An RF Shield Comparative Study of Different Materials and Types

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INTRODUCTION

An RF shield is an integral part of any MRI system. It has dual functionality, good high frequency conductivity for RF shielding and transparency to the gradient field to minimize eddy current losses. In finding an optimum tradeoff, the gradient coil impedance and RF coil Qs are usually compared for different RF shields. Compromising either performance of the RF coils or the gradient system can critically degrade the overall performance of the system. This work attempts to identify a best option among some solid, mesh and segmented RF shields.

METHOD

The thickness or effective thickness in terms of the skin depth at 64 MHz was calculated for solid copper sheets of different thickness and stainless steel and phosphor bronze mesh sheets having various wire densities and thickness. Sample materials were acquired and installed into gradient coil cylinders for comparison of RF and Gradient performance. The best-case scenario was measured for both the gradient, having no RF shield, and the RF coil, using solid copper for maximum conductivity.

The RF shields were tested using a GE Twinspeed gradient coil (Zoom - 40 mT/m @ 150 T/m/sec, and Whole Body - 23 mT/m @ 80 T/m/sec). Each of the RF shields was installed on the inner diameter (65cm) of the gradient coil. Gradient resistance and reactance measurements were made using the HP4192A Low Frequency Impedance Analyzer, swept from 10Hz to 100kHz on each of the gradient coils 6 axis for comparison.

RF performance was monitored for each shield tested using a 1.5T (64MHz) 16-leg high pass birdcage body coil and a 3T (128MHz) 32-leg high pass birdcage body coil having elevated endrings. The corresponding 1.5T and 3.0T 16 leg birdcage head coils were also tested. Tuning center frequency and bandwidth were compared, showing maximum sensitivity and variation when using the 1.5T RF body coil. An S_{21} Network Analyzer measurement was collected using two flux probes at various orientations in the RF coils. Different probe sizes were used for the head and body coils.

RESULTS and DISCUSSION

Table 1 shows the measurement results for the impedance of the TRM Zoom z gradient coil at 1 kHz and 10 kHz and the unloaded Q of the RF body coil at 64 MHz. It can be seen that the TRM fingerprint shield has the lowest resistive loss as compared to any solid or mesh shield yielding similar unloaded Q values for the RF coil. For all the solid copper shields except for the one with a thickness of 36 μm, it is shown in Fig.1 that the change in the unloaded Q of the RF coil at 64 MHz is linearly related to that in the resistance of the gradient coil due to the presence of the different RF shields at 10 kHz. The same linear relationship is also found in the case for the stainless steel mesh shields, as shown in Fig. 2. Although not shown here, it should be pointed out that this linear relationship is valid for the resistance of the gradient coil at 1 kHz as well. This relationship between the unloaded Q of the RF coil and the resistance of the gradient coil indicates that it is not possible to find a solid or mesh shield which will enhance the RF coil performance without causing a corresponding increase in the resistive loss in itself induced by the gradient coil.

Table 1: Measurement results for Z zoom gradient and 1.5T Body Coil Q	R [Ohms] @1kHz (Zoom Z)	L [mH] @1kHz (Zoom Z)	R [Ohms] @10kHz (Zoom Z)	L [mH] @10kHz (Zoom Z)	Q Unloaded @ 64MHz
36um Solid Copper	2.475	0.938855	10.87	0.449931	400
Phosphor Bronze Mesh 325x325, 36un	0.965	1.221037	19.8	0.976893	350
51um Solid Stainless Steel	0.965	1.22	19.4	0.978	275
4um Solid Copper	0.834	1.223583	11.28	1.075569	250
TRM Fingerprint Shield	0.784	1.224379	6.63	1.09419	250
Stainless Steel Mesh 120x120, 94um	0.846	1.22	12	1.07	215
2um Solid Copper	0.809	1.22422	9.39	1.089734	200
Stainless Steel Mesh 150x150, 66um	0.82	1.22	10	1.09	190
Stainless Steel Mesh 200x200, 58um	0.82	1.23	9.86	1.09	184
Stainless Steel Mesh 200x200, 53um	0.812	1.23	9.14	1.09	170
Stainless Steel Mesh, 325x325, 36um	0.814	1.228835	8.69	1.085118	150
1um Solid Copper	0.784	1.225016	7.23	1.099761	141
Stainless Steel Mesh, 400x400, 25um	0.788	1.23	7.13	1.1	121
0.5um Solid Copper	0.776	1.225493	6.45	1.10358	115
Stainless Steel Mesh, 325x325, 28um	0.796	1.229313	7.21	1.091325	115
0.25um Solid Copper	0.765	1.225652	5.47	1.105968	67.5
No Shield	0.755	1.225811	4.62	1.104058	10

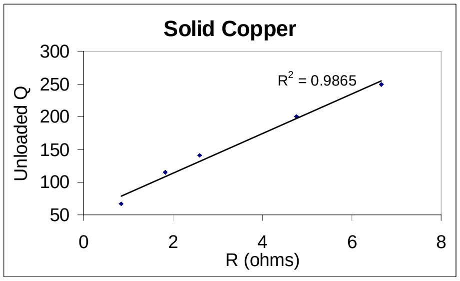
An interesting finding of this study is that the resistive loss in the solid copper shields induced by the gradient coil reaches the maximum at smaller shield thickness than the unloaded Q of the RF coil, as shown in Fig. 3. This is rather counter-intuitive since the skin depth of copper at 10 kHz is 80 times larger than at 64 MHz, which would imply that the unloaded Q of the RF coil reaches the maximum first. A further investigation is needed to explain this phenomenon though it is suspected to be related to non-plane wave propagation of the RF and gradient fields.

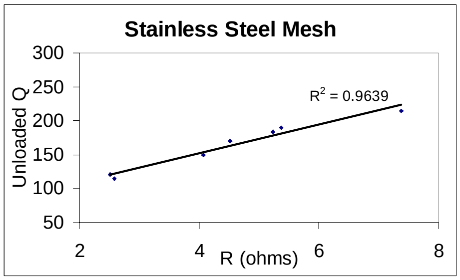
CONCLUSION

In conclusion, for an RF shield to enhance performance of the RF coil without causing much resistive loss induced by the gradient coil, the shield has to be segmented in such a way that it allows the flow of the eddy currents induced by the RF field while blocking the eddy current by the gradient coil.

References

1. Frederick,P., *et al.*, Double-sided RF shield for RF coil contained within gradient coils used in high speed NMR imaging, US Patent # 5,680,046.
2. Morich,M., *et al.*, Integrated MRI gradient coil and RF screen, US Patent # 5,406,204.





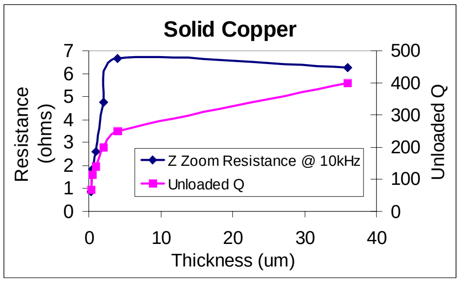


Figure 1 (Left): Unloaded Q vs. Resistive Loss in Solid Copper Shields
Figure 2 (Center): Unloaded Q vs. Resistive Loss in Stainless Steel Mesh Shields
Figure 3 (Right): Unloaded Q and Resistive Loss as Functions of Copper Thickness