of events that inexorably cause a degenerative chronic stage mainly favored by the non-permissive environment and limited capacity for axonal regrowth. Multifaceted strategies are considered the unique solution for functional restoration by including cell substitution, neuroprotection and axonal growth promotion. RISEUP project proposes to attain neuronal functional regeneration after SCI by an unprecedented and unique bio-hybrid-compatible electro-activated and wireless rechargeable implantable technology. RISEUP introduces high voltage microsecond electric pulses (micropulses) stimulations and low amplitude direct currents on a combination of stem cells (induced neural stem cells and multipotent stromal cells), whose transplantation is facilitated by an innovative scaffold biomaterial. The RISEUP concept is that micropulses, being able to impose and control cytosolic Calcium oscillations [2, 3], will facilitate cell maturation, survival and neurotrophic factors secretion. Because Calcium signaling is essential for neuronal activity, endogenous neuronal re-connections will also be favored. RISEUP goal, even if ambitious, is concrete due to the multidisciplinary partners' competences, initiating from TRL1 a radically new line of technology (electro-activated, remotely controlled, biocompatible, biodegradable cell-containing implants for the repair of neuronal lesions) establishing its proof-of-principle (TRL3). The long-term vision of RISEUP is the radical change in SCI treatment modality to assure the cure delivery without any machinery connection, dramatically improving patients' quality of life.

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Figures

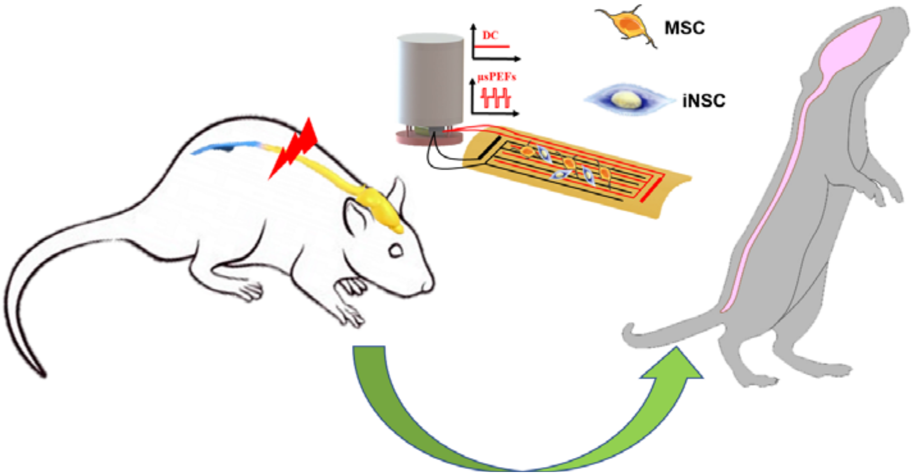

Figure 1. RISEUP project synthetic description

PS-26 [15:00]
STUDENT PAPER

Design of a low-cost modular 5G RF-EMF exposure sensor

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Presented by: Kenneth Deprez

Spatio-temporal radiofrequency (RF) electromagnetic field (EMF) exposure assessment is currently of great interest as concerns about RF-EMF exposure of the public and governmental bodies arise. To perform long-term spatio-temporal EMF exposure assessment in current and future telecommunications networks, low-cost RF-EMF exposure sensors have been designed to measure up to four frequency bands, which are determined based on the project and/or environment specifications, that are used by current telecom technologies (2G up to 4G) and in the upcoming 5G New Radio (NR) networks. Sufficiently high sampling rates for the targeted application are feasible and thus highly detailed temporal exposure assessment over a long period is possible.

Introduction

Modifications of the wireless communications infrastructure are altering the everyday exposure to environmental radiofrequency (RF) electromagnetic fields (EMFs). The fifth generation of telecommunications networks (5G New Radio (NR)) introduces new frequencies between 700 MHz and 30 GHz. To correctly inform both governmental entities and the general public, spatio-temporal RF-EMF exposure assessment systems are of interest [1]–[5]. However, these assessments are still challenging due to the vast amount of EMF sensors needed to be densely distributed to measure exposure accurately [6]. Due to the advent of Internet of Things (IoT) infrastructure, it is feasible to deploy distributed networks of low-complexity, and thus cheaper sensing devices to monitor environmental parameters such as humidity, temperature and air quality over a long period [7]. Here, we propose a low-cost fixed 5G NR RF-EMF sensor that can be deployed alongside the above-mentioned sensors. By fixing the EMF sensor to the power grid, a high sampling rate can be obtained, which enriches long-term exposure measurements with fine temporal granularity. Our goal is to distribute these sensors densely, so that spatio-temporal EMF exposure mapping can be realised by using the data obtained by these (5G) RF-EMF sensors.

