DECOUPLING OF TX/RX COILS USING A TX-ARRAY SYSTEM: APPLICATION TO UTE AND CEA

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Introduction: In this study, a novel method for decoupling of radio frequency (RF) coils is developed and implemented in a Transmit Array system. Concurrent excitation and acquisition (CEA) and ultra-short echo time (UTE) imaging are demonstrated using this method for decoupling. Ultra-short echo time imaging is a commonly used technique in imaging of tissue with T_2<1ms such as tendons, ligaments, menisci and periosteum [1]. UTE sequences require radio frequency (RF) systems that are capable of fast switching between transmit and receive modes, as well as providing high peak transmit RF fields to minimize RF duration, thus TE [2]. NMR of solid materials (T_2<30us) require more sophisticated approaches such as continuous-wave NMR, where a frequency swept RF is applied and MR signal is recorded during excitation [3]. First NMR images published in a paper of P. C. Lauterbur measured the absorption of continuous-wave (CW) RF energy by the test sample as projections along specified directions [4]. The main reason for pulsed FT NMR becoming more popular than CW techniques is that CW-NMR fails to reach the signal to noise ratio levels of pulsed NMR measurements due to inherent non-linearities of the spin systems and distortions caused by rapid frequency sweep [5]. However, CW-NMR still remains an open research area and has advantages over pulsed NMR methods such as broadening the signal bandwidth and observing structures with short coherence time without loss of information. The fundamental problem of CEA is the isolation between Tx/Rx coils. Spins resonate also at the excitation frequency and there is a few orders of magnitude difference in MRI signal and B_1 excitation signal voltage levels. The method for decoupling employed in this study provides isolation over 80dB between Tx/Rx coils and enables observing spin characteristics during excitation, as well as it eliminates the need for detuning diodes for pulsed FT applications. Recent methods proposed for CEA include sideband excitation and hybrid coupler isolation [6, 7]. In this study, magnetic field decoupling is achieved by manipulating amplitudes and phases of the transmit elements. This approach is advantageous over other methods for providing more isolation, flexibility of applied RF waveforms, and reduced dynamic range requirements [8]. Use of Tx-arrays to cancel B_1 induced currents stands for an alternative decoupling method or an additional procedure to provide extra decoupling which increases MRI signal level relatively by reducing B_1 induced currents.

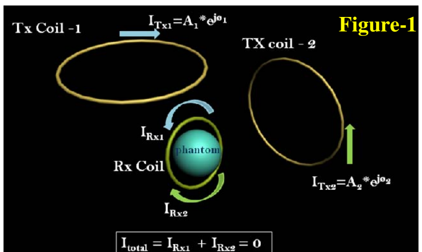

Figure-1

Theory: In a CEA experiment, acquired signal can be considered in four parts: B_1 induced voltage, MR signal, transmit noise induced voltage, and the thermal noise. Decoupling procedure helps remove B_1 induced voltage. An individual transmit coil is driven by an RF current I_{Tx1} induces a certain amount of current $I_{Rx1}=I_1*a_1$ on the receive coil, where a_1 is a position dependent complex coefficient. A second transmit coil is driven by I_2 induces I_2*a_2 in the receive coil. Amplitude and phase of the second transmit coil is adjusted such that $I_{Rx1}+I_{Rx1}=I_1*a_1+I_2*a_2=0$, meaning that the total induced current in the receive coil is zero. For a transmit array system with N channels, the decoupling task can be expressed as $I_+ = \mathrm{SUM}^{N}_{n=0}(I_n*a_n) = 0$, where I_+ is the total current induced in a receiver coil due to N transmit coils. One can solve for position dependent magnetic field component by B_1 mapping of each element of the transmit array, but for our problem it is enough to know voltages induced by transmit coils individually and when they are combined to solve equation of I_+ to find individual amplitude and phase values of transmit channels.

