MATLAB Tools for RF Pulse Design

• Simulator

- * Calculation of α and β abr
- * Slice Profiles ab2ex, ab2se, ab2inv, ab2sat
- * Spatial scale gt2cm
- Basic 1D RF pulse design dzrf
 - * Designs small-tip, 90's, 180's, sat pulses
 - * Min, max, and linear phase
 - * Many options, most with defaults
- 2D pulse design
 - * Spiral 2D pulses dz2d
 - * Echo-planar spin-echo pulses dzepse
- Utilities
 - * Scale RF to kHz rfscale
 - * Verse verse
 - * Conversion to signa waveforms signa
 - * Reading Signa 5X waveforms loadwave
- Location
 - * Files are in

lad:/user/local/mrsrl/matlab/rf_tools
This should be in your matlab path

RF Simulator

- Basic rf simulator abr
 - * Assumes no T_1 or T_2 decay
 - * Computes all slice profiles at once
- Simplest invocation:

$$\gg$$
 [a b] = abr(rf,x);

* rf scaled so that

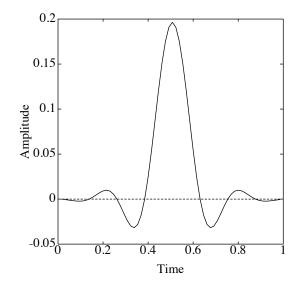
$$sum(rf) = flip angle in radians$$

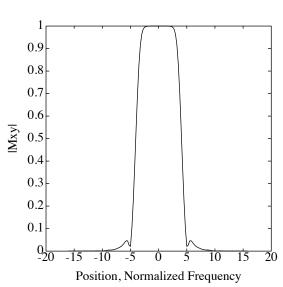
- * x scaled in normalized frequency
- * Constant gradient of area 2 * pi
- Example:

>>
$$rf = (pi/2) * msinc(64, 2);$$

>> $[a b] = abr(rf, x);$

$$>> \operatorname{cplot}(2 * \operatorname{conj}(a). * b);$$





Simulator – Outputs

- Output can be either α and β vectors, or a matrix containing each as a column
- Vectors are more convenient if
 - * You are really interested in α and β . For most people his will be almost never.
 - * Example:

```
>> [a b] = abr(rf, x);
>> cplot(b)
```

- Matrix is more convenient if
 - * You are really interested in a slice profile. This is the usual case.
 - * Example:

```
>> ab = abr(rf,x);
>> cplot(ab2se(ab))
```

Slice Profiles

- Several routines convert α and β to slice profiles.
 - * Inputs can be either vectors or a matrix
 - * Output is a complex vector or matrix
- Available routines:
 - * ab2ex excitation profile $2\alpha^*\beta$ from initial M_z
 - * ab2se spin-echo profile $i\beta^2$ from initial M_y
 - * ab2inv inversion profile $1 2|\beta|^2$ from initial M_z
 - * ab2sat saturation pulse profile, same as ab2inv
- Examples:
 - >> cplot(ab2ex(abr(rf,x)))
 - >> cplot(ab2inv(a,b))

Simulator Options

- A time varying gradient g can be specified. This should have a k-space span of 2π for consistancy with other routines.
 - * Example: gv is a time-varying gradient, and rfv is a VERSE'd rf pulse

$$>> mxy = ab2ex(abr(rfv, gv, x))$$

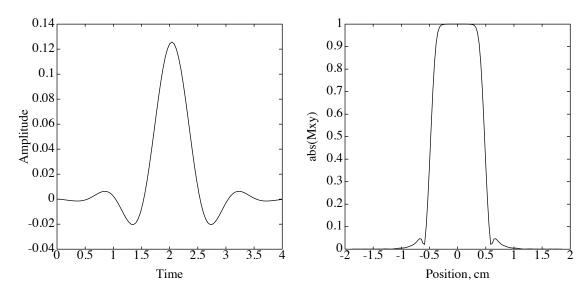
- A two dimensional gradient may be specified, simlated either over one dimension, or over a two dimensional surface.
 - * The gradient is specified as the complex vector
 - * Example:

```
>> g = gx + i * gy;
>> x = [-16:15]/4;
>> y = [-16:15]/2;
>> ab = abr(rf, g, x, y);
>> mxy = ab2ex(ab);
>> mesh(abs(mxy))
```

Spatial and Frequency Scale

- Conversion of normalized frequency to space gt2cm
- Inputs:
 - * Vector of normalized frequencies
 - * Gradient strength in G/cm
 - * Pulse duration in ms
- Example: an rf pulse played with a 0.5 G/cm gradient for 4 ms.

