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Design, Calibration and Validation of a Low-Cost Broadband Add-On RF-EMF Exposure Sensor for Legacy and 5G NR Technologies

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Abstract Subject Area(s)

["Experimental dosimetry","RF/Microwave","Occupational exposure","Risk assessment"]

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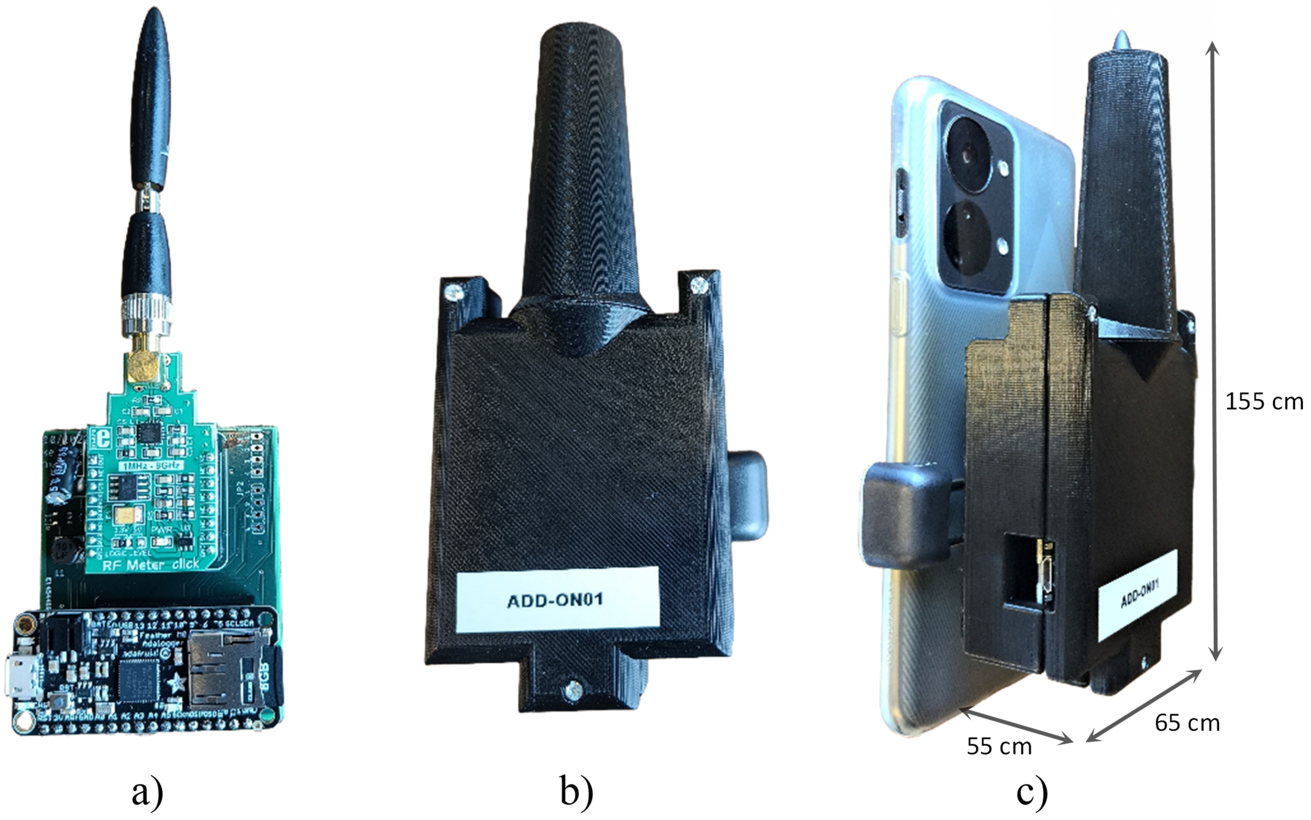

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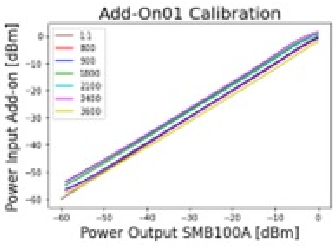

