Rapid estimation of conductivity and permittivity using Bloch-Siegert B1 mapping at 3.0T

S. B. Bulumulla[1], S-K. Lee[1], T. Yeo[1], W. T. Dixon[1], and T. K. Foo[1]
[1]GE Global Research, Niskayuna, New York, United States

Introduction:

Tissue conductivity and permittivity are critical to estimating local RF power deposition during MR imaging. These electrical properties may also have diagnostic value as malignant tissue types have been shown to have higher permittivity and conductivity than surrounding healthy tissue [1]. In this work, we explore rapid estimation of electrical properties that will prove to be useful in real time estimation of local RF power deposition or in conjunction with images, prove to be of diagnostic value in identifying tissue abnormality. The target time for estimation is time acceptable for routine clinical use.

Methods:

The spatial distribution of transmit RF field (B1+) is related to the electrical properties of the imaging object. This relationship is used to obtain expressions for conductivity and permittivity in terms of complex B1+ [2].

$$\hat{\sigma} = \mathrm{Re}\left\{\frac{1}{j\omega\mu B1+}\left(\frac{\partial^2 B1+}{\partial x^2}+\frac{\partial^2 B1+}{\partial y^2}+\frac{\partial^2 B1+}{\partial z^2}\right)\right\} \quad \text{-- (1)} \qquad \hat{\varepsilon}_r = \frac{1}{\omega\varepsilon_0}\mathrm{Im}\left\{\frac{1}{j\omega\mu B1+}\left(\frac{\partial^2 B1+}{\partial x^2}+\frac{\partial^2 B1+}{\partial y^2}+\frac{\partial^2 B1+}{\partial z^2}\right)\right\} \quad \text{-- (2)}$$

These equations are formulated in terms of difference equations for efficient computation [3]. The recently introduced Bloch-Siegert B1+ mapping technique is used for obtaining B1+ magnitude [4]. For estimating permittivity only [5], B1+ magnitude is used in Eq. (2). For estimating permittivity and conductivity, B1+ phase is required. In a quadrature, switched mode birdcage coil, the B1+ phase has been shown to be half of the spin echo image phase [6a,b]. However, the spin echo image phase has variations unrelated to sample properties, introduced during image reconstruction. These first and zero order phase variations are removed using the Ahn and Cho algorithm [7]. Then complex B1+ is obtained and Eq. (1) and (2) are evaluated to obtain estimates of conductivity and permittivity.

In applying the methods, a breast phantom filled with distilled water, 2.2g/L of sodium chloride and 1g/L of copper sulphate is used. The imaging is carried out at 3.0T (Discovery™ MR750, General Electric Company, Waukesha, WI, USA) using a quadrature, switched mode, birdcage head coil. Post-processing and calculations of Eq. (1) and (2) are carried out using Matlab® (Mathworks, Natick, MA, USA) in a Latitude D630 laptop computer (Dell, Round Rock, TX, USA) with Intel® Core™ Duo CPU T7250 @ 2.00GHz processors, and 1.99GB RAM. Three axial slices, FOV 24cm and slice thickness 12mm are used in the estimation of electrical properties for the central axial slice at 128x128 resolution. The time taken for each step is documented to obtain the total time for permittivity estimate and conductivity estimate.

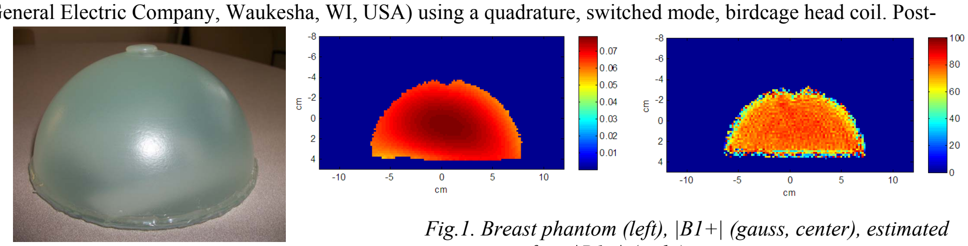

Fig.1. Breast phantom (left), |B1+| (gauss, center), estimated permittivity from |B1+| (right)

Results:

The breast phantom, B1+ magnitude for central axial slice estimated with Bloch-Siegert B1+ mapping method and the estimated permittivity are shown in Fig. 1. The estimated permittivity is 70.5 (mean), 74.95 (mode – most frequent value) compared to expected value of 81.