>> plot(gt2cm(x, 0.5, 4), abs(ab2ex(abr(rf,x))))



- Also, conversion of normalized frequency to kHz t2hz
 - * To plot the previous example in kHz instead of cm,

$$>>$$
 plot(t2hz(x,4),abs(ab2ex(abr(rf,x))))

RF Pulse Design

- RF pulse design front end is dzrf
- Inputs are the number of points and the time-bandwidth of the pulse. The pulse type is optional.

$$>> rf = dzrf(160, 8, 'se');$$

• Types of pulses are:

'st' - Small tip exciation pulse (default, returns filter)

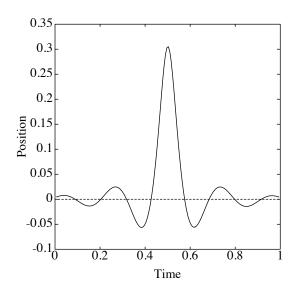
'ex' $-\pi/2$ excitation pulse

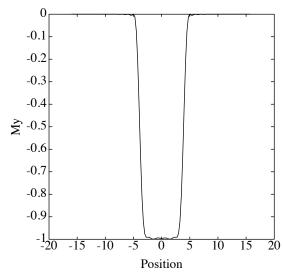
'inv' - Inversion pulse

'se' – Spin-echo pulse

'sat' $-\pi/2$ saturation pulse

- Default assumptions:
 - * In-slice and out-of-slice ripples are 1%
 - * The underlying filter is designed using least-squares





RF Pulse Design – Filter Types

- The method used to design the underlying digital filter can be specified.
 - * Example: to use an msinc to design a saturation pulse,

$$>> rf = dzrf(160, 8, 'sat', 'ms');$$

• Filter options are

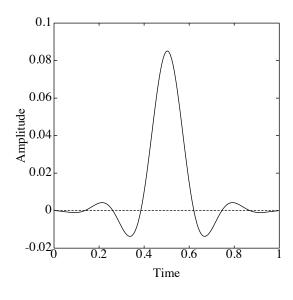
'ms' - Msinc, Hamming windowed sinc

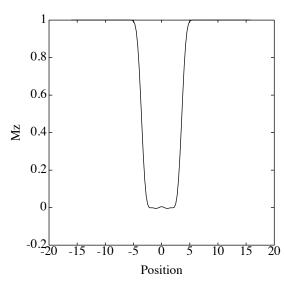
'pm' – Parks-McClellan equal-ripple (can be slow)

'ls' – Least-squares (default, recommended)

'min' - Minimum-phase using factored pm filter

'max' – Maximum-phase using factored pm filter



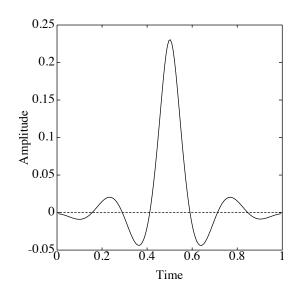


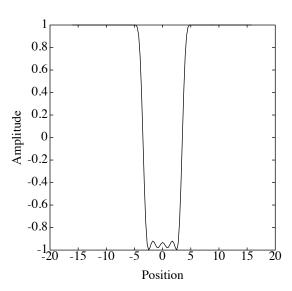
RF Pulse Design – Ripple Specification

- In-slice and out-of-slice ripple can be specified. Transition widths are automatically calculated.
- Default in-slice and out-of-slice ripples are 1%.
- Example: to design a least squares inversion with 0.1% out-of-slice, and 5% in-slice,

$$>> \text{rf} = \text{dzrf}(160, 8, '\text{inv}', '\text{ls}', 0.05, 0.001);$$

>> plot(x, ab2inv(abr(rf,x)));