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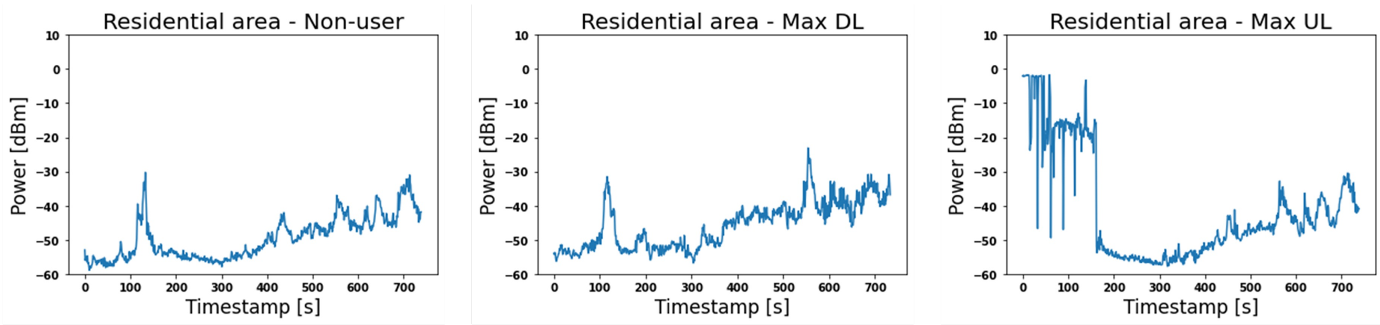

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INTRODUCTION

Radiofrequency electromagnetic field (RF-EMF) exposure assessment is nowadays becoming a hot topic as the deployment of 5G New Radio (NR) base stations continues. This emerging new technology raises concerns among the public and governments regarding the general health. Over the last couple of years, new measurement equipment has been tested and methods have been developed [1-4] to provide accurate spatio-temporal assessment of 5G NR exposure. In a time when this new technology coexists with the current telecom technologies (2G-4G), the latter still have to be measured as well to determine the exposure and check whether the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines are satisfied [5]. Still, it is difficult to quantify the auto-induced transmission uplink (a-UL), i.e. the RF-EMF exposure induced within the user by their own device [2]. Current devices to reach this goal, like the ExpoM exposimeter (Fields at Work, Switzerland [6]), are large compared to a smartphone. A smaller device with an efficient form factor and a wide frequency and power range, which can be attached to a smartphone and thus keeps a relatively small and fixed distance to the smartphone under test, is desired. Several software solutions are available to also measure this not negligible exposure component, e.g. smartphone applications like QualiPoc [7] and Nemo. Despite the qualitative and detailed measurement results, these solutions remain rather expensive and are complicated to use for non-experts. That is why these are infeasible to use for large-scale measurement campaigns and an alternative is required. For these reasons, there is a need for a low-cost and low-complexity personal a-UL exposure sensor. This paper describes the design, calibration and in-situ validation of such a device.

The proposed device, which can be attached to a mobile phone and is thus called 'add-on sensor', will be used in activity-based microenvironmental surveys in the GOLIAT EU project, conducted in several European countries, to asses RF-EMF uplink exposure from legacy, current and emerging wireless technologies. Personal exposure will be assessed in geographical areas, divided into smaller microenvironments (MEs) based on the main activity performed by the public (e.g. residential, commercial, schools, industrial, public transport) [2]. In this study, 4G and 5G experiments with the add-on device in a microenvironment, more specifically a residential area in Ghent, Belgium, were performed for three usage scenarios.

METHODS

Design

Figure 1 presents the proposed add-on device (Figure1.a) and its housing and position when attached to a mobile phone (Figure1.b-c). It is intended to be low-cost, so it is designed with only off-the-shelf components and a custom Printed Circuit Board (PCB). The size is another important property, the sensor is sufficiently small (115x65x55 mm^3) and furthermore, easily attachable and removable from a smartphone to ensure flexible usage.

