Wi-Fi tuning/detuning switch for inductively coupled wireless phased array coil for intraoperative MRI applications

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Target Audience: This paper is directed towards engineers and researchers with interest in MR coil hardware design.

Purpose: Wireless communication in RF coil technology has been introduced with a very limited success and its initial focus was on transferring large amounts of MR data through MR pre-amplified receiver signals between arrays of RF coils and RF receiver channels embedded in the spectrometer with the promise that there will be no SNR drop.[1] Proving at the present time that transferring such large amount of data wirelessly is a challenging task while trying to maintain the SNR integrity of the coil array, researchers have turned their focus to different applications of wireless communications inside MRI such as remote tuning frequency of RF coil.[2] For MR guided intraoperative and surgical applications of the abdomen and lower pelvic region, the use of massive multichannel arrays is recommended to cover the entire human torso at once. However the massive cable required connecting these arrays to the system as well as the weight and size of associated electronic components increases significantly the overall weight of the coils and limits the numbers of the channels the coil can have. Wireless coil technology introduced four years ago bypasses these obstacles and provides a better alternative for imaging large field of views on the torso and pelvic areas[3]. However, the desire introducing more receiver loop arrays to the wireless technology became challenging without the presence of cables and control lines. For wireless array coil technology targeting multi positioned intraoperative MRI such as continuous spine scanning, it is impossible to control (tuned/detuned) each coil element without wired PIN diode control bias, as well as it is difficult to avoid mutual coupling among distant neighbor RF coils without preamp decoupling. In order to overcome this issue, in the present paper, a wireless (Wi-Fi) switch for tuning/detuning frequencies of separate inductive loop array coils or combination of them coils is introduced enabling us to introduce large numbers of inductively coupled wireless array coils with wide FOVs and optimum SNR performance by activating/deactivating the desired number of the elements on the region of interest (ROI).[4] Furthermore, we demonstrate how to tune/detune the frequency of the inductively coupled wireless RF coil remotely and test MR compatibility for employed components (Fig 1(a)).

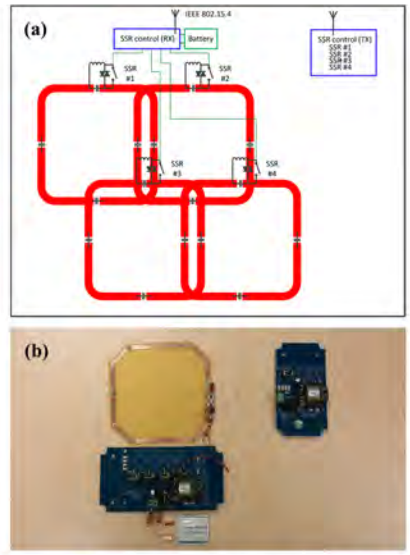

Fig 1. (a) the block diagram of the wireless control system for four channels inductive wireless array coil. (b) the assembly implementing RF coil tuned at 3T MRI and the wireless transceiver PCB.

Methods: A wireless Bluetooth RF module was utilized to remotely tune/detune each loop coil of the phased array at 1.5T MRI. The Wi-Fi switch was designed for high-throughput applications requiring low latency and predictable communication timing. For tuning/detuning the RF frequency, the solid state relay (SSR) was employed on the passive detuning circuit on the coil tracer. It was connected on the crossed pair PIN diode in parallel as shown by Fig1. Since SSR has 0.5pF distributed capacitance on output terminal with switch off and 3Ω resistance with switch on, it doesn't have misalignment on tuning/detuning frequency. The wireless Wi-Fi RF receiver and circuits that activate the SSR were placed on circuit that is part of the coils circuitry and was located besides the RF coil tracer (Fig 1 (b)). The MR compatible rechargeable lithium battery generates 600mA at 3.7V enough to drive the SSR and other components including the PIN diodes. The hand held wireless RF transmitter and SSR control switch were located on 4~5m away from the coil to control the tuning/detuning circuit. In order to evaluate the effectiveness wireless modules, the circuit was embedded on a wireless square shaped loop array coil with width of 160mm and length of 160mm. The wireless loop array was tuned at 63.65MHz with Q_u=400. The tuned/detuned coil frequency response by the Wi-Fi switch was measured with the network analyzer. The wireless coil array incorporating the Wi-Fi switch was used to image a bottle phantom in MR scanner (1.5T Espree, SIEMENS AG., Germany). Phantom images were acquired utilizing the whole RF body coil while the inductively coupled wireless RF coil is detuned during the transmit phase and tuned during the receive phase. In order to investigate the MR compatibility of the Wi-Fi switch and its effects to MR image integrity, B_1 and B_0 distortion tests were performed as well.

