A 3T linear phase volume excitation coil

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INTRODUCTION: RF coils that generate transverse magnetic fields with uniform amplitude and linear phase variation across the imaging volume have been shown to be optimal for excitation fidelity in parallel transmission (1) and are useful for reduced SAR slice selective excitation and for gradient-less imaging (TRASE) (2). Such field profiles have been obtained with twisted birdcage coil designs (2,3). Previous work proposed a novel excitation coil design based on a non-resonant microstrip design (4) that achieved very uniform amplitude transverse magnetic fields with linear phase variation along the z-axis of the coil (5). This coil design was simulated at 1GHz and could not achieve enough linear phase to be useful at 3T frequencies. Our previous work used distributed capacitors along the length of a single non-resonant microstrip to increase the electrical length of the line (6). The goals of this work were to control the phase along a microstrip line and set its value for a given line length as implemented in a volume coil made of non-resonant microstrip linear phase coil elements at 3T frequencies.

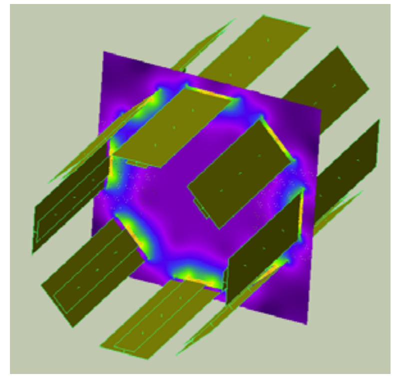

Fig 1: Eight element microstrip coil array forming a volume coil. Each coil element has a ~180° phase shift along its length.

THEORY: Increase in the effective dielectric of a microstrip transmission line increases the electrical length of the line. This work utilizes a different approach to increase the electrical length of a microstrip line with the use of distributed lumped element capacitance along the line. This does not change the dielectric properties of the material between the conductors, the added capacitors increase the dielectric constant between the conductors at discrete positions and the electrical length of the line is increased. The added capacitance results in a change of the characteristic line impedance.

METHOD: Using the results from a single microstrip coil design (distributed capacitance values and load and source impedances), a volume microstrip coil consisting of 8 individual microstrips around the surface of a 24cm diameter cylinder (see Figure 1) was simulated (Remcom Inc.). Each microstrip had a center conductor that was 25mm wide, 5mm from the ground plane, and 40cm long. Each microstrip was fed with a voltage source that varied in phase according to its relative angular position in order to produce a circularly polarized field inside the volume of the coil. Capacitors were used to achieve increased phase shift down the length of the coil, equivalent to a dielectric material constant of 10 between the conductors. This was accomplished using air between the conductors and 7 capacitors (14 pF) equally spaced along the transmission line to create a characteristic line impedance of ~18 ohms in each non-resonant microstrip line. Resistors were used to terminate each line.

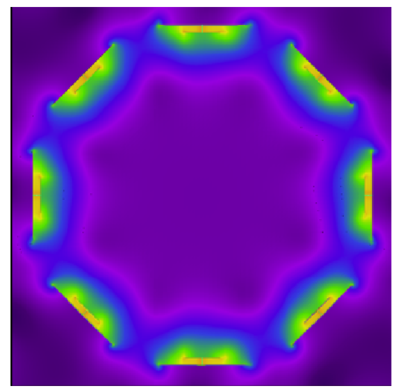

Fig 2: Axial view of the 8-element microstrip coil with a steady state magnetic field profile plot.

RESULTS: Figure 2 shows the steady state field plot from the coil simulation. It can be seen that there is a large volume in the center of the coil that provides relatively homogeneous B-field. Assessment of the field in this central region shows that it is circularly polarized with little Bz field component (see figure 3A). The phase rotation down the axis of the coil is very linear except near the ends of the coil array (see figure 3B). These nonlinearities are likely due to truncation of the volume coil and to source and load termination effects at the ends of each microstrip. The net phase shift for this coil was about 130°, but increasing the distributed capacitor values to 18 pF changes the line impedance to ~12.5 ohms and results in a phase shift of ~180°.

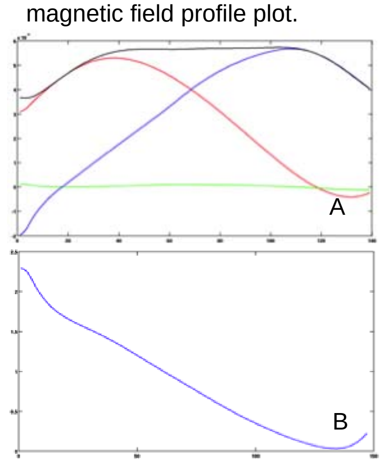

Fig 3: A) Field profile plot along axis of coil. Red/blue/green/black = Bx/By/Bz/|Bxy|. B) Phase profile of Bxy along the coil axis.

DISCUSSION AND CONCLUSION: This work indicates that using lumped element distributed capacitors to control the phase of the transverse magnetic field down the length of microstrip coil elements is feasible for the development of volume coils at 3T frequencies. The limits of this technique have not been determined, but this work suggests that 180° phase shift in coils that are on the order of 30-40 cm long is not unreasonable. In addition, the 8 element volume coil can be reconfigured to provide 2 separate 4 element volume coils where each 4 element volume coil has its own linear phase change down the center, and the linear phase from each coil is rotating in opposite directions. This may prove useful for SAR reduction techniques. Future work will more fully investigate the characteristics of these linear phase coils including phase shift limitations, electric field profiles, and loading effects on the phase properties.

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