

Optimization of an RF Microstrip Resonator for High Field Imaging

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Synopsis

Optimization of MRI RF coils has been difficult in the past, since simulation tools only approximated the inductive behavior and did not predict losses. Recently, the multi-conductor transmission line (MTL) model [1,2] has proved reasonably accurate in simulating the transverse electromagnetic (TEM) resonator [3]. This method allows detailed calculation of inductive, capacitive and loss characteristics of the unloaded coil within the constraints of the quasi-TEM approximation. This work presents a case study in strip width optimization for an 8-element microstrip TEM resonator using the MTL model. The resulting strip width optimizes the coil quality factor, filling factor and field uniformity.

Optimization criteria

The efficiency of RF coils is typically assessed through the ratio of the unloaded to loaded quality factors. Since the MTL model is unable to predict loaded coil behavior, the approximate performance characteristic is $efficiency \sim \left[\frac{B_1^{1W}}{\sqrt{Q \cdot 1W}} \right] \sqrt{Q}$, where B_1^{1W} is obtained at 1W input power, and Q is the unloaded quality factor.

The bracketed quantity relates to the filling factor, and is independent of coil quality factor. The actual B_1 can be obtained as $B_1 = \left[\frac{B_1^{1W}}{\sqrt{Q \cdot 1W}} \right] \sqrt{Q_{actual} P_m}$.

The B_1 field uniformity is quantified as the maximum diameter of a circular region in the transverse plane where the B_1 field magnitude varies at most ± 1 dB (or ± 3 dB) from its value in the coil center.

Methods

The MTL model treats the TEM coil as a system of coupled transmission lines. It analytically solves the multi-conductor transmission line equations subject to circuit-type termination (capacitors, driving circuits). The MTL parameters are the per-unit-length L , C , R , and G matrices that characterize the coil inductive, capacitive, resistive and dielectric loss components respectively. These are computed by solving a Laplace's equation-type PDE in two dimensions, which can be done to high accuracy (3-6 decimal digits).

In this work, a custom 2D boundary element (BEM) PDE solver was used to compute the MTL parameters as well as the B_1 field distributions in the unloaded coil. The modeled coil quality factor can be expressed as $1/Q = 1/Q_L + 1/Q_e + 1/Q_c + 1/Q_{stray}$ with the constituent components due to losses in copper strips, former dielectric, terminating capacitors and stray impedance respectively. Each Q component is computed by simulating the coil with all other loss mechanisms disabled.

Results

The examined 8-element microstrip TEM volume coil has an inner diameter of 7.25cm, an outer diameter of 10.5cm and a length of 10.2cm. The coil is built on a polycarbonate former with wall thickness of 3mm. The strips reside on the inner surface of the former, while a cylindrical shield is placed on the outer surface. The strips are terminated to the shield using ATC 100B capacitors (Q available in the datasheet), with two capacitors in parallel at each strip end. For a more realistic simulation, a stray capacitance of 1pF and Q of 50 is added in parallel to each terminating capacitance. All simulations are performed at 200MHz (protons at 4.7T).

Figures 1-3 demonstrate the effect of strip width on different Q components, filling factor, and field uniformity respectively. All the performance criteria are nearly optimal when the strip width is 60-70% of inter-center distance. A particularly sharp optimum is seen for the quadrature mode B_1 field uniformity near 61% strip width. The corresponding simulated B_1 field distribution is depicted in Figure 4. To confirm this result, a coil prototype was built with 1.75cm strip width. Figure 5 shows a RARE image of a 6.75cm diameter (93% of ID) oil phantom obtained using the prototype operated in quadrature.

Conclusions

A microstrip TEM resonator can be optimized using detailed information available from the MTL model. In this case study, a strip width of ~61% of inter-center distance provides near-optimal performance in all criteria, especially quadrature B_1 field uniformity. A quadrature coil only needs eight elements to achieve satisfactory field uniformity when using the optimal strip width. For most birdcage and TEM resonators, the optimal strip width is expected to be in the range of 60-70% of inter-center distance, which is wider than what is typically used.

References

- [1] Baertlein BA et al. IEEE Trans Biomed Eng 2000;47:535-545.
- [2] Bogdanov G, Ludwig R. Magn Reson Med 2002;47:579-593.
- [3] Vaughan JT et al. Magn Reson Med 1994;32:206-218.

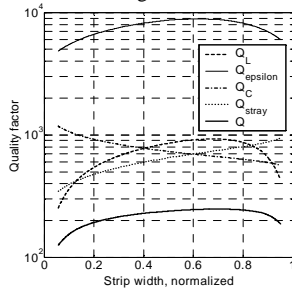


Figure 1. Quality factor components as functions of strip width.

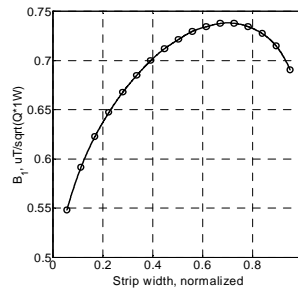


Figure 2. B_1 field strength (Q -normalized) as a function of strip width.

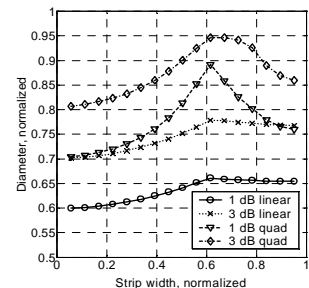


Figure 3. Uniform field diameters as functions of strip width.

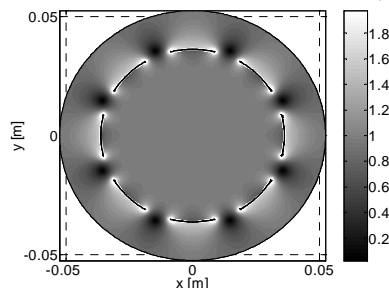


Figure 4. Computed optimal B_1 field distribution in quadrature mode.

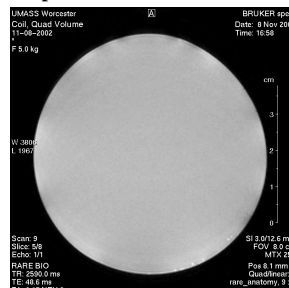


Figure 5. RARE image of an oil phantom using an optimized quadrature coil.