Simultaneous TMS and fMRI

Henry H. Wheeler Jr. Brain Imaging Center

Outline

I. Basic TMS Physics

II. TMS and the BIC Today

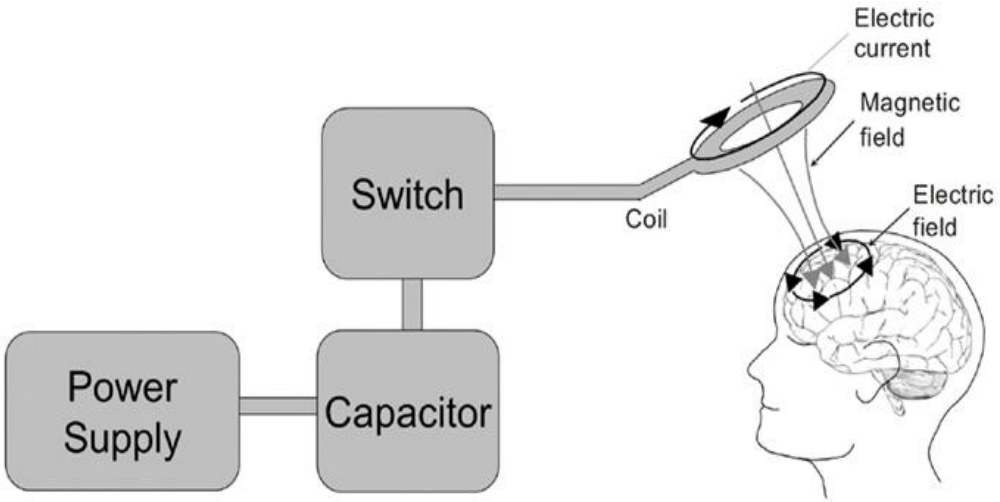
III. TMS and fMRI System Interactions

IV. BIC Works in Progress

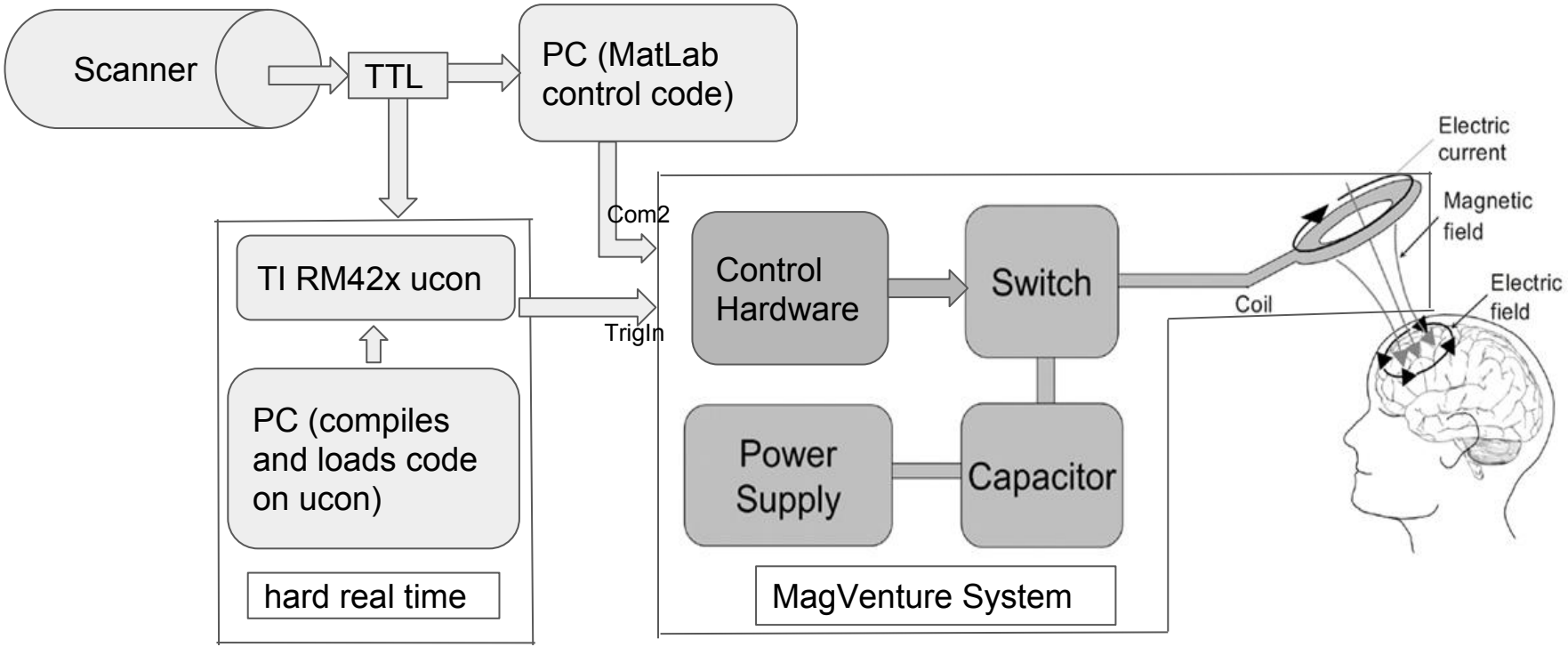
V. The Future

Basic TMS Physics

- Timing-varying current ⇒ Time-varying magnetic field (Ampere's Law)
- Time-varying magnetic field ⇒ Time-varying electromotive force (Faraday's Law)
- Electric field perturbs n



TMS and the BIC Today: Hardware

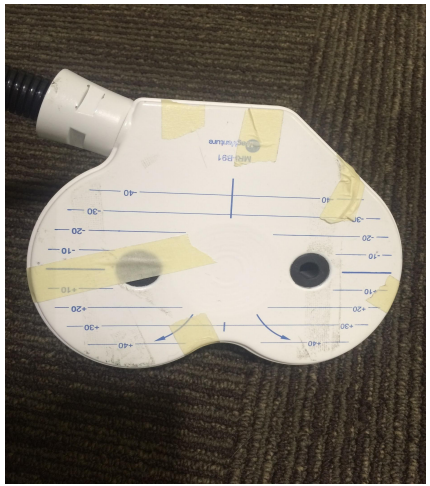


Although important I won't be mentioning TMS-to-MRI registration issues.

TMS and the BIC Today: The Coil

- MagVenture TMS MRi-B91 Coil
- Designed for biphasic pulse use only
- Copper litz wire windings
- Oval rather than circular loops for better positioning within MRI receiver.

MRi-B91 with facade



Windings in the C-B60

TMS and the BIC Today: MagVenture Control

- Motherboard (running Windows Embedded OS)
- Microcontroller for timing control
- Motherboard communicates with the microcontroller to handle different operation demands.
- When using the COM2 port get no guaranteed timing accuracy or upper on worst case performance. Motherboard polls for external signals and has many the scheduling issues associated with a usual mulitasking OS
- When using the TrigIn port (hardware interrupt communication with the Magventure microcontroller) get hard real time performance.

TMS and the BIC Today: MagVenture MRI Compatible Stimulator

- RF filter to prevent introduction of noise in MRI shielded room
- Temperature sensors limit unsafe TMS waveforms and temperature increases
- Leakage current protection circuit (Presently reduces the leakage current down to 10uA. Upgrade will reduce it to 1uA.)
- Variable stimulator recharge delay (0-12.0 ms)
- Emergency stop button for subjects in scanner

TMS and the BIC Today: BIC Control

Option 1: MatLab on PC

- Interpreted code on a multitasking OS
- Polls port that synchronizes with the scanner
- Lots of sources of timing inaccuracies

