A New Dual-Channel Array Coil for Breast Imaging at 1.5/3.0T

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INTRODUCTION

The design of breast cancer screening coils for MRI systems is influenced by the need to obtain a high signal-to-noise ratio (SNR) while maintaining good B_1 field coverage. These factors guarantee improved image quality and the high spatial resolution as required for the detection of small tumors [1]. In this work, we discuss the development of a localized receive-only, dual-channel RF coil for breast cancer detection in 1.5T/3.0T MRI systems. This novel design is inspired by the multi-channel array concept where multiple microstrip conductors are arranged such that an anatomically conforming profile is achieved with the goal of improving sensitivity and filling factor. In addition, the unique design provides two resonant modes that can be operated in a single-channel quadrature configuration, thus providing a high SNR in conjunction with good B_1 field coverage. Alternatively, the received signals can be picked up independently and connected to a multi-channel receiver as part of a two coil system for bilateral breast imaging.

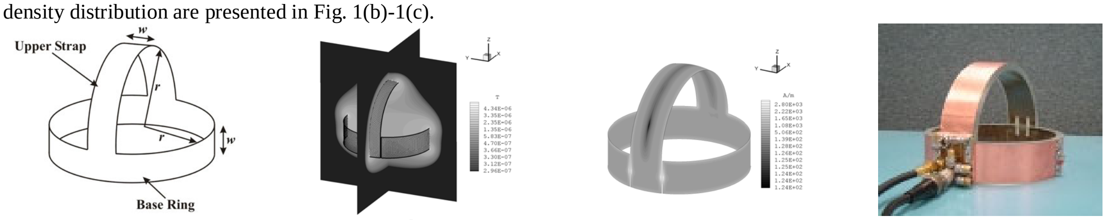
THEORY

To theoretically investigate the performance of this dual-channel RF coil configuration, we consider the geometry shown in Fig. 1(a). The system consists of multiple cylindrical conducting strips that define a base ring element and a strap element. The current paths along the coil profiles result in two resonant modes whose resonance behavior can be tuned with two variable capacitors placed at the base ring such that a single resonance response of 63.87 or 127.74 MHz is achieved. The two resonant modes produce B_1 field distributions that complement each other and exhibit a substantial region of overlap where quadrature operation is observed. Numerical simulations based on the Method of Moments [2] have been carried out in order to determine the electromagnetic characteristics of the coil system. These simulations were based on the Electric Field Integral Equation (EFIE) given by equation (1) where the unknown current density $\mathbf{J}(\mathbf{r}')$ is approximated by basis functions as shown in equation (2).

$$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi j\omega\varepsilon_0}\int_S \nabla'\cdot\mathbf{J}(\mathbf{r}')\nabla\frac{e^{-jk|\mathbf{r}-\mathbf{r}'|}}{|\mathbf{r}-\mathbf{r}'|}dS - \frac{j\omega\mu_0}{4\pi}\int_S \mathbf{J}(\mathbf{r}')\frac{e^{-jk|\mathbf{r}-\mathbf{r}'|}}{|\mathbf{r}-\mathbf{r}'|}dS \qquad (1)$$

$$\mathbf{J}(\mathbf{r}') = \sum_{n=1}^{N} I_n f_n(\mathbf{r}') \qquad (2)$$

The function $f_n(\mathbf{r}')$ in (2) is a modified version of the Rao-Wilton-Glisson (RWG) basis function [2] while I_n represents the unknown surface current distribution. The modifications in $f_n(\mathbf{r}')$ allow a convenient incorporation of lumped capacitive elements as well as voltage element sources into the coil profile. In fact, the EFIE formulation enables us to model the coil profile with triangular mesh elements. We associate the unknown surface current I_n with each non-boundary edge of the triangulated structure and define the current density within each triangular element using equation (2) where N is the number of non-boundary edges. The EFIE can then be expressed in terms of I_n and transformed into a system of linear equations for I_n using the Method of Moments. Numerical simulations of the B_1 field coverage and the surface current density distribution are presented in Fig. 1(b)-1(c).



(a) (b) (c) (d)

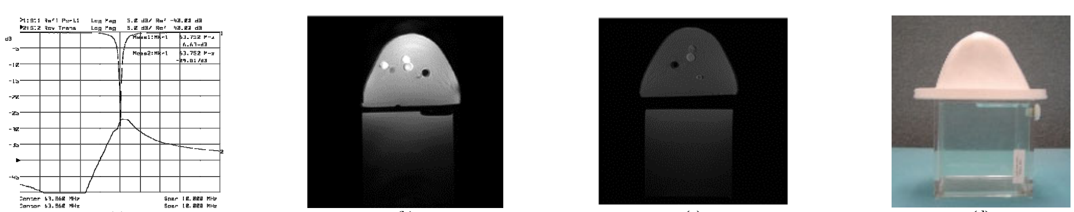
Fig.1: (a) basic coil configuration, (b) simulated B_1 field coverage, (c) simulated current density distribution, (d) prototype construction.

COIL CONSTRUCTION

The coil prototype was constructed on a cast acrylic cylindrical former with an outer diameter of 120mm and a thickness 6.35mm. The width of each cylindrical section was chosen to be 30mm. Adhesive copper strips were installed on the outer surface of the former to form the conducting coil profile. Capacitors were placed along selected cuts on the conducting profile to improve quality factor and reduce parasitic inductance. The printed circuit board containing the tuning and matching circuits as well as the RF connectors was also placed along the conducting profile on the base ring. The completed prototype is shown in Fig. 1(d).

RESULTS

Scattering parameter measurements of the loaded prototype coil are presented in Fig. 2(a). We observe a high level of signal isolation of better than 28dB between the two channels. Preliminary tests conducted with phantoms at McLean Hospital, an affiliate of Harvard Medical School, and Dartmouth-Hitchcock Medical Center indicate superior performance in SNR and B_1 field coverage when compared with their existing breast coil configurations. The improvement in SNR can be seen in Fig. 2(b) and 2(c) where a direct comparison was made between the dual-channel coil and a commercially available 4-channel open breast array coil in a GE-1.5T Signa MRI scanner. The phantom arrangement is shown in Fig. 2(d). The images were acquired using the T_2 weighted imaging sequence with TR=4050ms, TE=97.99ms, 1 echo, 2 averages, 256×256 matrix, 22cm FOV, and a slice thickness of 4mm. The calculated SNR for the dual-channel coil was 412 as compared with 27 for the 4-channel array coil. Clearly, the 15 fold improvement in SNR underscores the success of the design.



(a) (b) (c) (d)

Fig.2: (a) S-parameter measurements, (b) Dual-channel loop coil, (c) 4-channel array coil, (d) Phantom arrangement.

CONCLUSION

We have developed a new receive-only dual-channel RF coil for breast cancer screening. The unique design offers a superior SNR as well as good B_1 field coverage. Current research is geared toward extending the development efforts to establish a multi-channel dual coil system for bilateral imaging.

REFERENCES

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