquid with relative permittivity 39.2 and electric conductivity 1.8 s/m at 2.45 GHz as per IEC standards.

An RF WPT transmitter sized 60 cm $\times$ 60 cm was first placed under the phantom at a 42 cm vertical distance to its bottom. Because of the fixed dimension of the phantom's supporting frame, 42 cm was the maximum distance available at the first stage of the measurements. As a result, a three-wavelength distance

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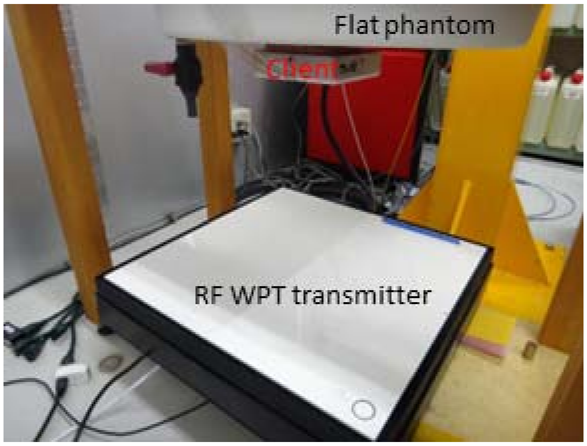

Figure 1. SAR measurement setup of WPT system under test.

from the transmitter to the phantom corresponds to the radiative near-field operation of the WPT transmitter antenna. The SAR measurement setup of the RF WPT system is shown in Figure 1. Next, the WPT client was located to the phantom's side wall to consider different operations of the RF WPT system. In the measurements, as the WPT client was placed to the bottom and side wall of the phantom, the corresponding effects on the SAR distribution were studied.

The DASY5 measurement system was programmed to record SAR distributions within the 35 cm × 30 cm scan plane located 2 mm above the bottom of the phantom.

3. SAR Measurement Protocol

Figure 2 depicts the proposed SAR measurement protocol. In the first part of the SAR measurements, the RF WPT transmitter was placed underneath the elliptical phantom with its center point located exactly under the phantom center. That was the case of broadside array operation, as shown in part 1 of Figure 2. Next, a lateral shift of the transmitter by 30 cm to 36 cm was introduced to assess the RF WPT system operating with antenna beam scanning to the client placed at the bottom and side wall of the phantom. In this case, all array elements operate in the line-of-sight condition with respect to the center of the WPT client, as depicted in part 2 of Figure 2. For some locations of the client with respect to the phantom, a partial obstruction was produced when some of the 256 array elements could not focus directly to the client. Such a scenario is illustrated in part 3 of Figure 2. In the case of partial obstruction by the phantom, the transmitter output power was automatically lowered to limit the RF exposure, and, as a result, the power received by the client decreased from the 35 dBm to 18 dBm. When the client was placed at the side wall, its center was at the extension of the phantom's minor axis. The client was attached to the bottom and side wall of the phantom by adhesive tape. Placement of the client to the side wall increases the vertical distance from transmitter to the

