

## EE469B: Assignment 6

Due Wednesday, Nov. 4

This problem set requires several m-files that are available on the course web site. These are:

dinf.m, fmp.m, dzpm.m, dzls.m, dzmp.m

These are located in the directory

<http://www.stanford.edu/class/ee469b/mfiles/>

as usual.

Note that this assignment is due in *two weeks*, since the ISMRM abstract deadline is next week. There will be one more assignment after this.

**1. SLR Pulse Design** The mfiles `dzls` and `dzmp` provide an interface to the matlab `firpm` and `firls` routines using the relationships we discussed in class.

These should be invoked by

```
>> bls = dzls(N, tb, delta1, delta2)
>> bpm = dzpm(N, tb, delta1, delta2)
```

where `N` is the filter length, `tb` is the time bandwidth, and `delta1` and `delta2` are the passband and stopband ripple amplitudes. These use the m-file `dinf.m` that computes the  $D_\infty(\delta_1, \delta_2)$  function, provided on the class web site.

Once you have  $B_N(z)$ , you can design an RF pulse by computing the corresponding minimum phase  $A_N(z)$ , and then doing the back recursion. There are m-files `b2a.m` and `ab2rf.m` that perform these functions. The `b2a.m` routine requires `mag2mp.m` which is also available on the web site. To design an RF pulse for a flip angle `theta`,

```
>> b = dzls(N, tb, delta1, delta2);
>> bs = b*sin(theta/2);
>> a = b2a(bs);
>> rf = ab2rf(a, bs);
```

Note that the passband and stopband ripples should be chosen according to they type of RF pulse you are designing, and the amount of ripple you can allow in the magnetization profile.

**a) Short Spin-Echo Pulse** Design a spin-echo pulse with  $\delta_1 = \delta_2 = 0.001$ , and a time-bandwidth  $TBW = 3.4$ . Use a least-squares design. How long is the pulse, if the RF is limited to 0.2 G? Plot the RF waveform, and the spin-echo slice profile. What is the gradient amplitude for a 5 mm slice? This is a very typical spin-echo pulse.

**Solution:**

First we have to figure out what ripple amplitudes to use to design beta, which are

$$\begin{aligned}\delta_1 &= 0.001/4 \\ \delta_2 &= \sqrt{0.001}\end{aligned}$$

Then use `dzls` to produce beta, and designing alpha, and the rf waveform

```

b = dzls(256, 3.4, 0.001/4, sqrt(0.001));
a = b2a(b);
rf = ab2rf(a, b);

```

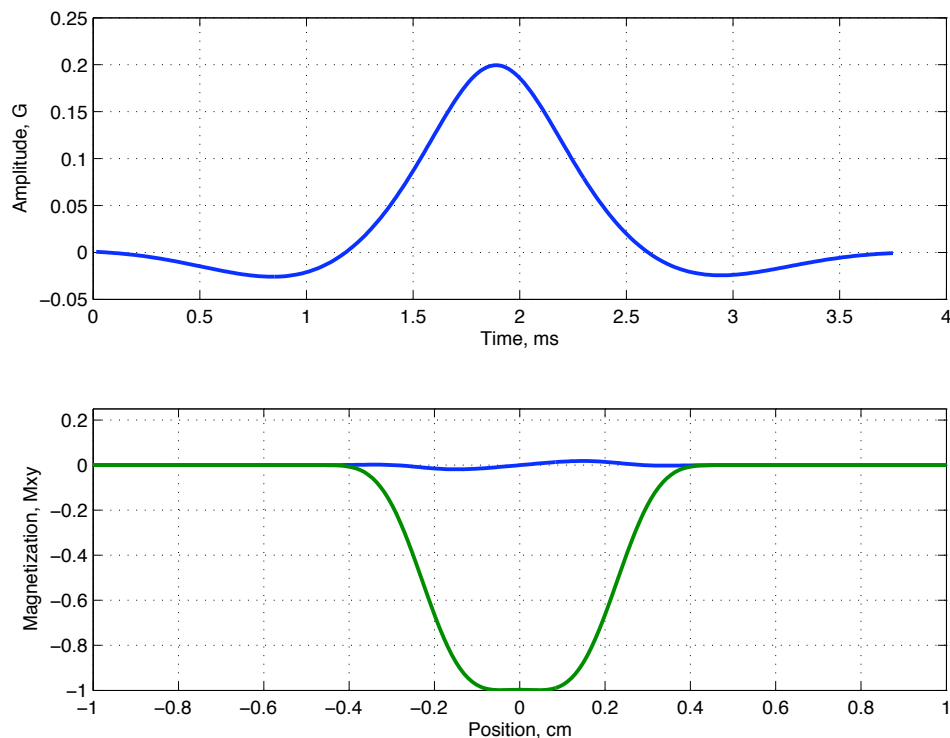
By trial and error, we can find a pulse length of 3.75 ms for 0.2 G amplitude. The bandwidth of the 3.75 ms pulse is  $(3.4/(3.75 \text{ ms})) = 0.9 \text{ kHz}$ . The gradient that produces a 5 mm slice is then found by solving