Materials and methods

Sensor design

To ensure a low-cost (5G) RF-EMF sensor, off-the-shelf components are used. Up to four frequency bands are measured at once. Table 1 provides an overview of the four frequency bands included in this 5G EMF sensor. The considered frequency bands for this RF-EMF sensor are used in Belgium by the second to fifth generation (2G – 5G) cellular telecommunications technologies. Hence, the sensors are future proof by adding a 5G frequency band, but can still assess EMF exposure in legacy wireless communication technologies. The considered technologies are Global System for Mobile Communications (GSM; 900MHz and 1800MHz), Universal Mobile Telecommunications System (UMTS; 900MHz), Long Term Evolution (LTE; 800MHz and 1800MHz), and 5G New Radio (5G NR; 3600MHz). The frequency bands dedicated to 2G to 4G contain only downlink communications, i.e. from the cellular base station to the user due to Frequency Division Duplex (FDD), whereas the 5G NR frequency band contains bidirectional communications due to Time Division Duplex (TDD). Due to the use of separate antennas, the dimensions of the sensor are 180 x 180 x 150 mm^3 (l x w x h). However, this sensor is designed to be attached to a building, put on top of a car, etc.

For each frequency band, a dedicated narrowband planar half-wavelength dipole antenna was designed in-house. Each vertically polarized antenna is connected to a sub-miniature A (SMA) connector, and the induced current is filtered by a frequency-specific Surface Acoustic Wave (SAW) filter. It is important to note that by using frequency-specific components, the EMF sensors are easily adaptable. The output of the filter is then fed to a true-root-mean-square (tRMS) RF detector (HMC1020LP4E), which has a dynamic range of 70 dB for frequency band 1 to 3 and 60 dB for frequency band 4 (see Table 1), with lower detection levels of -65 dBm and -56 dBm, respectively. The analog output provided by the detector is converted to a 12-bit value using an analog-to-digital convertor (ADC; ADS1015), with a programmable data rate of 128 Samples per Second (SPS) up to 3.3 kSPS. The converted values are finally processed by an off-the-shelf microcontroller (Arduino) by means of a look-up table (LUT) to obtain the linear average, median and/or maximum RF power at a programmable interval, determined by the internal sample rate and the needs of the project. Stacking headers are placed on the printed circuit board (PCB) to enable easy switching between IoT platforms, depending on the required communication standard (e.g. LoRa, WiFi, Ethernet, USB).

Table 1: Specifications of the RF-EMF sensor.

Frequency range	791–3700 MHz
- Frequency band 1	‘800 MHz’: 791–821 MHz
- Frequency band 2	‘900 MHz’: 925–960 MHz
- Frequency band 3	‘1800 MHz’: 1805–1880 MHz
- Frequency band 4	‘3600 MHz’: 3550–3700 MHz
Outer Dimensions (L x W x H)	18 x 18 x 15 cm^3
Dynamic range	60 - 70 dB
Sensitivity	5 mV/m
Supply voltage	5 VDC USB power
Output sampling time	1000 ms
Internal sampling time	11 ms

Calibration

The sensors were calibrated to ensure correct RF-EMF assessment along one axis. Both on-board and free-space calibrations were performed. The goal of the on-board calibration was to determine the output voltage of the RMS power detector in the used frequency bands as a function of the incident power. Hence, in each separate frequency band, a sinusoidal signal was swept using a calibrated signal generator (type R&S SMB100A) and a LUT per frequency band was obtained for each sensor. During the free-space calibration, each EMF sensor was placed in the far field of a vertically polarized transmitting antenna on a rotational platform. The EMF sensor continuously registered the received power when rotated at two degrees per second in a horizontal plane. In total, ten EMF sensors were calibrated and validated in-lab by means of a NARDA SRM-3006 connected to a NARDA 3502/01 isotropic antenna. Finally, an in-situ validation was performed, with the setup shown in Figure 1. The sensors are placed in an arbitrary manner around an SRM-3006 field strength analyser for validation. The radiation measured originated from (at least) two base stations, which were respectively 507 and 538 meter separated in distance from the measurement setup (i.e., the SRM-3006). Five measurements, during six minutes (ICNIRP guidelines [8]), were performed to assess the functioning of the EMF sensors. All EMF sensors were placed in the same orientation. In subsequent tests, each sensor was turned 90 degrees (so measurement 5 equals measurement 1).