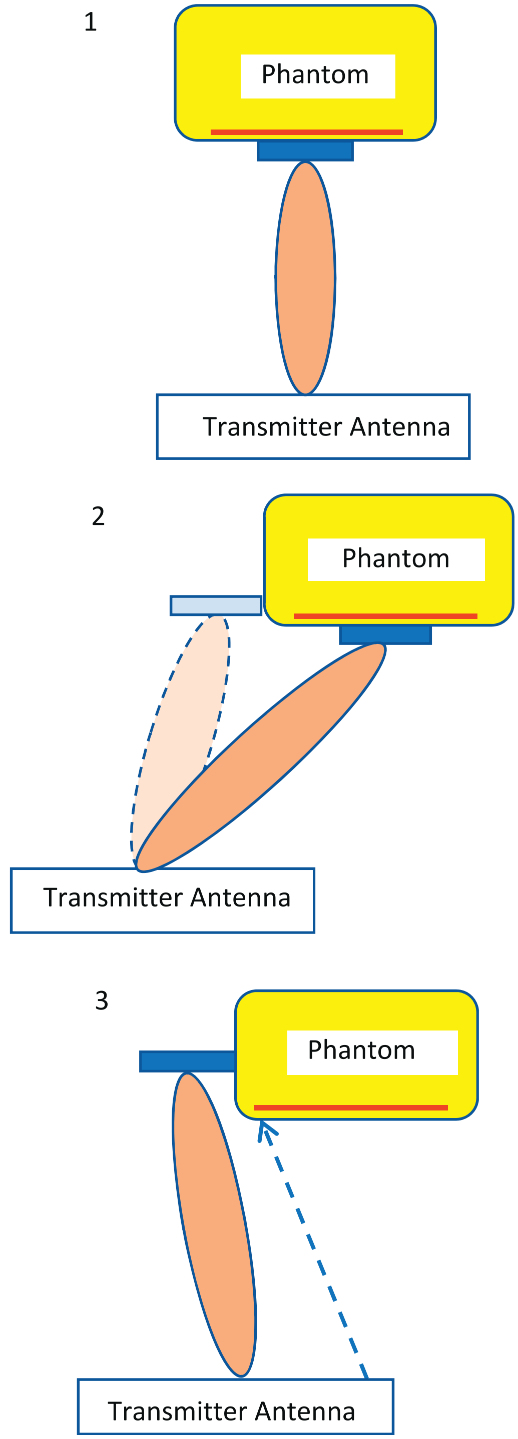

Figure 2. Proposed SAR measurement protocol. Part 1 considers the broadside operation of the WPT transmitter. The beam-scanning is utilized in part 2, while the case of partial obstruction of the charging device is realized in part 3.

client by 7 cm (part 2 of Figure 2) and by 12 cm (part 3 of Figure 2) of the measurements.

During all the measurement steps, the obtained SAR distributions were analyzed to verify how the RF

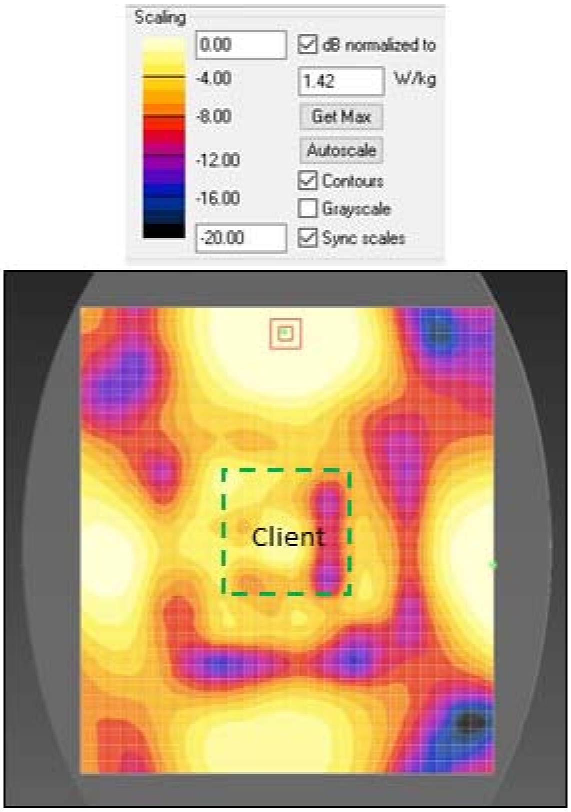

Figure 3. Measured 10 g average SAR distribution for the case of the central location of the client shown in Figure. 1. The phantom dimensions and the client's location with respect to the scan area are also shown.

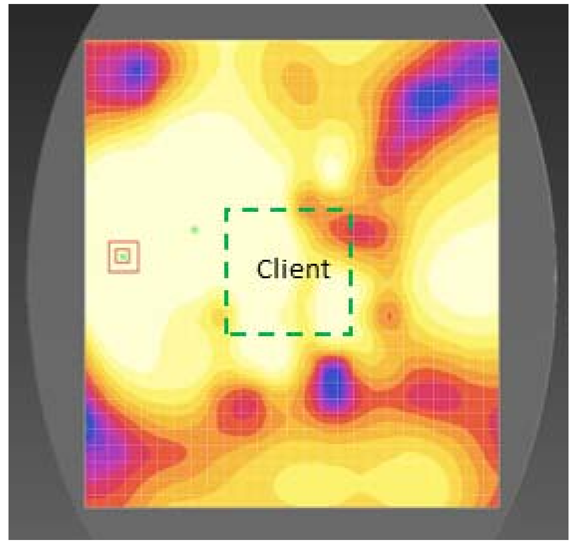

Figure 4. Measured 10 g average SAR distribution for the case of a 33 cm lateral shift of the RF WPT transmitter and the central location of the client. The phantom dimensions and the client's location with respect to the scan area are also shown. The 0 dB scale is the same as in Figure 3.

beam produced by the WPT transmitter was focused to the WPT client.

The proposed protocol corresponds to all typical application scenarios of the RF WPT system operating close to a human body. One of the goals of the SAR measurements carried out in this study was to determine the exact location of the client on the phantom relative to the position of the WPT transmitter that yields the highest possible RF exposure.

4. Measured SAR Results

Measured SAR distributions were analyzed for each location of the WPT client on the phantom. The recorded peak 10 g average SAR values were assessed versus the ICNIRP general public restriction of 2 W/kg. For the case of the central location of the client and the WPT transmitter, as shown in Figure 1, the measured SAR distribution is presented in Figure 3, where a 0 dB scale of SAR is normalized to 1.42 W/kg. It is the result of a two-dimensional scan on the bottom of the phantom, and the location of the maximum value is marked with double square sign. Higher SAR values were observed at four spots around the client, and the maximum recorded 10 g average SAR = 1.32 W/kg.