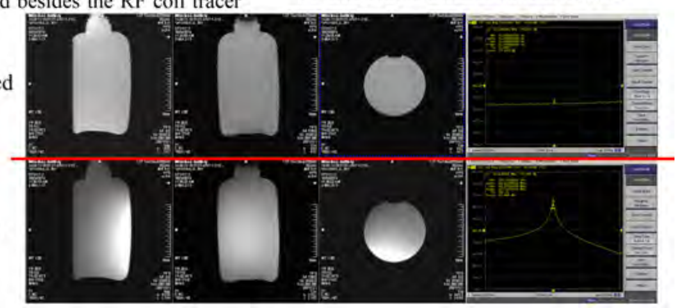

Fig 2. The acquired MR images and measured RF spectra from Wi-Fi switch ON (the first column)/OFF (the second column).

Results: As the tuned/detuned coil frequency response of Fig 2 indicates, the Wi-Fi switch employed on the wireless coil technology was well operated by an MR compatible battery in MR bore. Especially, it detuned/tuned the inductive wireless coil with no artificial noise resulted from the operation of Wi-Fi switch on MR phantom images (Fig 2). Furthermore, B_0 and B_1 tests of the Wi-Fi switch circuitry indicated that the electronic components did not cause any ferromagnetic distortion or RF interference on MR phantom images (Fig 3).

Discussion: The MR safe Wi-Fi switch with a MR safe battery was designed to detune/tune various elements of the inductive coupled wireless array coil for multi positioned intraoperative MRI procedures. The switch module was successfully implemented on the coil with no apparent artifacts or any new noise introduction. No degradation to the coil's SNR was observed and no deterioration on MR image quality was noticed. All the electronic components that were part of the module did not show any ferromagnetism artifact.

Conclusion: A novel Wi-Fi switch was introduced as part of the wireless inductive coil technology that would enable us to control multi-channels wireless inductive coil structures covering large portion of the human anatomy. It was perfect matched for multi-positioned intraoperative MRI. MR compatibility tests indicate that the suggested Wi-Fi switch is MR safe and it did not introduce any detrimental effects in terms on the wireless coil's SNR value, as well as its RF field uniformity and sensitivity characteristics

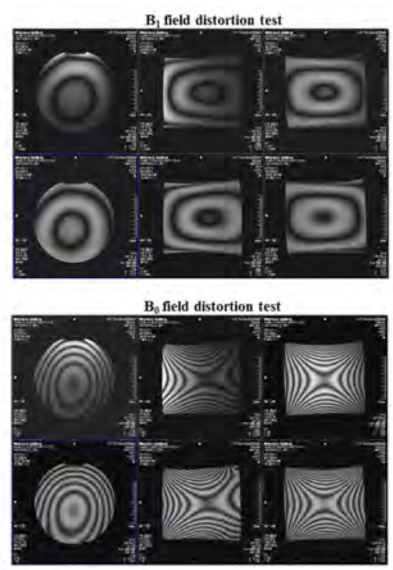

Fig 3. The B1 / B0 field distortion test for components employed on Wi-Fi switch module including battery

References: 1. Heid O, *et al.* cutting the cord-wireless coils for MRI. *Proc. Intl. Soc. Mag. Reson. Med.* 2009:100. 2. Reykowski A, *et al.* A Wireless Digital Capacitor Module for Tuning Receive Coil Arrays. Proc. *Intl. Soc. Mag. Reson. Med*. 2014:1276. 3. Haoqin Zhu, *et al.* A novel multichannel wireless receive phased array coil without integrated preamplifiers for high field MR imaging applications. *Proc. Intl. Soc. Mag. Reson. Med.* 2012:2788. 4 Ha S, et al. RF phased array coil using wireless tuning/detuning control module. 2014; *US Patent Application, Patent Pending.*