Option 2: BIC hard realtime

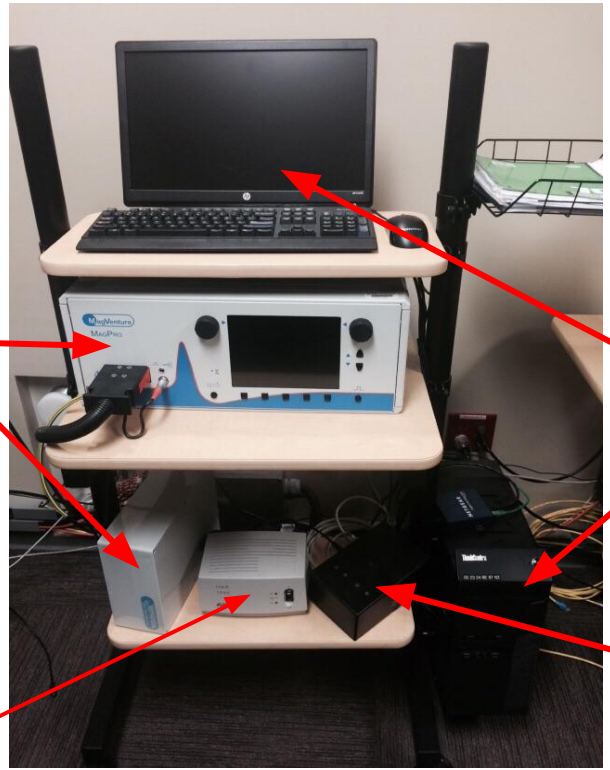
- Dedicated microcontroller board: 100 MHz Texas Instruments RM42x
- Uses hardware interrupts to detect TTL from the scanner.
- SN74LVC245AN level shifter.
- Hard real-time performance with worst case timing accuracy of 5 us

TMS and the BIC Today: Time lags

- May need to account for these determinant time lags in the system
- Time from the trigger being sent to the MagVenture TMS (on trig-in port) to leading edge of TMS pulse: ~75 us (Triac switching time?)
- Length of biphasic TMS pulse: ~215 us

TMS and the BIC Today: 3T Control Room

MagVenture System



Dual function PC: Run MatLab code and run TI code communicating with RM42x microcontroller

TI microcontroller and level shifter box

Surge protector for PC

TMS and the BIC Today: Receiver Coil

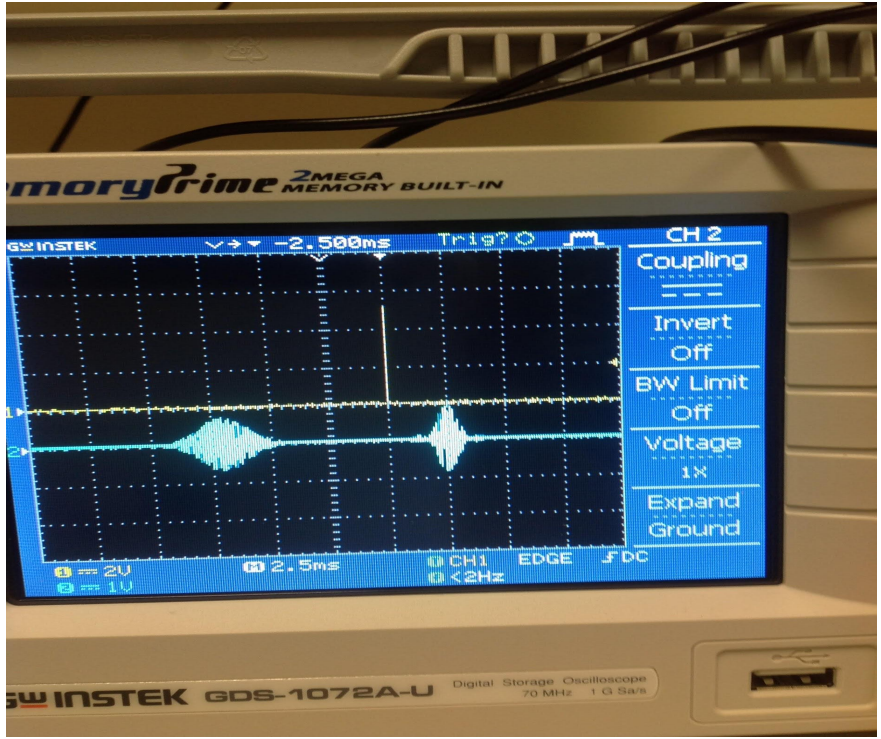
- Larger internal diameter than 12 channel coil to accommodate the TMS coil
- Birdcage provides better receive field homogeneity than 12 channel

TMS and the BIC Today: Magventure probe

- Useful for checking timing of events
- Can sense MRI rf excitation events and TMS pulse
- Connect probe to one channel of an oscilloscope

TMS and the BIC Today: Magventure probe

- Other oscilloscope channel can be connected to the TTL signal box from the MRI scanner.
- Synchronizing TTL signal from the MRI scanner between the fat-sat and slice select rf event.