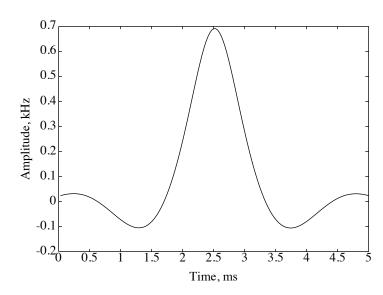
RF Scale

- RF amplitude on signa is limited
 - * Phantoms about 1 kHz
 - * Humans about 700 Hz
- RF amplitude for a given duration rfscale
- Inputs:
 - * RF pulse, area normalized to flip angle in radians
 - * Pulse duration in ms
- Example:

$$>> rf = dzrf(160, 4, 'se');$$

$$>> t = [1:160]/160;$$

$$>>$$
 plot(t * 5, rfscale(rf, 5));



VERSE

- Verse an RF pulse verse
- Inputs:
 - * RF pulse
 - * Time-varying gradient (always positive)
- Example:

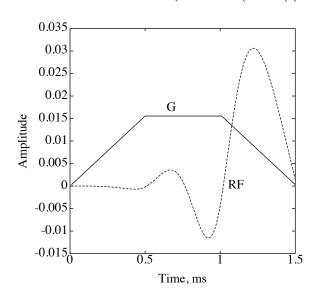
$$>> gv = [[1:50]/50 \text{ ones}(1,50) [50:-1:1]/50]$$

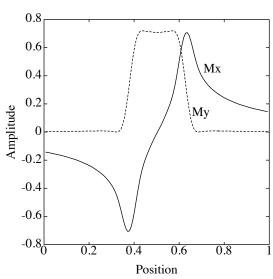
$$>> rf = dzrf(200, 8, 'st', 'ms');$$

$$>>$$
rfv = verse(gv, rf(1:100));

$$>>$$
 plot(t, gv, t, rfv);

>> cplot(ab2ex(abr((rf,x))));





Signa Waveform File Conversion

- Save a signa waveform file signa
 - * Rescales to full scale, unless specified
 - * Masks off low bit
 - * Creates a 4.X waveform file
 - * Use xlatebin to translate to 5.X
- Inputs:
 - * RF pulse
 - * File base name, .wav is automatically appended
 - * An additional .r and .i are appended for complex waveforms
- Example: this creates the signa file new_se.wav
 - >> rf = dzrf(160, 4, 'se');
 - >> signa(rf,'new_se');

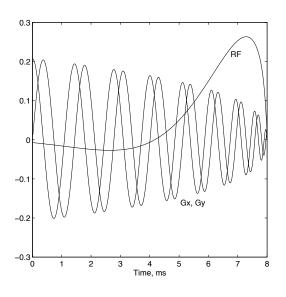
2D Spiral Pulses

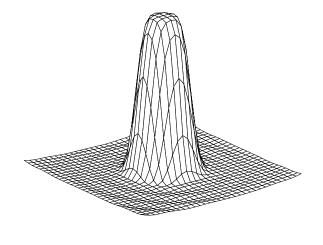
- Design spiral gradient and rf waveform dz2d
 - * Inward slew and amplitude limited spiral
 - * Windowed jinc k-space weighting
- Example: design an 8 ms 8 turn spiral and simulate it

$$>> [rf g] = dz2d(8,1,4,512,1,2);$$

$$>> xs = [-16:15]/2;$$

>> mesh(abs(ab2ex(abr(rf*(pi/2),g,xs,xs))));





Echo-Planar Spin-Echo Pulses

- Spectral-spatial and EP pulses dzepse
 - * Full 2D inverse SLR design
- Example: a 20 ms spectral-spatial spin-echo pulse using a trapezoid waveform g1

>> g1 = [[0.5 : 15.5]/16ones(1,16)[15.5 :
$$-1$$
 : 0.5]/16];

>> rf = dzepse(pi, g1, 4, 1.5, 13, 0.15);

$$>> g = [g1 - g1 \dots g1] * 2 * pi/sum(g1);$$

>> om = ones(1, length(rf)) * 2 * pi/length(rf);

>> mesh(-imag(ab2se(abr(rf,g+i*om,xs,xs))));

