EE469B: Assignment 4

Due Wednesday, Oct. 21

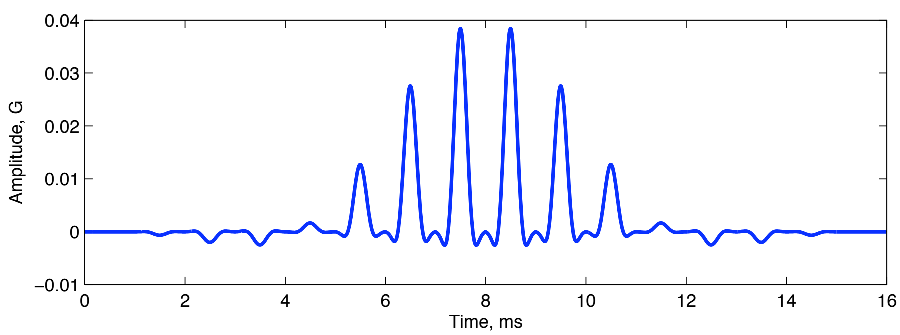
1. True Null/Flyback Spectral-Spatial Pulses True null and flyback designs are very closely related. In this problem we look at the properties of the flyback pulse sidelobe structure to predict the characteristics of the opposed sidelobe in the true null design.

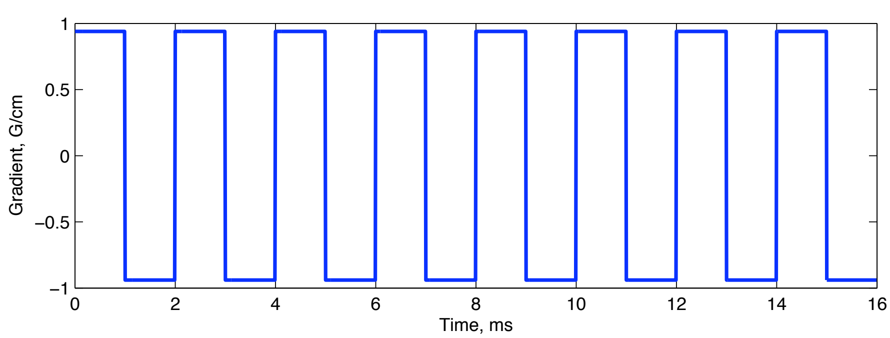
a) True Null Pulse Design Design a true null spectral-spatial pulse, with a spatial $SBW = 4$ profile, and a spectral $TBW = 4$ profile. For convenience, assume the gradient slew rate is unlimited, so the gradient sublobes are perfect rectangles. Also for convenience, assume the lipid null is centered at 250 Hz from water. Design for a 1 cm slice, and spectral passband of ± 125 Hz. Sample the RF and gradient waveforms at 10 us. Plot the RF and gradient waveforms.

Solution:
This will be a TBW 4 spectral envelope, with TBW 4 subpulses. If the subpulses are 1 ms, the true null will be at 250 Hz, as specified. The spectral passband is 0.25 kHz, so the pulse duration T can be found from

$$\begin{aligned} T(BW) &= 4 \\ T(0.25 \text{ kHz}) &= 4 \\ T &= 16 \text{ ms}, \end{aligned}$$

so we have a 16 ms RF pulse, with 1 ms subpulses. The subpulses are also TBW 4, and 1 ms, so the bandwith is then 4 kHz. To get a 1 cm slice, we want 4.257 G/cm$G * (1 \text{ cm}) = 4$ kHz which gives a gradient strength of about 0.94 G/cm. The RF and gradient waveforms are plotted below.





b) True Null Excitation Profile Simulate the excitation profile using the same method you used to simulate 2D spatial RF pulses in the previous assignment. The gradient waveform is scaled as usual. The spectral dimension is simulated with a constant gradient,

