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A Wideband Smart EMF Detector for Mobile Devices

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ABSTRACT

A wideband electromagnetic field (EMF) sensor system is introduced in this study. This small form factor, low-cost system is intended for use with smart mobile devices and can precisely measure the imminent field strength through the combination of a wideband omnidirectional receive antenna, RF, and audio mixing front-end as well as signal processing algorithm in the mobile unit. A detection dynamic range of 30 dB is shifted toward the high-field intensity regimes to enable its use as a hazardous EM field detector. The total diameter of the device was 13 cm with a cylindrical thickness of 1.6 mm (standard FR4), and it can interface with the audio port of any mobile device including cell-phones or tablets. Field strengths in the range of 5 V/m–50 V/m can be detected in approximately by 10 MHz–3 GHz RF transmission bands.

Keywords: EMF Sensor, wideband antenna, sensor electronics, EM field hazard, mobile device, smart sensors

Introduction

Due to the increase in the demand for higher bandwidth and longer-range communication systems, we are beginning to observe an increase in the number of RF antennas and transmission systems around us, even in intensely populated urban areas. However, it is an established fact that long-term exposure to high intensity (electromagnetic) EM fields may cause health problems. As proposed in Sambo [1], many organizations have conducted different projects and experiments to determinemethods of reducing the specific absorption rate (SAR) and EM exposure in order to define the guidelines for EM exposure. For example, as shown in Ahlbom [2], experimental studies conducted by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) on volunteering humans who were exposed to low levels of EM radiation over a period of 30 minutes revealed that the exposure resulted in up to a 0.5 °C increase in the body temperature. Nevertheless, harmful levels of tissue temperature have been observed for SAR values of >4 W/Kg. Furthermore, some researchers [3] have concluded that EM exposure from a standard GSM mobile phone adversely affects human cognitive functions. Moreover, The National Radiological Protection Board (NRPB) of the UK has given their recommendations on the limits of exposure to EM radiations from mobile phones, base stations, and other sources of EM radiation exposure in different reports [4-6].

Ironically, these high power transmission antenna systems are not only set-up in the middle of densely populated cities, but they are also in most cases camouflaged with naturally looking artificial structures like trees, balloons etc., such that, the chance that an unaware individual can be exposed to an extreme field intensity is quite high. Moreover, it is not only in the vicinity of these high-power antennas that health safety is a concern. Overall, EM noise levels in any arbitrary location of an arbitrary city have been on the rise in recent years. In order to quantify the elevated noise problem, the time-average of the ambient EM field measurements with R&S ESR-3 EMI receiver and R&S HL562 Ultra log-Antenna in a city with a population of 2 million people was conducted. The measured spectrum showed noise floor peaks as high as 75 uV/m, as shown in Figure 1. These field strengths could be at tens of volts/m levels, around the vicinity of the base station transmitters.

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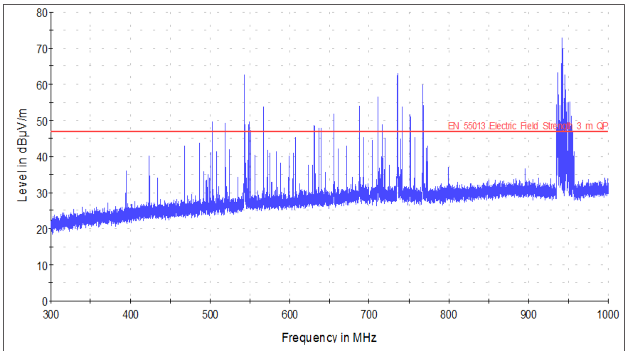

Figure 1. Average ambient noise floor along arbitrary locations in a mid-sized urban area

In order to be aware of dangerous field intensities around us, we need to be able to sense them. A regular cellphone can provide quite a limited sense of field intensity with a limited low-end dynamic range through its received signal strength indicator (RSSI) subsystem. The RF front-end in most phones has a limited attenuation range and switches into the clamp mode in case very strong signals are encountered. Hence, a low-cost small size custom electronic sense system is needed with a universal interface.

This paper presents a smart universal detector system, composed of a wideband front-end antenna, passive mixers and attenuators, and audio microphone path emulation circuitry to interface into mobile devices, that is, phones or tablets. Through a signal processing application in the device background, an accurate EM intensity level could be extracted. The system is fully passive and hence, does not require any battery or any other power source, except for some trickles of power from the device's audio port itself. The paper is organized as follows: section 2 provides the system architecture and the theory, section 3 presents the details of the wideband custom spiral PCB antenna design that was optimized for the target bands of the application along with the corresponding circuits, section 4 presents the measurement results of a test prototype, and section 5 is the conclusion.

