An Improved Volume Coil for High Field MRI

J. Thomas Vaughan
MGH-NMR Center – Harvard Medical School
Boston, Massachusetts

Objective: To improve the TEM volume coil for better eddy current immunity, and for higher field operation.

Introduction:
The TEM resonator is finding increasing use in MRI, especially for efficient high frequency head coils and body coils. The shield or cavity wall integral to the design of the TEM coil, supports transient $B_0$ gradient field induced eddy currents. By keeping the cavity wall to 1/e skin depth thickness (~ 5 microns at 128 MHz), these eddy currents are sufficiently suppressed to enable many successful anatomic imaging and spectroscopy applications. With eddy current caused ghosting on the order of 1% or more in EPI images however, fMRI measurements are adversely affected when using the conventional, “solid shield” TEM head coil. (Figure 1) When the TEM cavity wall is near the gradient coils as is the TEM body coil, or as is the head coil inside gradient inserts, problematic gradient coil loading conditions occur. A method of solving the eddy current problem in the TEM coil is described below.

Figure 1 demonstrates the TEM ghosting problem in EPI, gradient echo images of an aqueous phantom at 1.5T. Even though the SNR=131 of the TEM head coil image (left) compares favorably to SNR=108 of the commercial birdcage head coil (right) the signal-to-ghost of the TEM coil is half that of the unshielded birdcage.

Methods:
To interrupt eddy current propagation in the TEM coil, its cavity wall was slotted. While the approach is similar to that used in the bird cage shield, the slot pattern is quite different for the TEM coil compared to the “thumb print” pattern optimized for the birdcage [2]. As seen in Figure 2, straight-line slots divide the TEM cavity wall, front to back. These slots work well enough in single sided foil; for enhanced shielding, overlapping slots etched in double sided foil clad substrates may be used. Eddy current problems are most diminished when the number of slots in the coil’s cavity wall correspond to, and are centered with the coil’s inner elements. These elements may be flat, two-sided strip-line elements, split coaxial elements [3], or single line copper conductors[4]. The functional unit of this segmented TEM coil is the internal line element in balanced resonance with the external cavity segment. A simple LC loop, this functional element can be divided capacitively into one through four or more sections at points suggested by the azimuthal line points A, B, C, etc. As in a simple surface coil, the number capacitive “splits” in each resonant unit can be chosen to be few (one at points A for example) when a more inductive, lower frequency TEM coil is desired. Two or more splits in each functional unit can be used to extend the size and frequency of the TEM volume coil. These splits can be bridged by discrete capacitors for smaller or lower frequency coils, or by distributed circuit analogs for larger, higher frequency head and body coils.

Figure 2. The slotted TEM volume coil. The coaxial slots along the coil’s length serve to interrupt switched gradient induced eddy propagation. Reactively bridged azimuthal slots around the TEM coil’s outer wall, end walls, and inner “wall” further limit eddies, and extend the coil’s frequency band and dimensional options.

Results:
The slotted TEM coil images show signal-to-ghosting to be insignificantly more than in unshielded birdcage images, without sacrifice in Q or $B_1$(<1dB) efficiency. In a controlled 3T study, the slotted TEM coil measured SNR=180 for a 61% improvement over the same whole head FOV as compared with a commercial birdcage (SNR=112), while requiring half the transmit power (Figure 3). By slotting TEM coils by the methods described, successful head coils (20cm with end x 27cm i.d.) have been bench tested to 450 MHz, and “body” coils (50cm x 52cm i.d.) to 340MHz.

Figure 3. The slotted TEM head coil is shown, with adjustable mirror and bite-bar brace. EPI Images from the TEM coil (left) show negligibly more ghosting than a comparable unshielded birdcage, but significantly more SNR and transmit efficiency.

Conclusions:
A TEM volume coil with improved eddy current immunity and operational bandwidth is reported. This volume coil has been tested to match the range of NMR frequencies and bore sizes allowed by the present magnet technology.

References:
5. NCI-IR-O1-CA7653-015, NCRR-IR-41-RR13230-01