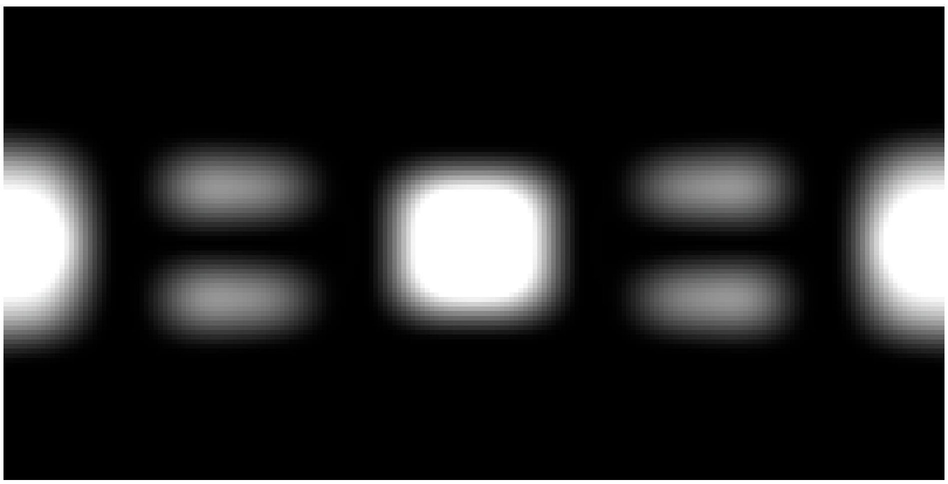
```
>> gy = 2*pi*dt*ones(1,length(rf));
```

The spectral profile will then be in kHz, if `dt` is in ms. Simulate the profile from $\pm 1/(\Delta T)$, the sampling frequency, and ± 2 cm. Plot the response as an image using

```
>> imshow(abs(mxy),[0 0.5]);
```

where the scale factor is included to make the sidelobes more apparent.

Solution:
The excitation profile is shown below:

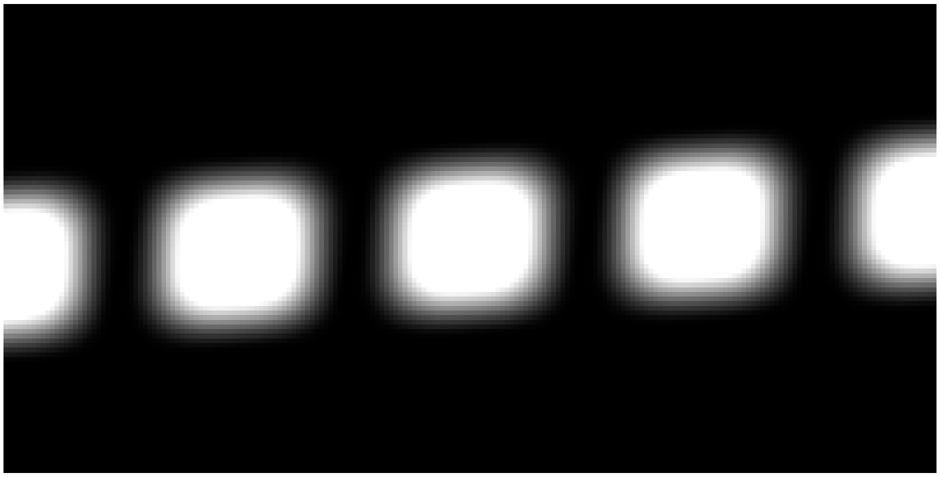


The image goes from +/- 1 kHz in frequency, and +/- 2 cm is space. Note that there is a true null at +/- 250 Hz.

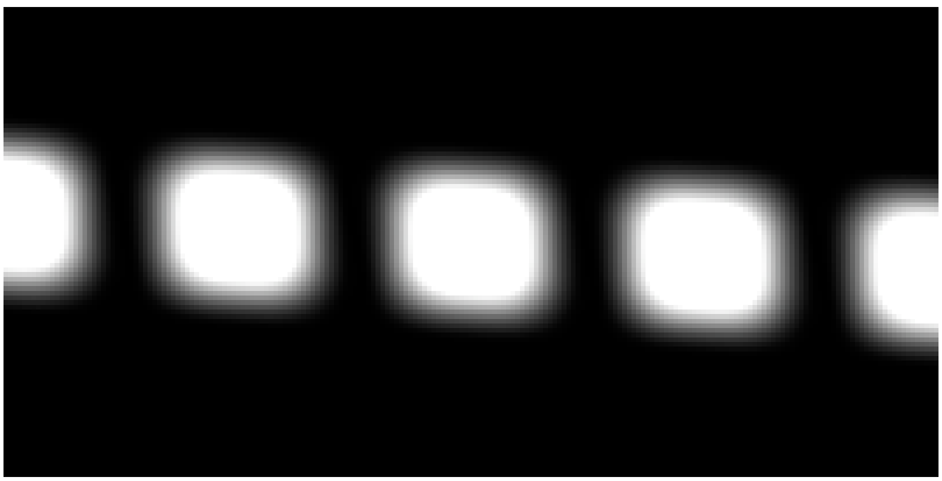
c) Flyback Excitation Profile Generate two flyback pulses, one by zeroing out the even subpulses, and another by zeroing out the odd subpulses. Double the amplitude of the remaining subpulses, so that the total flip angle remains the same.