System Design and Theory

The circuit block diagram of the proposed field strength detection system is shown in Figure 2. The system front-end starts with a triple wideband custom spiral PCB antenna to sense all the bands of interests, namely, 700–760 MHz low LTE frequencies, 850 MHz–950 MHz GSM low band and LTE frequencies, and 1750 MHz–2000 MHz high band GSM and LTE. It is followed by a direct DC down converter through a peak detector. It should be noted that a simple signal amplitude rather than the content is required for field intensity detection; therefore, a peak detector alone is sufficient to sense the signal levels from the antenna. The voltage mode downconverter is a very low parasitic high impedance circuit that allows voltage doubling at the feed. Note that, although lower impedance antenna designs may improve the detection dynamic range, a 50 Ohm antenna was targeted to ease the measurements and characterization of the prototype. After the filtering block, audio transistors mix the amplitude information back to the audio band AC signal. The audio-band content is then attenuated and fed into the mobile device through an audio interface circuitry and a standard 3.5 mm jack.

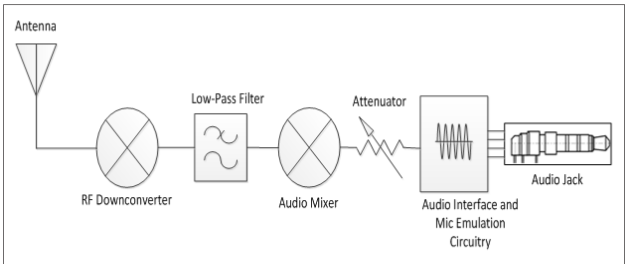

Figure 2. Schematic block diagram of the proposed sensor architecture

The basic frequency domain operation of the system is also shown in Figure 3. The wideband RF detector first extracts the peak of the wideband signal to DC, which is later up-converted back to the 16-KHz AC with the desired level of attenuation to

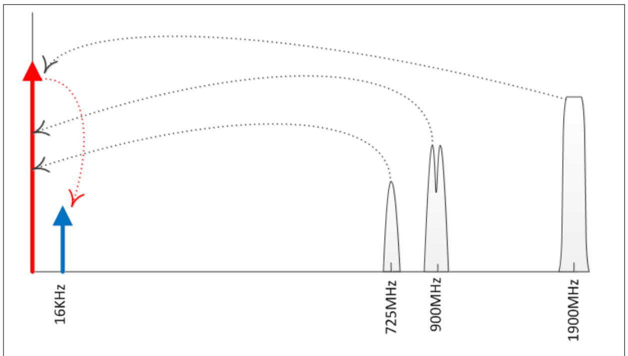

Figure 3. Frequency domain operation of the wideband EM sensor

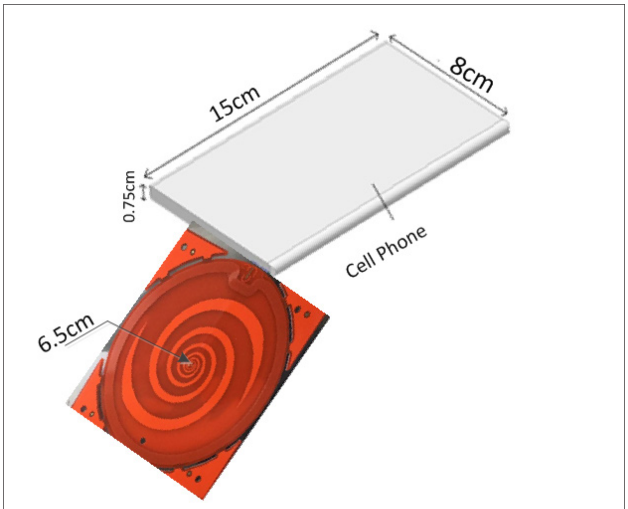

Figure 4. 3D conceptual drawing of the system

fit the mobile audio interface dynamic range. An attenuation does not harm the system dynamic range since the common microphone path dynamic range of 60–80 dB is excessively wider than what is needed for the target application. The 3-D visual drawing of the device is shown along with a cell phone in Figure 4. The whole system components including the passives and ICs are implemented on a two-layer low cost FR4 PCB with a large circular shape footprint, which yielded a wideband operation.

