EE469B: Assignment 7

Due Wednesday, Nov. 11

The assignment this week is to think about a project. You can choose anything related to RF pulse design. If you have a project from your research work, that is fine. Or, if you know of an interesting problem, you can work on that. Otherwise, there is a list below of possible topics. Projects will be graded on the difficulty of the basic problem, how far you get with it, and how well it is presented.

Projects are due the day of the final exam, which is MondayDec 7, from 8:30 to 11:30. You have the choice of a 10-15 minute oral presentation (turn in your presentation slides), or a 10-15 page report. A one page abstract will be due the last class.

Send me the title your project, and a brief description of what you would like to do. If you would like to talk about possible topics, I'll have office hours 10-12 Friday Nov.6, and 10-12 Tuesday Nov. 10. If these times don't work for you, send me email and we can arrange some other time.

Multi-Dimensional Small-Tip-Angle Pulses

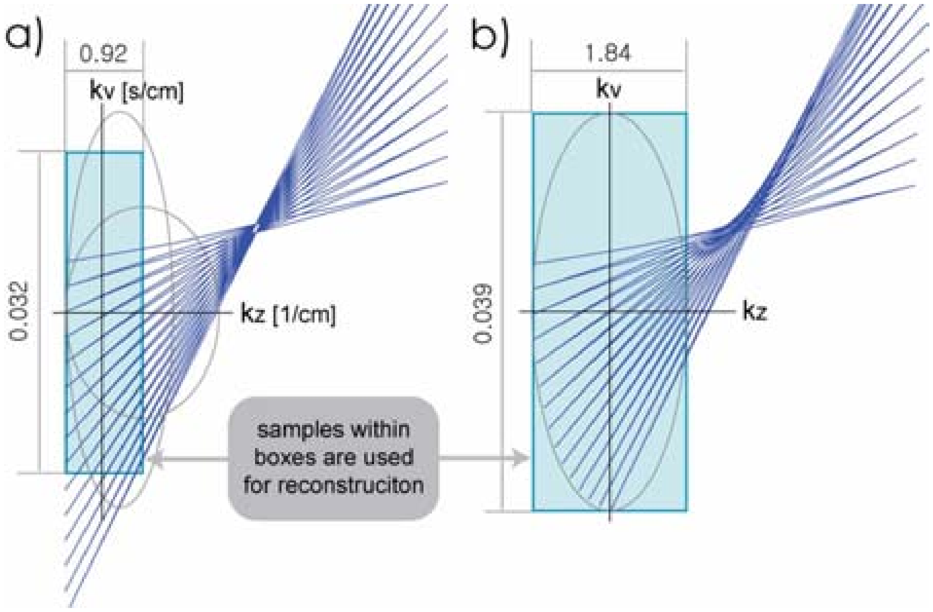
1) Velocity Effects in Multidimensional Pulses So far have been concerned with spatial and spectral selectivity of RF pulses. Velocity also contributes phase shifts, for example, as blood moves through a vessel. These phase shifts can be modeled as another spatial frequency axis, k_v, where

$$k_v(t) = \frac{\gamma}{2\pi}\int_t^0 sG(s)ds$$

which is proportional to the first moment of the remaining gradient. We can use this to understand velocity effects on multidimensional pulses.

a) Velocity in Spectral-Spatial Pulses Velocities in the heart can range up to 1 m/s in healthy people, and much higher for people with valvular disease. What effect does this have on the spatial and spectral profiles? How are different types of spectral-spatial pulses effected? Calculated and simulate what the impulse response will be as a function of space and velocity, for given spectral frequencies. Develop guidelines for how to design spectral-spatial pulses in the presence of motion.

b) High Performance Spatial-Velocity Pulses From this perspective it is possible to design high-performance pulses that are selective in velocity and space. If we use a simple oscillating gradient, we get a waveform that looks like the one on the left, below. This is taken from an abstract (Lee et al, ISMRM 2007, p2549) that uses k_v-space on reception, but we can use the same ideas on excitation. The $k_z - k_v$ space trajectory looks like a bow tie, and we will only use part of it for RF. The problem with the trajectory on the left is that too much time is wasted. However, if we modify the gradient waveform, we can get the trajectory on the right, which covers k-space more efficiently. More importantly, it would provide more time for RF.



There are several issues to address, beyond desiging the gradients. Since k_v space is covered asymmetrically we will need a minimum phase weighting in k_v, or a gradient that produces symmetric weigthing. Another is that the density will be non-uniform, so density compensation will be important. Finally, the off-resonance sensitivity will have to be considered.

2) 2D-Spatial, 1D-Spectral Pulses One way to design a spectral-spatial pulse was to consider it to be a spectral hard-pulse sequence, made up of spatially selective subpulses. We considered the case where the subpulses were slice selective. For this project, examine the case where the subpulses are 2D spiral excitations. To make it interesting, assume you have a dedicated head gradient system with 8 G/cm gradients, and 40 (G/cm)/ms slew rates. Some points to consider are how long can the subpulses be, what do the sidelobes look like, and what spatial resolution that you want achieve.