Simulate these profiles, and plot the responses.

Solution:
The profiles of the even and odd sets of subpulses are shown below:



Odd Sublobes



Even Sublobes

d) Characteristics of the Flyback Profile The flyback excitation profiles are inclined. Find an analytic expression for this angle in cm/kHz. Does it agree with your simulation?

Hint: How far does is each spatial subpulse shifted in space, for a given frequency shift.

Solution:

For the flyback design, all of the sublobes have the same polarity. Each sublobe shifts in space due to the increasing frequency offset. A gradient of 0.94 G/cm corresponds to 4 kHz/cm. Hence at 1 kHz, the subpulses are each spatially shifted by 0.25 cm. This is the source of the inclined profile. The slope is 0.25 cm/kHz.

d) Opposing Null In the small-tip-angle case we are considering here, the excitation profiles are linear functions of the applied RF. Hence, the true null profile from part (b) should be the same as the sum of the two flyback profiles of part (c), divided by 2.

Consider the opposed null in the true null design. Explain why it is the sum of the two $1/(2\Delta T)$ sidelobes of the flyback profiles.

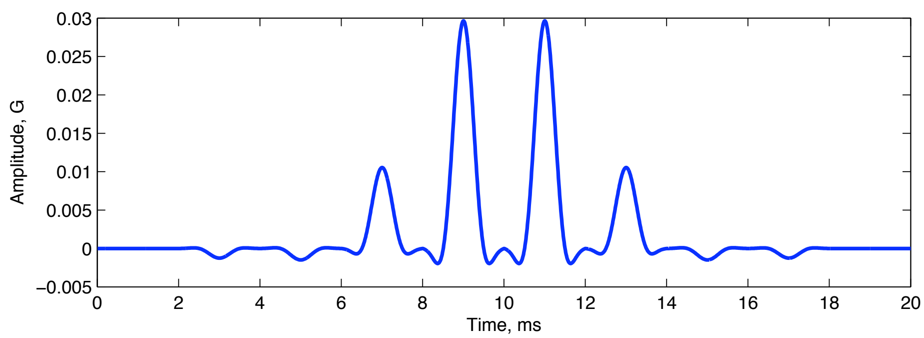
Hint: The second flyback pulse is shifted by ΔT in time. What does that do to a sidelobe at $1/(2\Delta T)$? Also, why isn't the cancellation perfect?

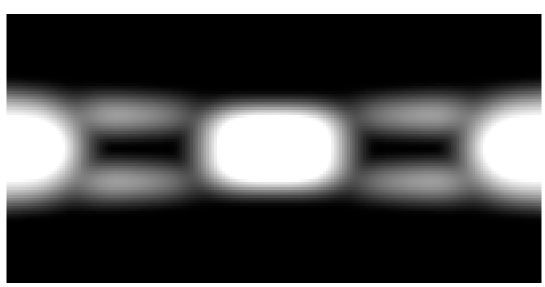
Solution:
The profiles of the even and odd sets of subpulses are very similar, but oppositely included. In addition the even subpulses are delayed by one subpulse with compared to the odd subplulses. In the spectral dimension, this delay corresponds to a (+1, -1, +1 -1 ...) modulation of the sidelobes. When these are added to the profile of the odd subpulses, the even sidelobes add, and the odd sidelobes cancel. However, since the profiles are inclined, the cancellation is imperfect, and we are left with the asymmetric sidelobes at half the sampling frequency.

2. Improved Opposed Null Design Traditionally, the opposed null RF pulses are designed with water on resonance, and the opposed null on the lipid frequency. A better approach is to design the lipid stopband on resonance, and the passband where the opposed null would have been. The null is then perfect. The passband is degraded slightly, but not significantly.

a) Conventional Opposed Null Design Design an opposed null RF pulse for the parameters of problem 1, with the passband at 0 Hz, as usual. Reduce the spectral bandwidth to ± 100 Hz to keep the pulse from getting too short. Plot the pulse, and simulate and plot the excitation volume.

