An 8 channel Transceiver phased array coil combined with a Surgical Robot for an MR assisted Robotic surgery.

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Introduction: It has been well established that Magnetic resonance imaging is a modality that provides superior soft tissue sensitivity of the human anatomy better than any other modality. Recently however, successful efforts have been made to combine MRI tissue sensitivity with other imaging modalities that provide high specificity such as PET, SPECT, and Optical imaging. The recent emergence of MR hybrid systems was made possible either with the emergence of new technologies (APDs for PET, CZT for SPEC and Optical Imaging) which made these technologies capable for seamlessly integrating with an MR system or with placing components in the areas where the magnetic field is null (MR combined with LINAC systems) without having any detrimental effect on the on the performance of both modalities. One common important aspect for these technologies was the ability to integrate the detectors with the RF coil as close to the examination region as possible in order to take advantage of both the sensitivity of RF coil and the sensitivity of the detector.[1]

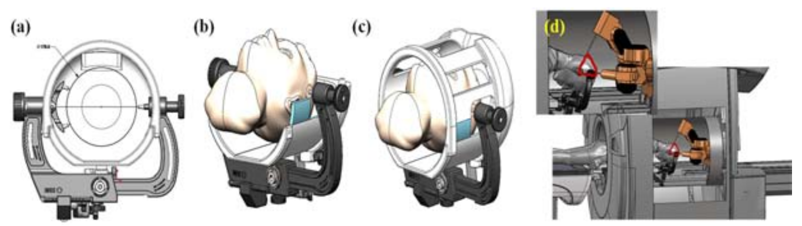

Figure 1. (a) Assembly with RF coil & HFD. (b) Loading human head in the bottom coil and HFD. (c) RF coil &HFD assembled with human head. (d) Fully integrated robot system in MRI

In this paper, following the same philosophy on RF coil proximity to the targeted volume, we design a coil suitable for MR guided Robotic assisted surgery. In that situation, in order to reduce RF heating, susceptibility artifacts, and ensuring that the MR compatible robot continues to operate in the presence of the MR and RF field, a local transceive array coil is the design of choice. Thus, the proposed design includes a detachable 8 channel transceive array coil which is seamlessly integrated to an MR safe Head Fixation Device (HFD) and operates in-sync with an MR guided Robot inside a 3.0 T MRI system. The choice of transceive array coil design is in order to reduce the RF power delivered during head surgery, reduce the RF heating effects on the Robot (since it is outside the RF field), increase MR image uniformity and SNR, and allow parallel imaging techniques to be utilized during the MR guided robotic assisted surgery.

Methods: The requirements for the local RF coil assembly were following: 1) The RF coil should not disturb the sterile field during surgery,2) the RF coil has to be seamlessly integrated with the HFD and should not need repositioning or disturbing the surgeon and the patient or the HFD if the RF coil need to be removed. 3) The RF power needs to be minimized near the surgical Robot, thus the RF coil has to be a transceiver coil to reduce SAR and localize the RF power. . To meet those requirements, we designed the eight channel transceiver array coil (Fig 2(b)). On the dome shaped RF coil frame (265mm inner diameter and 260mm length), eight rectangular loop coils circumferentially placed around the dome. In order to maintain the sterile field, the coil is separated into two parts. The top coil has three loops while the bottom coil has five loops. Special previsions were made in order the patient to be pinned to the HFD without the coil to interfere with the process The coil assembly was tuned to 3T (123.2MHz) . Since it is a transceiver coil, each loop was isolated from its next nearest neighbor using capacitive decoupling and butterfly loop decoupling to avoid strong mutual coupling[2]. The eight loop transceiver coil was driven by homebuilt 8:1 power splitter, tuned on 123.2MHz, for RF transmission (Fig.2.(c)). Decoupled loop coils through $\lambda/2$ coaxial cable were connected to the power splitter with 45° phase difference each. The coil elements among non-adjacent coil elements were also decoupled by 90° or 180° phase difference by the power splitter. The received FIDs were amplified by LNA connected at the output of the loop coils (Fig.2 (a)). Isolation between adjacent coil elements was measured from the S21 parameters after plugging the two coils to a network analyzer. The array coil was simulated using a full wave electromagnetic field simulation program SEMCAD X (Ver. 14.6.1 Schmid & Partner Engineering AG, Zürich, Switzerland) to investigate SAR distribution in a numerical human model. The B_1^+ and B_1^- field were calculated as well. For B_1^+ simulation, eight individual RF sources (250W p-p) were driven with the phase matched to the ones coming out from 8:1 power splitter. The cumulative B_1^- was calculated as a conventional receiver array coil.

