Gaining Space with an Embedded Rf Body Coil Shield

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Introduction
The MRI rf body coil, typically a birdcage resonator, is generally isolated from the gradient coils by an rf shield. The shield prevents rf energy from being dissipated in the gradient coils and causing a reduction in efficiency of the rf coil. The shield must achieve this function while at the same time being as transparent as possible to the gradient fields. Gradient field pulses cause eddy currents in the rf shield, causing heating and a reduction in the fidelity of the gradient pulses.

Radial space is a critical performance parameter for both the gradient and the rf coils. Both gradient efficiency and rf efficiency increase very rapidly with increased separation between their respective shields and primary coils (1). The distance between the rf body coil conductors the rf shield is typically less than 25 mm.

The rf shield is usually placed on the inside surface of the gradient coil assembly. If it were possible to increase this separation by moving the rf shield outward, say, outside certain gradient coils, one could increase the efficiency of the rf body coil. Alternatively, we could maintain the efficiency of the rf body coil and use the space to improve the gradient coil performance by decreasing the gradient coil ID. A third alternative is to maintain the performance of both coils and allocate the space to an increased patient bore diameter.

There are two dangers in moving the rf shield to the interior of the gradient coil. One is that the rf fields will interact with the gradient coils that are no longer outside the radius of the rf shield. The other is that we might increase the coupling between the gradient and the rf shield.

A typical gradient coil stackup (from ID to OD) for a shielded gradient is inner windings z, y, x followed by outer windings z, y, x. In a cylindrical horizontal magnet, the x and y coils are identical fingerprint patterns rotated by 90° around the cylindrical winding form. The z coil is an antisymmetric solenoid with varying pitch.

A birdcage resonator body coil primarily generates radial rf and the net flux in the z direction is zero when integrated over the coil. In the z-gradient coil the current distribution is antisymmetric about z = 0. A birdcage resonator body coil would therefore not couple inductively to the z-gradient coil provided that the birdcage coil is coaxially and longitudinally centered inside the z-gradient coil. It is therefore possible to place the inner z-gradient coil between the rf coil and rf shield.

The purpose of this work is to study the feasibility of embedding the rf shield in the structure of a shielded gradient set. In particular, effects on the rf and gradient performance are evaluated.

Methods
A standard GE Signa Horizon gradient set was assembled with different types of rf shields in between the inner z and inner y gradient coils. For each type of rf shield we measured the Q of the rf body coil and the complex impedance of the gradient coils as a function of frequency. The body coil Q tells us how SNR would change for different rf shield configurations. The real part of the gradient impedance is an indication of the heat that would be generated during the pulsing of the gradients. The difference between the real parts of the impedances with and without an rf shield allows us to deduce the additional heat dissipated in the rf shield. The imaginary part of the impedance shows the gradient inductance which affects gradient slew rate. As above, tests with and without the rf shield isolate the effect of the shield.

A variety of rf shields was investigated: fingerprint shields in which the pattern was varied, mesh shields in which the size of the mesh was varied, and solid shields in which the material and the thickness were varied.

Results
As a reference point, initial rf measurements were done with a 70 μm thick solid copper shield. This would be far too thick and have too much dissipation to use with a realistic gradient system, but it represents an upper limit of rf coil Q that we can expect to achieve. A high pass 16 rung birdcage resonator, built with 25 mm wide copper strips, diameter 614 mm, length 430 mm had a Q of 420 and a frequency of 62.9 MHz when the rf shield was applied on the ID (654 mm) of the inner z-gradient. When the shield was moved to the OD (676 mm) of the gradient, Q = 417 and the frequency was 57.4 MHz. The sensitivity of the rf coil increased by 2.4 dB, due to a drop in effective volume (1). This shows that the concept is feasible from the rf perspective.

Many different types of shields were tested to minimize gradient eddy currents and maintain high Q. For simplicity we show here a comparison between the winner, a mesh shield on the OD of the z-gradient (dotted), our existing fingerprint shield pattern on the ID of the gradient (dashed), and no shield (solid) in Fig. 1A for the real part of the z-gradient impedance, and Fig. 1B for the imaginary part of z-gradient impedance (expressed as inductance). Most of the deviations occur above 1 kHz for all 3 gradients. The mesh on the OD of the gradient results in a Q of 310 for the rf coil. It is a phosphor bronze mesh shield with mesh size of 325 lines per inch.

Discussion
The resistive part of the gradient impedance has increased due to the embedded shield. However, calculations show that the pulse sequence DW-EPI, which provides the largest thermal load in the gradient coils, dissipates only an additional 800 W in the rf shield. All pulse sequences dissipate less than 1500 W in the rf shield. These heat loads are readily manageable by existing cooling methods. The frequency contents of DW-EPI (Fig. 2) shows that most energy is dissipated below 1 kHz where the real part of the impedance associated with the mesh shield does not deviate significantly from that with the existing fingerprint shield on the ID of the gradient. In this frequency range the inductance of the gradient coil is identical for the different shield types shown, so no change in slew rate is expected.

References

Figure 1. Gradient impedance with different rf shield configurations. A) real impedance, B) imaginary impedance expressed as inductance. Solid line, no rf shield; dashed line, fingerprint shield; dotted line, mesh shield.

Figure 2. Power spectrum of DW-EPI pulse sequence.