Simple Approaches to Current Control for Transmit Array Elements at 7 Tesla

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INTRODUCTION: It is clear that multi-transmit technology is likely to be required for clinical imaging at 7 Tesla. A number of groups have demonstrated sophisticated technology for phase and amplitude control of currents on multiple elements [1,2], and hardware solutions from the manufacturers are clearly on their way, but not in general available at this time. This abstract examines some very simple approaches for controlling current and/or phase on multiple element arrays using a single transmit channel. In the case where the elements are decoupled from one another, conventional power splitters and phase shifters can be easily constructed from passive components to give adjustable phase control. This is demonstrated with a completely printed two-element array. In the case where the elements are coupled to one another, forced current excitation (FCE) [3,4] can be used to enforce either in-phase or out-of-phase currents with reasonable insensitivity to coil configuration and coupling. This is demonstrated by using a three-element, co-axial array of strongly coupled loop elements to simulate a solenoid coil with a highly homogeneous pattern over a large and adjustable field of view.

METHODS: Arrays: Two arrays were constructed: **1)** A two element array of 9.5cm i.d. loops, with a printed co-planar shield [5] was printed in-house (**Figure 1**). The equivalent of five segmentation capacitors per coil were inserted using printed capacitance made by appropriate overlap of segmented coil traces on a dual sided PC board (Taconic CER-10, ε_r=9.8, 1.27mm). The coils were overlapped for maximal decoupling. **2)** A three element array of strongly coupled, co-axial shielded loops was constructed (**Figure 2**). This coil targets a solenoid-like large field of view, potentially useful in breast imaging [6]. Each loop was 14.5 cm in i.d., and the loops were spaced approximately 4 cm apart; however that spacing is adjustable to the desired region of interest without any design consequences due to the excitation technique described below.

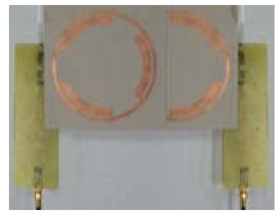

Figure 1. Two element array of 9.5cm i.d. loops. Each element contains an integrated planar shield and the equivalent of five segmentation capacitors fabricated using overlapping traces on a two-sided PC board. Array overlap for decoupling can be easily adjusted because of the planar flexible construction.

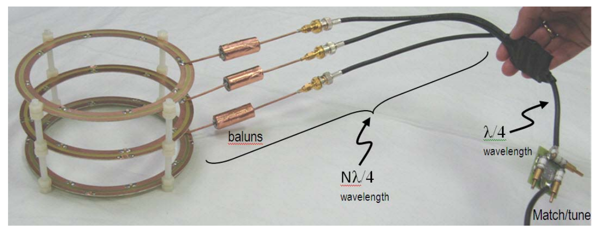

Figure 2. Three element coaxial array of strongly coupled 14.5cm i.d. shielded loop elements. Equal currents at the excitation ports are enforced despite the coupling by applying the 'Forced Current Excitation' (FCE) technique based on transmission line theory.

Current Control in Decoupled coils: In the decoupled two-element array, each element was matched to 50 ohms. Power was split using a simple Wilkinson divider, which consists essentially of two quarter wave transmission lines. Power is split equally and with equal phase, to two matched ports. Phase can be controlled in this case by simple addition of a transmission line; however, commercial line-stretchers are available that allow constant impedance phase variation by simple mechanical adjustment of two nested coaxial cables. In our bench experiments, a General Radio 874-LTL line stretcher was used, enabling simple phase adjustment of over 90 degrees without switching cables. When imaging, quarter and half-wavelength cables were used.

Current Control in Coupled Coils: Of greater interest is the coupled coil case, where the impedance of the elements can vary greatly with positioning and loading of the coils. A conventional power splitter will therefore deliver power and current unequally and unpredicatably to the different elements. We have previously used current source amplifiers to enforce the desired current in the face of coupling, but have not implemented this at 7T. Instead, we have applied a 'Forced Current Excitation' (FCE) technique to create equal currents at the excitation ports [3]. FCE connects each coil directly to a common point through quarter wave transmission lines. Transmission line theory shows that the current at the feed port of each element is given by $I_L = -jV\left(\lambda/4\right)/Z_o$ where I_L is the current at the load (feed port), Z_0 is impedance of the transmission line, and $V\left(\lambda/4\right)$ the voltage at the common point. This remains true when multiple loads are connected – the voltage may change as the total impedance changes, but all feed ports maintain the same current. We have demonstrated this technique using up to 8 elements tied to the common feed point. The phase between elements can be altered by 180 degrees while still maintaining the same current magnitude by inserting a half-wave cable between the coil port and the common connection point.

RESULTS: Figure 3 shows the predicted patterns of the two element planar array for interelement phase shifts of 0, 90 and 180 degrees and the measured images. The 90 degree phase shift was obtained through a quadrature combiner. While the 90 degree case is likely the best for 1H imaging, the 180 degree case allows decoupling from a centered third coil used for simultaneous 13C spectroscopy. **Figure 4** shows axial and coronal images through a cylindrical phantom inside the three element coupled coil array. The pattern is uniform in the along the array axis, indicating in-phase current on each element despite very strong coupling.

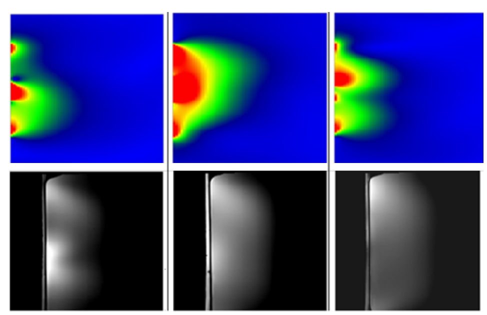

Figure 3. Calculated B1 maps (top) and measured images (bottom) using 0, 90 and 180 degree phase offsets between two overlapped loops. The 180 degree case allows decoupling from a centered 2nd nuclei coil.

DISCUSSION: While waiting for the widespread availability of multi-transmit capability for 7T systems, a number of simple methods can be used to investigate some transmit array configurations. Decoupling the array elements allows relatively simple phase only variations; however, at 7T even decoupling elements becomes difficult. Forced current excitation enables equal or out-of-phase currents to be achieved, which can be useful for a number of applications. For example, a solenoid coil has been simulated using forced current excitation using an array of three strongly coupled co-axial loops fed in parallel from a single matching network. These methods, in particular the forced current excitation, should be of interest for investigating transmit-array coil configurations.

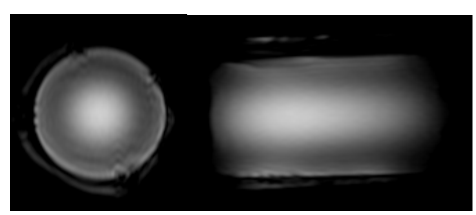

Figure 4. Coronal and sagittal images from the three element array of coupled loops driven with forced current excitation method, showing uniform excitation throughout the volume.

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