TMS and MRI System Interactions

- Coupling of MRI receive birdcage coil to the TMS coil.
- Spin dephasing effects from TMS generated magnetic field.
- Heating effects on susceptibility related artifact
- Eddy current effects.
- Acoustic noise. Mechanical ring down time 2-3 ms.

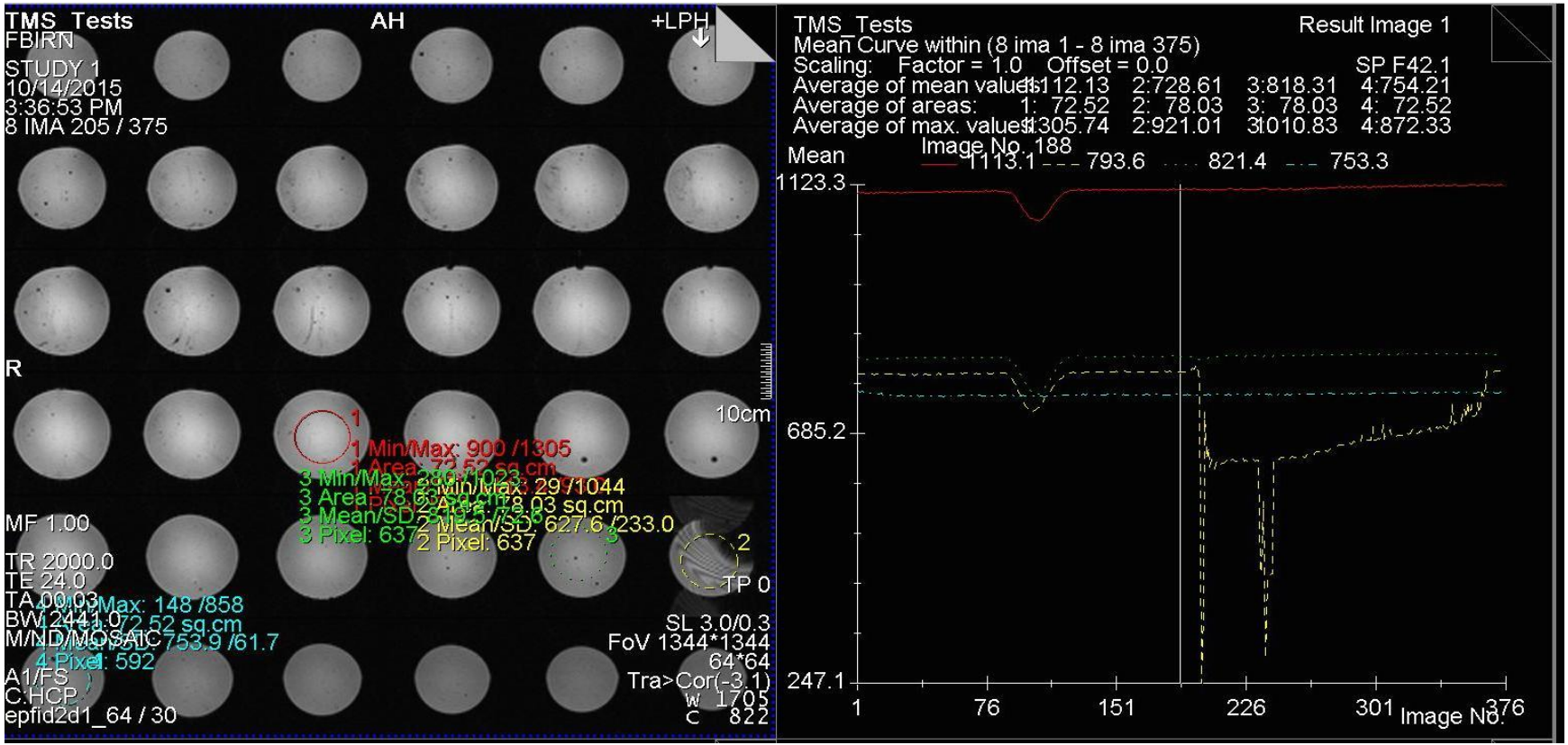
Direct coupling - TMS coil to MRI Receive coil

- Phantom removed from scanner
- TMS biphasic pulse in ADC period of slice 7
- Coupling depends upon overlap of spectra: Birdcage (centered at 120 Mhz) and TMS pulse (centered at 4 KHz). Very little overlap!
- But! Also depends upon TMS B field strength which is large compared to that generated by spins in MRI.

