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

Live Demo

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To use the software package designated for the morning categorical course, you will need to unzip our file (**morningCategoricalRFShimmingIbrahim.zip**). **Matlab is required on a Windows platform with Optimization Toolbox to run the program**.

Please go to

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

You will have the following folders and files:

- morningCategoricalRFShimmingIbrahim.zip
- ReadMe.pdf.zip
- Syl_ISMRM_2015.pdf.zip

Background Information is available up request (**tibrahim@pitt.edu**)

How to Unzip the File:

Software should be available to unzip your file. Programs such as WinZip, 7-Zip, etc. can be utilized to run the file. If you do not have any of these programs, you can unzip the **morningCategoricalRFShimmingIbrahim.zip** file using **7-Zip**. The software can be downloaded from http://www.7-zip.org/download.html.

Open the 7-Zip File Manager. Go to the appropriate directory where the file **morningCategoricalRFShimmingIbrahim.zip** and extract where you would like the files to be. Select '**Extract**' within the **morningCategoricalRFShimmingIbrahim.zip** as it is shown below:
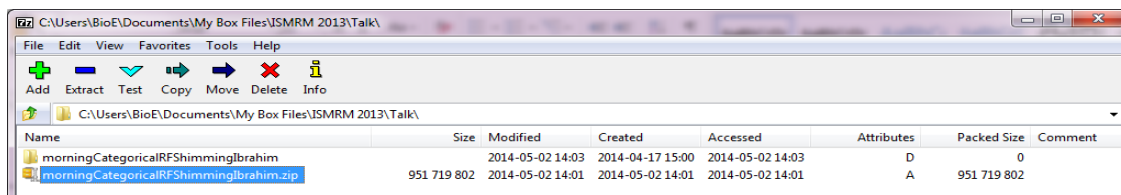
Optimization Package:
You will need to use a Windows Platform to run the optimization package. The package consists of the following:

- Main folders:
  - Head: includes magnetic and electric fields (**Bfields_head** and **eFields_head**) of the 8 channels inside one of our head models.
  - The GUI Function package (**OptimizeGUI**).

Before RF Shimming:

The optimization toolbox shows the initial conditions of 20 elements that are combined into 8 Channels. These values are the amplitudes and phases that were used to compute the B_1^+ field and SAR statistics prior to RF Shimming (pseudo quadrature excitation.) All statistics were computed for the 2D axial slice (at slice position 50) and 3D volume (slices 42-58) of the human head model. The B_1^+ field statistics are computed using the Coefficient of Variation (CoV) and ratio of maximum /minimum. The SAR statistics are the peak and average SAR (This is to achieve continuous mean B_1^+ field = 2 micro tesla)
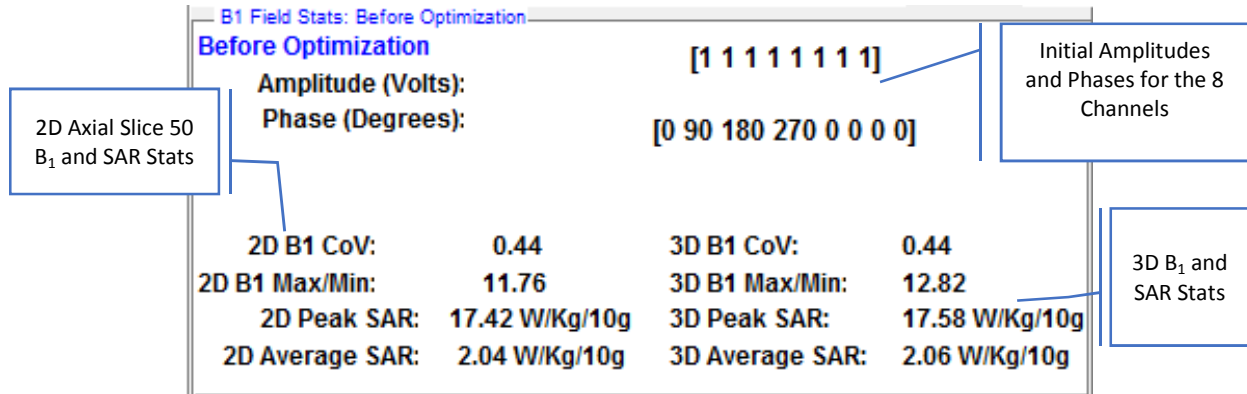

