Rapid B_1 Mapping Method for Multi-channel RF Transmit Coil Using Phase-difference

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Introduction Multi channel RF transmit coil is used in high field MRI systems and recently the number of transmit channel is increasing [1]. By using multi channel RF transmit coil, some applications in high field MRI like RF shimming [2] and Transmit SENSE [3] are available. These applications require B_1 map for each transmit channel. B_1 map for each transmit channel can be measured repeatedly for each transmit channel. However, increasing the number of transmit channels, scan time is multiplied by the number of transmit channels in the case of single transmit channel. By using Bloch-Siegert method [4] that is one of fast B_1 mapping method, scan time is 128 sec for 20-channel transmit coil. Or by using method proposed in [5], that repeat B_1 mapping for transmit channels with using only 21 images for 20-channel transmit coil, scan time is 278 sec.

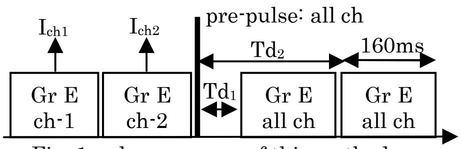


Fig. 1 pulse sequence of this method

In this study, we developed a new fast method to acquire B_1 map for each transmit channel. In this method, only one time acquisition with using all transmit channels is used for calculation, and the acquired B_1 map is decomposed to B_1 map for each transmit channel by using the information of phase difference between transmit channels. Without repeating B_1 map acquisition, short scan time is achieved, for 20-channel transmit coil, scan time is only 4 sec.

Theory For simplicity we discuss 2-channel case here, but extension to general number of transmit channel is straightforward. Fig. 1 is pulse sequence of this method. Short TR, small flip angle Gradient Echo (GrE) sequence is used for fast imaging. Scan parameters of all GrE sequences are quite same, but only different on transmit channel. Before pre-pulse is applied, 2 images are acquired by using only single channel of transmit RF pulse. First image (I_{ch1}) is acquired by using only channel-1, and second image (I_{ch2}) is acquired by using only channel-2 of transmission. The pre-pulse is transmitted with using all channels. After pre-pulse is applied, two images are acquired by using all channels to transmit RF pulse at two different delay time (Td_1 and Td_2). Signals were received by all channels of same coil as transmission, and QD combined to image reconstruction. From these four images, B_1 maps for each transmit channel are calculated as follows; 1) Calculate B_1 map using all channels ($\left|\vec{B}_1^{all}\right|$) using multi Td method [6], 2) Calculate phase difference between B_1 for channel-1 and B_1 for channel-2 (θ), 3) Calculate phase difference between B_1 for all channel transmission and B_1 for channel-1 transmission (φ). 4) Calculate resulting B_1 maps by using $\left|\vec{B}_1^{all}\right|$, θ, and φ. Because same procedure (QD combine) is applied for all received signal, phase difference between transmission channels is calculated by dividing acquired images as $\theta = a\tan\left(\frac{I_{ch2}}{I_{ch1}}\right)$, $\varphi = a\tan\left(\frac{I_{ch1}+I_{ch2}}{I_{ch1}}\right)$. Fig. 2 shows B_1 of 2-channel RF transmit coil at one spatial point. B_1 of channel-1 and 2 are denoted as $\vec{B}_1^{1ch}$ and $\vec{B}_1^{2ch}$. Since B_1 is vector quantity, $\vec{B}_1^{1ch}$ and $\vec{B}_1^{2ch}$ make a parallelogram, and $\vec{B}_1^{all}$ is diagonal line of this parallelogram. As $\left|\vec{B}_1^{all}\right|$, θ, φ are known, the triangle made by $\vec{B}_1^{1ch}$, $\vec{B}_1^{2ch}$, and $\vec{B}_1^{all}$ is determined. So $\left|\vec{B}_1^{1ch}\right|$ and $\left|\vec{B}_1^{2ch}\right|$ can be calculated as eq. 1.

$$\left|\vec{B}_1^{1ch}\right| = \left|\left|\vec{B}_1^{all}\right| \times \frac{\sin(\theta-\varphi)}{\sin\theta}\right|, \quad \left|\vec{B}_1^{2ch}\right| = \left|\left|\vec{B}_1^{all}\right| \times \frac{\sin\varphi}{\sin\theta}\right| \qquad (1)$$

