Feasibility of Active Cable Trap to Attenuate MRI-Induced RF Currents

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Introduction: We have previously demonstrated optically-coupled technology to measure the RF currents induced on guidewires, to monitor RF safety during an MRI scan [1]. At present, only passive cable-traps [2] and Q-spoiling loads [3] can reduce these currents to prevent tip heating. An alternative, potential solution to this problem is to create an active cable-trap, i.e., an automatic negative feedback control system that senses the RF current to drive its inverse and completely cancel the total current on the wire. In this work, we present our new prototype active cable-trap and describe methods and results of our investigation on the feasibility of active cancellation of RF-induced wire currents. For the first time, we measure the wire currents directly and demonstrate over 30 dB of active attenuation.

Material Methods: A traditional cable-trap is a passive, resonant device (shown in Figure 1b) whose capability to attenuate wire currents is significantly limited by component loss and tuning interactions with wires. An active cable-trap (shown in Figure 1a) could achieve, instead, a wire current attenuation equal to the system loop gain G in a range of frequency designed to match the known bandwidth of RF excitation. As shown in Figure 2, our active cable-trap uses a Cartesian (quadrature) down/up-conversion scheme [4], so that amplification is obtained at baseband, where values of gain up to 100 (40 dB) and bandwidth of hundreds of KHz can be obtained. To eliminate the possibility of quadrature errors caused by phase and amplitude mismatches, the baseband amplifier is an active polyphase filter with complex center frequency offset far away from DC [5]. For feasibility bench testing, we induced currents near 64 MHz in a looped-wire using a 3 inch diameter transmit coil, controlled by a Network Analyzer, and transformer-coupled the looped-wire to the control loop. (In later implementations, the transformers will be replaced by toroid couplers that can slide over wires.) We independently measured the wire currents using a sense resistor in series with the wire. We drove the down- and up-converter with a local oscillator (LO) frequency of 64 MHz. Using this setup, shown in Figure 3, we have characterized the open-loop voltage amplification of the active cable-trap and studied the effect of closing the feedback network on the wire currents induced by the transmit coil in the frequency range 63-65 MHz. We compensated for the loop phase shift by varying the relative phase shift of the LO frequencies of the down- and up-converter and studied the conditions that guarantee loop stability and maximize attenuation of the wire currents [6].

Results: Figure 4 shows the normalized open-loop voltage transmission of the active cable-trap. Figure 5 shows the open-loop and closed-loop wire currents in the range of 63 MHz to 65 MHz, measured on the bench for several values of relative LO phase at the down- and up-converter frequency. At high values of relative phase (160º and 170º in Figure 5), the loop is unstable as expected. At low values of relative phase (10º and 20º in Figure 5), the loop is stable and actively attenuates the wire currents by over 30 dB within a bandwidth of 100 KHz at 64.2 MHz. If the wire tip were in contact with tissue, this is equivalent to a 1000x reduction of heating generated by currents induced by the RF fields of MRI.

Conclusion: We have designed, built, and characterized a prototype automatic Cartesian feedback control electronics loop and successfully used it to demonstrate the feasibility of active attenuation of the induced RF currents in a looped-wire. Our active cable-trap is inexpensive, compact, and attenuates the wire currents substantially at the desired frequencies. It is a promising device for enhancing the safety of the patient during MRI in the presence of elongated conductors. Further work will focus on studying the feasibility of using a toroidal sensor and toroidal driver, measuring the current attenuation for wire configurations other than the looped-wire presented in this work, and studying the effect of multiple active cable-traps placed along the length of a wire.

References: [1] M.G. Zanchi *et al.*, "An optically coupled system for quantitative monitoring of MRI-induced RF currents," Proc. 16th ISMRM; [2] C.M. Hillenbrand *et al.*, Proc 13th ISMRM, 2005; [3] R. Venook *et al.*, ISMRM 2037, 2006; [4] D. Hoult *et al.*, "The NMR Multi-Transmit phased array," JMR 2004; [5] K. Linggajaya *et al.*, "A new active polyphase filter for wideband image reject downconverter," Proc. ICSE 2002; [6] J. Dawson *et al.*, "Automatic phase alignment for Cartesian feedback power amplifier system," IEEE SSCS 2003.

Figure 1: Concept block diagram of active cable-trap (a) and passive cable-trap (b).

Figure 2: Detailed block diagram of the active cable-trap showing the architecture of the baseband polyphase amplifier.

Figure 3: Board with the active cable-trap controlling the current in a looped-wire.

Figure 4: Measured open loop voltage gain (normalized) of the active cable-trap.

Figure 5: Wire current in the open and closed loop configuration, for different values of relative phase locking the LO of the down- and up-converter.