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:

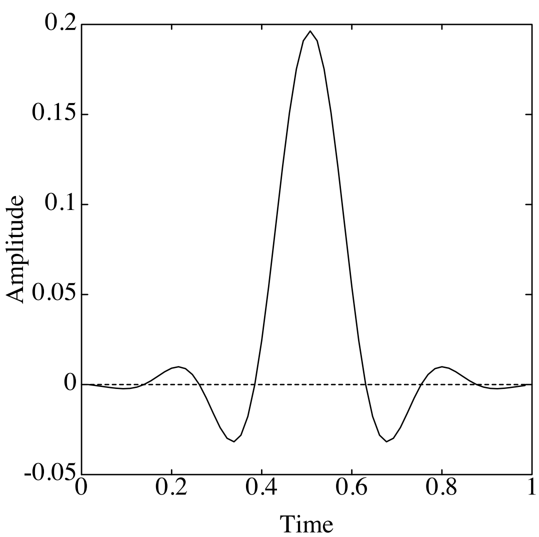
  >> [a b] = abr(rf, x);

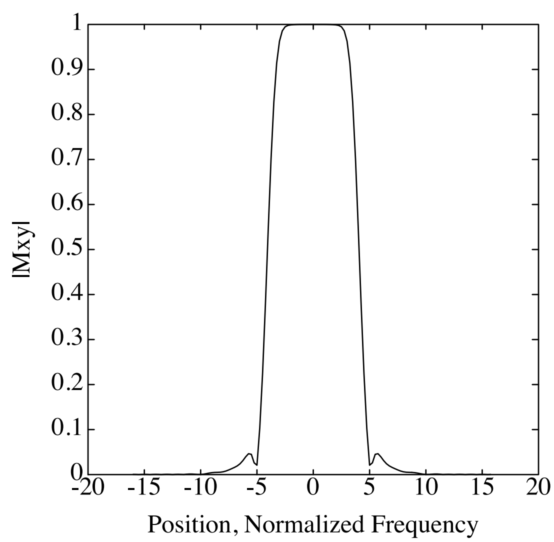
  - * rf scaled so that

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

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

    $>>$ $[\mathrm{a\ b}] = \mathrm{abr}(\mathrm{rf}, \mathrm{x});$

    $>>$ $\mathrm{cplot}(\mathrm{b})$
- Matrix is more convenient if
  - * You are really interested in a slice profile. This is the usual case.
  - * Example:

    $>>$ $\mathrm{ab} = \mathrm{abr}(\mathrm{rf}, \mathrm{x});$

    $>>$ $\mathrm{cplot}(\mathrm{ab2se}(\mathrm{ab}))$

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

    $>> \ \mathrm{mxy} = \mathrm{ab2ex}(\mathrm{abr}(\mathrm{rfv}, \mathrm{gv}, \mathrm{x}))$
- 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:

    $>> \ \mathrm{g} = \mathrm{gx} + \mathrm{i} * \mathrm{gy};$

    $>> \ \mathrm{x} = [-16 : 15]/4;$

    $>> \ \mathrm{y} = [-16 : 15]/2;$

    $>> \ \mathrm{ab} = \mathrm{abr}(\mathrm{rf}, \mathrm{g}, \mathrm{x}, \mathrm{y});$

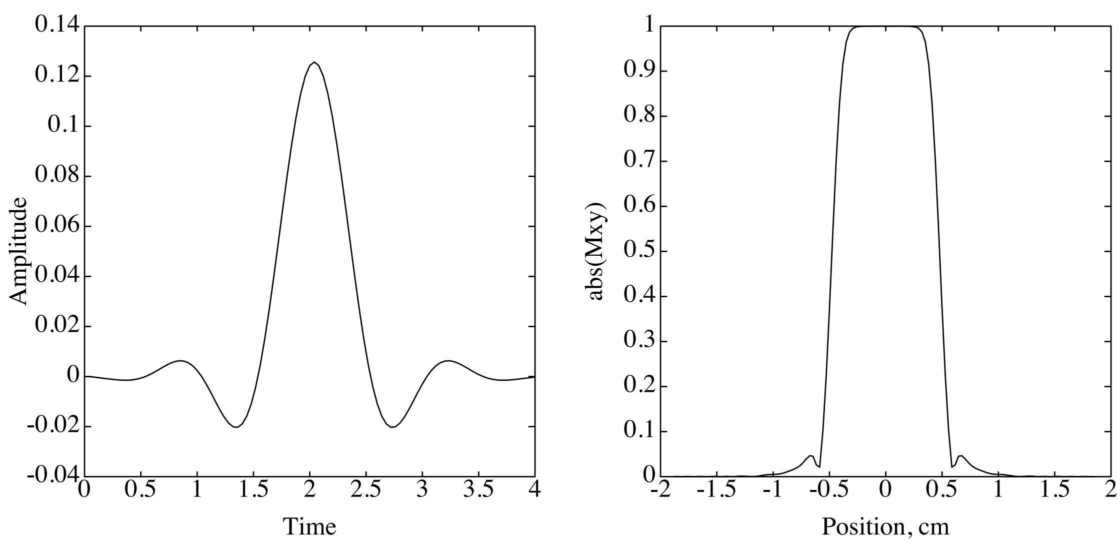
    $>> \ \mathrm{mxy} = \mathrm{ab2ex}(\mathrm{ab});$