$$\gamma G(0.5 \text{ cm}) = 0.907 \text{ kHz}$$

for G, or

$$G = 0.9 \text{ kHz}/((0.5 \text{ cm}) * (4.257 \text{ kHz/G})) = 0.42 \text{ G/cm}$$

The RF pulses, and its slice profile is plotted below.



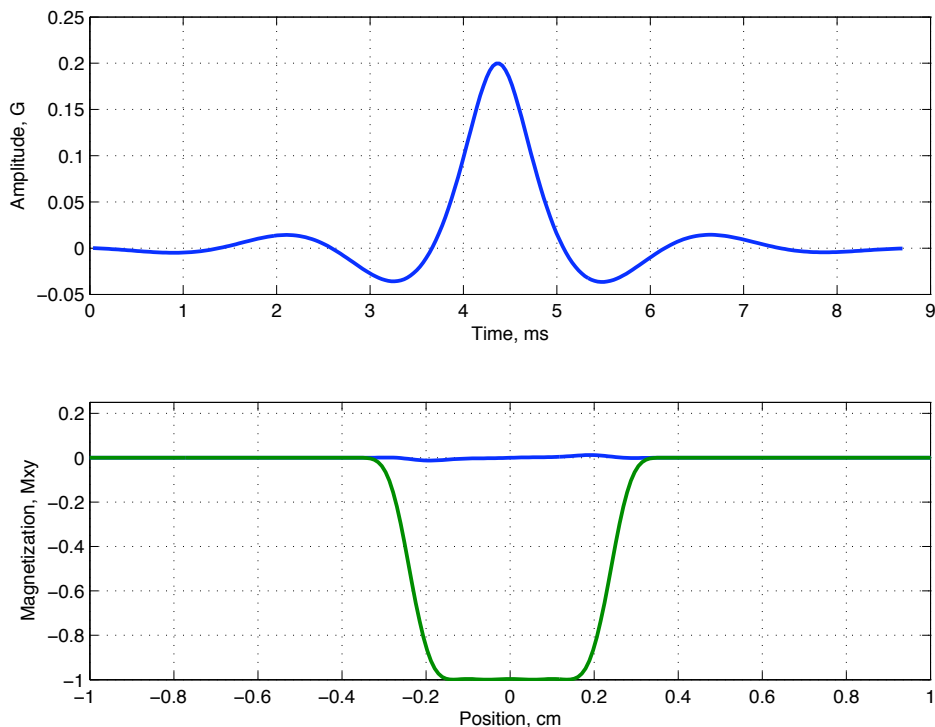
**b) Long Spin-Echo Pulse** Redesign the pulse for a time bandwidth  $TBW = 7$ . How long is the pulse, if the RF is limited to 0.2 G? Plot the RF waveform, and the spin-echo slice profile. What is the gradient amplitude for a 5 mm slice?

**Solution:**

Using the same procedure, we find that we need about 8.7 ms for this pulse. The bandwidth of this pulse is  $7/(8.75 \text{ ms}) = 0.800 \text{ kHz}$ . The gradient strength for a 5 mm slice is

$$G = 0.8 \text{ kHz}/((0.5 \text{ cm}) * (4.257 \text{ kHz/G})) = 0.376 \text{ G/cm}$$

The pulse and its slice profile are plotted below.



**2. Power in Accurate 180 Pulses** Design a "perfect"  $B_N(z)$  for a time-bandwidth  $TBW = 8$ , and passband and stopband ripples of  $\delta_1 = 1e - 6$ , and  $\delta_2 = 1e - 3$ .

```
>> b = dzls(256, 8, 1e-6, 1e-3);
>> b = b / (1 + 1e-6);
```

where we have scaled  $b$  to be exactly one at the ripple peaks. Design a sequence of RF pulses by scaling  $b$  by 0.99, 0.999, 0.9999, and 0.99999.

- What flip angles do these correspond to?
- Plot the RF pulses on a common axis. Describe how they differ.
- Plot the peak power as a function of flip angle.

