6.S02 MRI Lab 1

2. Acquire MR signals

Connecting to the scanner Connect to VMware on the Lab Macs. Download and extract the following zip file in the "MRI Lab" dropbox folder:
https://www.dropbox.com/s/ga8ga4a0sxwe62e/MIT_download.zip

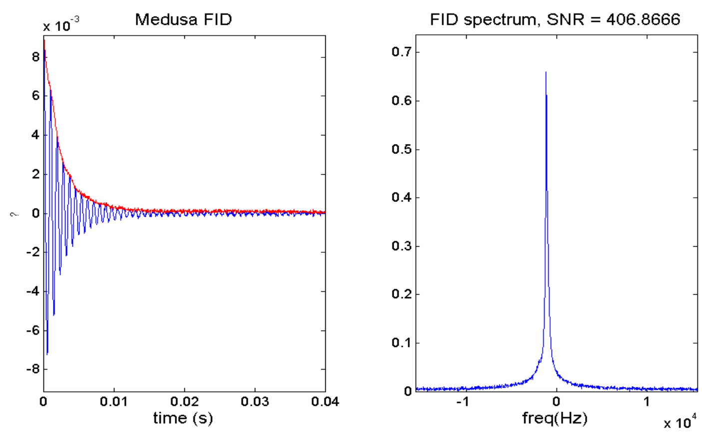
Plug in the Medusa's USB and install the driver by –Open Device Manager: "control panel" > "Hardware and sound" > "device manager"

Right click on medusa device and select "update drivers"

Select "Browse my computer for driver software" and select "medusa_driver" folder from the unzipped files you downloaded.

2.1 Free Induction decay (FID)

- Insert RF coil into magnet bore. Insert full water tube (phantom #1) into coil. Run FID GUI sequence, by typing "FID_GUI" into the command window. Make sure the MRI Lab folder has been added to the MATLAB path. Look in your magnets box for a piece of paper with the recorded Larmor Frequency for your magnet; type this into the GUI for frequency. Click "Run Scan". You should see something that looks like this:



On the left is the time domain signal, and the right is the frequency domain signal. The frequency domain is displayed with the center frequency (0Hz) corresponding to the frequency you typed into the FIDGUI in the "frequency" box (e.g. 8.150e6). The red curve on the FID is the magnitude of the signal and the blue trace is the real component (M_x component). The number of repetitions can be increased to continuously acquire FID signals, repeating every TR seconds, where TR stands for "Time to Repetition" and is also a GUI input (defaulted to 1s).

Known Bugs: Note if the signal inexplicitly goes away. Stop the software and press the reset button on the Medusa console. Sometimes when changing the frequency, the Medusa console gets confused and even a reset doesn't bring it back. In this case power cycling can help.

- Adjust the system console frequency f0, until the peak is centered at 0 Hz. Note that the "wiggles" in the free induction decay disappear when the signal is at 0Hz.
- Set the # of repetitions to a high number (so it runs over and over). Reach in and slowly adjust the coil position inside the magnet. Take the sample out to make sure the signal fully goes away. Position it for maximum signal.
- While acquiring an FID signal, perturb the field by moving the external permanent magnet close to the B0 magnet. What happens?
- Find the RF TX amplitude that corresponds to a 90^o flip angle and a 180^o flip angle. You can do this by stopping the run, checking the "flip angle calibration" box in the gui then starting again. This steps thru the amplitude of the RF excitation pulse and plots the amplitude of the FID as it goes. It steps from 0W power to ~1W. The 90^o flip angle occurs when amplitude of the FID signal is maximized. The 180^o flip angle occurs at the power of the first minimum after the first maximum. Sometimes there will be a second maximum because a 270deg rotation will be reached. Record the 90 degree power setting:______________
  Enter this power setting on the FID_GUI.
  Sketch and label the relevant features of the FID power calibration plot:

- Uncheck the "flip angle calibration" box. Record a single FID (# Repetitions =1). Save the time domain signal. Filename:___________________________
- What is the digitization readout length (ms)? __________
- How many complex points are recorded in the FID signal vector? ___________
- Compute, dwell time (sampling period); δt= _____, spectral width; ±1/ δt =__________
- Write a matlab script or function that:
  - Plots the frequency domain signal (using fft code from previous labs)
  - **SNR anlaysis:** Measure the signal to noise ratio in the frequency domain. SNR = peak amplitude/standard deviation of the noise. Record SNR = _____________________
  - **Spectral Energy analysis:** Measure the area of the spectrum in the frequency domain (integral of ABS(spectrum).)
  - **T_2^* analysis:** Find the T2* of the signal. T2* is the time constant of the free induction decay. It can be measured by:
    - fitting an exponential in the time domain or a Lorenzian function to the frequency domain.

- measuring the line-width (the full width of the peak at ½ the maximum (FWHM) amplitude) of the frequency domain peak. $\Delta v = 1/\pi T_2^*$

Check off 1: Explain to a staff member how you determined SNR, and T2* and show your FID amplitude vs pulse power sketch. Explain what happens when external magnet is held near the system.