Results

Figure 2 shows the result of the in-situ validation. An average of all custom sensors is shown by the red dashed line per frequency band, while the SRM measurement is shown by the black dashed line. The maximum average deviation between tests was 2 mV/m, 10 mV/m, 6 mV/m and 5 mV/m for the 800, 900, 1800 and 3600 MHz frequency bands, respectively. However, as the validation was performed in-situ, there was no control over the emitted power of the telecom signals. Variance in exposure induced by the base stations also contributed in the average deviation.The expanded measurement uncertainty (for isotropic measurements) of the SRM-3006 is 2.3 dB to 2.0 dB / -3.1 dB to -2.6 dB, depending on the frequency range.The frequency ranges for measurement uncertainty are 750-1800 MHz and 1800-4000 MHz.The absolute median errors when compared to the SRM-3006 were -5.2 dB, 0.7 dB, -2.9 dB and 0 dB, respectively. Hence, in the 800 MHz band, 50% of the field levels were underestimated by at least 5dB. In the 1800 MHz frequency band, an underestimation of 2.9 dB was observed. The 900 MHz band lies within the measurement uncertainty of the SRM-3006 while no conclusions can be drawn about the 3600 MHz frequency band. In conclusion, the individual errors of the fixed RF sensors compared to the SRM setup must be added as an additional correction factor. It must be noted that the SRM measures three polarizations while the designed EMF sensors can only measure vertical polarization. Furthermore, it can be deduced that the rotation in a horizontal plane had no real influence on the field values. For the first test in the 3600 MHz frequency band, an average of 5 mV/m was obtained, which can be contributed to interference, as there was no 5G working base station nearby. The culprit of the interference was unclear and did not appear on further testing.

A separate test was performed to validate the EMF sensors' measurements in the 5G NR frequency band. Two sensors were placed near a working 5G base station. The test setup thus differed from the one shown in Figure 1. The test aimed to investigate whether the designed EMF sensor can correctly assess 5G EMF exposure. Two situations were considered: with and without user traffic. User traffic was induced by an iPerf tool with an user equipment (UE) as explained in Ref. [9]. This method has been tested and verified in-situ in Bern, Swiss [10]. Figure 3 shows the result of these measurements. Until 11:10, no traffic was induced by the UE on hand (a 5G-enabled smartphone). In this timeslot, the assessed exposure (0.1 - 0.2 V/m) was induced by the control signals of a 5G base station (i.e., the Synchronisation Signal Block (SSB)). Starting from 11:10, traffic was induced on-and-off until 11:50, and the electric field strength increased to maxima of 2 V/m and 0.26 V/mfor sensor 1 and sensor 2, respectively. The difference between the two sensors can be explained by the different placement of the sensors as EMF sensor 1 was placed optimally (2 meter behind the UE), while sensor 2 was placed further away from both the base station and UE (10 meter behind the UE) on the top of a vehicle, which had a negative influence on the EMF field strength. In conclusion, the designed EMF sensor can assess 5G EMF exposure but a more extensive measurement is needed to ensure correct 5G EMF field exposure assessment.

Conclusions

Low-cost 5G NR EMF sensors were designed and validated in-situ. The low-cost EMF sensors have been calibrated both on-board and in the far field and validated both in a lab setting as in-situ for all currently used frequency bands and telecom technologies. By means of a high sampling rate, high detailed exposure assessment over a long period will now become feasible and might open new insights in everyday EMF exposure from both current technologies as the technology of tomorrow, i.e. 5G NR. Future work will consist of distributing these sensors and analyse the obtained data and increasing the number of sensors significantly.

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Figures

Figure 1. Setup of in-situ validation. A) NARDA SRM-3006, B) one of the ten EMF sensors. The probe of the SRM-3006 was installed on a height of 1.2m, the height of the tables is 0.8m.