    $>> \ \mathrm{mesh}(\mathrm{abs}(\mathrm{mxy}))$

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.

  $>>$ $\mathrm{rf} = \mathrm{dzrf}(160, 8, 'se');$

- Types of pulses are:

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

  'ex' – $\pi/2$ excitation pulse

  'inv' – Inversion pulse

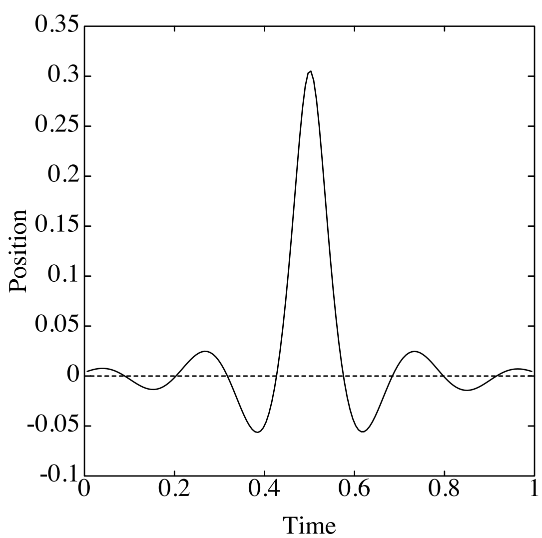
  'se' – Spin-echo pulse

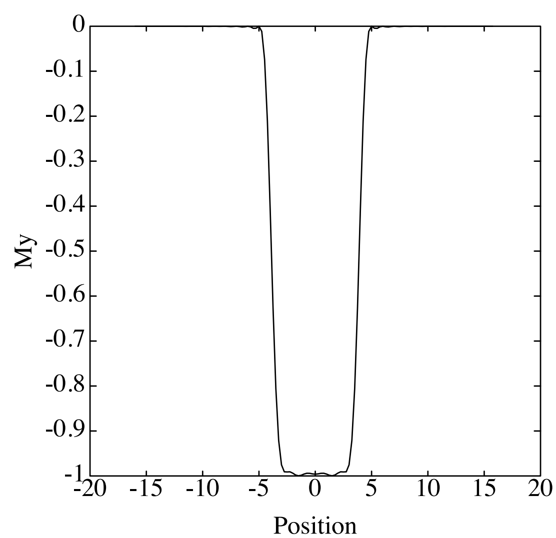
  'sat' – $\pi/2$ saturation pulse

- 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

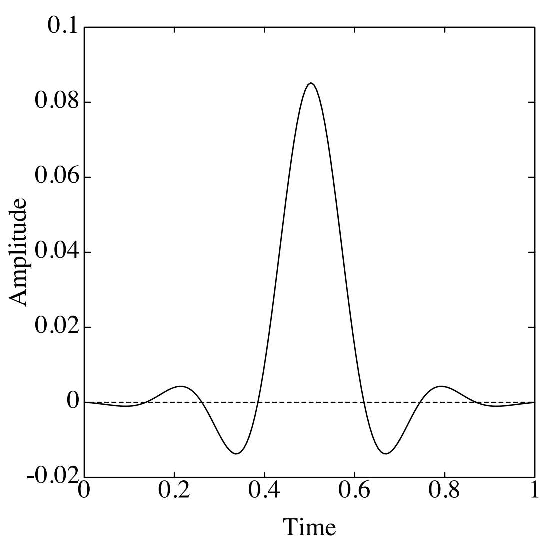
  'ms' – Msinc, Hamming windowed sinc

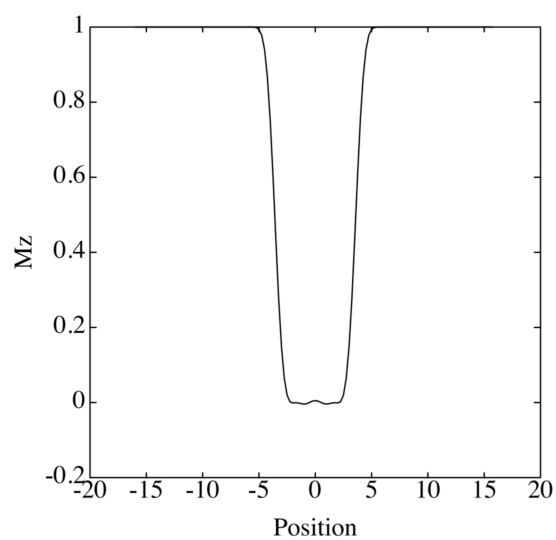
