Measuring coil sensitivities of transmit and receive arrays with demonstration of RF shimming

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Introduction: The development of transmit-SENSE[1,2] based on arrays of transmit and receive coils (combined or separate) has introduced a new calibration problem since spatially dependent sensitivities for both transmit and receive fields are needed. Here we propose and test a means of obtaining the required information and demonstrate its use for RF shimming.

Methods: The method for RF mapping proposed by Akoka[3] is extended to measure the transmit and receive sensitivities of coil elements concurrently. In this approach, a spin echo image and a stimulated echo image are acquired in a single acquisition using an α-2α-α sequence. Taking the general case of transmitting on coil *j* and receiving on coil *i*, the signal intensities of each image are given by equations 1 & 2. *A(x,y)* is a function describing the anatomy that is dependent on NMR properties and acquisition parameters. $R^i(x,y)$ is the spatially-varying receive sensitivity of coil *i*. Since data for each image are acquired within the same TR, a difference in T_1 recovery occurs only during the mixing time, TM, between the second and third pulses used to generate the stimulated echo. The anatomical signal from each image can be considered approximately equal when TM is sufficiently short with respect to T_1, such that $exp(-^{TM}/_{T1}) \approx 1$. $|SI_{SE}^{i,j}|$ and $|SI_{STE}^{i,j}|$ have different dependence on transmit sensitivity allowing the magnitude of the spatially varying transmit sensitivity $|T^j(x,y)|$ to be calculated from the images received on the same coil *i* using equation 3. When *i* > 1, multiple estimates of the transmit sensitivity are obtained simultaneously, allowing averaging to achieve an improved estimate of the transmit sensitivity. For the case of multiple transmit channels, the relative phase between channels is also required if the relationships between the coils is to be exploited, e.g. via parallel excitation. For a given transmitter *j* this could be estimated with respect to a reference coil, e.g. coil *r* as in equation 4. The relative complex receive sensitivities, $R^i(x,y)$, can also be determined from this acquisition with respect to a reference, e.g. a particular coil or sum-of-squares of all coils. Equation 5 expresses this for the case of coil *r* as a receive sensitivity reference. Each image acquired by transmitting on coil *j* gives an estimate of all receive sensitivities $R^i(x,y)$, allowing averaging to improve the estimate of the sensitivities. Considering the application of RF shimming, the measured transmit sensitivities can be used in an optimisation to determine the RF required to achieve a uniform resultant transmit field. In the small tip angle (STA) regime[4], the excitation induced by a given coil is the product of the Fourier Transform of the applied RF field, $B_1(t)$, and the coil's measured sensitivity. The optimisation minimises the sum of squares difference between the desired uniform excitation profile, $P_{des}(x,y)$, and the actual excitation profile, $P_{act}(x,y)$, which is the sum of the contributions from each coil, i.e. $P_{act}(x,y) = \sum_j T^j(x,y) FT[B_{1j}(k_x,k_y)]$. The method was tested using a Philips 3T Intera scanner operating with single coil transmit/receive and with single coil transmit, array coil receive on human volunteers and on a copper sulphate doped water phantom. Field mapping data acquired in 1min and STA regime RF shimming were implemented.

$$SI_{SE}^{i,j}(x,y) = A(x,y).\sin^3[T^j(x,y)].R^i(x,y) \quad [1]$$

$$SI_{STE}^{i,j}(x,y) = A(x,y).\sin^3[T^j(x,y)].\cos[T^j(x,y)].R^i(x,y) \quad [2]$$

$$|T_x^j(x,y)| = \cos^{-1}\left[\frac{|SI_{STE}^{i,j}(x,y)|}{|SI_{SE}^{i,j}(x,y)|}\right] \quad [3]$$

$$\angle T_x^j(x,y) = \angle\left(\frac{SI_{SE}^j(x,y)}{SI_{SE}^r(x,y)}\right) \quad [4]$$

$$R_x^i(x,y) = \frac{SI_{SE}^i}{SI_{SE}^r} \text{ or } R_x^i(x,y) = \frac{SI_{STE}^i}{SI_{STE}^r} \quad [5]$$

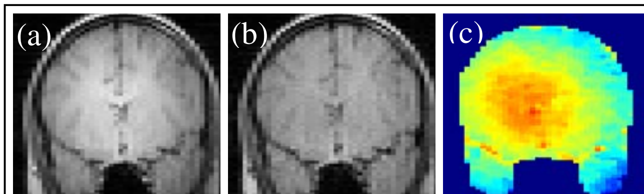

Fig.1: SE (a), STE (b) images and derived transmit sensitivity (c) of a single channel T/R head coil.

Results: Figure 1 shows an *in vivo* measurement of the transmit sensitivity of a single channel transmit/receive coil. Figure 2 shows a result from RF shimming to improve the B1 inhomogeneity in the phantom. Although there is still variation in the shimmed transmit field, it can be seen that the domed appearance of the field has been reduced.

Discussion: An efficient method for measuring transmit and receive sensitivities of an array of coils has been described and tested on phantoms and human subjects. For *j* T_x coils and *i* R_x coils, there will be 2**j***i* complex images from *j* SE/STE acquisitions obtained by transmitting sequentially on each of *j* coils and receiving on all coils for each acquisition. The unknown quantities are *j* $T_x(x,y)$ fields, *i* $R_x(x,y)$ fields and the anatomy. Taking the example of multiple transmit coils with *i* = *j*, i.e. each coil element capable of transmit and receive, the system of equations becomes over-determined for *j* ≥ 2 coil elements. However, for *j* ≥ 3 T_x/R_x there is the potential to no longer acquire both the SE and STE while still having a well-conditioned system. The robustness of such an approach is currently under investigation.

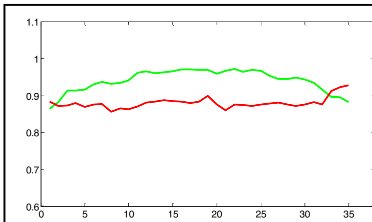

Fig. 2: Profiles through transmit field of uniform phantom corrected for receive sensitivity before (green line) and after (red line) RF shimming at 5^0.

References: [1] Katscher U. *et al.* MRM 2003;49:144-150. [2] Zhu YD. MRM 2004;51:775-784. [3] Akoka S. *et al.*, MRI 1993;11:437-441. [4] Pauly J *et al.* JMR 1989;81:43-56.

Acknowledgment: We thank Philips Medical Systems for grant support.