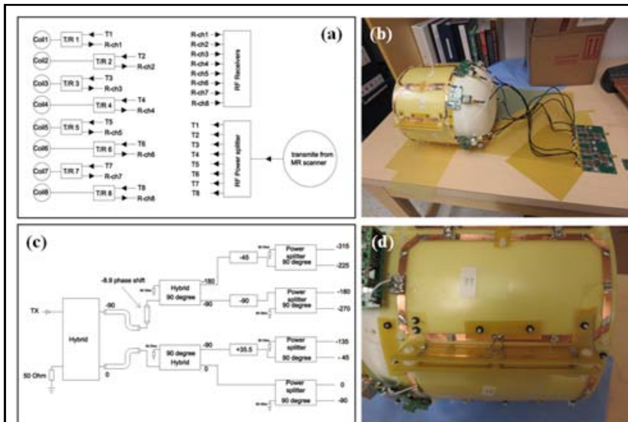

Figure 2. (a) The block diagram about driving method for TR array coil. (b) Constructed TR array coil. (c) The block diagram for 8:1 power splitter. (d) Applied butterfly decoupling loop.

Results: Using the 8 channel transceive array coil, the measured isolations among all loop coils were mapped as shown by Fig.3(a). Adjacent loops were well decoupled owing to capacitive decoupling and butterfly loop decoupling. Especially, the bottom coil was still operational because of the butterfly loop decoupling which does not need any electrical connection with the top part of the coil.[3] The next nearest neighbor mutual couplings were resolved by quad (90°) and out of (180°) phase of the power splitters during the TX stage, as well as using preamp decoupling during the RX stage. Q-factors of each of the coils were Q_u=196~200 (unloaded). Since each individual loop was driven with its own geometrical phase and phase of the TX splitter, the simulated B_1^+ field was characterized such as driving a birdcage coil mode (Fig.3(c)).[4] B_1^- field was calculated by processing eight independent RF receivers (Fig.3 (d)). The deposited peak average SAR (10g) into a human brain model was 3.09×10^{-17}W/kg. The heaviest deposited SAR in a human brain was skin (3.36×10^{-17}W/kg). In the white matter and the grey matter, the values were 1.47×10^{-17}W/kg and 2.32×10^{-17}W/kg respectively (Fig.3 (b)).

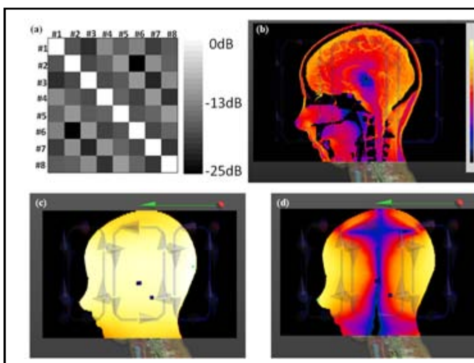

Figure 3. (a) Measured isolation map among neighbor loop coils. (b) SAR (c) B_1^+ field (d) B_1^- field dissipated in human head model. (b~d) are normalized maps separately. SAR is normalized with 1.0×10^{-15}W/kg as 0 dB. B_1 fields are done with 5.0×10^{-15} V as 0 dB.

Discussion and Conclusion: A novel detachable 8 channel transceiver array coil that is fully integrated with a Head fixation device suitable for neurosurgery is proposed for an MR-guided robotic assisted surgical systems, To ensure for a superior image quality, high SNR and MR safety, the coil was designed as well as simulated to minimize peak and average SAR and optimize B1 field distribution in the numerical human model. In order to reduce mutual coupling between elements and optimize SNR for the proposed coil geometry, the coil was constructed utilizing two decoupling methods. Also, home built ultracompact 8:1 power splitter/driver was successfully implemented for RF transmission.

References:

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