Nuts & Bolts of Advanced Imaging: Theory and Demonstration for Coils, RF Shimming and SAR

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Highlights:

- At high frequency MRI operation and electrically large (≥ 7T head, ≥ 3T body), asymmetrical, inhomogeneous, and/or irregularly-shaped loading, integer multiples of phase-shifts and uniform amplitudes are not necessarily the ideal characteristics to impose on the voltages driving the transmit array/coil in order to obtain a homogeneous transmit (with safe electric field) and/or receive fields.
- If none of the coils on the Tx Array is producing a good excitation in the ROI, PTX and/RF shimming will not work.
- Image voids due lack of RF excitation are caused by inhomogeneities and/or unsuitable polarization of the electromagnetic fields.
- At 7T, there is typically good intensity of RF magnetic field across the volume of human head. At many instances, it possess unsuitable polarization.
- While the physics (Maxwell's) is well established, it is really difficult to make up definitive rules regarding SARs (especially local SARs)

Target Audience:
Imaging researchers and students who would like to learn more about the practical issues involved in Transmit Arrays, RF shimming and SAR.

Outcome & Objectives
From the theory lecture of the course, participants will learn about approaches to designing transmit arrays, conducting RF shimming, calculating and constraining SAR. Before coming to the interactive hands-on lecture, it is imperative that participants download the following files from:

https://www.dropbox.com/sh/x77nav1l2z4ggy7/0EysZD4osx

To download all files, you can click on top right corner and then download as a zip.

- ***In-house Matlab RF shimming package. This requires Matlab and Matlab Optimization Toolbox.***

- ***Files of RF magnetic and electric fields (calculated at 298 MHz) and human head/phantom meshes.***

- ***A description of the RF shimming exercises that will be conducted during the interactive hands-on lecture***

The files will be available for download on 5/5/2014. *For any questions/difficulties please contact the instructor by email/phone*. In the interactive hands-on portion of the course; using RF shimming package, participants will explore RF shimming exercises and evaluate the SAR associate with RF shimming.

Purpose:

Multi-transmission methods have not yet evolved to realize a full scale scientific/clinical research. Many of the obstacles that faced such methods include

1. Mapping the B_1 field for every subject,
2. Significant RF excitation (B_1^+ field) spatial intensity losses associated with current multi-transmit arrays due to increased local/global power deposition in tissue at lower flip angles, and
3. Concerns regarding the unclear RF safety assurance of the multi-transmit experiment (to this date, the power deposition/electric field in the human body are not measurable using MRI techniques.)

In this course, we will evaluate many of these intertwined issues through the context of RF coils/arrays, RF shimming and SAR. We will also perform a live demonstration of RF shimming.

Methods:

B_1 Inhomogeneity and SAR

Higher field strengths and/or large organ imaging correspond to increased operational frequencies. Unlike the case at lower field strengths, the electromagnetic waves now have to "travel" significant electrical distances in the human head. As a result, the electromagnetic fields become non-uniform which will result in inhomogeneous B_1^+ and B_1^- fields in biological tissues as well as inhomogeneous electric fields and, therefore, localized SARs. Both which can have a devastating effect on the integrity of the images and on the safety of the patient.

RF Shimming

Variable phase/amplitude multi-port excitation or B_1 shimming (in electromagnetic terms: phased array antenna excitation) is based on the fact that for high frequency MRI operation and asymmetrical/inhomogeneous/irregularly-shaped loading (human head/body), integer multiples of phase-shifts and uniform amplitudes are not necessarily the ideal characteristics to impose on the voltages driving the transmit array in order to obtain a homogeneous transmit field. Furthermore, overall as well as localized RF field excitation in high field human MRI may be achieved with rather distinctive and non-obvious amplitudes/phases associated with the excitation voltages.

Coils and Transmit Arrays

Many designs of transmit arrays [1-17] have been used in exciting the RF field at various MRI field strengths. Transmit arrays can be coupled or uncoupled. For example, It is expected that each excited element of a 7 tesla loaded TEM head/body coupled-coil [18-20] to experience unique coil/load impedances that may differ significantly from those incurred by other coil elements. Moreover, the frequencies at which each coil element experiences real input impedances (resonances) may vary as well. In such cases, the resonance frequencies of the different modes will differ from one element to another. This particular issue will not be resolved with the use of matching circuits, since it is difficult to be “on mode” (the imaginary component of the input impedance to be zero) using all the coil elements simultaneously at the same frequency. In this regard, coupled-arrays are at a disadvantage compared to decoupled arrays. A coupled-array element however tends to provide significant B_1 field intensity within deep head/body tissue as well as a generally wide B_1 field distribution. This is an advantage over decoupled-arrays in which strong coupling exists between the array elements and the subject (thus their performance and operation are sensitive to the imaged subject.) It would be more difficult to obtain relatively deep penetration for volumes as electrical large as the human abdomen at ≥ 3 tesla and as human head at ≥ 7 tesla with decoupled-arrays.

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