Wideband Antenna and Circuit Design

This section discusses the wideband antenna topology choices. It also presents the required electronic circuitry to interface a mobile device audio subsystem. Helical antenna have been used in various applications since they were first invented in 1947 [7]. Initially, antenna were used for line of sight communications. However, they have become quite popular with mobile consumer applications due to their low profile size and their relatively higher gain. In [8-11], researchers could propose ultra wideband helical antennas. However, the gain pattern in this case is not omnidirectional. An ultra wideband antenna was also proposed in [12]. Nevertheless, it cannot operate at different bands simultaneously. In [13-15], various studies have proposed antennas for LTE and GSM band mobile communications. However, the size of the proposed antennas was relatively large with respect to the attainable gain levels. In [16-17], although the proposed antennas were extremely wideband, covering various applications like GSM, LTE, Bluetooth, and WIMAX, the gain was not omnidirectional again. In [18], an array approach was used to enhance the gain; however, the size in this case was quite large.

This work has rather proposed a PCB-based planar spiral antenna system to provide a low-cost solution along with the electronic circuitry and, at the same time, to enable the smooth integration with a mobile phone, which itself is a planar structure. The detailed circuit schematic diagram of the electronic detector system is shown in Figure 5. It is composed

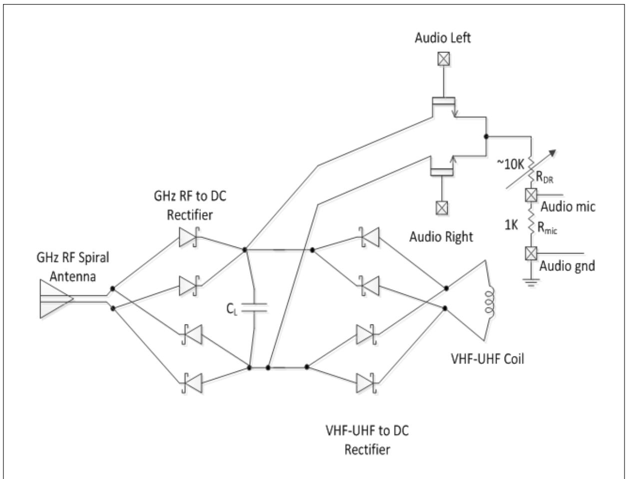

Figure 5. System and circuit schematic

of coil-based HF, VHF, UHF-to-DC rectifier as well as a GHz RF-to-DC rectifier joining to a common load capacitor C_L. Two N-type mosfet transistors, which are driven by the left and right non-overlapping clock-emulation audio signals, up-convert the rectified DC signals back to the audio band in order to read out the signal levels in the mobile device by only a standard audio jack. A passive resistive attenuator after the rectifier and audio upconversion passive mixers are utilized to enhance the detection dynamic range by fitting the signal levels into the range that fits the best to various mobile audio mic interface levels.

The bottom view of the PCB is shown in Figure 6. It includes a pair of GHz rectifier Schottky diodes in the center, audio mixer devices, and a jack at to bottom.

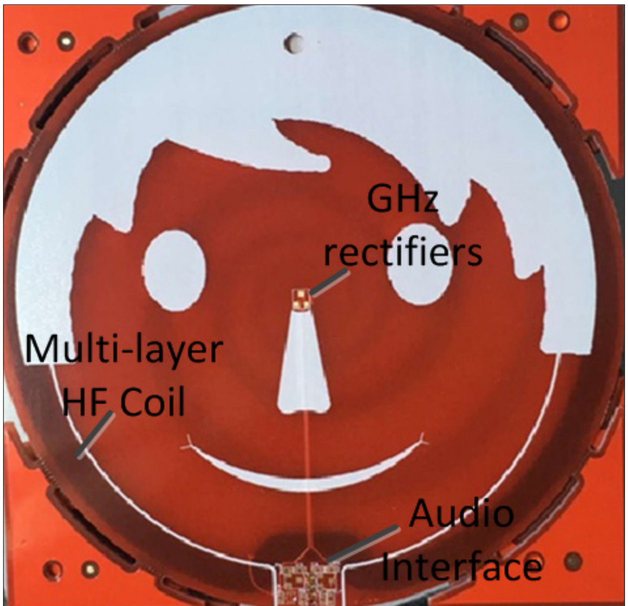

Figure 6. Bottom view of the electronic system PCB

The top level view is also shown in Figure 7. It involves a very wideband GHz planar spiral differential antenna in the center which can cover the bands from 700-MHz low LTE up to a 3-GHz range. The multilayer HF/VHF/UHF coil utilizes both the top and bottom copper layers for increased number of turns without impacting the GHz antenna in order to be able to pick-up large harmful levels of EM noise at relatively lower bands as well.