**Solution:**

The  $b$  scaled by 0.9, 0.99, 0.999, 0.9999, and 0.99999 corresponds to flip angles of 128, 164, 175, 178, and 179.5 degrees.

The rf pulses are plotted in Fig. 1. As  $b$  gets closer to 1, the RF pulses become wider bandwidth (narrower main lobe) and higher amplitude. Most remarkable is the change from 178 to 179.5 degrees, a very small change, still produces a significant change in the RF pulse.

The peak and average power are plotted in Fig. 2.

This example shows that it is very expensive to produce a true 180 degree pulse. Very small gains in the spin-echo profile require very large increases in peak and average power. This is very important to keep in mind.

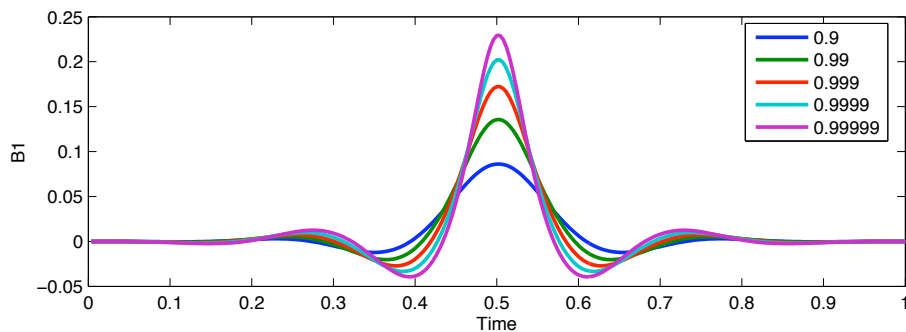


Figure 1: Spin echo pulses for  $b$  scaled by 0.9, 0.99, 0.999, 0.9999, and 0.99999 corresponding to flip angles of 128, 164, 175, 178, and 179.5 degrees.

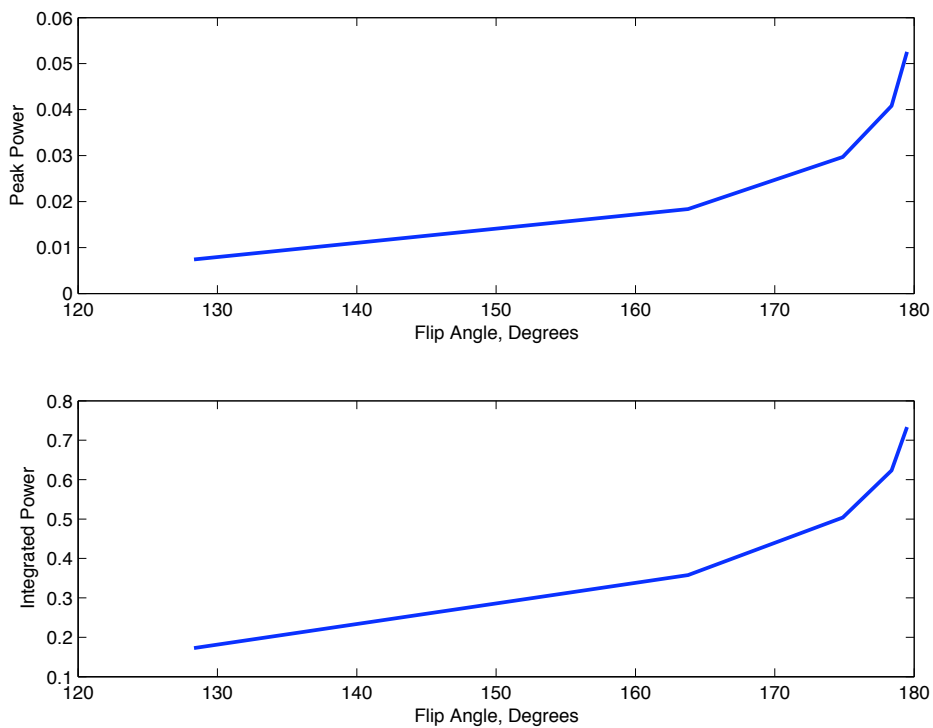


Figure 2: Peak and average power for a spin echo pulse, as a function of flip angle.