Figure 1- Initial B_1^+ Field and SAR Calculations prior to Optimization shown on 'Stat' Tab
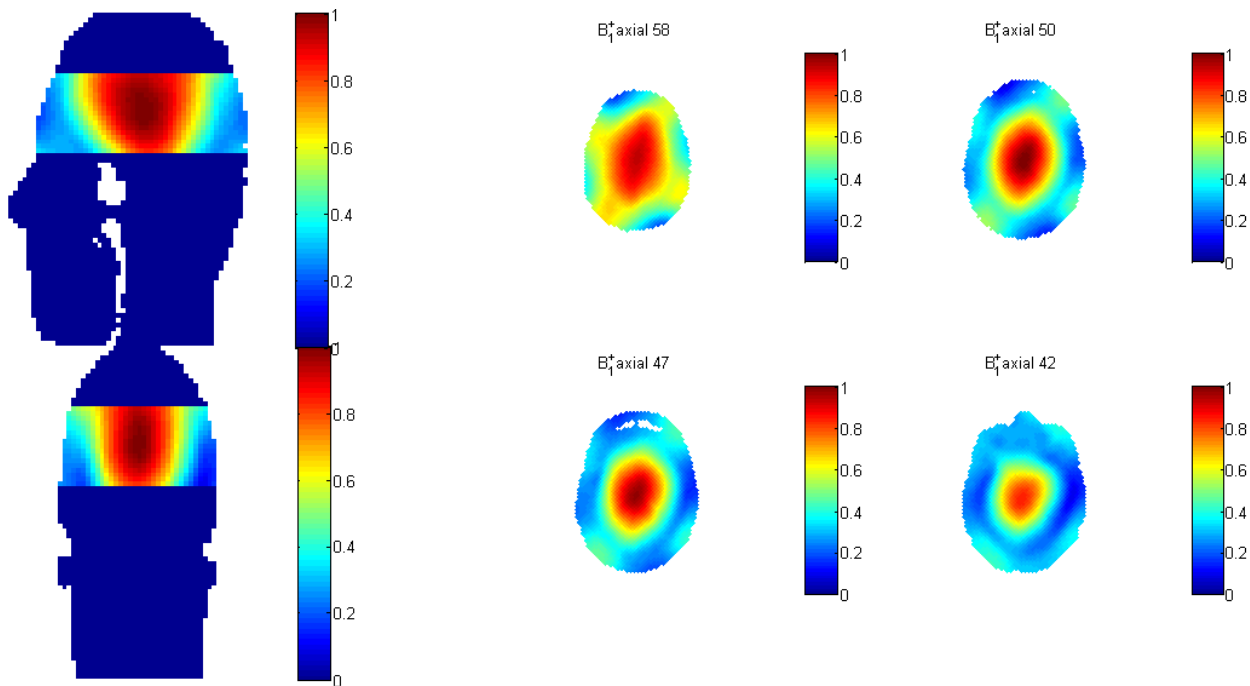

