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An Optimized Four-channel Microstrip Loop Array at 7T

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Introduction

The microstrip transmission-line (MTL) transmit/receive loop array has been recently developed for MR applications at ultrahigh fields (>4T) [1-4]. There are several advantages of the microstrip array over the conventional surface coil array at high fields: better decoupling among loops due to confined B_1 fields [4]; reduced radiation losses and higher signal-to-noise ratio (SNR)[5,6]. In this study, the relationship between the geometry of the microstrip array and its performance was analyzed and a capacitive decoupling method was employed for further improvement of decoupling in the microstrip loop array design. Finally an optimized four-channel microstrip loop array was built and tested at 7T.

Method

(1) *Thickness of the substrate and inter-gap between elements*

B_1 fields of four-channel microstrip loop array with different substrate thickness and inter-element gap have been simulated and compared by using finite difference time domain (FDTD) method. Coil elements are all 12cm in length and are built on a cylinder of 17cm-I.D. by 18cm-long. A cylindrical phantom with 12cm diameter is used to mimic the human muscle in our simulation. The negative (B_1^-) component of each coil element, which affects the receive component of NMR signal intensity, was calculated one by one, then combined to the whole B_1^- fields of the array. Fig. 1(a)-(c) show that the B_1 penetration increases with the thickness of the substrate. $|B_1^-|$ fields in Fig. 1 (c)-(e) reveal that the narrower inter-gap (1cm) can improve signal intensity not only between the coils but also in the whole field of view.

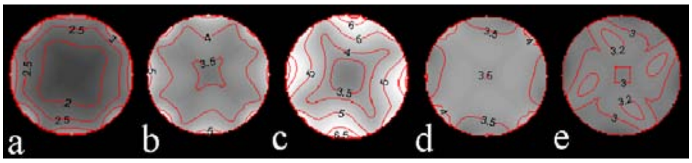

Fig.1. Simulated $|B_1^-|$ fields of four-channel loop microstrip coil array at 7T(scaled to the center of the phantom and shown in arbitrary units). In a-c, the inter-gap of elements are all 1.0cm, the substrate thickness is 3mm, 4.5mm and 7.5mm, respectively. In d and e, the substrate thickness are all 7.5mm, the inter-gap between elements is 3.0cm and 5.0cm, respectively.

(2) *The optimized decoupling method*

From the above comparison results, the array with thicker substrate (7.5mm) and closer inter-gap (1cm) has the optimized B_1 field distribution. However, the mutual coupling between the coil elements increases for this geometry. The capacitive decoupling technique [2] could be analyzed and optimized as the follows.

The required decoupling capacitance C_d could be expressed as:

$$C_d = \frac{1}{L\omega^2}\cdot\frac{(1+k^2)m}{k^2(1-m^2)-2km(1+m)}, \text{ for } k > 2m/(1-m), [1]$$

where $k=C_e/C_1$, C_1 is the tuning capacitor shown in Fig 2, and C_e represents the equivalent serial tuning capacitor except C_1.In Eq.1, $m=M/L$ where M is the mutual coupling between coils and L is the equivalent inductance of each coil. Based on Eq.1, the required C_d can be further illustrated in Fig.3. For a practical value of C_d, a smaller k has to be chosen.

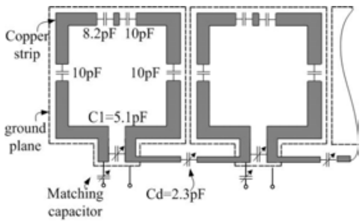

Fig.2. Schematic of the microstrip loop array .

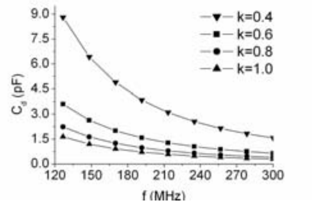

Fig.3. Relationship of C_d and f. Assuming L = 0.5 μ H, m = 0.1.

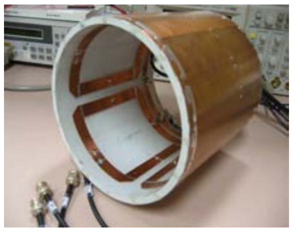

Fig.4. The photo of the four-channel microstrip loop array for 7T.

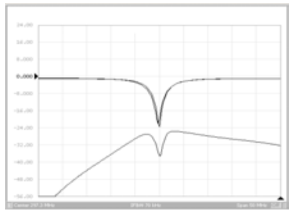

Fig.5. S parameters of the adjacent elements. S21=-35dB

According to the above analysis, a four-channel microstrip array for 7T was built as shown in Fig. 4. Each element was an 11cm×12cm microstrip loop. The inter-gap between adjacent elements was 1.0cm. The coil was built on a 7.5mm thick acrylic cylinder with length of 18cm and inner diameter of 17cm. The width of the copper strip was 1.27cm. The tuning capacitors on the loop were chosen to decrease k so that the required C_d can reach 2.3pF, which is reasonable for adjusting. The MR experiment was performed on a 7T/90cm magnet (Magnex Scientific, UK) interfaced with the Varian INOVA console (Varian Associates, polo Alto, California).

Result

A cylindrical phantom (53.5% water, 1.5% Nacl and 45% sugar) with 15cm length and 9cm diameter was used. If there is no decoupling capacitor, the mutual coupling between adjacent elements cause the resonance peak split. By employing the capacitive decoupling circuit, the coupling isolation between adjacent elements is improved and the S21 is better than –31dB (Fig.5). The isolation between opposite elements is better than -25dB. Imaging results at 7T shown in Fig.6a confirmed the good isolation among elements. In Fig.6b, the combined image corresponds with our simulation result.

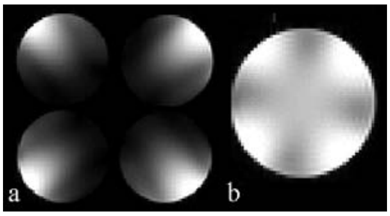

Fig.6. Phantom images obtained from each channels (a) and their combination by Sum-of-Square. (b) Image parameters: FOV: 30cm×30cm, matrix size: 128×128, flip angle:less than 22°

Conclusion

Four-channel optimized microstrip array has been analyzed, fabricated and tested at 7T. In this array, 7.5mm substrate thickness, 1.0cm inter-gap of coil elements are chosen for optimizing the B_1 field. To avoid the small decoupling capacitance, the proportion of the tuning capacitors is selected to decrease k so that the required decoupling capacitor has reasonable value.

Acknowledgement

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Reference [1]. Wichmann T et al., Proc ISMRM 12,1578 (2004); [2] Adriany G et al., Proc ISMRM 11,474 (2003); [3]Wichmann T et al., Proc ISMRM 13, 680 (2005); [4]. Zhang X. PhD Thesis, University of Minnesota, 2002; [5]. Zhang X. et al., MRM 46:443-450 (2001); [6]. Beck B. et al., Proc ISMRM 13, 943 (2005).