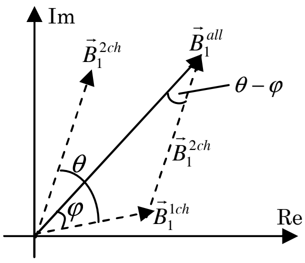


Fig. 2 B_1 of one spatial point (2-channel case)
Known quantity is solid line, and B_1 map for each channel is dashed line

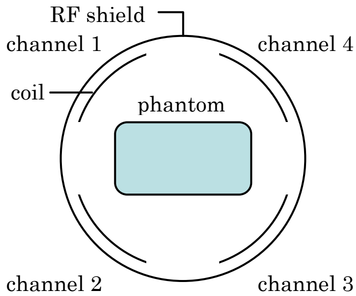


Fig. 3 4-channel RF coil

Materials and Methods 3T whole body MRI system and 4-channel RF transmit/receive coil (Fig. 3) was used for imaging of a torso phantom (300 [mm]×200 [mm]×300 [mm], T1=200 [ms]). Scan parameters of imaging sequence are as follows, FOV=500 [mm], TR/TE/FA=2.5 [ms]/1 [ms]/3 [deg,] slice thickness=10 [mm], and measurement matrix=64×64×1. FA of pre-pulse was 90 [deg.] and Td_1/Td_2=20 [ms]/550 [ms]. Scan time was 1 sec for 4-channel RF transmit coil. The images acquired before pre-pulse were also used to make mask of B1 maps for signal threshold. No smoothing or filtering was used to B_1 maps.

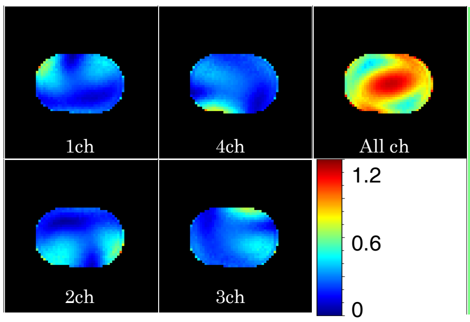
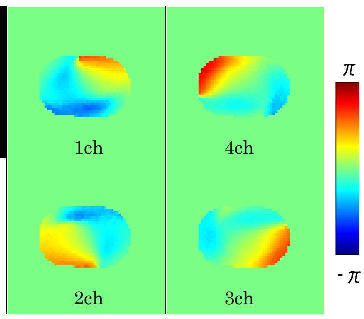


Fig. 4(a) B_1 map for each channel and all channels



(b) phase difference between transmit channel

Results and Discussion Fig. 4 (a) shows B_1 maps for each channel of 4-channel coil and B_1 map for all channel transmission. Fig. 4(b) is phase difference between each channel and all channel transmission. To extent this method for n-channel transmit coil case, n-images should be acquired by changing transmit channels before pre-pulse is applied and 2 images using all channels of transmit coil after pre-pulse is applied. So (n+2) images are needed to calculate B_1 maps of n-channel RF transmit coil. Then scan time is only $(n+1)\times 160 + Td_2$ ms. The B_1 map calculation is same as 2-channel case. Another advantage of this method is the required accuracy of B_1 map is relaxed by using B_1 map for all channel transmission.

Conclusion Simple relation between B_1 map for each and all channels was discovered. By using phase information, B_1 map acquired by using all channels to transmit RF pulse can be decomposed to B_1 map for each channel of multi channel RF transmit coil. Because fast B_1 mapping for each transmit channel is achieved, this method improve workflow of clinical routine practice using RF shimming or Transmit SENSE.

Reference [1] T. S. Ibrahim, et al; 2807 ISMRM(2012), [2] T. S. Ibrahim, et al; MRI 18(2000) 733-742, [3] U. Katscher, et al; MRM49; 1(2003), 144-150, [4] L. I. Sacolick, et al; MRM 63; 5, 1315-1322, [5] H. P. Fautz et al ; 1247 ISMRM(2008), [6] K. Ito et al ; abstract for JSMRM(2012)