Figure 1: a) Add-on device. b) 3D-printed protection case. c) Add-on attached to smartphone.

The main component of the RF-EMF add-on is the RF Meter Click by MikroElektronika, which includes an AD8318 logarithmic RF detector and a MCP3201, a 12-bit Analog-To-Digital Converter (ADC). The RF detector has a frequency range from 100 to 8000 MHz, which covers the current frequencies used for telecommunication (2G-5G, Wi-Fi but also FM radio etc.). This range is limited by the selected antenna, a wideband monopole antenna, which covers a frequency range of 600-6000 MHz. However, the current telecommunication technologies (2G to 5G) all use frequencies (i.e. the frequencies of interest) within this range. Since a broadband antenna is used, the add-on cannot discern the different frequencies and thus the currently measured frequency is not included in the measurement data. The resulting data obtained is thus a summation of all frequencies, within the range, being received at that time. The RF detector has a suitable dynamic power range of 60 dB. The output of the ADC is read by an off-the-shelf Adalogger Feather M0 manufactured by Adafruit. During 0.5 s, 500 samples are taken with a sampling frequency of 1kHz. In the following 0.5 s the statistics (including average, median, minimum and maximum) are calculated. This leads to an output of 1 value for these statistics every second. With a micro SD-card slot, this microcontroller board can directly store the measurement data to a removable data card. Finally a DC-DC conversion circuit is included to convert 3.3 V from the Arduino to 5 V, required to power the RF Meter Click. Table 1 provides an overview of the abovementioned specifications.

Table 1: Specifications of the add-on sensor.

Frequency range	600 – 6000 MHz
Case dimensions	115 x 65 x 55 mm^3
Dynamic range	60 dB
Supply voltage	3.3 V
Reported accuracy	1.0 dB over 55 dB range
Output sampling time	1 s

The RF-EMF sensor is placed inside a protective case, 3D-printed with PLA (polylactide) filament (Figure1.b), which consists of two components connected with three screws. A cut-out is incorporated into the side to make the micro-USB port accessible. This is necessary for powering the sensor: either powered by a portable battery, power bank, or by the smartphone itself via a micro-USB-to-USB-C cable. The sensor can be attached to the mobile device through a spring-based phone holder (Figure1.c). The case must be opened to access or remove the micro-SD card.

Calibration

In order to ensure accurate exposure assessment, an on-board and an in-situ calibration (denoted as free-space calibration from now on) were executed. As for the on-board calibration, the goal was to quantify the power loss induced by the electronic circuit and verify the power response of the hardware. The add-on was connected to a calibrated signal generator by Rohde & Schwarz (type: SMB100A) via an RF cable to determine the output voltage of the RF detector as a function of the incident power [1]. This was done for frequencies going from 500 MHz to 8000 MHz, in steps of 50 MHz, and input powers from -70 to 0 dB in steps of 1 dB. The output response was stored into a look-up table (LUT). The cable loss and antenna factor were also taken into account to ensure an accurate calibration. These were acquired by measuring the cable and the monopole antenna with a Vector Network Analyzer (VNA). This large dataset was reduced to 1 single calibration factor, since the add-on does not have any frequency information while performing measurements. This calibration factor is obtained by taking the median of the errors compared to the power of the signal generator for the most common frequencies (800 MHz, 900 MHz, 1800 MHz, 2100 MHz, 2400 MHz and 3600 MHz) used for wireless telecommunication in Belgium and then taking the average for those frequencies. The calibration plots of these frequencies are presented in Figure 2. With this average error being approximately 1.43 dBm, this is a good calibration factor which leads to a fully calibrated add-on sensor. With the antenna factor also included, an overall calibration value of 27.33 dBm is achieved.

Figure 2: Onboard calibration add-on sensor.