1D SLR Pulses

3) BURST Pulses One interesting RF trick is BURST pulses. The idea is that N hard pulses, separated by gradients, will produce 2N echoes. By choosing the right amplitudes and phases, we can make N of those echoes be close to zero, and the other N of amplitude $1/\sqrt{N}$. Remarkably, these coherences all coexist in the transverse plane at the same time! This was used for an imaging sequence called BURST, which isn't much used now. However, know how to store this many coherences is often very useful, and the same ideas turn up in other problems.

Several different methods for designing BURST pulses are described in Heid et al, MRM 38(4), p 585, 1997. Another alternative is based on choosing a $B_N(z)$ of the form

$$B_N(z) = 1 - (rz^{-1})^N$$

This has zeros uniformly spaced inside the unit circle. Zero flipping gives different phase profiles. Then search for minimum peak amplitude. You also have to find a reasonable value for r, the distance from the unit circle should be about the zero spacing. You will find that certain lengths N are magical, such as 9. Also, will be able to find solutions where a gradient reversal calls back the echoes, and another solution where a spin echo is required.

4) Wide-Bandwidth Saturation Pulses In class we will talk about one approach for minimizing the peak power of saturation or inversion pulses, that involves designing a minimum phase $B_N(z)$, factoring it, and searching over all possible phase profiles to find the minimum amplitude $B_N(z)$. This is practically limited to $TBW = 18$ or so. Ideally, we would like to design pulses with $TBW = 32$ or even 64. There are several possible options.

One is to use the complex Remez algorithm `cremez` in matlab, to specify a complex phase profile in addition to the amplitude profile. You will need to determine how to specify the phase profile to minimize peak amplitude. One possibility is to assume a polynomial for the phase profile, and optimize the polynomial coefficients. (Schulte, et al, JMR 166(1):111-22).

This problem crops up in different forms in many different applications.

5) Phase Matched Pulses Usually with spin-echo imaging, the 90 and the 180 are designed to be linear phase. However, this need not be true, all that we need is that the *echo* be linear phase. Show how to design the 90 and 180 to be phase compensated. This is particularly important when spatial selectivity of the 180 is important, since we can use a non-linear phase design with lower peak power, and then simply compensate with the phase of the 90. You will find that for perfect compensation the 90 should be twice as long as the 180. What can you do when the two are the same length?

6) Universal Rotation Pulses Spin-echo pulses are the only 1D pulses that perform a pure rotation by 1800° around one axis. There are pulses that have been designed by numerical optimization that perform rotations by arbitrary angles (see papers by Helen Geen and Ray Freeman, the Freeman paper in *Progress in Nuclear Magnetic Resonance Spectroscopy*,32(1), p 59, 1998 is a good overview, and H. Geen, R. Freeman, J. Magn. Reson. 93 (1991) 93 covers these pulses specifically). These could be designed as an extension of self-refocusing pulses, that we will be talking about later in the course, but this is an open questions.

Adiabatic Pulses

In their simplest form, these pulses produce inversions that are almost completely insensitive to variations in B_1, provided B_1 is above a threshhold.

7) Numerically Optimized Sweeps The usual explanation for how adiabatic pulses work is described by a sweep in B_1 amplitude and frequency, with the hyperbolic secant being the most widely known. This is perfect over a very wide range of B_1 amplitudes. In practice we would like shorter pulses that are adiabatic over a more limited range (say ± 10-20%). Develop an algorithm to optimize the sweep to minimize the pulse duration given a range of B_1 variations.

8) Sampled Adiabatic Pulses, and Spectral-Spatial Adiabatic Pulses Interestingly, adiabatic pulses are still adiabatic when sampled, with relatively small number of samples. These sampled adiabatic pulses can be used for the spectral envelope for adiabatic spectral-spatial pulses. Determine the tradeoff between the number of samples and the adiabatic sensitivity. For example, how many samples are required for $\pm 20\%$ variation in B_1.

Parallel Transmit

One of the most active areas in RF pulse design right now is the use of parallel transmit coils. This has several potential advantages, including better control of the flip angle on high-field systems, and restricting the FOV for high-speed imaging. The problem closely follows the pallel reconstruction problem, and can be formulated in almost exactly the same way. We will talk about this at the end of the quarter. There are many possible projects here.

9) Assume that the volume is surrounded by a sent of N single loop coils, for which you can compute the sensitivity. How many coils, of what size, do you want to be able to most efficiently excite a given volume? This corresponds to the g-factor limit in 2D parallel reception.

10) For EPI 2D pulses with a single transmit channel, we can design large-flip-angle pulses by using a sampled SLR pulse as the envelope. How can we do this with multiple transmit coils?

Higher-Order Gradients

The next big change in MRI is going to be dynamically controlled higher order ”gradients”. These are spatially variant fields that are quadratic order, or higher. Typically these have been used as shims that are used to correct the main field. Increasingly, these are dynamically controllable. Another example are local gradients, such as surface gradients. The major question is how these can best be used.

11) Assume that you have a linear gradient and a quadratic gradient in one dimension. How can you use this to improve slice selection. Assume they are constant (not dynamically switched) for now.

12) Now assume that both the linear and quadratic gradients can be independently controlled. What can you do with this? How would you analyze it?

13) One gradient structure that has been proposed is quadratic in radius. If you also had the usual linear terms, what could you do with this system?