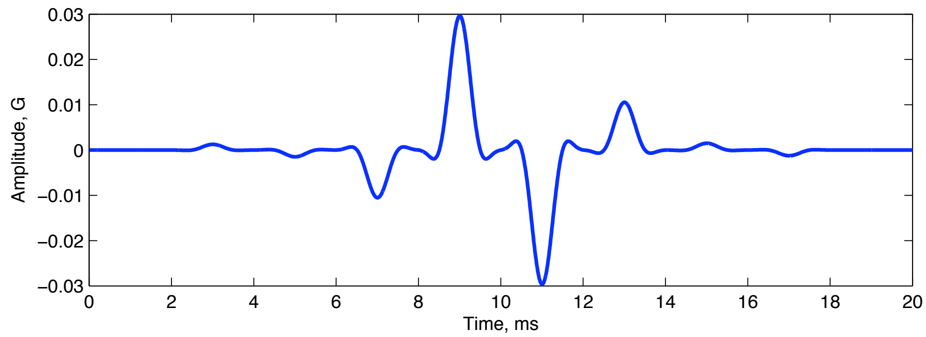
Solution:
The subpulses are now 2 ms long, the sampling frequency is 500 Hz, and the antisymmetric sidelobe is now right on 250 Hz, exactly on the lipid resonance. The spectral bandwidth is 0.2 kHz, so with a TBW of 4, the pulse length is 4/(0.2 kHz) = 20 ms, and there are 10 subpulses. The RF pulse, and the excitation volume are plotted below.

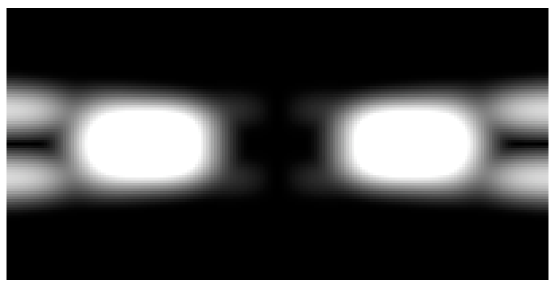




b) Improved Design Now alternate the signs of the RF subpulses, which moduates the passband to $/1(2\Delta T)$, and leaves the stop band on resonance. Plot the pulse, and simulate and plot the excitation volume.

Solution:
After modulating the RF, the RF waveform and the excitation volume are now:





Note that the stopband is now perfect, although the passbands are only slightly distorted.

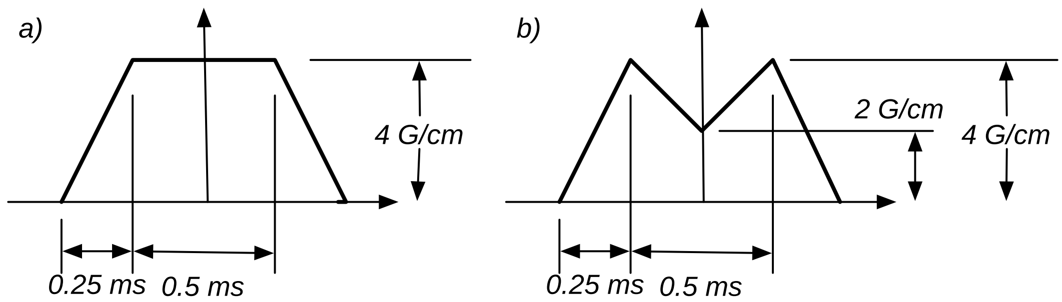
One place where this type of design is important is for 3T systems. At 3T the spectral separation of water and fat is twice that at 1.5T, so the subpulses have to be half as long. However, the gradient system performance is the same. Hence it is difficult to get enough gradient area for a true null design to reach 3 mm slices, which you would like for cardiac imaging. This technique solves this problem.

3. Reduced Peak Power The peak amplitude of the spatial subpulses can be a problem. One solution is to vary the gradient amplitude. Recall from the small-tip-angle solution, the RF waveform for a 1D pulse should be

$$\gamma B_1(t) = |\gamma G(t)| W(k(t))$$

Generate $TBW = 4$, flip angle $\pi/3$ spatial subpluses for each of these subpulse gradients. Use the entire gradient waveform in either case. Find $k(t)$ by numerically integrating $G(t)$. The samples of the windowed sinc $W(k)$ are non-uniformly sampled. You can either compute these samples explicitly, since you have an analytic expression for $W(k)$, or you can sample $W(k)$ uniformly, and interpolate, using the matlab command `interp1`.

Plot the RF pulses and gradients, and simulate the 1 D slice profiles.

