A method for increasing electrical length of microstrip waveguides

R. Hadley[1], D. Parker[1], and G. Morrell[1]
[1]Radiology - UCAIR, University of Utah, Salt Lake City, Utah, United States

INTRODUCTION: RF coils that produce transverse magnetic fields with uniform amplitude but linear phase variation across the imaging volume have been shown to give excellent 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 elements (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 variation to be useful at 3T frequencies. This work uses distributed capacitors along the length of a microstrip transmission line to increase its electrical length. The goal is to achieve larger linear phase shifts over the length of the microstrip to enable its use in a “linear phase” volume coil at 3T.

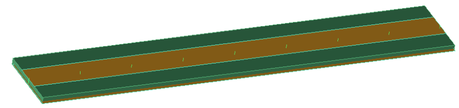

Figure 1: A single microstrip non-resonant coil. One end is fed with a source and the other end is terminated with a resistor that is equal in value to the line impedance. The microstrip in this study was 40 cm long with a center conductor of 25mm width and a 5mm height from the groundplane.

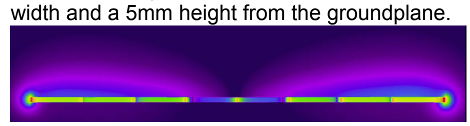

Figure 2: A cross sectional view of one time point in the FDTD simulation showing the magnitude of the magnetic field (dB). The null of the propagating wave is over the central capacitor. The other capacitors are visible between the center and ground conductors. The center conductor is on top and the ground conductor is

THEORY: Increase in the effective dielectric of a microstrip transmission line shortens the wavelength and increases the electrical length of the line. Common methods for increasing the effective dielectric constant include using a substrate material with a higher dielectric constant or embedding the entire microstrip in a material that has a higher dielectric than air. Unfortunately, high dielectric materials are typically hard to get, expensive, and have high loss tangents. To imbed the microstrip in a dielectric material can limit its usefulness for many applications. This work utilizes a different approach to increase the electrical length of a microstrip line by using distributed lumped element capacitors along the length of the line. Although there is no change in the dielectric constant of the material between the conductors, the added distributed capacitors effectively increase the dielectric constant between the conductors at discrete positions and the electrical length of the line is increased. The added distributed capacitance results in a change of the characteristic impedance of the line.

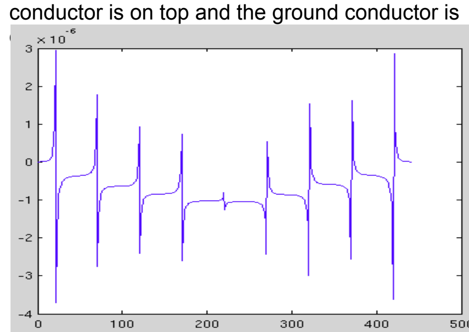

Figure 3: Central Bfield along the length of the microstrip (40cm) for one point in time. The normally sinusoidal distribution is broken up at the positions of the capacitors, but results in a ~180° phase shift over the length of the line.

Table 1	caps	input impedance		
# caps	(pF)	mag	phase	VSWR
1	46.3	18.83	-1.36	1.04
3	22.5	18.6	0.253	1.03
7	12.5	18.23	2.651	1.05
15	6.5	18.4	-1.03	1.02

METHOD: A single microstrip line (Fig 1) was simulated using xFDTD (Remcom Inc.). Using standard microstrip analytic equations (6), the characteristic impedance of this line was calculated to be ~50 ohms and the electrical length was 59°. In order to achieve a 180° line length, a substrate dielectric constant of 12 would be required, resulting in a line impedance of 16 ohms. Therefore, for the FDTD simulations, a 16 ohm impedance was used as the load and source impedance and the substrate material was air. Distributed capacitance values were determined using Smith Chart calculations based on the number of capacitors used and the associated segment lengths between capacitors. Approximate capacitor values were determined to achieve the desired input impedance. Capacitor values were then optimized using FDTD by adjusting the values for proper input impedance, minimum VSWR, and the desired phase shift along the specified line length. The original goal of this work was to investigate the use of capacitors to simulate a dielectric constant of 10 in an air substrate coil with an associated line impedance of 18 ohms. Simulations using different numbers of capacitors were performed to assess the number of capacitors needed to get a smooth propagating waveform down the length of the line.

RESULTS: For the single microstrip coil simulations, different numbers of capacitors were used to achieve the increased electrical line length down the length of the microstrip. Table 1 shows some of the results for different numbers of capacitors. The use of more distributed capacitors resulted in smoother wave propagation down the line. Fewer capacitors resulted in choppy and rapid transitions of the null point propagation. Using 7 capacitors of 18 pF resulted in a line impedance of approximately 12.5 ohms and 180º phase shift across the length of the line. The reflection coefficient at the source was 0.03 with a phase of 90°. The Bfield magnitude along a central slice of the microstrip conductors is plotted in Figure 2 and the Bfield between microstrip conductors is plotted in Figure 3.

DISCUSSION AND CONCLUSION: Addition of capacitors along the length of a single microstrip transmission line can increase the electrical length of the line, creating greater amounts of linear phase variation along the line. This technique may be useful to create a “linear phase” coil which has interesting properties for parallel transmission. Distributed capacitance results in reduced impedance compared to the line impedance of the original microstrip line. By adjusting the microstrip dimensions for high impedance and adding distributed capacitance, a 50 ohm characteristic impedance could be achieved.

ACKNOWLEDGMENTS: The authors wish to acknowledge the Ben B. and Iris M. Margolis Foundation for their support.

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