RF current measurements in implanted wires in phantoms by fiber optic current clamps

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Target Audience: Basic researchers and scientist evaluating RF safety of wire type implants

Purpose: RF currents induced in wire type structures as pacemaker or neurostimulator leads, guide wires and catheters are a cause of MR safety concerns and RF current sensors for special applications have been developed [1, 2]. In patients it is only possible to access the protruding ends of implanted conductive structures. This work presents a time domain RF current clamp with fiber optic readout for measurements at the protruding end of implants inside MR scanners.

Methods: An RF current sensor was developed based on a toroidal shield with a slit which ideally is only penetrated by the magnetic field induced by the current in the wire and a Rogowski coil for sensing the field (Fig 1a). A time domain electro-optic transducer (PH-0655, Seiko Giken) and a 10 m optical fiber to the controller of the OEFS sensor system outside the RF cabinet is used for readout. A high speed PCIe transient recorder card (Spektrum M3i.4142) in a Linux host computer was used for recording. The sensor was calibrated at 123 MHz with an RF current of 2 A in a loop with 50 Ω resistive load tuned to Im[Z] = 0. The coil was fed via a TEM cell [3] to measure the applied RF voltage by a flip angle experiment [4]. Copper wires (Ø 2 mm) were mounted in the shoulder or the head of an ASTM body phantom filled with tissue equivalent liquid based on TWEEN 20 ($\varepsilon = 62.7$ and $\sigma = 0.81$ S/m, measured at 128 MHz) [4]. The 20 cm long sections inside the phantom were insulated, only 1 cm at the tip had electrical contact to the phantom liquid. The sensor was mounted 5 cm from the phantom wall with the wire in its centre (Fig 1b). Phantom and sensor were placed on the patient bed of a 3T scanner (Siemens Verio) and moved through the 40 cm long body coil in 5 cm steps. For each position, the sensor signal was recorded with and without wire to remove residual displacement current signals via complex subtraction. Two situations were investigated: a wire in the shoulder and a wire in the head (Fig 1c). For the latter, three different configurations of the wire extension outside the phantom were studied: i) 20 cm bent up, ii) 20 cm straight, iii) no extension.

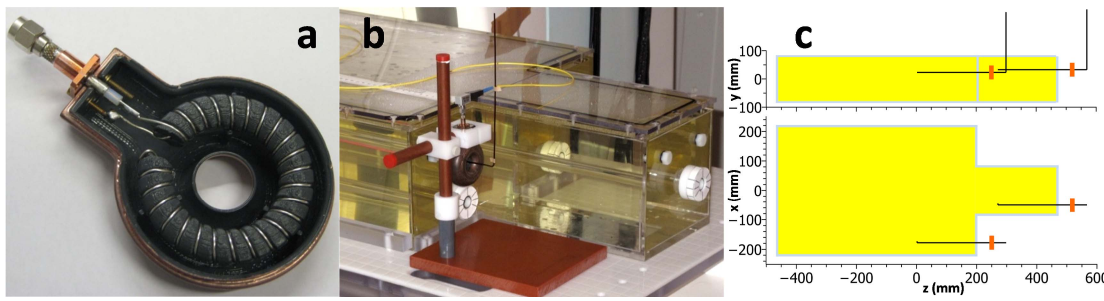

Figure 1: a) interior of RF current sensor, b) sensor around wire in the shoulder of the ASTM phantom, c) sketch of the wire positions in the head and shoulder of the ASTM phantom.

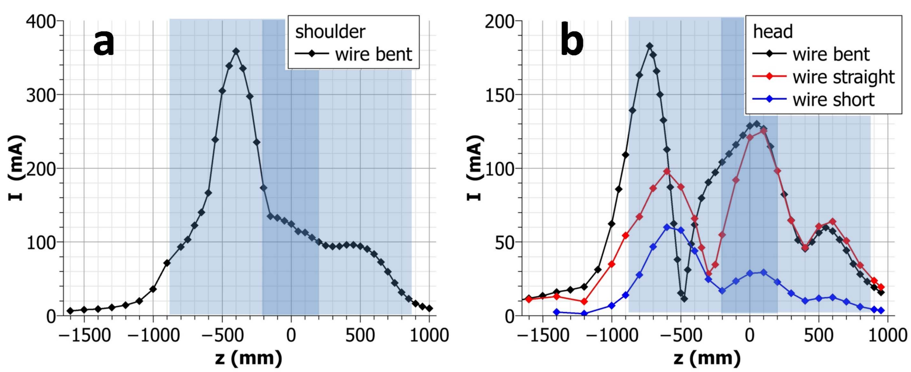

Figure 2: Current amplitude induced in a wire in the shoulder (a) and in the head (b) of the ASTM phantom vs. z position of the phantom center relative to the isocenter. 1 kW nominal transmitter power. At z = +670 mm the rear edge of the phantom leaves the body coil. The shadings indicate the extensions of RF body coil and 3T magnet.

Results: The highest currents occur when the bent tip of the wire enters the first end ring of the body coil and the rest of the wire and the phantom are still outside the body coil both in the shoulder (Fig 2a) and in the head (Fig 2b). However, induced currents are measured till the phantom has left the body coil entirely. In this position the wire tip inside the phantom is separated 470 mm from the end ring for the shoulder measurement and 740 mm for the head measurement. The curves for the bent and the straight wire extension almost coincide for z > 0 mm, i.e. in the region where the head section of the phantom has left the body coil. At negative z values the current in the straight wire has a maximum when the head edge of the phantom enters the body coil. A short straight wire (no extension) shows a similar z-dependence but lower currents.

Discussion: It is not unexpected, that the maximum of induced RF current occurs when the bent tip of a wire passes the end ring. However it is less obvious that a maximum appears only at one of the end rings. Also not necessarily expected are induced currents of up to 100 mA at P_{RF} = 1 kW when all parts of the wire are already 30 cm outside the RF coil. This indicates the generation of induced currents to be quite complex and the need for more investigation. The presented current sensor appears to be well suited for this purpose.

Conclusion: A toroidal time domain sensor with fiber optic readout was developed for in situ measurement of induced RF currents in the protruding ends of implanted conductive structures with diameters up to 10 mm inside an MR scanner. Such a sensor could be used with patients to assess currents in implants at low RF power.

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