Optimized Quadrature Surface Coils incorporating Circular, Figure-8 loops, and Strips

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Introduction: It has been shown that with appropriate 90° phase shift or sum-of-the-squares signal combination, quadrature MRI detectors can improve the SNR by a factor of $\sqrt{2}$, and halve the power efficiency when used in transmit mode[1]. Combined surface circular loop and figure-8/butterfly-shaped elements are routinely used as quadrature MRI/MRS detectors in applications such as spinal cord imaging. While the optimum loop element for MRI at depth d has radius $a = d/\sqrt{5}$ [1], the optimum configuration for figure-8/butterfly coils is unknown. Here we determine the optimum geometry for an ideal figure-8 shaped detector both theoretically, using numerical electromagnetic (EM) method-of-moment (MoM) analysis, and experimentally. We combine figure-8 and loop coils to create a quadrature detector that is optimal for this geometry, and introduce a novel 'phi'-shaped MRI surface quadrature detector comprised of an optimized MRI strip [2] and a circular loop. The intrinsic SNR (ISNR) of the phi-coil is theoretically and experimentally compared with the optimal figure-8/loop detector, and with a 2-loop phased-array optimized for the same depth at 3T.

Methods: The optimal figure-8 coil radius for a depth d was determined by calculating ISNR for radii in the range of 10 mm $\leq a \leq$ 90 mm as a function of depth. ISNR was determined by calculating the transverse component of the magnetic field and the noise resistance of the loop with 1A excitation in a homogeneous semi-infinite muscle (ε=63.5, σ = 0.72 S/m) at 128 MHz using *FEKO* (South Africa) MoM EM analysis software. Figure '8' elements are "numerically" tuned with one parallel and nine series capacitors.

For experimental verification, four figure-8 loops of radii 20-50 mm were fabricated, and ISNR measured on a large CuSo4-doped 0.35% saline phantom with a gradient-recalled echo sequence (90° flip-angle; TR=800 ms) in a Philips Achieva 3T MRI scanner. A phi-coil was fabricated from a 200 mm strip with an a=40 mm loop. Its ISNR was compared with a figure-8/loop pair comprised of a 52 mm radius figure-8 and an a=40 mm loop, and with two a=40 mm overlapped loops (a 2-loop phased-array; see Fig. 1). All detectors were tuned, matched to 50Ω, and included decoupling and balun circuitry. Finally, T2-weighted turbo-spin-echo MRI of the lumbar spine of a healthy volunteer was done with the phi-coil and the figure-8/loop pair for comparison.

Results: The radii of coils producing the maximum ISNR on the axis of figure '8' loop are plotted in Fig. 2. The slope indicates that the optimal figure-8 loop diameter is ~1.5d, in agreement with an experimental result of ~1.4d. The experimental ISNR values of the three detectors in Fig.1 optimized for d ~ 90 mm, show an SNR advantage for the phi-coil over other two detectors close to the plane of detectors (<40mm), with all detectors performing almost equally for d >40 mm (Fig. 2). Similar results were obtained analytically. The experimental isolation between elements was higher for the phi-coil (-43 dB vs –32 dB for figure-8/loop pair and -20 dB for overlapped loops). Fig. 3 shows axial lumbar spine images from phi-coil and the figure-8/loop.

Conclusions: The optimal diameter for the figure-8 detector is ~1.5 times the MRI depth of interest. Thus, the optimum geometry of all 3 basic detector types-the loop [1], the strip [2] and now, the figure-8, are determined. The phi-coil, a novel quadrature surface detector provides a better SNR close to the detector than the standard figure-8/loop pair, and a pair of overlapped loops.

References: 1. Chen CN, Hoult DI, Biomed.Magn Reson Tech,1989, pp156,160; 2. Kumar A, Bottomley PA, Magn Reson Med, 2006; **56**: 157.

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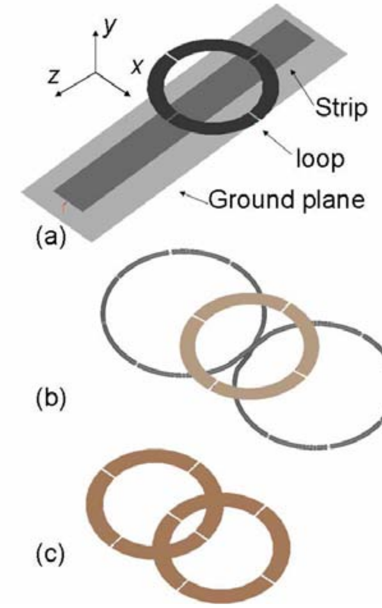

Fig. 1: (a) phi-coil; (b) figure-8 plus loop; (c) 2 overlapped loops.

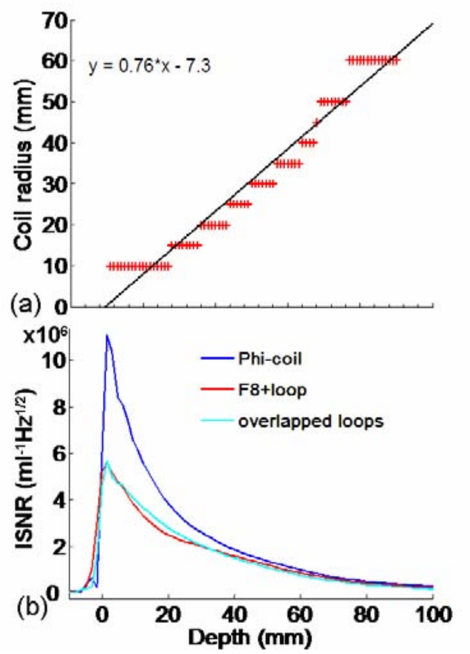

Fig. 2: (a) Maximum theoretical ISNR of figure '8' coils; (b) experimental ISNR.

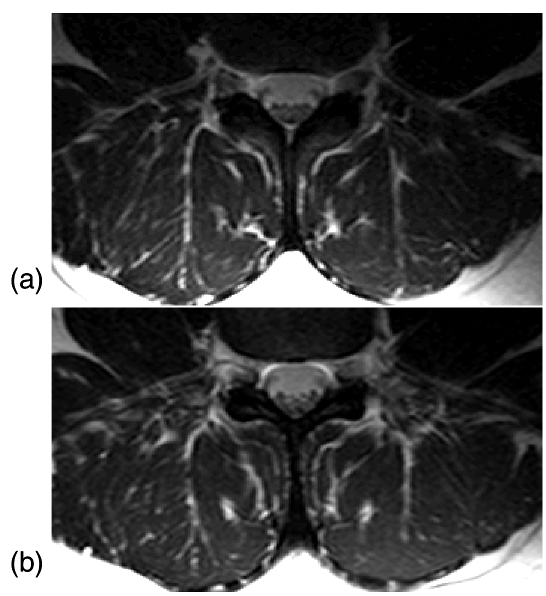

Fig. 3: 3T Spine MRI from Phi-coil (a) and figure-8 plus loop (b).