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:

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

  - * rf scaled so that

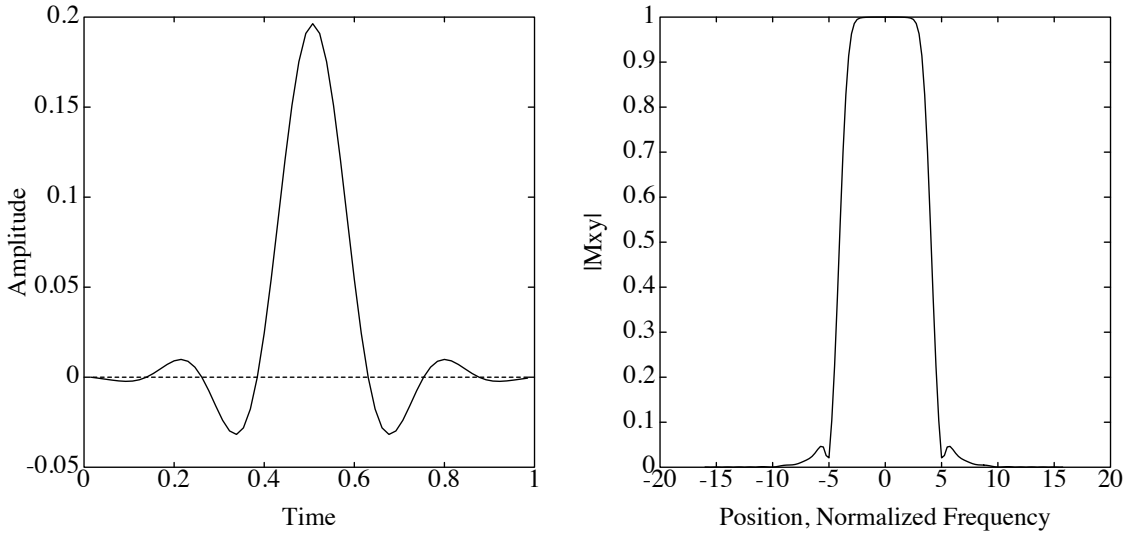
    $$\text{sum(rf)} = \text{flip angle in radians}$$

  - * x scaled in normalized frequency
  - * Constant gradient of area $2 * \text{pi}$
- Example:

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

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

  $>>$ cplot(2 * 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);

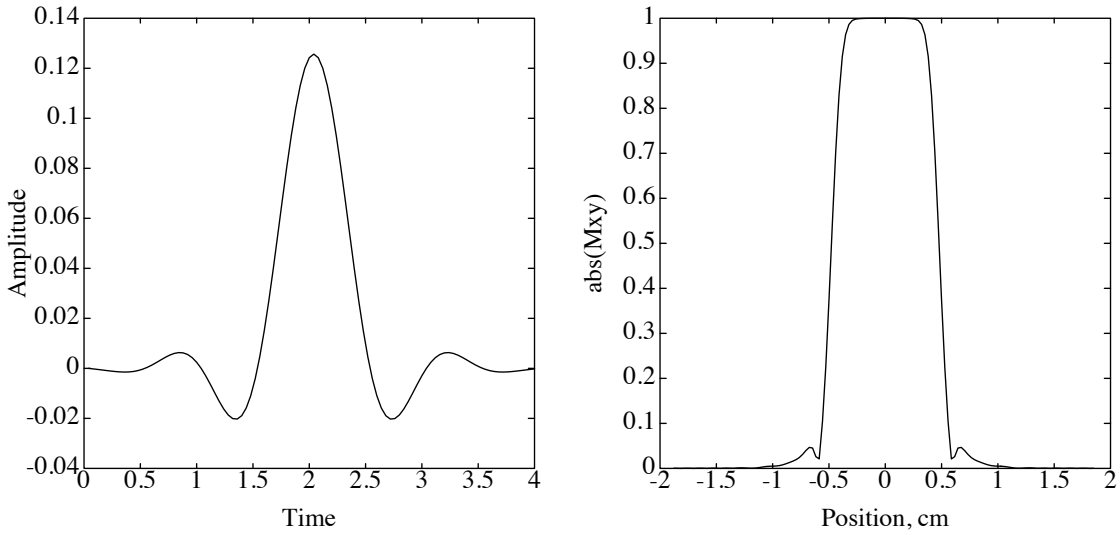
    >> mxy = ab2ex(ab);