A free-space calibration was performed besides the on-board calibration to quantify the response of the add-on sensor with the broadband antenna with regard to the output of the smartphone (type: OnePlus). This step was performed by making a comparison between the add-on sensor and QualiPoc, a multifunctional smartphone based tool for monitoring voice and data service quality and RF optimization by Rhode & Schwarz, during in-situ measurements [7]. QualiPoc can track the incident and transmitted power from the smartphone under test. When the add-on and QualiPoc software are used simultaneously, a comparison in power measured by the add-on and reported by Qualipoc can be made, which leads to a free-space calibration factor of the add-on. In addition, QualiPoc measurements are able to provide further detailed parameters.

The add-on device was validated in-situ in Ghent, Belgium. A trained researcher followed a predetermined route on foot through a defined residential microenvironment with a smartphone equipped with an add-on exposure sensor and QualiPoc software. The researcher turned his own device to airplane mode as to not affect the measurements by his own network traffic. In this residential area, measurements were conducted for three usage scenarios. First, a non-user scenario, for which the smartphone is turned into airplane mode. This means that only environmental exposure induced by the devices of passers-by or in houses and base stations in the vicinity will be measured by the add-on. For the second scenario, the smartphone performs a maximum downlink, i.e. repeatedly downloading a file of 500 MB from a File Transfer Protocol (FTP)-server. Finally, the smartphone uploads a large file to the server, thus a maximum upload scenario. It is possible to switch between these different scenarios in a user-friendly way through an in-house developed android application. The smartphone and add-on were put away in a backpack to avoid influence by the human head and hands.

RESULTS

The experimental measured power by the add-on sensor for the three usage scenarios obtained in this microenvironment are shown in Figure 3 (a) for non-user, b) for maximum downlink (DL) and c) for maximum uplink (UL)). The received power is displayed as a function of the time. Each scenario is estimated to last no longer than fifteen minutes in order to have a larger feasible number of measurements over the global measurement campaign.

Figure 3: 4G and 5G power measurements with add-on sensor and smartphone in a residential microenvironment for 3 usage scenarios in Ghent. a) Non-user. b) maximum downlink. c) maximum uplink.

These results provide an indication of the total observed exposure. The maximum measured power in the non-user scenario was -30.26 dBm, which is as expected lower compared to -23.1 dBm and -1.68 dBm for the max DL and max UL respectively. The high values in the maximum UL scenario can be explained by the very large file being uploaded by the mobile phone with the add-on attached. The phone is forced to transmit as many resources as possible. Hence, it is expected that the transmit power is as high as possible. After about 180 seconds it seems the network connection is interrupted and the measured power decreases. The minimum values are -58.92 dBm, -56.83 dBm and -57.79 dBm respectively for the three scenarios. Starting from 300 seconds, for the three plots, about the same rising trend occurs. This may be due to the presence of a base station in the close proximity near the end of the route. Because the maxima and minima values are located within the interval -60 to 0 dBm, it is shown that the dynamic power range of the add-on is sufficient.

As stated before, the add-on cannot distinguish frequency bands or used telecommunication technologies. However, using the location of the base stations in the neighborhood and the QualiPoc data, it is determined that the larger proportion of the powers are originated from Long Term Evolution (LTE; 800 MHz and 1800 MHz, thus 4G traffic). Also a fraction of the total exposure originated from 5G NR (3600 MHz) base station, as there was a 5G base station on the route and within this microenvironment. This presence of 4G and 5G was also established by the QualiPoc experiments.

CONCLUSIONS

An add-on RF-EMF exposure sensor was designed to provide a low-cost solution for auto-induced uplink exposure assessment. With a wide frequency range of 600 MHz to 6000 MHz, the resulting device is able to perform exposure assessment for the legacy and 5G wireless telecommunication technologies as well as 5G NR, which is emerging in Belgium. To ensure proper operation and reliable measurements, an on-board calibration was performed to quantify the power losses induced by the hardware and a free space calibration with the monitoring application QualiPoc. The device was validated in-situ in a residential microenvironment in Ghent, Belgium. Future work entails that these add-on sensors in combination with smartphones can be deployed for large scale measurements for exposure assessment in micro-environments in different European countries when the telecom networks of tomorrow are further rolled out.

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