Noise Figure Limits for Circular Loop MR Coils

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Introduction: Loop coils are the fundamental building blocks of phased arrays. With the advent of parallel imaging using large numbers of loop elements [1] along with high-field MR, the geometric size of the loops is critical in determining detection and/or transmission efficiency. As loop size decreases, the coil noise becomes dominant and adversely affects the realizable signal-to-noise ratio (SNR) by increasing the noise figure (*NF*) of the detector system. Consequently there are real limits to the gains in SNR that can be achieved as the number of array elements are increased and the size of elements is reduced. These limits depend on coil design and size, field-strength, and array size. The purpose of this study is to determine these relationships in order to optimize array design and to investigate possible limits to the number of channels that can reasonably benefit an MR system.

We use a combination of analytic formulae, numerical EM analysis and experimental measurements to quantify the effect of loop radius, coil design, and number of array elements to determine the practical limits to coil *NF* over the frequency range 64-400 MHz.

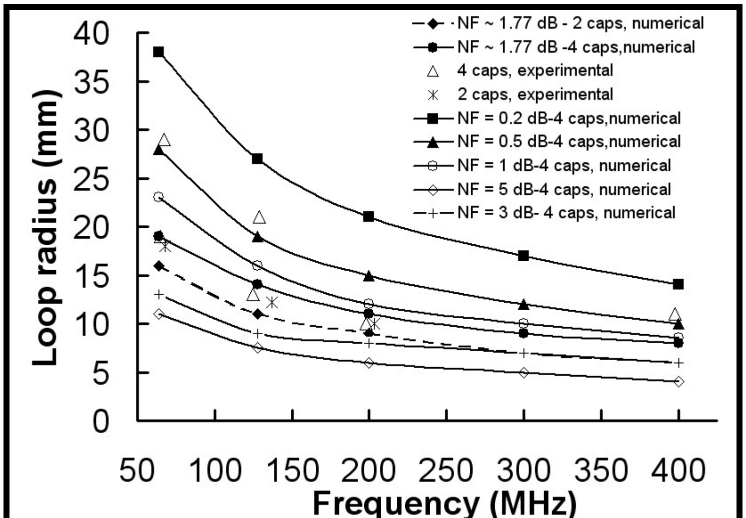

Fig. 1 Loop radius vs MR frequency for single tape coils.

Methods The *NF* of a resonant coil in dB is $NF = 10\log\left[\left(Q_U/Q_L\right) \div \left(Q_U/Q_L - 1\right)\right]$ where Q_L and Q_u are the loaded and unloaded *Q*. This *NF* measures the reduction in SNR due to the losses in the loop coil only [2]. $NF = 1.77$ dB , for example, corresponds to a 50% coil noise contribution. This *NF* adds directly to the system *NF*. Losses in the coil stem from: (i) conductor surface resistance; (ii) effective series resistance (ESR) of capacitors; and (iii) solder joint resistance. Conductor loss is calculated from the standard skin depth conduction formula. Solder joint losses are measured by introducing solder joints and observing the effect on coil Q.

Coils are made of 4 mm wide copper (Cu) tape or 1/8” Cu tubing. Coils are loaded with a physiological-equivalent NaCl based agar gel phantom. Theoretical Q is calculated with analytical inductance formulae, with conductor and sample losses determined using full-wave numerical method-of-moments (MoM) EM analysis (FEKO, South Africa). Coil sensitivity (∝ B1) was also calculated using FEKO.

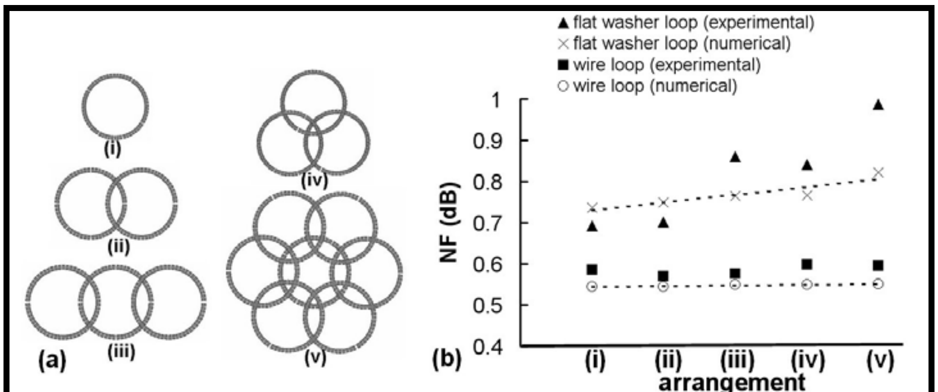

Fig. 2 (a) Array geometries (i-v) for wire loops and flat tape loops. (b) Effect of array geometry, (i-v), on *NF* for wire loops (*D* =46mm) at 128 MHz, and flat tape loops (outer diameter, 44mm; inner diameter, 36mm) at 128 MHz.

Results: Fig.1 shows the NF for a single coil as a function of frequency, coil radius and number of capacitors. The MoM calculations are confirmed by measurements at 64,130, and 400 MHz for 0.5 dB NF, and at 64,130, and 200 MHz for 1.77 dB NF, using loops tuned with 4 capacitors (Δ’s). Results show loops tuned with 2 capacitors actually perform better with smaller radii at 1.77 dB NF, as compared to those tuned with 4 capacitors (Fig. 1; dashed line). This is validated by measurements at 64, 130, and 200 MHz (Fig. 1; Xs). The 1.77dB NF coil (with 50% noise) has radius ~23 mm at 64 MHz decreasing to <10 mm at 400MHz.

Figure 2 compares arrays made with wire loops to arrays made with tape loops [1]. Fig.2(b) shows the *NF* at 128 MHz determined from Q measurements of the configurations in Fig.2(a). The wire loops behave significantly (0.1-0.4 dB) better.

Conclusions: We have determined *NF* values for circular MR coils as a function of radius, frequency and number of tuning capacitors. Increasing the number of capacitors to reduce E-field losses, actually increases *NF* of loops with small radii (r < 20mm) due to capacitor ESR. For arrays, loops made of Cu wire or tubing have reduced eddy currents and perform better than tape loops. As static field increases, the radii of coils that contribute a NF ≤1 dB, decrease. *Supported by NIH grant RO1 EB007829.*

Refs. [1] Wiggins GC Proc ISMRM 2007: 243. [2] Edelstein WA ISMRM 2006, RF Sys Eng Ed. Sess; 2.