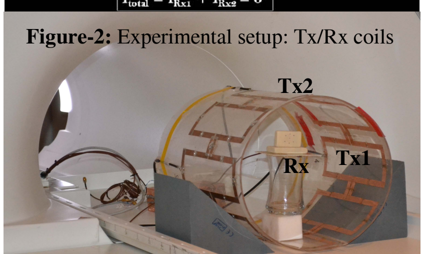

Figure-2: Experimental setup: Tx/Rx coils

Methods: Siemens Tim Trio 3T clinical scanner with 8 channel transmit array is used in the experiments. Transmit coils are two channels of a 30cm diameter 8 channel birdcage coil with rectangular coil elements of 7x20cm each. Receive coil is 9cm diameter surface coil built on an epoxy plate, tuned at 123.25MHz with Q=240 (Fig-2). We drive Tx_1 from a Tx-array modulator output via a15dB LNA, while Tx_2 is driven directly from the modulator output without amplification. Orthogonal placement of Tx_1 and Rx is significant to reduce transmit noise coupled on the receive coil in CEA applications. Decoupling is done by adjusting individual amplitudes and relative phases of Tx_1 and Tx_2 so that individual B_1 induced currents on Rx coil is cancelled. %50 ethyl alcohol-water solution is used in CEA spectroscopy experiment. A 5cm length rubber with 2mm diameter holes which is measured to have a T2* of 60us on it is used as phantom for 2D UTE and CEA. For UTE sequence, radial inside out kspace trajectory with 128 radial projections of the rubber onto xy plane are acquired with RF pulse duration 100us and peak voltage 30V, maximum gradient amplitude 24mT/m, and acquisition bandwidth is 980Hz/pixel. Acquired raw data is mapped onto a Cartesian grid of size 128x128 for $[-k_{max},k_{max}]$ using a home-made zero order gridding algorithm developed in MATLAB (The MathWorks) which assigns the average value of 8 closest samples in non-uniformly sampled k-space data to a point on the Cartesian grid. Inverse 2D FFT is applied afterwards. For CEA sequence, the same k-space sampling trajectory is employed. Chirp RF pulse of 0.5V with 4.2ms duration and 4.2kHz sweep range is applied and acquisition is started 200us after RF starts. Reconstruction of CEA data starts with subtracting the remaining RF leakage induced in the receive coil. Deconvolution of the expected MR signal with the applied RF field is done afterwards for each line projections [9, 10]. The rest is the same gridding approach as in the UTE case. It should be noted that no filters or any other signal processing is applied to the raw data except the RF leakage subtraction, deconvolution, and the zero-order gridding operations.

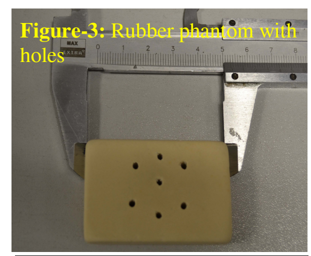
Figure-3: Rubber phantom with holes

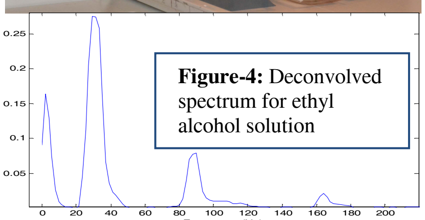

Figure-4: Deconvolved spectrum for ethyl alcohol solution

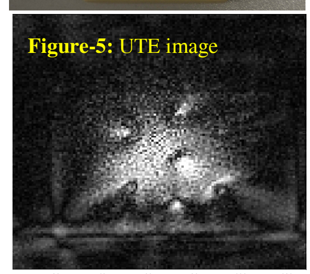

Figure-5: UTE image

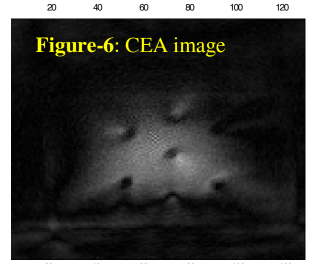

Figure-6: CEA image

Results: Resonant peaks corresponding to $_1$H with various bonding structures are observed in the deconvolved spectrum for ethyl alcohol solution (Fig-4). Images for UTE and CEA sequences are reconstructed from obtained data (Fig-5, 6). There are artifacts based on the projection reconstruction method employed here is not being so powerful. Center of k-space is also missed in UTE data which result in center brightening artifact. It is expected that the time delay between the RF turn off and acquisition start would be decreased with increasing amount of decoupling. In fact, a time delay of 10us between the transmit channels which resulted in spikes at the end of the RF pulse is observed and we had to put a 10us time delay at the end of the RF before setting out the acquisition in UTE sequence. However, the dots and the edges as high frequency information are represented in the image. We can observe the epoxy plate under the rubber. For CEA image the center of k-space is not missed since the spins are not dephasing during RF excitation. Therefore, we observe a smoother image and the holes are distinctive, but the edges are lost. Transmit noise induced voltage is measured to be lower than the receive noise floor.

Conclusion: We have demonstrated the UTE and CEA sequences using a transmit array system and the decoupling over 80dB is achieved which eliminates the need for a detuning diode in the receive coil. Subtraction of MRI signal and B_1 induced voltage is still required for image reconstruction of CEA. Advantages of CEA sequence are that it has much lower peak power and true zero echo time. Use of very low RF input powers could also be significant for some applications. The isolation method presented in this work is a potential solution to receiver dynamic range problems in implementation of CEA. Further isolation between MR signal and RF is achieved compared to other methods. Use of more than two transmit coils would help further reduction of remaining B_1 induced voltage after two-port decoupling. However, coupling between transmit coils should also be considered carefully.

References: *[1] doi:10.1016/j.mri.2004.08.018 [2] doi:10.1002/jmri.20851 [3] Fagan, A. J., & Lurie, D. J. cw-NMR Imaging in the Solid State. [4] Lauterbur, P. C., Nature 1973. [5] Ernst, R. R., Oxford, 1987. [6] doi:10.1016/j.jmr.2012.04.016. [7] Brunner, D. O. ISMRM Proc. 19 (2012) 625. [8] Ozen A. C., Atalar E., ISMRM Proc. 20 (2012) 2295. [9] doi:10.1002/mrm.22516. [10] doi:10.1016/j.jmr.2012.04.016.*