Measurements

The system tests were conducted in an antenna characterization EMC room with calibrated EM field exposure through a directive Yagi antenna. In the experimental setup, a basic signl generator output signal level was swept in the corresponding range and a standard hand-held EMF-Meter was first used to record the corresponding field intensity. Following this calibration measurement, the EMF-Meter was replaced by the proposed front-end, and the DC voltage levels corresponding to

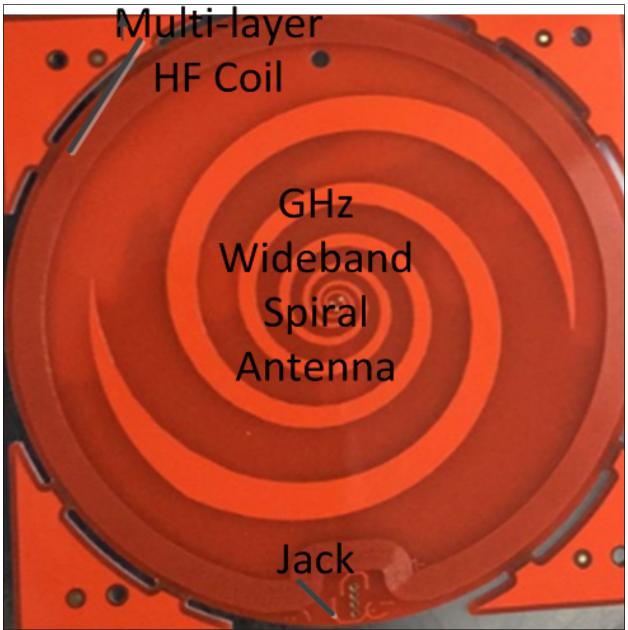

Figure 7. Top view of the electronic system PCB

the same signal level sweep were recorded. The picture of the assembled test PCB is shown in Figure 8 with some additional alterations to the low frequency sense coil. HSMS-8101 10-GHz RF diodes were used as rectifying down conversion elements in the front-end.

Figure 8. The assembled testboard for measurements

The input return loss (s11) of the antenna is also shown in Figure 9. Although it shifted to a slightly higher frequency from the target, it showed quite a wideband coverage with specific notices, corresponding to the popular GSM-LTE bands.

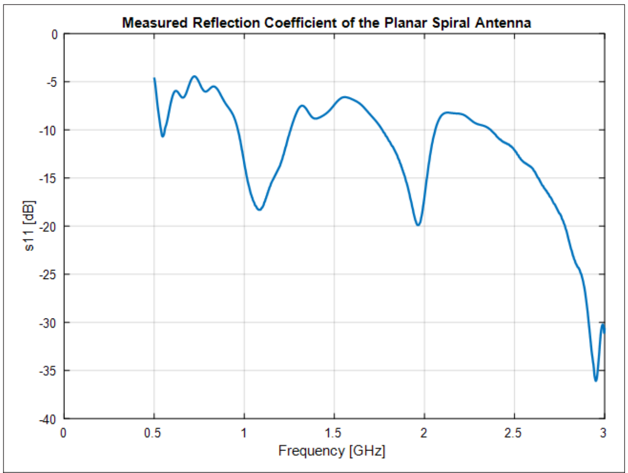

Figure 9. Input return loss measurements of the GHz antenna.

The transfer function of the system response to an EM field strenght sweep at a 900-MHz band is shown in Figure 10. Although quite nonlinear, it shows a significant sensitivity to large RF signals that may be deemed to be harmful. The particular nonlinearity at the lower detection range are due to the Schottky diode nonlinearity and can be compensated in mobile device signal processing algorithms.

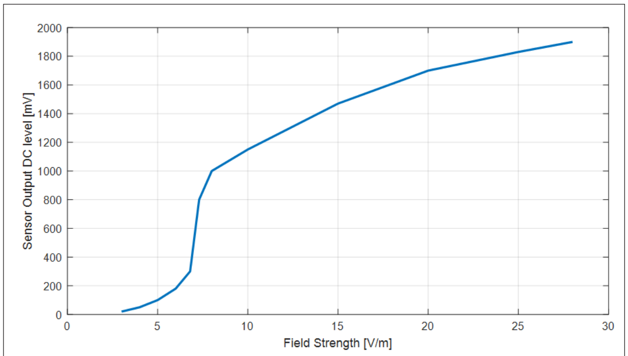

Figure 10. Down-converted output level vs field strength for a 900-MHz test case

Conclusion

A smart wearable wideband low-cost RF EMI detection system is presented along with the measurement results from to an initial system prototype. EMF exposure is becoming an important issue in our daily life activities and therefore, a significant amount of interest is being directed towards such hand-held field sensor equipment [19]. A low-cost plug-and-play and easy-to-use device is designed for personal and professional use. The device is intended to replace the bulky and expensive detectors in the market and to help the detection of harmful levels of electromagnetic fields around a user just by connecting it to the audio jack of a mobile phone.

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