    >> 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

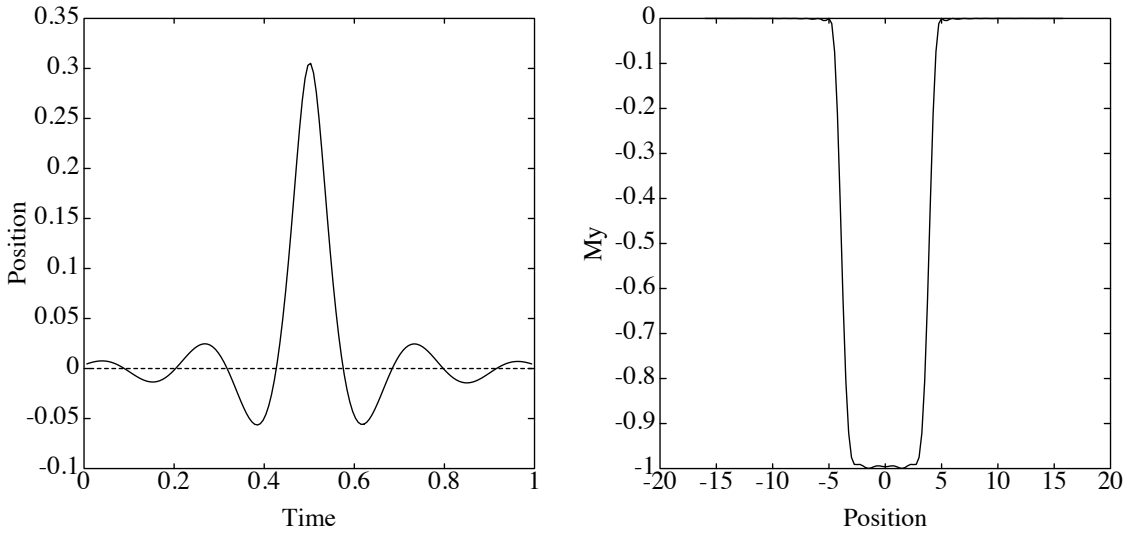
  'inv' – Inversion pulse

  '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

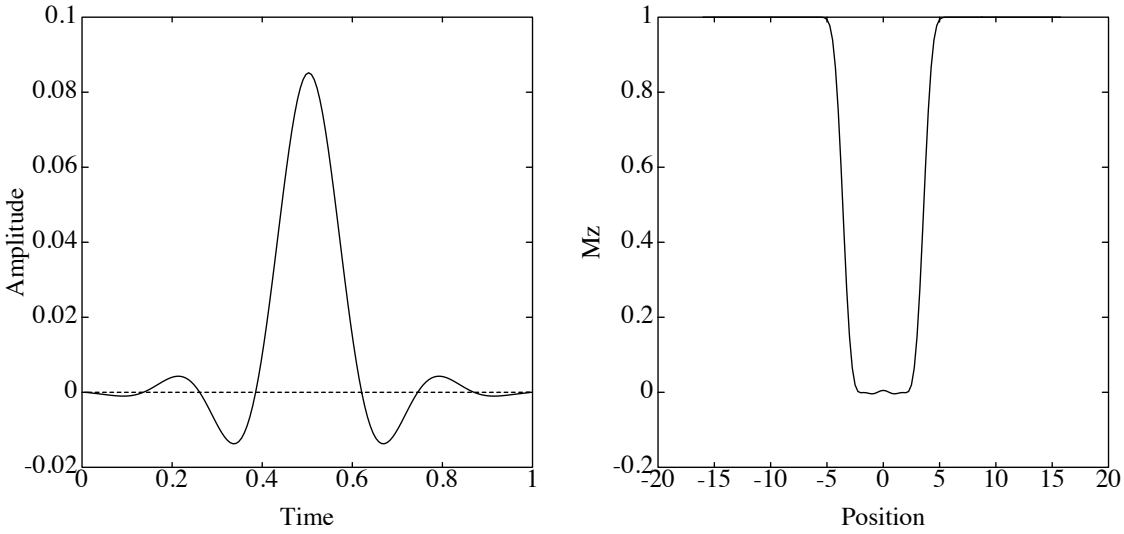
  'ms' – Msinc, Hamming windowed sinc

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

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