The time taken for estimation of permittivity is as follows: The B1 data were collected for 3 axial slices. The time taken for the 3 slices was 1min 42s for imaging and 1.2s for post processing to generate B1 maps. The calculation of Eq. (2) was carried out in 0.31s. The total time was 1min 44s.

The estimated permittivity and conductivity using complex B1+ are shown in Fig. 2. The estimated conductivity is 0.42 S/m (mean), 0.43 S/m (mode) and the estimated permittivity is 77.56 (mean), 85 (mode). Interpolating published results for conductivity of various concentrations of sodium chloride solutions at 1.5T[8], we expected 0.37 S/m conductivity for 2.2g/L sodium chloride solution at 1.5T. Taking in to account the higher frequency (3.0T vs. 1.5T), the estimated conductivity compares well with the expected results. The distribution of the estimated values is given in Fig. 3. The plot shows the mean and +/- standard deviation in error bars.

For obtaining complex B1+, the additional spin echo images required a time of 51s (TR360, TE30) and Ahn and Cho phase corrections required a time of 2.01s for the 3 slices. The calculation of Eq. (1) and (2) were carried out in 0.37s. The total time was 2min 37s.

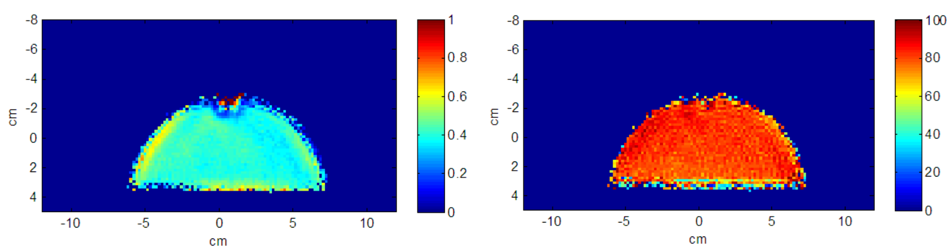

Fig.2. Estimated conductivity (S/m, left) and permittivity (right) from complex B1+

Discussion/Conclusions:

In this experiment, permittivity was obtained in approximately 1 ½ min and conductivity was obtained in an additional 1 min. The time can be reduced, with trade-offs in the quality of reconstructed conductivity and permittivity "images". The mean of estimated values remain nearly the same when the time is reduced, for example, when estimates are carried out at approximately 1min per slice.

Three slices are used for the estimation of electrical properties of a single slice, leading to an "overhead" of two slices. As the number of slices is increased, this overhead remains the same, (i.e. to estimate electrical properties of 10 slices, require B1+ data from 12 slices) leading to less estimation time per slice.

The total time is dominated by the imaging time for B1+ magnitude and phase estimate. The time taken for calculation of Eq. (1) and (2) is small, in comparison, an advantage for the method.

References: [1] Fear, et. al.,IEEE Microwave Mag., Mar 2002 [2] Bulumulla, et. al., ISMRM 2009 [3] Press, et. al., "Numerical recipes in C", Cambridge Univ. Press, 1992 [4] Sacolick, et. al.,ISMRM 2010 [5] Katscher, et. al., ISMRM 2010 [6a] Katscher, et. al., IEEE Trans. Med. Img, 2009 [6b] Lee, et. al., MR workshop, Korea, 2010 [7] Ahn, et. al., IEEE Trans. Med. Img., 1987 [8] Giovannetti, et. al., Concepts in MR, 2010

Acknowledgement: NIH 5R01EB005307-2

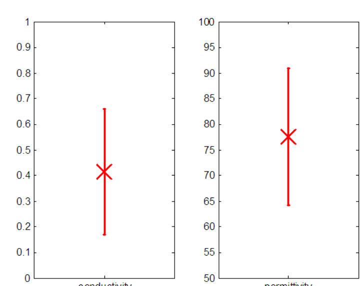

Fig.3. Distribution of estimated conductivity (left), permittivity (right)