TMS Spin Dephasing

- Any unbalanced (temporal integral ≠ 0) B field will cause dephasing
- TMS pulses are biphasic but not balanced sufficiently for such strong fields
- Therefore dephasing AKA signal loss
- Targeted slice 7 with phantom in scanner
- If TMS pulse is placed at any time during or following the slice excitation pulse we see dephasing signal loss

TMS Spin Dephasing

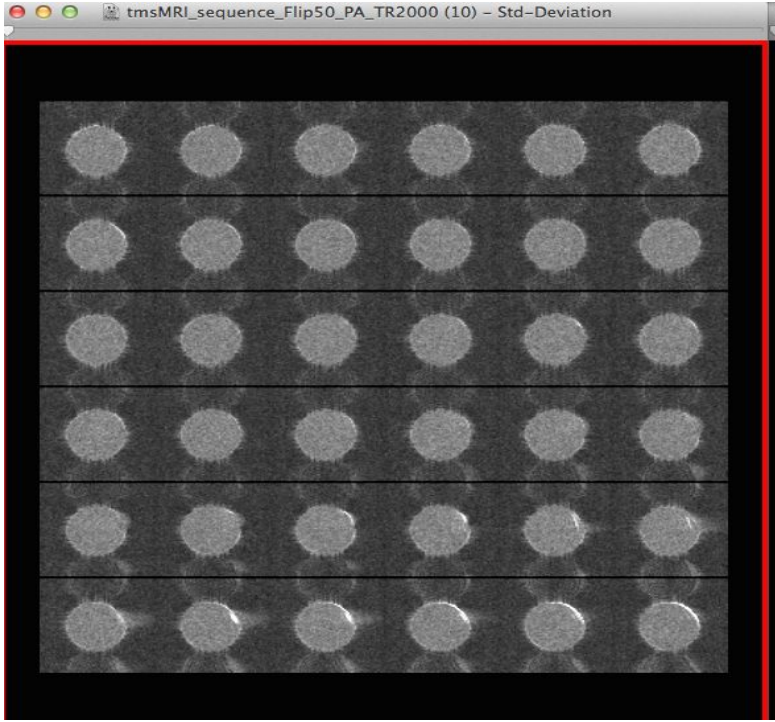


Heating Effects?

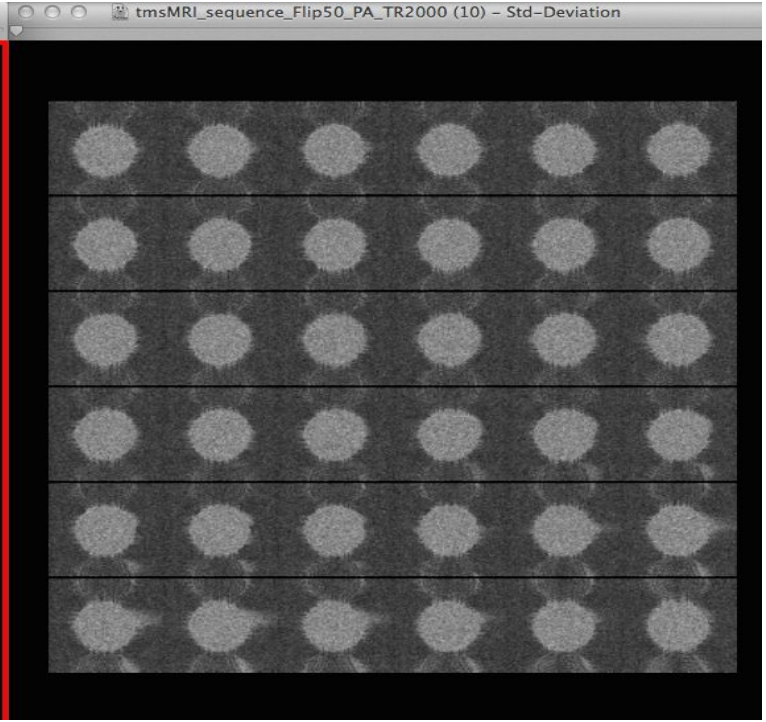
- Biphasic TMS applied during crusher gradient
- Slices 2,4,6,8,10 get TMS
- See what we think are heating-related susceptibility effects
- Needs further investigation without different TMS duty cycles

Std dev over 100 EPI volumes

With TMS



Without TMS



TMS and MRI System Interactions

TMS here? Get artifact in all slices.