  'pm' – Parks-McClellan equal-ripple (can be slow)

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

  'min' – Minimum-phase using factored pm filter

  'max' – Maximum-phase using factored pm filter



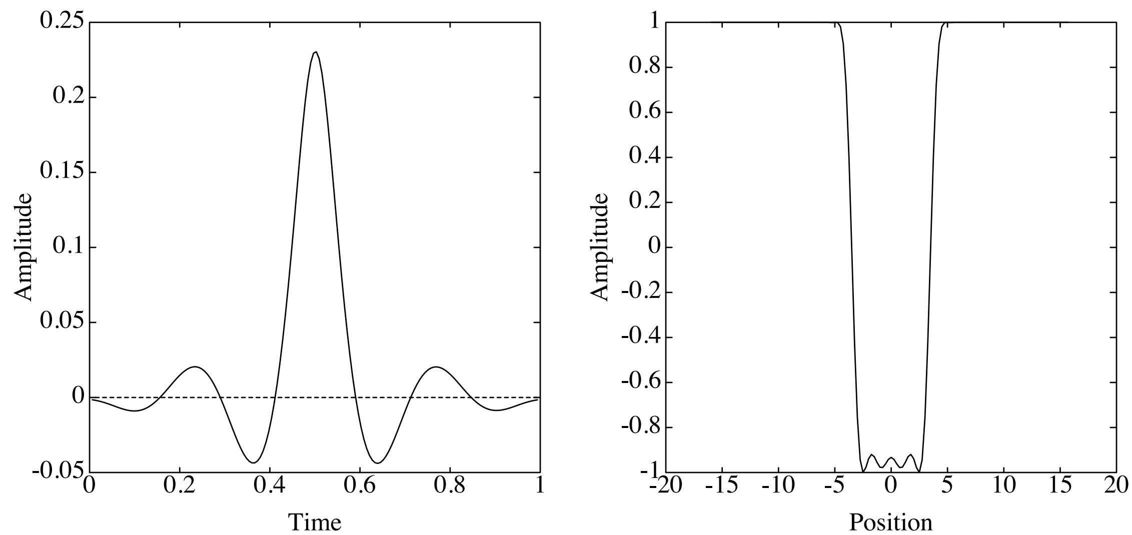


RF Pulse Design – Ripple Specification

- 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,

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

$$>> \ \mathrm{plot}(\mathrm{x}, \mathrm{ab2inv}(\mathrm{abr}(\mathrm{rf}, \mathrm{x})));$$



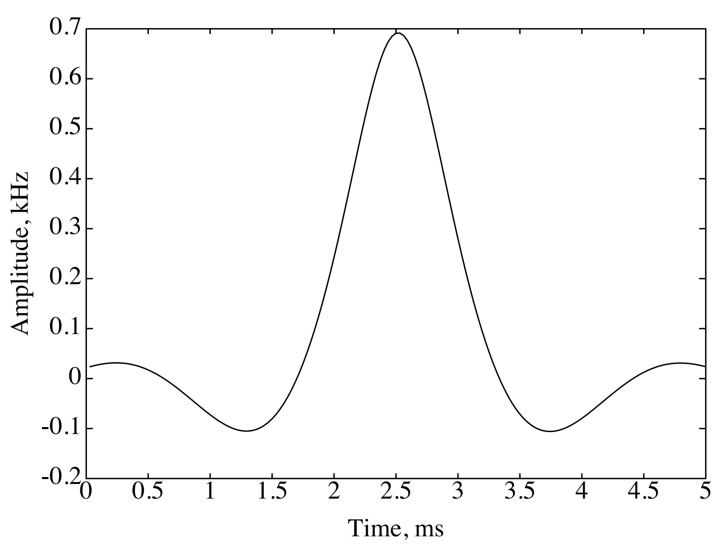
RF Scale

- 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:

$$>> \ \mathrm{rf} = \mathrm{dzrf}(160, 4,' \mathrm{se}');$$

$$>> \ \mathrm{t} = [1:160]/160;$$

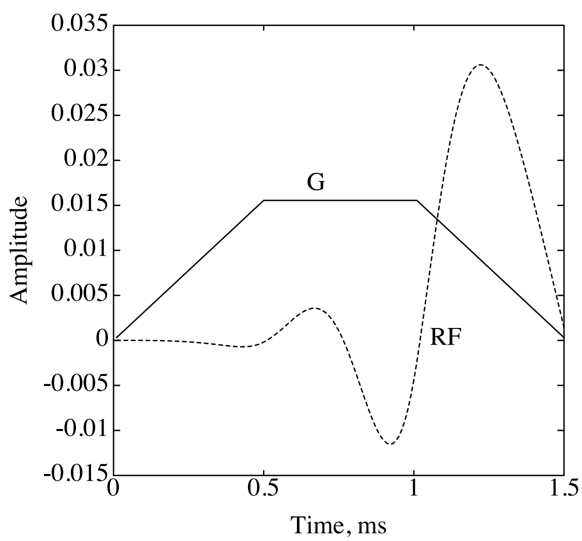
$$>> \ \mathrm{plot}(\mathrm{t} * 5, \mathrm{rfscale}(\mathrm{rf}, 5));$$

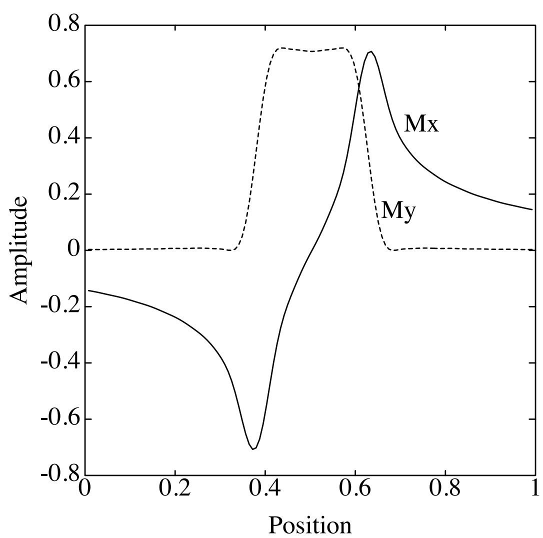


VERSE

- 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');
```

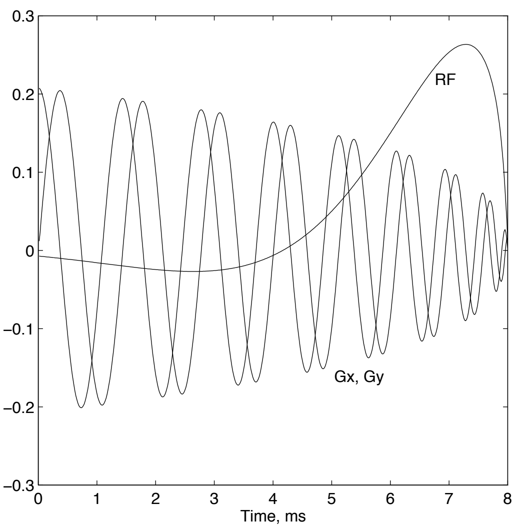
2D Spiral Pulses

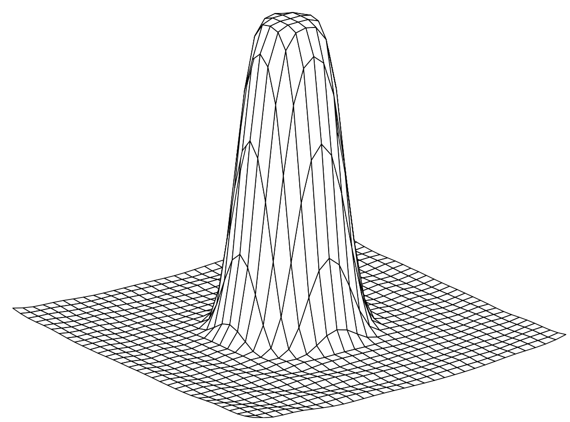
- Design spiral gradient and rf waveform – dz2d
  * Inward slew and amplitude limited spiral
  * Windowed jinc k-space weighting
- Example: design an 8 ms 8 turn spiral and simulate it

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

  $>>$ $\text{xs} = [-16 : 15]/2;$

  $>>$ $\text{mesh}(\text{abs}(\text{ab2ex}(\text{abr}(\text{rf} * (\text{pi}/2), \text{g}, \text{xs}, \text{xs}))));$





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

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

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

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

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

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