Figure 2 - B_1^+ Field Distribution in various planes with the pseudo quadrature excitation shown Figure 1.
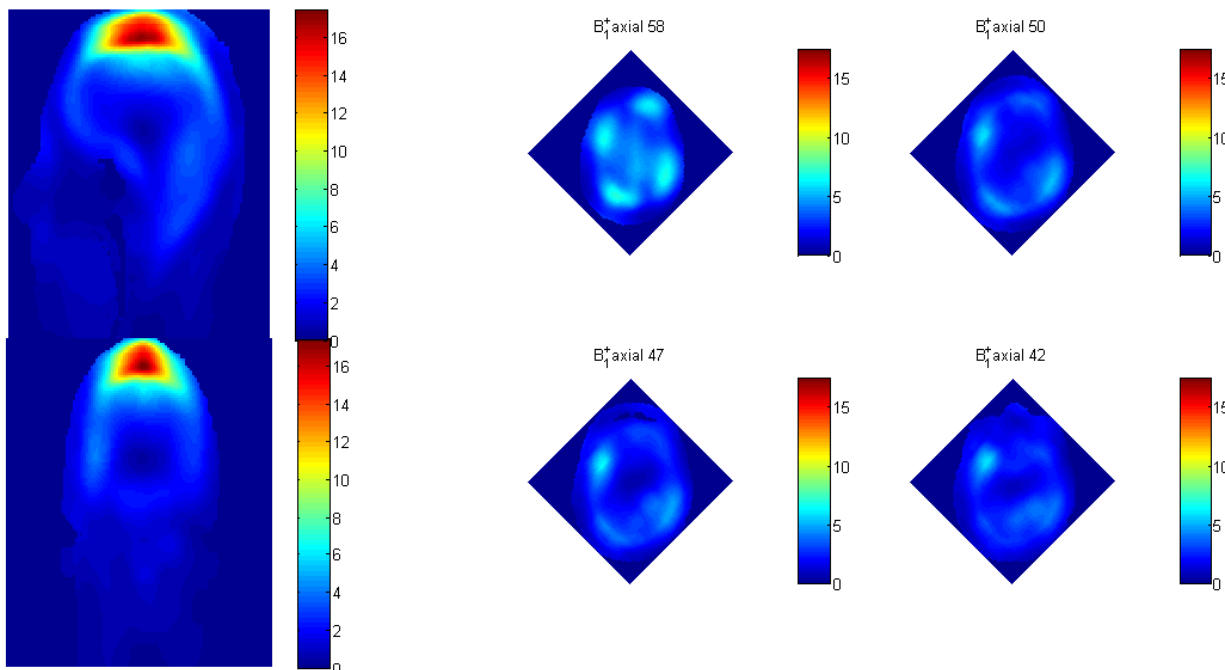
Figure 3 – SAR Field Distribution in various planes with the pseudo quadrature excitation shown Figure 1.

Instructions for Using the Optimization Package:

For any type of optimization you are running make sure your clear the workspace by typing

clear all;
In the command window.
Go to **morningCategoricalRFShimmingIbrahim** Directory
Go to **OptimizeGUI** Directory
Open **Full_BF_Sim_GUI_v209.m**
Click **Run**
The GUI will appear as Figure 4 (below.)

Figure 4- Full GUI B$_1^+$ Shimming Tool for Parallel Transmit Optimization Toolbox

In this toolbox, the positional plane view of the model is shown. Here you are able to see the axial view. To the right there are five main tabs 'Main', 'Optimization', 'Constraints', 'SAR/BField', and 'Stats' that will be reviewed below.
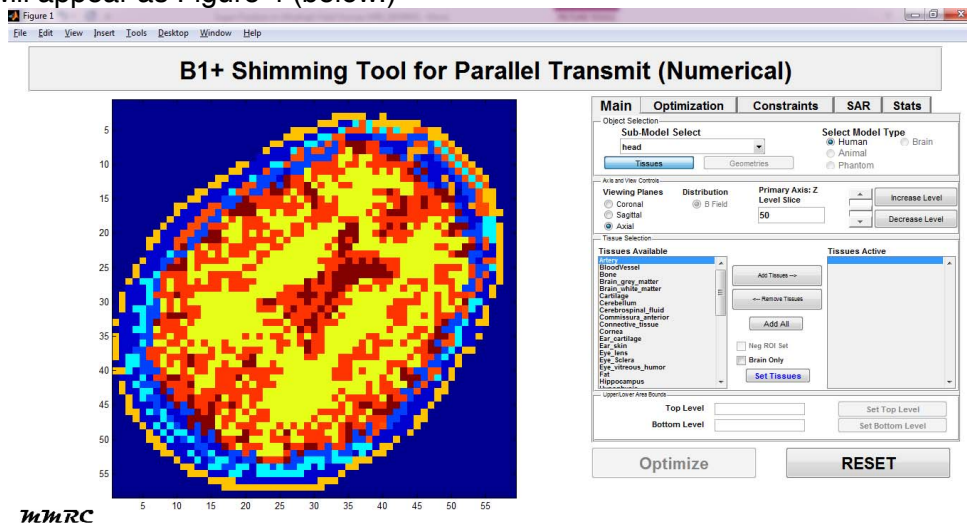
To avoid confusion, many of the optimization features have been disabled for this exercise.

