Towards the Optimum 7T Head RF Coil

G. McKinnon[1], E. Boskamp[1]
[1]GE Medical Systems, Waukesha, WI, United States

Introduction

Numerical simulations were used in an attempt to find the optimal configuration for a 7T head coil. The high-pass birdcage, the hybrid birdcage, and the TEM resonator were compared. The coil dimensions were kept as similar as possible. Performance was evaluated on the basis of normalized peak E field, SNR and B1 uniformity.

Methods

A base coil configuration was chosen, with rungs = 32, coil length = 16cm, coil radius = 15cm, shield length = 28cm, shield radius = 17cm, strip width = 1cm. For the hybrid birdcage, only the rung capacitors were varied. For the high-pass and TEM the various coil dimensions were varied individually. For the TEM and hybrid coils three discrete capacitors were placed along each rung. In all, twenty-four different configurations were examined.

The finite-difference-time-domain (FDTD) algorithm [1] was employed for the simulations. The FDTD cell size was 3mm in the x and y directions, and 9mm along z. The FDTD space extended 51cm in the x and y directions and 99cm along z, and was bounded by an eight cell thick perfect matching layer. Each simulation was run for 13,000 time steps (over 20 periods) to insure that a steady state was reached; then the B_1^+ field, RMS E field, and SAR were calculated over a subsequent period.

Visible-man data, with electrical properties appropriate for 7T [2], were used to simulate the human head. The visible-man data was positioned with the head in the center of the coil; and the data were truncated such that no tissue was closer than 6 FDTD cells from the perfect matching layer.

The coils were driven using current sources, supplying the ideal current, at the usual capacitor locations. This produces the same B and E fields as in a resonant coil operating with the same modal current. For the hybrid coil only the end-ring capacitors were replaced with current sources.

The peak B_1^+ was determined in the head. The peak E field value was obtained on a 14cm radius cylinder, and then normalized by the peak B_1^+. Relative SNR was defined as the peak B_1^+ in the head divided by the power deposited in the body. This definition of SNR assumes that the x-y magnetization is (somehow) maximized, and ignores losses in the coil. The B_1^+ uniformity was evaluated qualitatively. The capacitor value required for tuning was obtained using the source impedance method [3].

Results

The normalized peak E field of the optimal hybrid birdcage was about 23% less than that of the high-pass birdcage. However the SNR (and hence total SAR) was virtually identical.

The coil length had very little impact on the B_1^+ uniformity in the head for a given coil type; however the TEM coils had better uniformity at the top of the head.

The normalized peak E field of the TEM coils was about 65% higher than that for the high-pass coils; and the SNR of the high-pass was about 40% higher than for the TEM.

The optimal shield spacing appeared to be about 1cm for the TEM resonator, and about 2cm for the high-pass birdcage.

A copper strip width of 10mm was optimal for the TEM, whereas the high-pass performed better with a 15mm width strip.

The capacitors for the TEM coil were 2 to 3 times smaller than those for the high-pass birdcage.

Shield length had little effect on SNR. However the peak E field was lower with a short shield for the high-pass, whereas for the TEM the longer shield appeared better.

The number of rungs had no effect on SNR for both types of coils; however the peak E fields when using 16 rungs were almost twice those of the 32-rung cases.

Discussion

The hybrid coil performed best from a peak local E field perspective. However this corresponded to a rung to end-ring capacitance ratio of 0.1, which may lead to closely spaced modes [4]; and there was no total SAR advantage over the high-pass birdcage.

Both birdcage variants were superior to the TEM with respect to peak E field and SNR. Although note that the TEM coils here had discrete rung capacitors. It is not clear whether the oft-used distributed capacitors would ameliorate this.

Finally, there is a clear difference in the B_1^+ uniformity of the TEM and birdcage coils, with the TEM being superior in this regard. [Although, recent results indicate that good uniformity with the birdcage coils can be obtained by offsetting the coils superiorly.]

References

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