A Double Maxwell Sine Field RF Coil for a TRASE RF Phase Gradient Coil Set

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Introduction to TRASE: TRASE is a k-space imaging method which uses RF phase gradients instead of B_0-gradients. It is a general k-space method and 2D imaging and slice selection have been demonstrated (1). A 1D TRASE sequence consists of excitation followed by an echo train in which RF refocusing pulses are alternately applied with positive and negative B1 phase gradient fields. This results in k-space evolution occurring from one echo to the next, and sampling of an echo train yields a line of k-space. **Phase Gradient Coil Design:** RF coil design is particularly important for TRASE as the quality of the imaging results depend to a large extent on the RF phase gradient fields. A target phase gradient coil B_T with phase gradient (g_{1x}) can be considered to be composed of two halves: a cosine part and a sine part, thus $B_T = B_T^{COS} + B_T^{SIN}$. An x-direction gradient can be constructed from the two parts $B_T^{COS} = +\mathbf{j}|B_{1xy}|\cos(g_{1x}x)$ and $B_T^{SIN} = -\mathbf{i}|B_{1xy}|\sin(g_{1x}x) + \mathbf{k}|B_{1xy}|g_{1x}z\cos(g_{1x}x)$. Here we report an improved coil design for the B_T^{SIN} field, intended for a 0.2T MRI system, with the main field direction along the vertical direction Z, with patient axis Y. The general design aims are: uniformity of |B1|; strength of B1 phase gradient; efficiency; linearity of B1 phase gradient.

Methods:

Step 1- Coil Concept: The initial coil concept considers the 2 terms in B_T^{SIN}. The first term is the desired $\mathbf{i}|B_{1xy}|\sin(g_{1x}x)$ field which can be approximated by an opposed (Maxwell) pair of loops in the x-direction. The second term is the necessary concomitant field which arises from applying the constraint Div B=0. This gives: $\mathbf{k}|B_{1xy}|g_{1x}z\cos(g_{1x}x)$, which is z-directed with a null at z=0, so suggests another pair of opposed loops, but in the z-direction. So the initial coil concept consists of 4 loops. *Step 2 - 2D Design:* Since in this particular case target field is zero in the **j** direction, the 4-loop concept can be considered as an 8-wire 2D model, with currents flowing into or out of the 2D plane. The field distribution was optimized by changing the positions and the current amplitudes of the conductors (FEMLAB, Comsol). *Step 3 – 3D Design:* Based on the geometry and currents of the 2D model, a 3D model was created to allow simulation of a practical finite length coil with return paths (Remcom XFDTD7.0 software), Fig.2. The X and Z dimensions of the 3D model were scaled down by 2 from those in the 2D model. The Y dimension of the 3D model was selected close to the maximum dimension of Z. Simulations results were stored in 'Solid Box' sensors of 40x40x40cm and 20x20x20 central cubes. Code was written to convert the XFDTD data into slices which could be viewed as complex fields in our image viewer, (*Marevisi*, NRC-IBD). *Step 4 - Construction:* A double Maxwell coil was constructed according to the 3D model results. Current ratios were set by capacitors located at the middle of each of the eight legs. After fine adjustment of the capacitor values, the expected current ratios were achieved. A matching and tuning circuit was attached to the coil for operation at the magnet working frequency of 8.22MHz. Fig.4 shows the constructed coil. For comparison, a 3D model of the previous Maxwell coil (two circular loops, distance to diameter ratio - 32: 28) was also created in Remcom software.

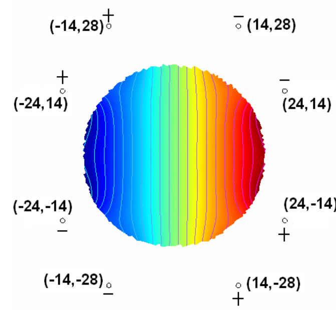


Fig 1. 2D 8-wire model and sine field (FEMLAB)

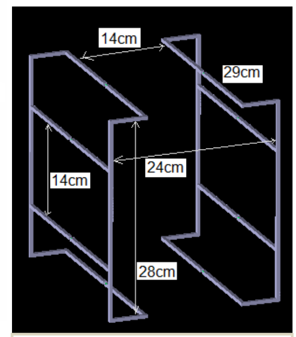


Fig 2. 3D model for double Maxwell coil (Remcom)

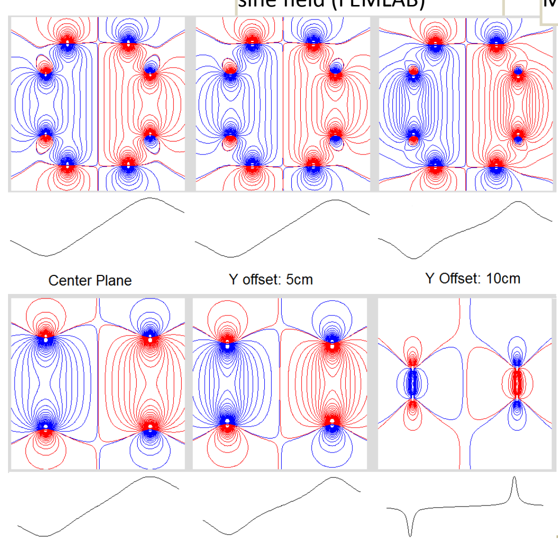
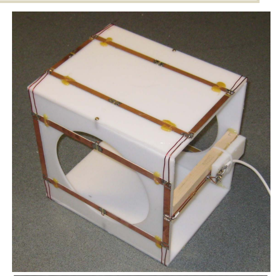


Fig 3. Field distribution and center line profile on planes at different y offsets. **Top** – New double Maxwell coil design. **Bottom** – Single Circular Maxwell



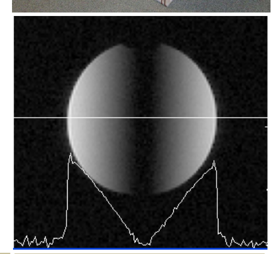


Fig.4 Constructed coil; **Fig.5.** GE B1 map, with abs(sine) profile

Results: Conductor positions and results of the 2D simulation are shown in Fig.1. The current ratio of the inner Maxwell pair to the outer Maxwell pair is 1.4:1. The center circular area of 33 cm diameter has a field distribution with < 10% deviation from the sine waveform. 3D simulation results show that the new design has a 91% larger usable imaging volume of (defined as <10% error) than the 2-loop Maxwell type coil.

Conclusions: Simulation results show that the new double Maxwell coil produces a sine field over a much larger volume than a 2-loop Maxwell coil. Future work will include combination of the Maxwell coil (sine field) with a cosine field coil to allow TRASE RF imaging experiments.

References: 1) Sharp-JC & King-SB, Magn. Reson. Med. (in press); Sharp-JC ISMRM (2009); Sharp-JC et al. p.829, p.1083 ISMRM (2008); King-SB et al. ISMRM (2007); King-SB et al. ISMRM p.2628 (2006)