Figure 4 shows the SAR distribution measured for the case of a 33 cm lateral shift of the WPT transmitter and the central location of the client attached to the phantom's bottom as per part 2 of the measurement protocol. Among all the measurements, this location of the transmitter and the client produced the highest SAR when the maximum value of 10 g average SAR = 1.95 W/kg has been obtained. In such a case, some "unfocusing" of the RF beam scanned to the client was observed, as the radiation from some of the transmitter array elements drifts to the phantom bottom.

When the client was placed to the phantom wall, higher SAR values were observed in the side close to the client location, as shown in Figure 5, but the maximum 10 g SAR was much lower, being equal to 0.61 W/kg. The transmitter antenna was "focusing" EM radiation to the client, and thus less absorption in the tissue-equivalent liquid was observed.

Figure 6 shows the SAR distribution measured for the case of a partial obstruction of the client placed on the side wall of the phantom. In this arrangement, as illustrated in part 3 of Figure 2, the phantom blocked the line of sight of some of the transmitter array elements so that they automatically powered off. Partial obstruction decreased the power delivered to the client from 35 dBm to 18 dBm. As a result, in such a case, the maximum recorded 10 g SAR = 0.49 W/kg.

In all the measurements, peak 10 g average SAR values varied between 0.49 W/kg and 1.95 W/kg, depending on the application scenarios described above. Analysis of SAR measurement results provides insight into how RF exposure may change for the cases of various locations of the client with respect to the human body and the scanning operation of the RF WPT transmitter.

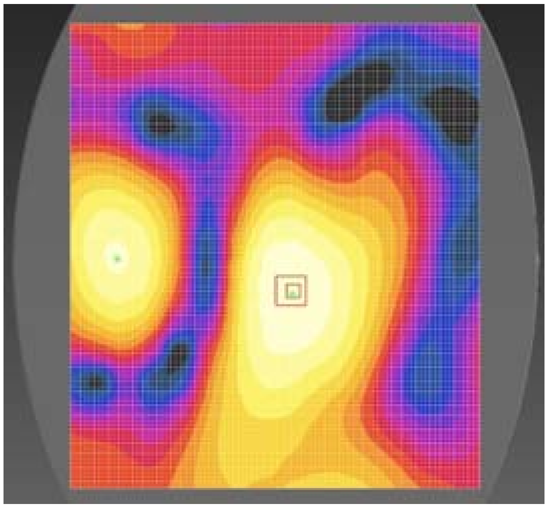

Figure 5. Measured 10 g average SAR distribution for the case of the client placed to the phantom's left side wall. The client is located on the left side of the SAR distribution.

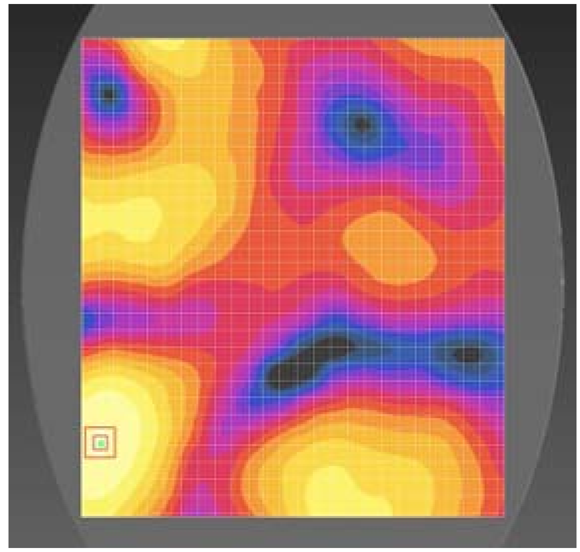

Figure 6. Measured 10 g average SAR distribution for the case of a partial obstruction of the client placed to the phantom's left side wall. The client is located on the left side of SAR distribution.

5. Conclusions

We have presented the SAR measurement method and an evaluation example of one particular RF WPT system operating at 2.45 GHz. Experimental RF exposure assessment presented in this work can be used as a benchmark compliance test of similar RF WPT systems that are expected to be introduced soon for the various practical applications. The use cases of the evaluated system include an application scenario when the charging device is located in close proximity to the human body. The mutual location of the charging device and the WPT transmitter with respect to the phantom producing the highest potential RF exposure was identified.

It should be noted that in addition to the SAR evaluation, the complete RF exposure assessment should also include accurate E-field strength measurements in the far-field and near-field zones of WPT transmitters.

6. Acknowledgment

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7. References

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