  'min' – Minimum-phase using factored pm filter

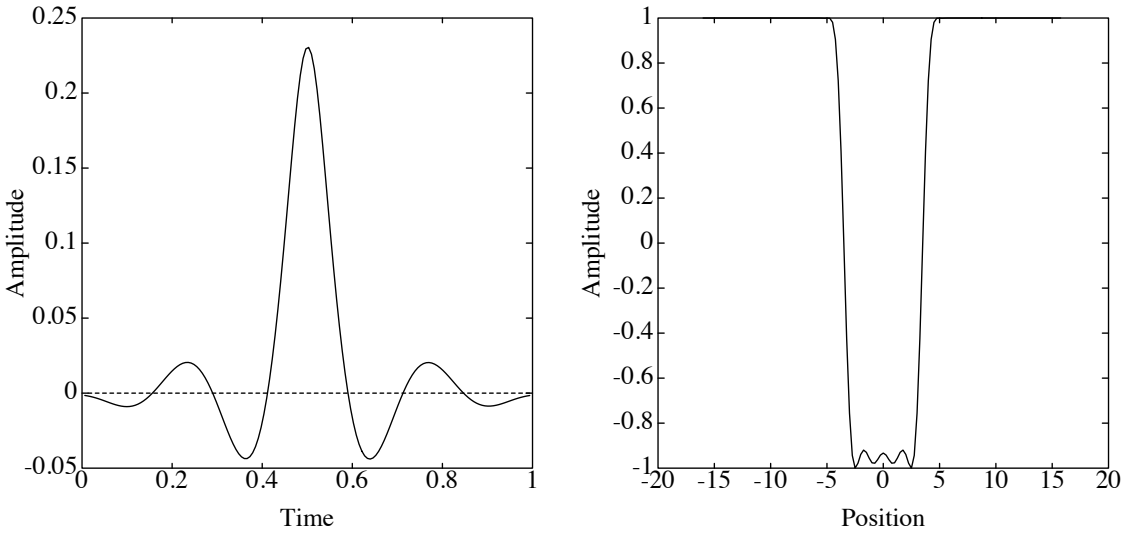
  'max' – Maximum-phase using factored pm filter



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,

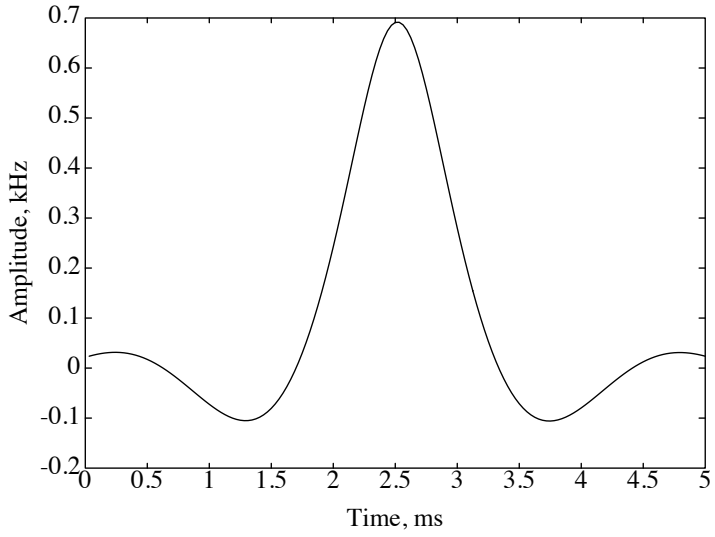
```
>> rf = dzrf(160,8,'inv','ls',0.05,0.001);
>> plot(x,ab2inv(abr(rf,x)));
```



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:

