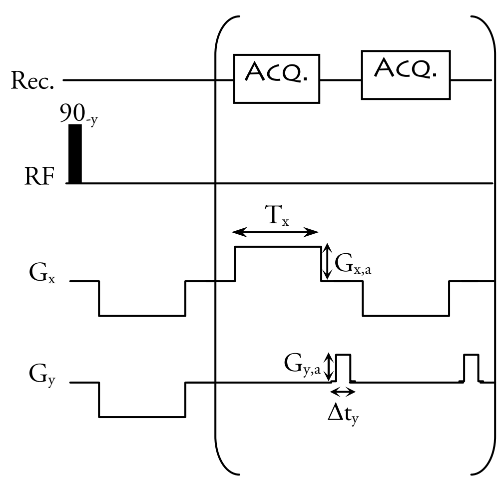
MRI Primer, Exercise #6
Due 12/Jan/2009

1. **Real-life Gradients**. So far we've used idealized, rectangular gradient waveforms in our discussions. In reality, turning on a gradient rapidly induces secondary currents in the MRI hardware, which may interfere with its operation; therefore, gradients must not be turned on faster than a specified rate, called the *slew rate* of the machine. It is given in Tesla/meter/second.
   a. Imagine a gradient turned on for a short period of time, Δt, at maximal slew rate, and then turned off before it reaches the maximal value allowed by the machine (about 40 mT/meter on the 3T Siemens, as an example). Calculate Δk for this case, assuming:
      i. The slew rate is known (denote it by SR).
      ii. Δt is short enough for the gradient not to reach its maximal value and plateau (making the waveform look like a triangle).

Idealized gradient — Realistic gradient — "Short" Δt gradient

   Hint: the answer is much shorter than the question.

   b. In the Siemens 3T machine we have, the slew rate is 200 Tesla/meters/seconds. The maximal gradient is 40 milli-Tesla/meter. Given a blipped EPI sequence, what is the **minimal** possible Δt_y (along the blipped k_y-axis), given that the size of the imaged object along the y-axis is 30 cm?



   c. Given Δt_y calculated in (b), and that you're trying to image an object of size 30cm along the y-axis, what is the average G_y gradient used?

2. **EPI Resolution**. Let's try and estimate that resolution using real-life parameters, and also use the results of question #1 in the process. Assume the object is 2D and rectangular, having dimensions 30cm x 30cm (this is approximately the size of an axial slice of the brain). Take Δt_y = 100 μsec, T_x = 0.5 milliseconds. Take the total acquisition time to be equal to about 50ms (the order of magnitude of T_2 for a "typical" tissue, say muscle or kidney, at 3T). Assume ideal gradients (no need to take into account the slew rate). The maximal gradient strengths are 40 milli-Tesla/meter along each axis. Calculate:
   a. The number of voxels (i.e. the "resolution") along the x & y directions. Assume that we demand equal resolution along both axes (same number of voxels).
   b. The size of the x & y gradients.

3. **Composite Pulses**. A frequent problem in many imaging machines is an inhomogeneous RF transmitter. This means that, while you choose a particular RF power for your irradiation, different regions in the sample will get tipped by different angles. For example, when exciting the spins using a 90 hard-pulse, according to $\gamma B_{RF}T=\pi/2$, some spins might get tipped by 85 degrees, while others by 92 or 94. One way to circumvent this is to **string-together** smaller-angle pulses with differing phases. These are called <u>composite pulses</u>. In this question we'll look at a composite π pulse.
   a. Starting from thermal equilibrium, and using a π_{-y} pulse, draw the trajectory and final state of the magnetization assuming an ideal RF transmitter.
   b. Repeat (a), now assuming a non-ideal RF transmitter, i.e., that the flip angle is – say – 170 degrees.
   c. Next, consider the sequence of pulses: 90_{-y} -180_{-x}-90_{-y}. Once again starting from thermal equilibrium, draw the trajectory and final state of the magnetization assuming an ideal RF transmitter.
   d. Repeat (c), only this time assume a non-ideal RF transmitter, e.g.: 85_{-y} -180_{-x}-85_{-y}. Explain why this sequence is better (i.e., gets you closer to the –z axis) when compared to (b), and how the 180_{-x} pulse[1] in the middle helps correct for the imperfections of the two 85_{-y} pulses.

   Note: this is basically a "proof-by-drawing" exercise, since we won't be getting into the mathematics of composite pulses in this course. Feel free to exaggerate angles somewhat to get the point across.

[1] We should've assumed the 180_x is non-ideal as well, but it is possible to show (we won't) that this non-ideality is negligible ("of 2nd order", as a mathematician might say) compared to that of the two 85_{-y} pulses. You can also hand-wave this with pictures.