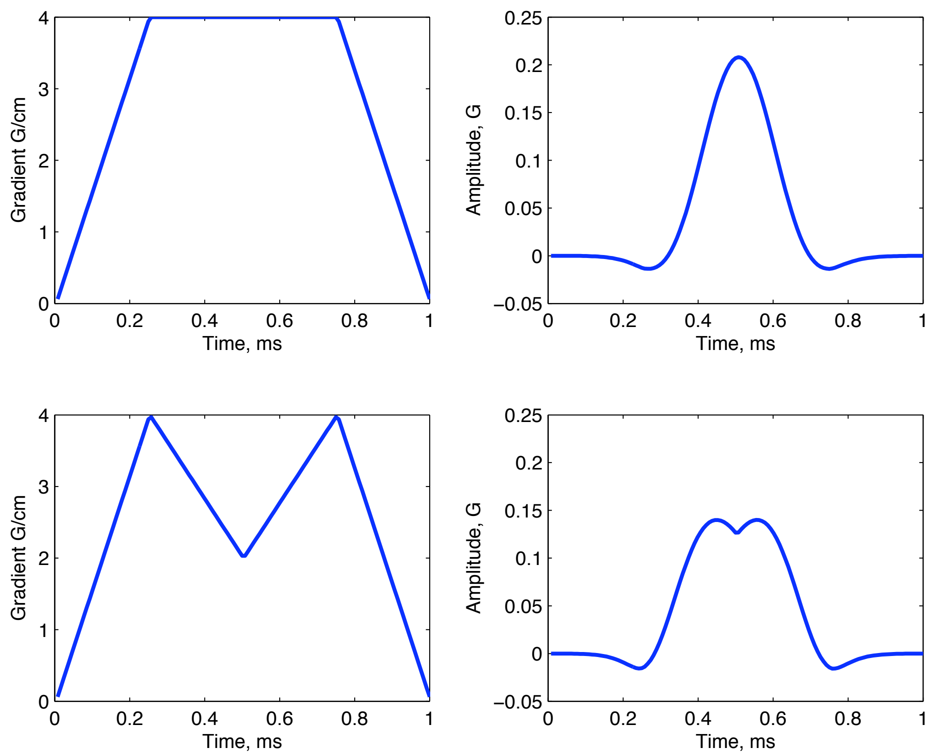


How much has the peak power been reduced? How much has the slice thickness increased?

This is an example of variable rate excitation pulses, or the VERSE algorithm. Although we have based the development here on the small-tip-angle case, VERSE is a quite general result that holds for any RF pulse.

Solution:

The gradient waveforms, and the corresponding RF pulses are shown below:

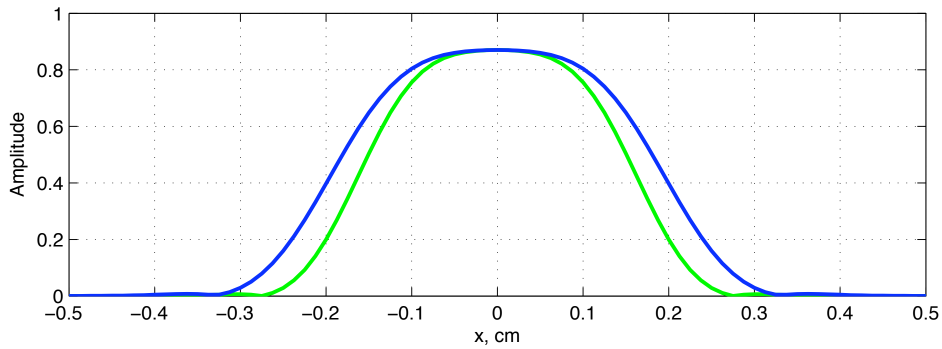


The peak amplitude has been reduced from 0.21 G to 0.14 G, or by 1/3 in amplitude. In peak power, the reduction is to 43% of the original power, or a reduction of 57%.

Note that the windowed sinc waveform has to be resampled, since the time varying gradient means that the samples are not uniformly sampled in k-space. If `g` is the gradient waveform, `rf` is the uniformly sampled RF, and `rfv` is the VERSED RF pulse, then we can use the matlab `interp1` interpolation routine

```
k = cumsum(g);
k = (m-1)*k/max(k);
g = m*g/sum(g);
rfv = g.*interp1([0:m-1],rf,k,'spline');
```

The slice profiles are:



By zooming in, we can measure that the half amplitude width has gone from 3.2 mm to to 3.8 mm.