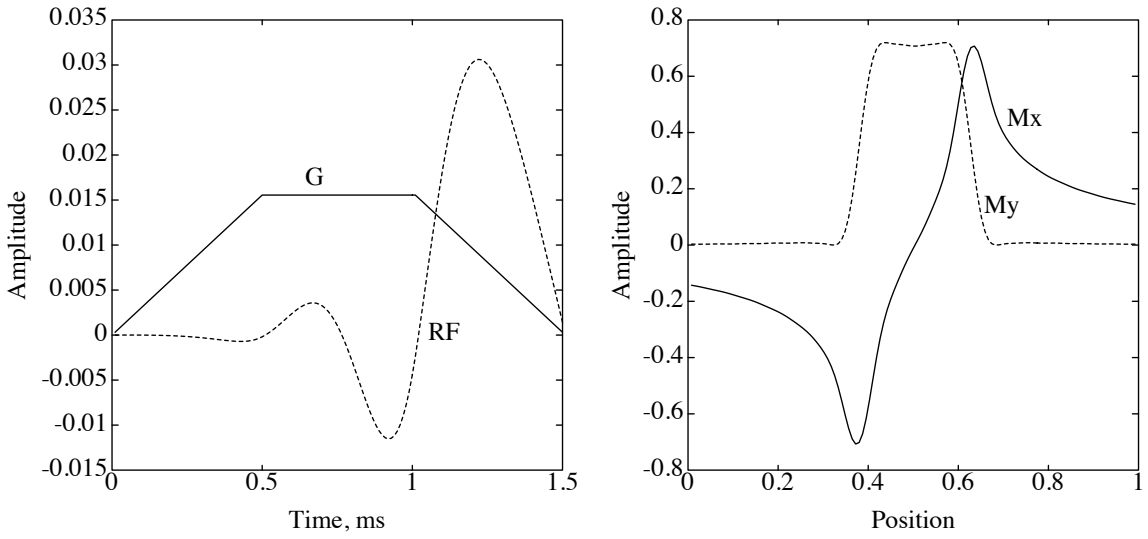
```
>> rf = dzrf(160,4,'se');
>> t = [1:160]/160;
>> plot(t*5, rfscale(rf,5));
```



VERSE

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

```
>> gv = [[1:50]/50 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');

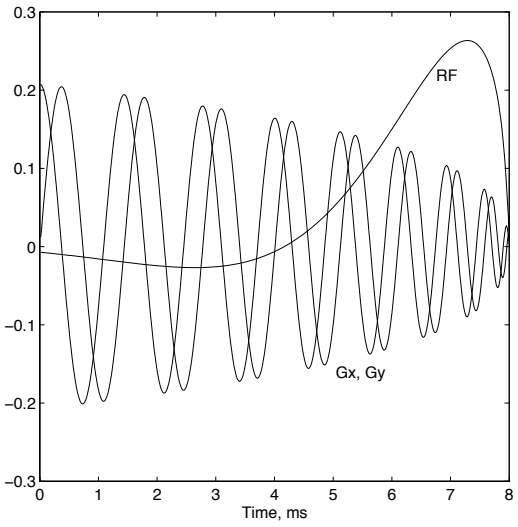
2D Spiral Pulses

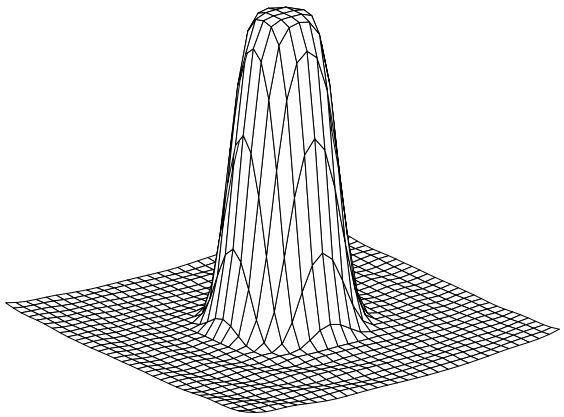
- Design spiral gradient and rf waveform – dz2d
  - * Inward slew and amplitude limited spiral
  - * Windowed jinc k-space weighting
- Example: design an 8 ms 8 turn spiral and simulate it

  >> [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 . . . g1] ∗ 2 ∗ pi/sum(g1);

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

  $>>$ mesh(−imag(ab2se(abr(rf, g + i ∗ om, xs, xs))));