An Inductive Resonator for 7T with Transmission Line Segments for Strong Coupling

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Introduction

An Inductive Resonator (Fig. 1) can be constructed of N mutually inductively coupled loops (1). The resonator will exhibit the mode distribution of a high-pass birdcage (2). Mode separation is increased with strong mutual inductance. We accomplish this in our design using transmission line segments to form the conductors of adjacent loops (Fig. 2a). We demonstrate that multiple virtual grounds within the legs or cross-members can be achieved at 7T, owing to the short wavelength of this frequency. This coil has a split RF shield (not shown) to reduce radiation and shield electric fields from the head.

Fig. 1. Inductive Resonator

Methods

For two meshes in close proximity, adjacent conductors form transmission line (TL) segments that can be broken in pairs to distribute capacitance in the legs. The inductive resonator we describe here has 24 meshes and TL segments, three capacitor breaks in each segment, but no capacitors in the conductors that form the end-rings. The current distribution of the coil can then be resolved into two distributions: differential currents flowing within the TL segments, and common mode currents flowing the same direction within the segments (see Fig. 2a). The common mode currents are distributed sinusoidally and provide the uniform field. The inductive resonator has a virtual ground in its central axial plane. The center capacitors are balanced about ground potential, so a single-ended model of the transmission line can be formed according to Fig. 2a (bottom), which is mirrored on the other side of the coil. Using a Smith Chart for this segment (Fig. 2b), the capacitive impedance of C1 at the center (point 1) transforms to an inductive impedance at the outside (point 2). A second capacitor pair (C2/2) is chose to restore the TL segment impedance to a capacitive value that can resonate with the inductance of the end-rings (point 3). In this shielded coil, the shield is placed on the inside of 14 inch cylindrical Lucite at 343 mm, and the RFcoil is mounted on the inside of 12 in Lucite at 298 mm. The TL cross-member is 8 mm wide Cu strips on eighth inch (3.2 mm) FR4, mounted vertically on the cylinder as in Fig. 1a. Each TL cross-member is 20 cm long as measured to the center of the end-rings. Capacitors in the cross-members were 12 pF everywhere. To further investigate the field distribution, a numerical model was built based on the coil geometry and a realistic human head model. The simulation was carried out with an improved FDTD method that can fully take into account the cross-members without excessive memory requirement.

Results

The modes of a resonator tuned for 7T is shown in Fig. 3. The resonator exhibits the 12 modes, typical of a 24 leg high-pass birdcage, and a HF longitudinal mode. Separation of the homogeneous k=1 mode and the k=2 mode is 22 MHz. The coil was tuned by placing high-value capacitors in the end-rings near points used to couple to the coil. We implemented 4-port coupling using two pairs of quad hybrids each connected to coil ports positioned 90 degrees apart. The coil was tested with Si and water phantoms using the GE 7T whole body MRI at the NIH. Images in Fig. 4 of the Si phantom show good B1 uniformity. Images of the water phantom show good inversion of the spins at the center of the phantom in the presence of a strong dielectric resonance (axial and sagittal images were almost identical). Inversion was achieved using a TG < 140 on the GE system using a single 4 kW transmitter. Fig. 5 illustrates the E-Field distribution of this coil in a sagittal plane, demonstrating the voltage nulls of the TL segments.

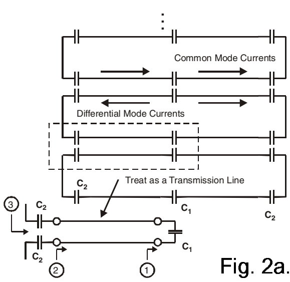


Fig. 2a.

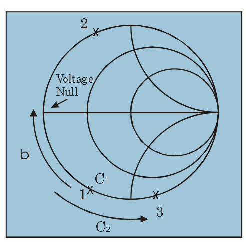


Fig. 2b.

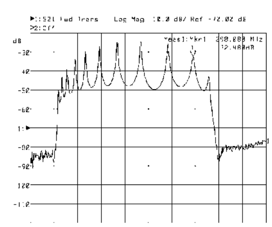


Fig. 3.

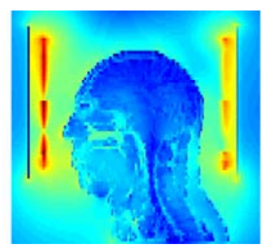
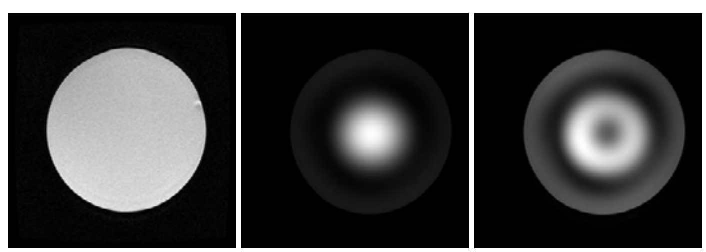


Fig. 5.

Discussion

We present a new inductive resonator circuit model for tuning this resonator to high frequency. Use of strong coupling via the TL segments demonstrates that good mode separation may be achieved without continuous end-rings. The common mode currents of the resonator may be further analyzed as transmission line segments located above the ground plane of the shield. The large shield-coil separation (23mm) can be reduced for higher frequency operation. A switched version of this coil has been successfully employed as the transmitter coil for a hybrid Tx/Rx16-element phased array coil for 7T.



(a) (b) 90 deg (c) 180 deg

Fig. 4. Gradient echo images of (a) Si phantom, (b) & (c) water phantom.

References

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2. WA Edelstein, JF Schenk, OM Mueller, CE Hayes, US Patent 4,680,548 (July 14, 1987).