Instructions for Performing B_1^+ Field Shimming on the Anatomically Detailed Human Head Model

A. <u>2D Axial - Human Head RF Shimming</u>
    RF shimming will be performed on an axial slice.

    To perform RF shimming on the head, select the following for each tab.

    Main Tab Features
    1. Select 'Axial' in the Viewing Plane and type **50** into the Primary Axis: Z Level Slice field.
    2. Select 'Add All' to choose all the tissue in the slice
    3. Select 'Set Tissue'
    4. Select 'Bottom Level' and 'Top Level in Lower/Upper Area Bounds (**50** and **50**)
    5. Select 'Optimize' to perform optimization.

    This optimization aims at minimizing the ratio of (maximum of B_1^+ field intensity in slice 50) over (minimum of B_1^+ field intensity in slice 50)

    Once the optimization is done, you can view the RF shimmed B_1^+ field distribution 1) through difference planes, by selecting 'Axial', 'Sagittal' or "Coronal" in the Viewing Plane, 2) through different slices, by typing slice number into the Primary Axis, although the optimized slice is slice 50 only.

    SAR/BField Tab Features
    1. Select 'Compute SAR'. The SAR statistics will be displayed in the "SAR Calculation" when it's done.
    2. The B_1^+ field and SAR distributions will appear in new plot windows.

    Stats Tab Features:

The BField statistics of the optimized result will be displayed in the Stats Tab. It can be used to compare with the initial 2D information.

B. <u>3D Human Head RF Shimming</u>
    Select "Reset" to perform RF shimming again which will now be performed 3D.

    3D RF shimming will be performed on axial slices 42 to 58. To perform RF shimming on the head, select the following for each tab.

    Main Tab Features
    1. Select 'Axial' in the Viewing Plane
    2. Select 'Add All' to choose all the tissue in the slices
    3. Select 'Set Tissue'
    4. Type **42** into the Primary Axis: Z Level Slice field and then Select 'Bottom Level'
    5. Type **58** into the Primary Axis: Z Level Slice field and then Select 'Top Level'
    6. Select 'Optimize' to perform optimization.

This optimization aims at minimizing the ratio of (maximum of B_1^+ field intensity in 3D) over (minimum of B_1^+ field intensity in 3D)

Once the optimization is done, you can view the RF shimmed B_1^+ field distribution 1) through different planes, by selecting 'Axial', 'Sagittal' or "Coronal" in the Viewing Plane, 2) through different slices, by typing slice number into the Primary Axis.

SAR/BField Tab Features
3. Select 'Compute SAR'. The SAR statistics will be displayed in the "SAR Calculation" when it's done.
4. The B_1^+ field and SAR distributions will appear in new plot windows.

Stats Tab Features:
The BField statistics of the optimized result will be displayed in the Stats Tab. It can be used to compare with the initial 3D information.

C. SAR Results Using TX SENSE

1. If there is time, it will be explained in the lecture.

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*** *"**morningCategoricalRFShimmingIbrahim.zip**". **This requires Matlab on Windows and Matlab Optimization Toolbox. Inside the package you will find 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 (ReadmeMe.pdf.zip)***

The files will be available for download on 5/1/2015. *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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