

A Completely Wireless Current Sensor for RF Safety

Christopher Ellenor¹, Pascal Stang^{1,2}, Maryam Etezadi-Amoli¹, John Pauly¹, and Greig Scott¹

¹Electrical Engineering, Stanford University, Stanford, CA, United States, ²Procyon Engineering, San Jose, CA, United States

Introduction. One of the main remaining hurdles in MRI safety is the interaction of imaging fields with long wires, which may be part of a medical device such as a pacemaker or neurostimulator, or may take the form of a guidewire or catheter in an interventional procedure. The RF imaging field is capable of depositing large amounts of energy in such wires, and tissue damage may result, precluding a large segment of patients from receiving MRI scans. The goal of quantitative, real-time monitoring of these interactions holds the promise of both increased safety during a scan, and more systematic evaluation of medical device interactions.

We believe that physical measurements are key to systematic assessment of both risk, and of safety measures. To measure induced RF current, a sensor which fits over an exposed segment of wire has been demonstrated in [1]. This sensor is toroidal in shape and couples flux from the region around the wire to produce a signal. The received signal is used to modulate a photodiode, which transmits the signal via optical fiber. In further work [2], the battery has been replaced by a photonic power supply and, and has been validated by an imaging study. In this abstract, we demonstrate a completely wireless version of this sensor, which is powered by a non-magnetic LiPo battery (Powerstream Technology, USA), and where the signal is digitized on board and transmitted using an 802.15.4 2.4GHz radio. A wireless link avoids the added infrastructure, inconvenience and risk of additional optical or coaxial cabling.

Methods. The signal from the toroidal detector is received by an RF power detecting IC (LTC5507, Linear Technology, Milpitas, CA), which detects power from -34dBm to 14dBm in the range of 100kHz to 1000MHz. The output returned by the LTC5507 is fed to a 10-bit ADC, which is on board an Atmel ATmega128RFA1 microcontroller, which has an integrated radio transceiver capable of up to 2 MB/s data transmission. Samples are acquired at 10ks/s, though rates up to 330ks/s are supported. The measurement is triggered wirelessly by a second transceiver, which is located in the control room and also receives the acquired data. It is connected to an antenna in the scanner by a coaxial cable.

For a demonstration, we have created a wire phantom using a length of wire inside a tube containing saline solution. The wire protrudes from the end of the phantom, and the sensor is placed over this wire. The wire phantom is placed inside a birdcage coil whose two drive points can be driven separately, effectively creating a phased array. The array configuration which minimizes current on the wire is determined by sweeping the amplitude of one channel up while the other is swept down and the phase between channels is varied rapidly. This effectively samples the parameter space of the array, and is illustrated in the lower panel of Figure 3.

Results and Discussion. The upper panel of Figure 3 shows the result of the current measurement described above. The radio transceiver timing is based on a 16 MHz crystal oscillator, giving rise to concern about interference in imaging. It was found that when the radio was placed within a few centimeters of the receive coil, some extra signal was observed at a single frequency, but in most images was undetectable. We expect that further improvements in shielding can alleviate this concern.

Because an RMS detection scheme is used, phase information of the measured current is not recoverable from the sensor. Despite this, using the scan shown, the sensor can be used to deduce the relative amplitudes and phases of contributions to wire current of any two elements of the array, and can therefore be used iteratively to construct null modes even in more complex systems.

Conclusion. A new, completely wireless current sensor has been demonstrated for the detection and monitoring of RF current in wires. Its small form factor and lack of cables make it a valuable tool in the typically congested MRI environment.

References. [1] Zanchi et al., IEEE Trans. Med. Imag. 29:169-178, 2010. [2] Etezadi-Amoli et al., Proc. 21st ISMRM, p723, 2013 NIH Grant Support: R01EB008108, R33CA118276, R21EB007715, P01CA159992.

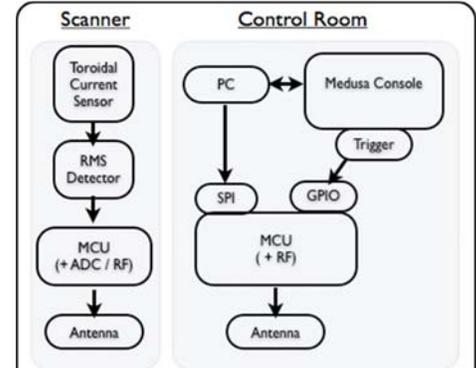
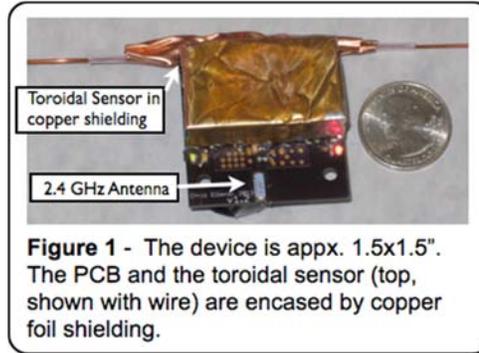


Figure 2 - System Diagram. The left panel shows the sensor unit, which averages, digitizes and transmits the sensed current. In the control room, the signal is received by a transceiver and transmitted to the PC via SPI. The transceiver also sends a start trigger to the sensor unit, based on a signal received from the Medusa console.

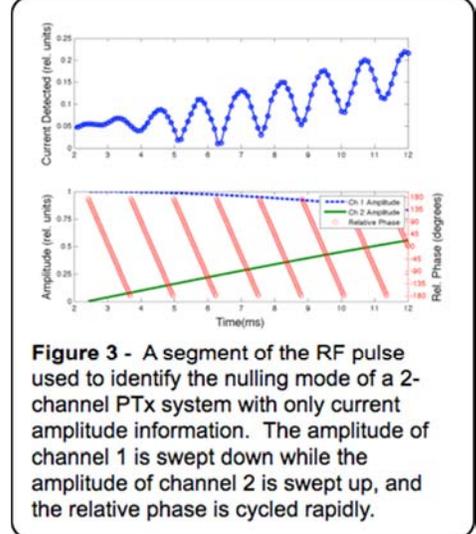


Figure 3 - A segment of the RF pulse used to identify the nulling mode of a 2-channel PTx system with only current amplitude information. The amplitude of channel 1 is swept down while the amplitude of channel 2 is swept up, and the relative phase is cycled rapidly.