A Separated Transmit-only, Receive-only Array for Body Imaging at 7T with Automated Tuning and Matching Capabilities

Carl Snyder[1], Lance DelaBarre[1], Aaron Hess[2], Chris Rodgers[2], Mattew Robson[2], and J. Thomas Vaughan[1]
[1]University of Minnesota, Minneapolis, MN, United States, [2]University of Oxford, Oxford, United Kingdom

Introduction: Described below is a surface arrays used for body imaging at 7T. This array consists of 16-TEM tranmit-only coils and 32 receive-only loop coils. Additionally, and more importantly, described below is a electromechanical method, using piezoelectric actuators, to completely automate the tuning and matching process for the transmit channels.

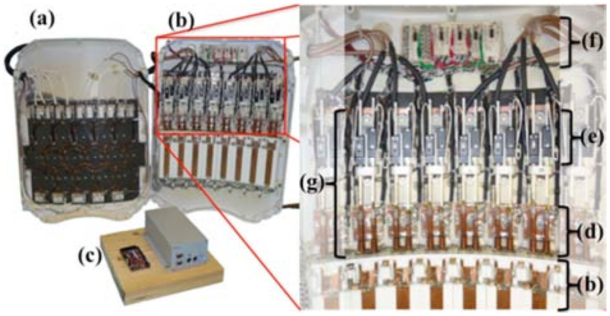

Fig 1: Half of the 16-channel Transmit-Only; 32-channel Receive-Only Array. (a) receive-only loop array (b) transmit-only TEM array; (c) Piezo controller and uC; (d) directional coupler and reflectometer behind the cylindrical capacitors (e) piezoelectric actuators and opto-isolators; (f) additional multiplexors to reduce digital control lines and analog feedback lines; (g) combination of the piezoelectric actuators and cylindrical capacitors create C_t and C_m.

Method: The body array consisted of a pair of arrays. Fig. 1 shows one of these arrays, opened, to show each array consisting of an 8-channel transmit-only TEM array [1] and a 16-channel receive-only loop array [2]. Every coil was independently tuned and matched to the Larmor frequency at 7T and decoupled from neighboring coils (capacitive decoupling for the TEM arrays; geometric and preamp decoupling for the loop arrays). Additionally every coil used PIN diode networks for active detuning.

Figure 2 shows the basic setup for the feedback driven automated tuning and matching process using piezoelectric actuation for a single coil[3,4]. From left to right, the signal generator is a 1kW pulsed power amplifier. A directional coupler is a custom-designed -35dB coupler fitted to the coil head (fig 1(d)). The reflectometer, also at the coil head (also fig 1(d)), measures the magnitude ratio and phase difference of the coupled forward and reflected signals and outputs the magnitude, $|\Gamma|$, and phase angle, $\angle\theta$, of the reflection coefficient (as DC voltages). In this case, the reflectometer is an AD8302 (Analog Devices, Norwood, MA). The piezo controller (fig 1(c))(E-861, PI, Germany) generates the drive waveforms necessary to motivate piezoelectric actuation. Since only one piezo controller was used, opto-isolators were requisite to multiplex the drive waveforms to the correct actuator. Piezo C_t and piezo C_m (fig 1(g)) are the tuning and matching capacitors, respectively. They are composed of the piezoelectric actuators (fig 1(e)) mechanically linked to sliding cylindrical capacitors (fig 1(d)). The microcontroller (uC) (fig1(c)) samples and digitizes the reflection coefficient from the reflectometer and provides the digital logic for controlling the piezo controller and opto-isolators.

In fig 2 the RF coil is the TEM transmit-only coil. While not shown in fig 2, to reduce the digital control lines and analog feedback lines from the array to the uC, a bank of multiplexors (fig 1f) were used.

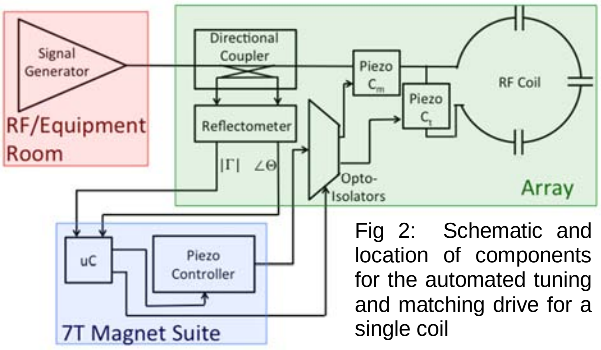

Fig 2: Schematic and location of components for the automated tuning and matching drive for a single coil

A greedy, pseudo-gradient descent algorithm, based on the reflection coefficient, was developed to automate the tuning and matching process. In short, C_m and C_t were moved back to a home position (~0.5pF). Then, using a turn-based method, the tuning and matching capacitance were varied to decrease the reflection coefficient. As the coil came closer to resonance, the capacitive step size decreased, thus, increasing the tune and match resolution.

Results: Prior to imaging, the array was loaded to a human torso and set on the Siemen's patient table. A 2ms hard pulse (30dBm at the coil head, 2% duty cycle) was used to tune and match each individual coil. On average it took 50s to tune and match each coil and on average each coil had an S_{11} greater then 20dB with no coil reflecting more then 2.5% incident power.

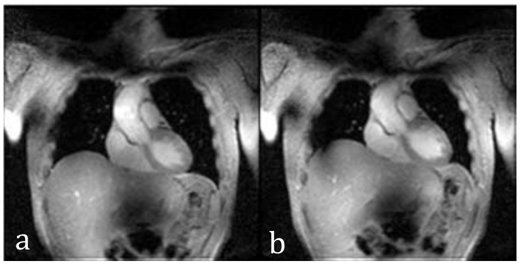

Fig 3: TGRAPPA of the human torso. (a) was acquired during inspiration while (b) was acquired during expiration.

Following tuning and matching, TGRAPPA images were acquired to access the array's imaging performance. Fig 3 shows two out of the 200 slices acquired; each image was acquired in 99 ms with 2.6 x 2.6 x 5.0 mm image resolution, and a reduction factor of 4 in the left-right direction. Due to the speed of the imagining sequence, breath holds were not needed. In both images, the heart is at end diastole, however, fig 3a was acquired during inspiration while fig 3b was acquired during expiration; this is most noticeable by the change in the position of the dome of the liver.

Discussion and Conclusions: The array described above shows significant advancements in array design and technology. The separated, 16-channel transmit-only array combined with the 32-channel receive-only array shows significant advancements over a single transeive array or a volume transmitter used in conjunction with a local receiver array. Also, and more importantly, we have shown the ability to automate the tuning and matching procedure with high fidelity; we believe this will become a significant paradigm shift in array design; benefitting both clinical and research studies.

References: [1] MRM,67:954-964 (2012); [2] 19th ISMRM, p 164, (2011); [3] 19th ISMRM, p. 3811, (2011). [4] US Patent 8 299 681 B2

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