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Prospects of absolute B1 calibration

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Summary: Many current MRI techniques fundamentally rely on having coil sensitivity information available. This e.g. includes receive / transmit parallel imaging and correction of RF-related image inhomogeneity. Common methods usually provide only relative coil sensitivity information that is the ratio of the single coil sensitivities and a reference denominator common to all coils. We propose to discuss the limitations of using only relative sensitivity information and possible ways of measuring absolute coil sensitivities. Future applications of absolute coil sensitivity information may include permittivity and conductivity imaging, and SAR monitoring.

Background: For a single transmit / receive coil, the measured image signal intensity can formally be described as (1):

$$M \propto \rho \left| \sin\left(I\gamma \left| \hat{B}_1^+ \right| \tau \right) \right| \hat{B}_1^- \angle\left(\hat{B}_1^+ \right), \qquad [1]$$

with ρ being the tissue contrast, I the transmit coil current, γ the gyromagnetic ratio, τ the excitation pulse duration, and $\angle$ indicating the phase function. Here, the transmit $\hat{B}_1^+$ and receive $\hat{B}_1^-$ coil sensitivity are determined by the positive and negative circular polarized components of the transverse magnetic RF field, respectively (1).

In parallel receive imaging the element-wise different reception properties of an array of receiver coils are used to partially substitute sequential gradient encoding (2-4). Sensitivity calibration can be achieved by dividing single coil images by a reference image of identical contrast (4). It is important to note though that this only results in relative coil sensitivity maps, i.e, the ratio of the single coil sensitivities and a reference denominator, which is common to all coils. While this is sufficient for suppressing aliasing, it does not yield the desired homogeneous image weighting, rather the reconstructed images are multiplied by the reference coil sensitivity (2,4). Similar considerations hold for parallel transmit imaging with tailored RF transmission through an array of independent transmitter coils (5-7).

Especially at high fields with increased RF interference effects, reference images become intrinsically inhomogeneous. In this sense image homogeneity would significantly benefit from having absolute coil sensitivity information available.

Difficulties in absolute B1 calibration: The major obstacle in acquiring absolute transmit / receive coil sensitivities consists in the entanglement of $\hat{B}_1^+$, $\hat{B}_1^-$ and ρ, as expressed by Eq. [1]. The most widespread method of measuring the modulus of $\hat{B}_1^+$ is the so-called double-flip angle method (8,9), which takes advantage of the non-linearity of the sine function in Eq. [1]. On the downside, this method is time demanding and does not yield the phase of $\hat{B}_1^+$.

This problem could potentially be solved by an extension of this method, in which the entire coil-object arrangement is rotated with respect to the direction of $\mathbf{B}_0$. In this fashion, also the z-component of $\mathbf{B}_1$ would come into play for the transmit / receive sensitivities. Mathematical analysis suggests that six rotations are required for determining the full $\mathbf{B}_1$ vector field and hence the absolute transmit / receive coil sensitivity information. However, such an approach would clearly be unpractical for human subjects.

Prospects of absolute B1 calibration: With absolute $\mathbf{B}_1$ information available, it would be possible to acquire images clear of additional shading by transmit and receive sensitivities. This would significantly improve image quality, in particular at high field strengths. However, besides the correction of image shading artifacts, having the full $\mathbf{B}_1$ vector field available would be highly interesting also for other applications, including:

***i.) Imaging dielectric properties**:* Having one single Cartesian component of the absolute $\mathbf{B}_1$ vector field - or a linear combination such as $\hat{B}_1^+$, or $\hat{B}_1^-$ - available might reveal information about the spatial distribution of the dielectric properties permittivity (ε) and conductvitity (σ). For a homogeneous object this can be illustrated by considering the Helmholtz equation:

$$\left(\Delta + k_0^2\right) B_{1,n} = 0 \quad \Rightarrow \quad k_0^2 = -\Delta B_{1,n} / B_{1,n} \text{ , with } \quad k_0^2 = 2\pi f_0 \omega \varepsilon \left(2\pi f_0 \varepsilon + i\sigma\right), \qquad [2]$$

with Δ the Laplace operator, k_0 the complex wave number, and f_0 the Larmor frequency. For a more realistic dielectrically inhomogeneous object, such as humans, Eq. [2] becomes somewhat more involved (10).

***ii.) Electric field and SAR quantification**:* Based on Mawell's equations and knowledge about the true $\mathbf{B}_1$ vector field, as well as ε and σ, permits determining the (non-conservative) electric RF fields, according to:

$$\mathbf{E} = \left[\mu(\sigma - i\omega\varepsilon)\right]^{-1} \nabla \times \mathbf{B}_1 , \qquad [3]$$

with ∇ the gradient operator. Knowing $\mathbf{E}$ and σ would hence enable quantification of the local SAR distributions.

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