TMS after this point? Get signal dropout in target slice only.

TMS here? Get better crusher.

Integrating TMS and MRI Sequences

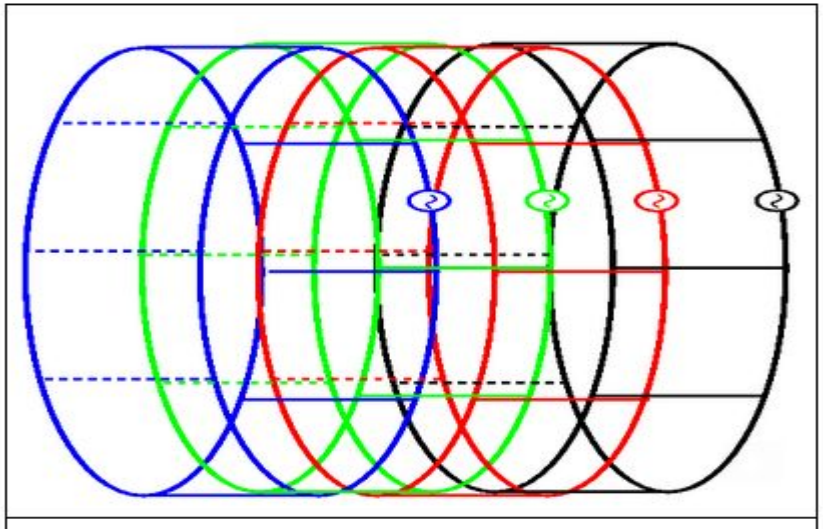
- Blank interval in every TR: Nice and clean but limits TMS sequence and hampers simultaneous multislice acceleration.
- TMS during crusher gradients: One every 55ms (18 Hz) in usual sequence. Doesn’t limit simultaneous multislice acceleration. Still limits TMS sequence.
- TMS at any time except during the fat-sat RF pulse and resample TMS contaminated slices: Great TMS sequence flexibility and doesn’t limit simultaneous multislice acceleration. Work-in-progres.

BIC Works in Progress

- Improved TMS positioning device
- Nested Birdcage coil for simultaneous multislice accelerated EPI
- MRI sequence and TMS sequence development
- Work with Siemens to turn off receive at all times except during ADC periods

BIC Works in Progress: Nested Birdcage Rx Array

- Big enough to accommodate TMS coil
- Better receive field homogeneity than other possible arrays
- Simultaneous multislice imaging in axial direction



BIC Works in Progress: Sequence Development

- Planning stage presently
- TMS and MRI communicate: Resample any slices acquired during TMS pulse
- Maintains steady state in EPI run
- TR period would be longer
- Doesn’t add temporal overhead not recoverable by Simultaneous multislice acceleration as is the case with inserting blank acquisition periods.

The Future of Simultaneous TMS - fMRI

- Better control of spatial distribution of the magnetic field (limited by fundamental physics)
- Better TMS waveform control
- MRI and TMS communication for greater flexibility of stimulus delivery and data acquisition through sequence manipulation
- Decrease MRI-TMS system interactions (acoustic effects, heating effects, etc)
- Improved MRI-TMS safety

The Future: TMS Coil Array and Stimulator

- Greater control of spatial distribution of TMS electromagnetic field through multiple current sources (Two coils - a simple start)
- Smaller current magnitude in each coil of the array
- Greater temporal control of TMS through use of amplifiers instead of discharging capacitors
- Fewer windings and less acoustic noise
- Balanced currents to limit consequences of Lorentz forces on TMS coils a critical part of any design.
- Built stepwise with neuroscience guiding steps

BIC Community Development and Resources

- GitHub: Lab notes for our TMS+fMRI and nested birdcage projects. Just google with search terms “github”, “tms” and “fmri” to find it.
- Study group: Meet twice per month to discuss physics, engineering and neuroscience of TMS alone and in the MRI scanner.

Fin

Thanks For Your Attention