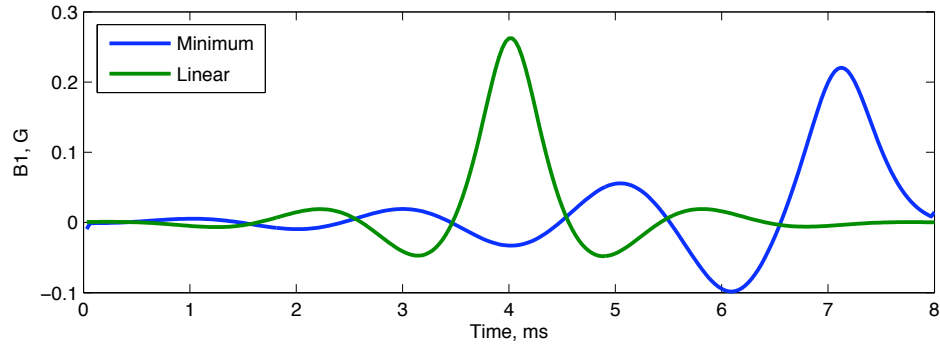


Figure 3: Minimum phase and linear phase RF pulses.

**3) Minimum Phase Inversion Pulses** This problem compares linear phase and minimum phase inversion pulses. In each case, use a time-bandwidth of 8, passband ripple of 0.001, and stopband ripple of 0.0001.

To design minimum phase filters, there is a matlab routine `dzmp.m` on the web site. This requires `fmp.m` and `mag2mp.m`, which are also available on the web site. The inputs to `dzmp.m` are the same as for the routines `dzls.m` and `dzpm.m` described on problem 1.

**a)** Design a linear phase equal-ripple inversion pulse, and a minimum phase inversion pulse. What are fractional transition widths? Assume the pulses are 8 ms, and plot both scaled to Gauss, on the same axis.

**b)** Simulate the slice profiles, and plot them. In one plot show the entire slice profile, and in a second plot, show the difference in transition width.

**Solution:** Using the expressions for the effective ripples for inversion pulses, the fractional transition widths are 0.412 for the least-squares design, and 0.2957 for the minimum phase design. The two RF pulses are shown in Fig. 3. The slice profiles are shown in Fig. 4.

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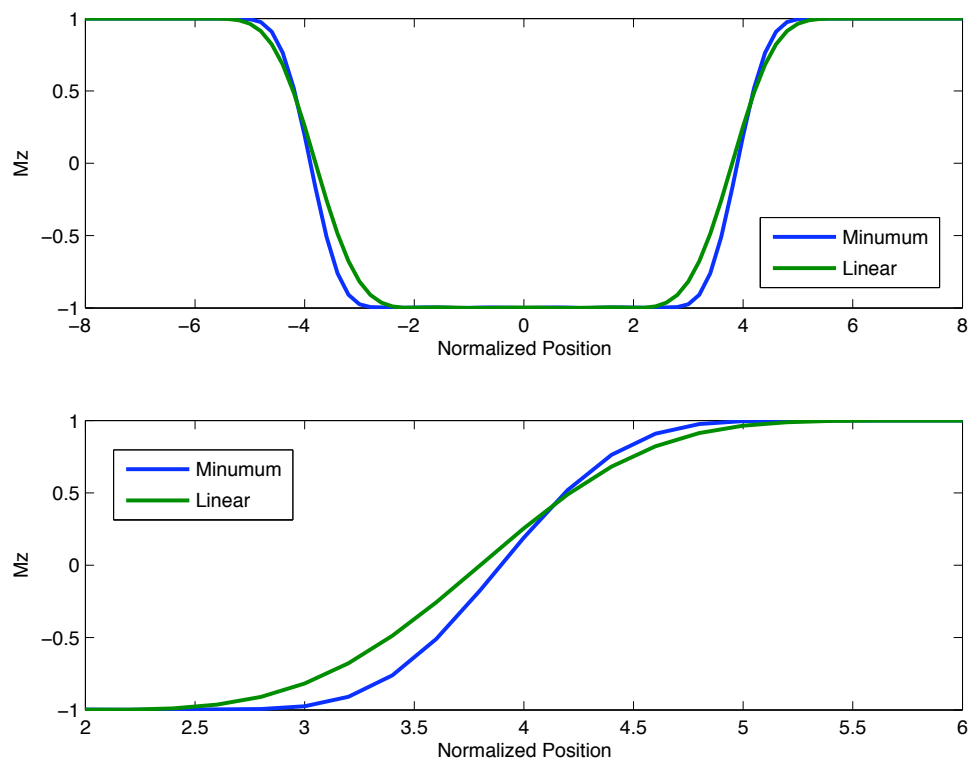


Figure 4: Minimum phase and linear phase inversion profiles.