**Bₜ** field comparison for RF coils in ultra-high-field MRI

H. Yoo, J. Lee, C.E. Akgun, A. Gopinath and J.T. Vaughan

This reported work demonstrates the use of convex optimisation to localise the transverse magnetic **Bₜ** field in regions of interest for recently proposed multi-sectioned alternating impedance coils and the traditional transmission line coil. An approach based on different axial slices to identical radio frequency (RF) coils except upper stripline structure is investigated. Electromagnetic simulation results are compared for RF coils and discussed in detail at 7.0 T.

**Introduction:** Ultra-high-field magnetic resonance imaging (MRI) systems (7.0 T and above) have been widely investigated for precise diagnosis of the human body since they provide better signal-to-noise ratios with high resolution [1, 2]. Owing to the shorter radio frequency (RF) wavelengths at high fields, however, the transverse RF magnetic **Bₜ** field inhomogeneity becomes one of the significant problems. In general, since MRI applications require uniform **Bₜ** field, which alleviates anomalous contrast over the subject, many methods have been studied. Several RF coil designs have been proposed to homogenise **Bₜ** fields, which are the phased array coil [3], the multilayer coupled coil [4] and multichannel transmission line coils supporting a transverse electromagnetic (TEM) mode [5]. Recently, parallel imaging with independently driven multichannel coils has played an important role and it produces a homogeneous magnetic field or RF excitation in a region of interest (ROI) [6]. To design the phase and the magnitude of the RF power from the individual RF coil element in a multichannel array, convex optimisation of the **Bₜ** localisation problem is applied [7, 8].

In this previous work, field localisations at high-field MRI systems were performed with the traditional TEM coil and the middle axial plane. In the present Letter, we propose multi-sectioned TEM coils to improve homogeneity, which are the 7-section TEM coil and the 3-section TEM coil which are used for **Bₜ** localisations in all axial planes. These coils have variation of the widths of the upper stripline to produce an alternating low–high impedance configuration. When the ROI is at the centre, the 3-section TEM coil provides the strongest peak value of **Bₜ** along the length of the coil in the axial slices, whereas the traditional TEM coil has a dominant **Bₜ** peak over all the slices for the case of the ROIs that are off the centre. Electromagnetic simulation results are compared for the RF TEM coils and discussed in detail at 7.0 T.

![Fig. 1 Transmission line (TEM) coil element with cylindrical phantom, and three different TEM coil elements](image1)

*a* Transmission line (TEM) coil element with the cylindrical phantom

*b-d* Three different TEM coil elements

**Method:** As illustrated in Fig. 1a, the 7.0 T (≈ 300 MHz) transmission line (TEM) coil element near a cylindrical phantom is simulated using the finite difference time domain (FDTD) method using the REMCOM XFDTD software to calculate the transverse RF magnetic field (**Bₜ**). The TEM coil element is positioned 2.54 cm (1 inch) away from the cylindrical phantom, which is 17.8 cm (7 inches) in radius, 30.5 cm in height and filled with brain-equivalent ($\varepsilon_r = 58.1$ and $\sigma = 0.5368$ [S/m]). Slice 0 denotes the middle slice of the phantom and slice $\pm n$ is $n \times 0.254$ cm ($n \times 0.1$ in) away from the middle slice 0. Note that all the slices are axial (xy-plane) and each coil is placed along the $z$-direction. Three different TEM coils are used for the simulations and each TEM element coil has identical dimensions, except the upper microstrip line structure as shown in Figs. 1b–d. The ratio of the width to the height in the microstrip transmission line is equal to unity.

![Fig. 2 **Bₜ** profiles of three coils along axial slice 0](image2)

![Fig. 3 Normalised peak value of **Bₜ** against slice number ±n](image3)

**Results:** As a start, the **Bₜ** profiles of the three different coils along the axial middle slice 0 are plotted in Fig. 2. The 8 channel (Figs. 2a–c) and 16 channel (Figs. 2d–f) are simulated for the traditional TEM coil (Figs. 2a and d), the 7-section TEM coil (Figs. 2b and e) and the 3-section TEM coil (Figs. 2c and f). As expected from [8], the 3-section TEM coil produces peak **Bₜ** at the centre of the middle slice of the phantom. Based on these results, we may predict that the 3-section TEM coil also has the strongest **Bₜ** fields when the ROI is at the centre near the middle slice. More detailed results with different axial slices and ROIs are discussed below.

Low loss polytetrafluoroethylene is used as a substrate with height and length of 1.24 and 13.97 cm, respectively. First, the traditional transmission line coil element having constant widths (1.24 cm) along the strip is analysed. Recently, multi-section alternating impedance transmission line coils were proposed to produce more uniform **Bₜ** fields along the length of the coil [9]. To compare the performance of the three different RF coils, the convex optimisation with an iterative method [8] is used. The objective of this method is to increase the **Bₜ** field in the ROI and also to keep the **Bₜ** field homogeneous in the region outside, which is the suppression region.
Fig. 4 $B_1^+$ profiles when ROI is at centre

When the ROIs move to the edge of the field of view, $B_1^+$ localisations are performed. In this Letter, two ROIs are considered, one of which is more shifted to the edge, and up to ±30 slices are used due to the length of the TEM coils. Fig. 5 shows that the traditional TEM coil has the strongest peak value of $B_1^+$ through all the slices for both the ROIs. The 3-section TEM coil’s peak value is a little larger than that of the 7-section TEM coil when the ROI is slightly off the centre (Fig. 5a), whereas the 7-section TEM coil has a stronger peak value than the 3-section up to slice ±10 for the fully edge closed ROI (Fig. 5b). In Fig. 6, three TEM coils’ $B_1^+$ profiles are plotted after normalisation to the maximum value of the same slice and the ROI. As expected from the graphs in Fig. 5, all the slices have higher $B_1^+$ distributions on the ROIs for the traditional TEM coil. On slice ±30 for the first case the ROI is off the centre (Fig. 6a), the localised ROI is somewhat shifted to the centre compared with other slices’ results because the initial $B_1^+$ fields are strongly located near the centre. However, this effect can be removed when the ROI is sufficiently away from the centre and is confirmed in Fig. 6b. With the middle slice 0 and the centred ROI, the 3-section TEM coil has dominant field strength over the other coils. It remains on slice ±20, but the field strength difference becomes close; finally, the traditional TEM coil’s field strength is absolute on slice ±40. For the case of the ROIs that are off the centre, on the other hand, the traditional TEM coil has the largest number of pixels through all the slices between the three coils.

Fig. 5 Normalised peak value of $B_1^+$ against slice number ±n

Fig. 6 $B_1^+$ profiles when ROIs are off centre

$\text{a ROI off centre – case 1}$

$\text{b ROI off centre – case 2}$

Conclusion: $B_1^+$ localisations have been investigated for three RF TEM coils using convex optimisation at 7 T. From the numerical simulations of a 16-element coil array, the results are compared in detail based on different axial slices. Theoretical analysis shows that the 3-section TEM coil produces the strongest peak value of $B_1^+$ along the length of the coil in the axial slices of the phantom when the ROI is at the centre, whereas the traditional TEM coil has a dominant $B_1^+$ peak over all the slices for the case of the ROIs that are off the centre. This approach realises that alternating impedance TEM coils generally provide stronger $B_1^+$ field distribution in the centre of the field of view. However, the traditional TEM coil has a more homogeneous $B_1^+$ peak value on the centred ROI by changing the distance from the middle slice, and produces better off-centred $B_1^+$ localisations.

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References