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

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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. \( \theta \) 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:

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix} =
\begin{bmatrix}
1 & 0 \\
-j2\alpha C_T & 1
\end{bmatrix}
\begin{bmatrix}
\cos(\theta/2) & jZ_0\sin(\theta/2) \\
j\sin(\theta/2)/Z_0 & \cos(\theta/2)
\end{bmatrix}
\]

(1)

\( Y_n \) of TLM is:

\[
Y_n = \frac{C_L + D}{AZ_L + B} Z_{\theta=0} = \frac{D}{B} = j \frac{2\alpha C_T Z_0 \sin(\theta/2) - \cos(\theta/2)}{Z_0 \sin(\theta/2)}.
\]

(2)

Set \( Y_n \) to zero and substitute \( \alpha = \theta \sqrt{\varepsilon_r} / l \), where \( c, \varepsilon_r, l \) are velocity of light in free space, effective permittivity, mean perimeter of coil respectively. The resonant frequency can be found

\[
\omega^2 = Y_\theta C_l (\sqrt{\varepsilon_r} / l C_T).
\]

Quality factor:

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

\[
Q = \frac{\tan^{-1}(\theta/2)}{20(1+\tan^2(\theta/2))} \left( c \tan(\theta/2) + \cos \theta \cdot \theta / (2 \theta) \right) \frac{\omega_0}{\alpha},
\]

where \( \alpha \) 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 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 permittivity. Experiments show that it has higher Q than the conventional surface coil and microstrip coil respectively. The resonant frequency and Q of TLM coil were analyzed from this equivalent circuit.

\[\text{References:}\]


Fig 1. (a) The structure of TLM coil for analysis and (b) its equivalent circuit.

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

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