Development of Quadrature Transmit Elements for Breast MRI/MRSI at 7T

A. Kumar[1], L. Blawat[1], M. Schär[2], and P. Barker[3]
[1]Resonant Research LLC., Baltimore, MD, United States, [2]Philips Healthcare, Cleveland, OH, United States, [3]Radiology, Johns Hopkins University, Baltimore, MD, United States

Introduction Breast cancer is the most frequently diagnosed cancer in women and is the third leading cause of death, according to the American Cancer Society. Very high-field (>3T) MRI and MRSI methodologies for detection and characterization of suspicious breast lesions are still in their early stages of development. Two key challenges in moving towards very high-field breast MRI/MRSI are to improve the excitation field homogeneity and to minimize the RF power deposition in the tissue. Here we focus on the development of a breast transmit coil with two elements in quadrature mode at 7T while addressing the associated field homogeneity and RF power issues.

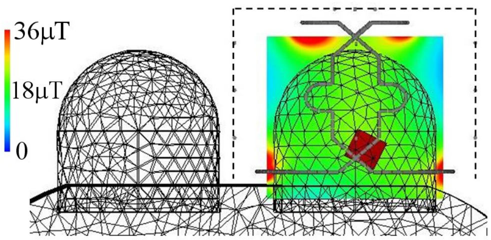

Figure 1. Quadrature loop transmit elements inside a cylindrical RF shield (dashed line). Breast torso model with peak SAR location (red cube), shown on axial field map. Input power to coil elements 200 W (rms CW)

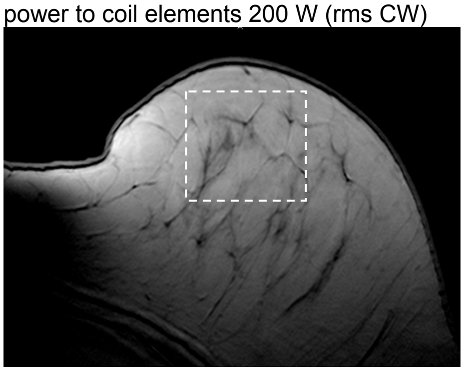

Figure 2. A healthy volunteer's left breast axial view scanned with a low-flip angle 3D high-resolution sequence. FA/TR/TE = 13˚/4/1.3 ms, pixel size 1.5x0.3x0.3 mm. ROI size 60x60 in dashed lines

Method Quadrature excitation in MR increases the power efficiency by a factor of two [1] and optimizes the circularly polarized excitation that improves the field homogeneity [2] degraded by the wavelength effects/phase variations at very high field. Full-wave electromagnetic (EM) Method of Moments combined with Finite Element Method (FEM) (*feko*, EM software systems, South Africa) was used in the modeling of RF coil elements and breast (dielectric constant, ε_r = 25, conductivity, σ = 0.3 S/m), torso (ε_r = 58, σ = 0.77 S/m) volumes to simulate transmit field ($B1^+$), specific absorption rate (SAR). Based on the model, a quadrature elements pair was built as shown on Fig.1 with a cylindrical RF shield around the elements. The quadrature efficiency [3] of the loop elements in phase, +90 degree and -90 degree phases was theoretically and experimentally verified. In the simulations, an estimate power was applied to coil elements and peak SAR and maximum $B1^+$ in the transverse FOV were calculated (see Fig.1). The rate of power deposition in a breast torso model was determined per unit $(B1^+)^2$ in W_per_kg_per_μT^2. This B1 to SAR conversion is used with the FDA/IEC SAR threshold of 10 W/kg (10 g average) to determine the maximal duty cycle for any given $B1^+$ value of an MR experiment using the following equation: $\boldsymbol{SAR=(B1^+)^2 \times duty\_cycle \times W\_per\_kg\_per\_\mu T^2}$. Calorimetric measurements using fiber optic sensors were performed on a spherical (10 cm diameter) gel phantom (1% agar, 20 mM NaCl, $CuSO_4$) applying a multi-spin echo sequence with a set average RF power of 20 W (B1 max = 40 μT). $B1^+$-maps were acquired with the actual flip-angle imaging (AFI) method [4] in the gel phantom and in a healthy volunteer. Based on the close agreement between simulated and measured B1 and temperature rise, we confidently applied the simulated B1 to SAR conversion rate on a breast torso model and determined safe power limits for an *in vivo* breast MRI study.

Results In the calorimetric measurements the expected temperature rise for a 6 minutes scan was 1.6°C based on the simulations, and the actual calorimetric measurement showed 1.3°C. The temperature probes were placed at four different locations including at the 'hot spot', which was predicted by simulations and the highest temperature rise occurred close to the location where the coil elements overlap. Quadrature excitation with +90 degree phase shift between the right and the left elements produced the most homogeneous field profile. The actual measured maximal B1+ was 14.5 μT and the predicted simulated value for the same RF power was 16.1 μT. And we successfully scanned the left breast of a healthy volunteer with good field homogeneity as shown in Fig.2 using the coil in transmit-receive mode. The mean B1 value in a 3-dimensional region of interest (ROI) as shown in Fig.2 is ~80% of the prescribed B1 of 11 μT, and the standard deviation is ~45%.

Conclusion Quadrature loop transmit elements developed for 7T breast MRI/MRSI with the aid of full-wave EM modeling and simulations gives homogeneous field profile in the ROI. A maximum $B1^+$ excitation of 11 μT was generated safely within the regulatory SAR limits.

References (1). Hoult DI *et al.* Quadrature detection in the laboratory frame. *Magn Reson Med* 1984;1:339-353; (2). Glover GH *et al.* Comparison of Linear and Circular Polarization for Magnetic Resonance Imaging. *J. Magn Reson* 1985;64:255-270; (3). Kumar A *et al.* Optimized Quadrature Surface Coil Designs. *MAGMA* 2008;21:41-52; (4). Yarnykh VL *Magn Reson Med* 2006;57(1):192-200

Acknowledgments We thank Michelle Battles, Terri Brawner and AbdEl-Monem El-Sharkawy for assistance and NIH RO1 CA125258 for grant support.