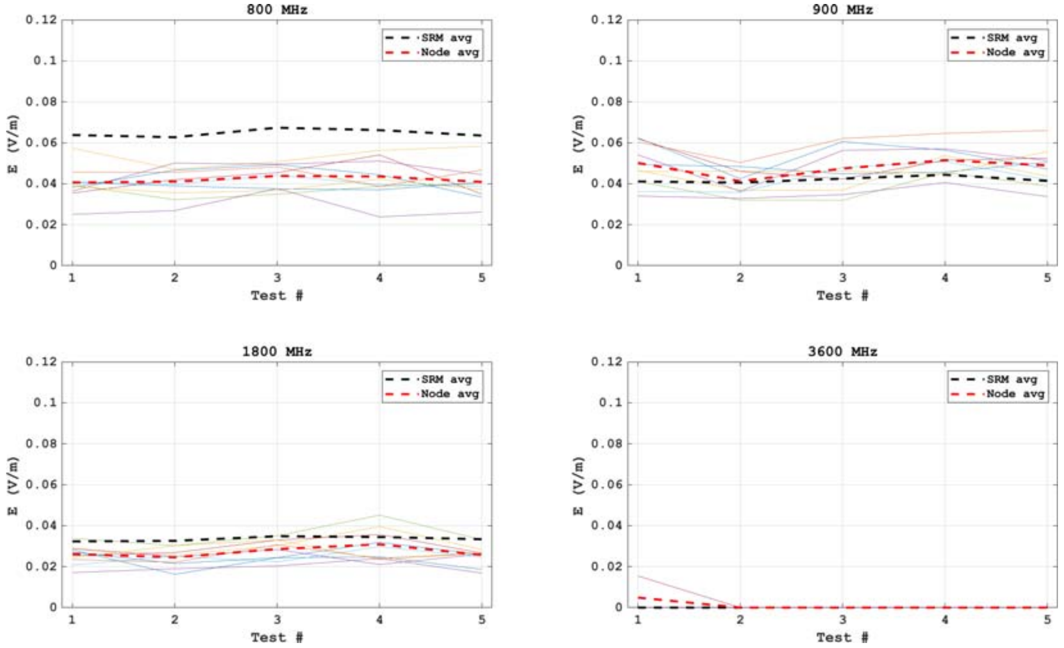

Figure 2. Overview of in-situ validation of ten EMF sensors. An average of all sensors is given by the red dashed line per frequency band, while the SRM measurement is given by the black dashed line.

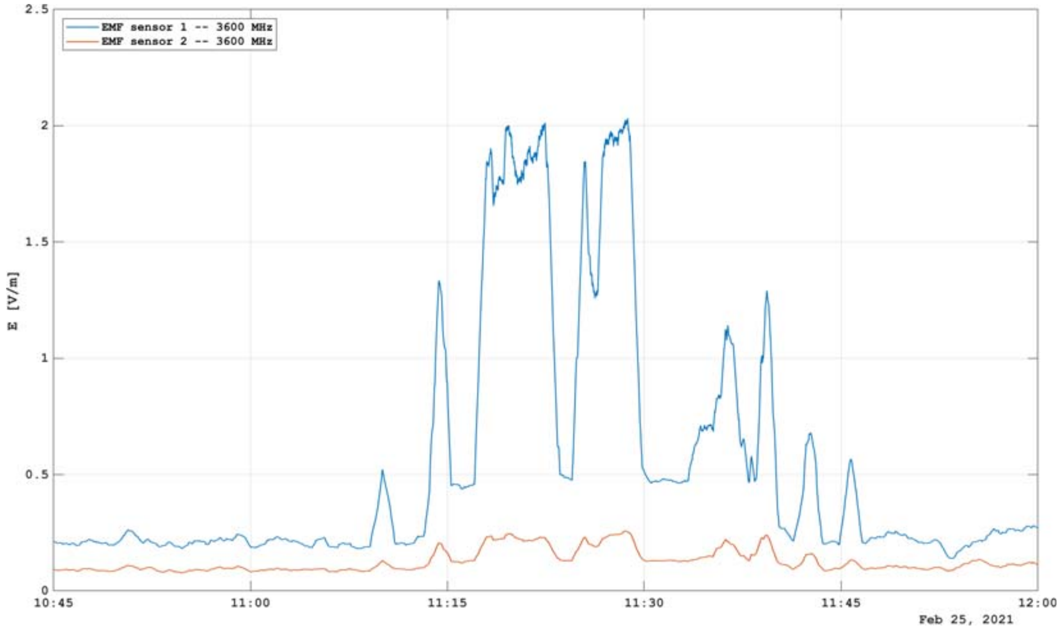

Figure 3. In-situ validation of 5G NR frequency band. Two EMF sensors were investigated near a 5GNR base station antenna. These measurements do not correspond to the measurement setup shown in Figure 1.

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