A novel RF coil: tunable loop microstrip (TLM) coil

B. Wu[1], P. Qu[1], J. Yuan[1], G. X. Shen[1]

[1]MRI Lab. Dept. of Electrical and Electronic Engineering, The University of Hong Kong, Hong Kong, China, People's Republic of

Introduction:

Microstrip coils terminated with open or short circuit have been presented to achieve better SNR than conventional surface coil in ultra-high field [1,2]. However, the coil dimension is critically limited by strip length and substrate permittivity. In addition, frequency tuning by changing strip length [1] is not convenient.

Ring resonator has been widely used in microwave measurement and filter design [3-5]. Ring resonator can achieve higher Q and less frequency shift with loading than microstrip coils terminated with open or short circuit [6]. Taking advantage of the ring structure, we design a novel tunable loop microstrip (TLM) coil for MRI.

Theory:

The basic structure of TLM coil and its equivalent circuit based on odd mode analysis [6] are shown in Fig 1. θ and C_T are electric length and tuning capacitance respectively. The resonant frequency and Q of TLM coil were analyzed from this equivalent circuit.

Resonant frequency:

The ABCD parameter of TLM coil can be expressed as the follows:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ j2\omega C_T & 1 \end{bmatrix} \cdot \begin{bmatrix} \cos(\theta/2) & jZ_0(\sin\theta/2) \\ j\sin(\theta/2)/Z_0 & \cos(\theta/2) \end{bmatrix} \quad (1)$$

Y_{in} of TLM is:

$$Y_{in} = \frac{CZ_L + D}{AZ_L + B}\Big|_{Z_L=0} = \frac{D}{B} = j\frac{2\omega C_T Z_0 \sin(\theta/2) - \cos(\theta/2)}{Z_0 \sin(\theta/2)}. \quad (2)$$

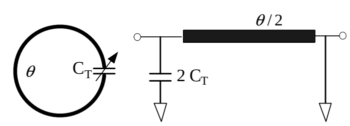

Fig1. (a) The structure of TLM coil for analysis and (b) its equivalent circuit.

Set Y_{in} to zero and substitute θ with $\omega l\sqrt{\varepsilon_{eff}}/c$, where c, ε_{eff}, l are velocity of light in free space, effective permittivity, mean perimeter of coil respectively. The resonant frequeny can be found

$$\omega^2 = Y_0 c/(\sqrt{\varepsilon_{eff}}\, l C_T). \quad (3)$$

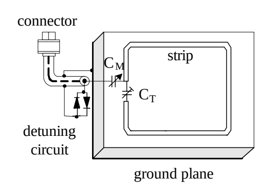

Fig 2. Schematic diagram of TLM coil. C_T and C_M are tuning and matching capacitor.

Quality factor:

From TLM equivalent circuit, unload quality factor of TLM coil can be expressed as

$$Q = \frac{\tan^2(\theta/2)}{2\theta(1+\tan^2(\theta/2))}(c\tan(\theta/2) + \operatorname{cosec}^2(\theta/2)\cdot(\theta/2))\cdot\frac{\omega}{\alpha v}, \quad (4)$$

where α is known as attenuation constant. From Eq. (4), Q is almost unchanged with coil length increment. Thus, coil dimension can be selected mainly based on sample size without loss of coil efficiency.

Experiments and results:

We built a TLM RF coil with resonant frequency at 63.88MHz for 1.5T Signa (GE Medical System) system. Fig 2 is the schematic diagram of the receive-only TLM RF coil. The dimension of the copper tape is 7.6 x 7.6 cm with the copper width of 1.25cm. Teflon with thickness of 6mm is used for substrate. The TLM coil was detuned from the whole body coil during transmitting by PIN diodes. A conventional surface coil and a multi-turn open-ended microstrip coil (7 turns with 3mm width copper tape) of the same dimension are used for comparison. Axial image by using TLM coil with 0.9% sodium chloride phantom is shown in Fig3. With the same frequency shift with loading (0.1MHz) and penetration (around 7cm), the TLM coil can achieve higher loaded Q (75) than conventional surface coil (40), In the same experiment for the multi-turn microstrip coil, its frequency shift is much higher up to 1 MHz and its loaded Q is only 30.

Careful experimental investigation also indicates that when the tuning capacitance is less than 20pF, resonant frequency can fit the theoretical calculation quite well, unload Q of TLM coil is up to 20% higher than one turn or multi-turn microstrip coil terminated with open or short circuit at 100MHz-280MHz.

Conclusion:

TLM coil, a novel modified microstrip coil, is much easier to be tuned and matched than conventional microstrip coils. It can be designed based on the sample size rather than on the required strip length and substrate permittivity. Experiments show that it has higher Q than the conventional surface coil and microstrip coil terminated with open or short circuit circuit at 1.5T. This new TLM coil can be easily applied to high and particularly to ultra-high field MRI systems.

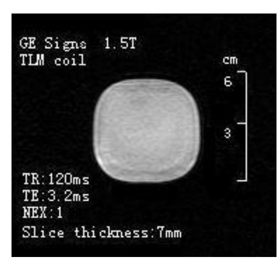

Fig 3. GRE 1.5T image of sodium chloride phantom using TLM coil. TR=120ms, TE=3.2ms, NEX=1, flip angle=60°, FOV=15cmx 15cm.

Acknowledge:

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References:

[1] X. Zhang et al., MRM 2001 Vol 46:443-450.
[2] X. Zhang et al., Proc ISMRM 2001: 1104.
[3] M. Makimoto et al., IEEE MTT-S 1986 Vol 86: 411–414.
[4] W.J.R Hoefer et al., IEEE 1975 Vol 23:1067-1071.
[5] B.S. Virdee et al., IEEE MTT-S International 2003 Vol 3:2161-2164.
[6] K. Chang, Microwave ring circuits. New York: Wiley, 1996.