2.2 Signal averaging

Setting the number of repetitions to 1 and the readout duration to 100ms, record an FID with 1, 2, 4, and 16 averages. Make sure each one is given a unique file name:

Filename ave=1: ____________________________

Filename ave=2: ____________________________

Filename ave=4: ____________________________

Filename ave=16: ____________________________

Q1 At home: Measure the SNR in the time domain. Signal SNR in time domain is the ABS of the largest time-point in the FID divided by the SD of the noise. The last 100 time-points can likely be considered noise. Plot SNR vs SQRT(# of averages). Determine the slope.

2.3 Magnet Shimming

- The goal of shimming is to narrow the linewdth of the frequency domain signal. We do this by adding small DC currents to the gradient coils. This produces a linear field variation that can cancel whatever first-order term exists in the magnet. Thus our goal is to maximize the homogeneity of the magnetic field over the sample. Since freq α B, this means as narrow a linewidth as possible. Since the area of the frequency domain signal peak (spectrum) is determined by the amount of magnetization (number of protons magnetized) and is fixed, the peak height is inversely proportional to line width. Thus to get a narrow line; maximize the peak height. Note there is a check box for autoscaling this, might turn this feature off.
    - An alternative strategy is to reduce the digitization width so that its easy to see changes in the FID decay and change the shims to prolong the FID decay (e.g. a readout duration of 15ms…)
- In the GUI Adjust current offsets to x,y,z gradient coils to apply linear shim fields. Try to further increase the magnitude of the frequency peak (thus make the line as narrow as possible.) Save your best shim settings (save shim settings),
  record the currents:_Xshim:______________ yshim:_______________ zshim:_____________
- Re-center the frequency if necessary. Record freq:_____________________
- Record your best shimmed signal. Filename:____________________

- *Repeat "T2* Analysis", "SNR Analysis" and "Spectral Energy Analysis"; Explain what has changed and why.*

- Remove full water sample, and insert small ball sample (phantom #2).
- Recenter freq and record the signal Filename of small phant:_________________________
- *Set the readout duration back to the value it was in part 2.1 (25ms)   Repeat T2*, SNR and Spectral Energy Analysis. Explain what has changed and why.*

Check off 2: Show a staff member your FID with the shims zeroed and with the shims optimized.

Filtering and Apodization

The goal of this section is to understand the effects on the signal and noise of multiplying the time domain signal by a function.   When x[n] is the recorded time domain signal (i.e. the FID), and X[k] is the frequency domain discrete signal. The two are related by the DFS:

$$X[k] = \frac{1}{N}\sum_{n=0}^{n=N-1} x[n]\, e^{-j\frac{2\pi}{N}kn} \qquad\qquad x[n] = \sum_{k=-\frac{N}{2}}^{\frac{N}{2}-1} X[k]\, e^{j\overbrace{\underbrace{\tfrac{2\pi}{N}k}_{\Omega}}^{\Omega_0}n}$$

In this case, n is the integer index for time, and x[n] is our Free Induction Decay, and k is the integer index for temporal frequency and X[k] is the spectrum.   One of the tyrannies of the Fourier world is that all of the data samples in x[n] contribute to all of the values in X[k]. But what if most of the FID is noise? (for example if a long readout is used so that the signal has decayed to near zero for most of the samples.) Then surely there is something we can do? Can't we just zero these and reduce the noise in X[k] without really effecting the spectral shape?

We can, but the elegant way to do this is apodization, a close cousin of filtering.   If we multiply x[n] by a function w[n] to create a new time-domain signal; x'[n] = x[n] w[n], then the spectrum of this new function, X'[k], is also modified. The multiplication step is called "apodizing" the FID (from the Greek for "removing the foot"). Our goal is to choose a benign apodization window, that doesn't affect the properties of the spectrum too much, but reduces noise.

Read in your small phantom signal in MatLab. Look at its DFS (spectrum). Record the spectral SNR by recording the max of the spectrum amplitude (S_{max}) and noise SD by taking the standard deviation (SD) of the last 50 pts in the spectrum. S_{max}=___________ N_{SD} = _____________________

Boxcar window #1:   Multiply the complex FID by a real valued boxcar function that is 1 for the first 10 points and zero after that. Take the DFT and examine its spectrum. S_{max}=___________ N_{SD} = _____________________

Boxcar window #2:   Now do the same thing but with a boxcar where the transition occurs when the FID drops to an SNR of 5. Apply the boxcar, take the DFS and examine its spectrum.

S_{max}=___________ N_{SD} = _____________________

Exponential window: Now read in the small phantom signal in Matlab and multiply by an exponentially decaying function with unit amplitude (magnitude of first point), and same time constant (T2*) as you measure for the acquired FID. Plot the DFT of the apodized data and examine it.

S_{max}=___________ N_{SD} = _____________________

Check off 3: Explain to a staff member what the effect of apodization in the time domain has on the spectrum and be ready to defend your choice of best apodization function.

Q2 At home: What were the changes in the shape of the spectrum and the noise levels? Compute the SNR (amplitude of spectral peak/ noise SD) did they improve? Which seems the best apodization function?

Another popular apodization function is the Hann window: $w(n) = 0.5\left(1 - \cos\left(\frac{2\pi n}{N-1}\right)\right)$