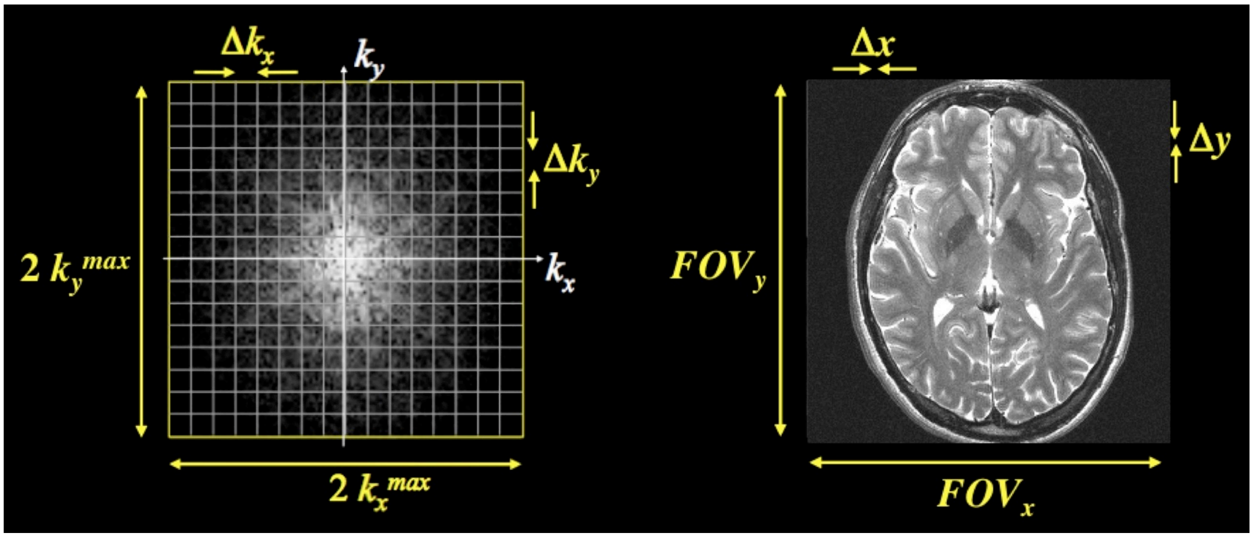
Prelab 9 *6.S02 – Spring 2013*

MRI – 2D Imaging

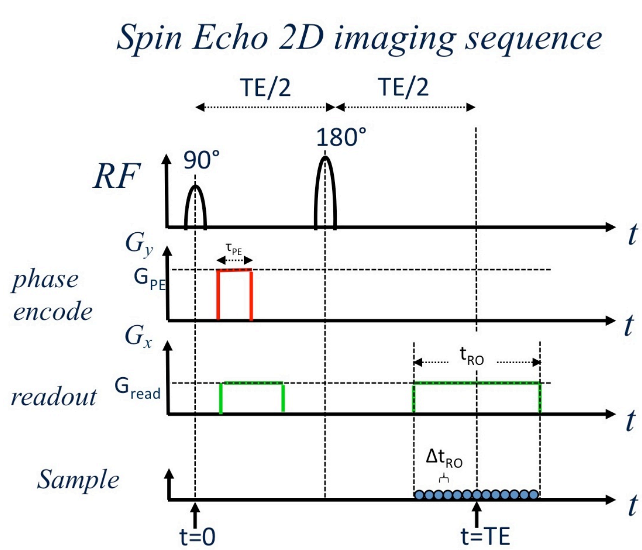
--CZ Cooley, L.L. Wald, May 2013

Designing your image acquisition The design of the image acquisition starts with deciding the resolution and Field of View (FOV) needed in the image (image space). These decisions immediately tell you the pixel dimensions of the image (imaging matrix). For example if 0.2mm resolution is desired in y (Δy=0.2mm) and 0.1mm in x; (Δx=0.1mm) and the FOV needs to be 20mm in each direction (FOV_x and FOV_y), then a N_x x N_y = 200 x 100 matrix is needed. The next step is to calculate the equivalent parameters in kspace; Δk_x, Δk_y, and k_x^{max}, k_y^{max} for the kspace matrix you will need to acquire to produce this image. Note that the reciprical relation between the units of kspace and space mean that $\Delta k_x=1/FOV_x$ and $\Delta x=1/2k_x^{max}$. From these relations we calculate Δk_x, Δk_y, and k_x^{max}, k_y^{max} . Note that the kspace matrix will be the same matrix size as the image; i.e. N_x x N_y.



The next step is to convert these into the control parameters of the scanner. These parameters are the strength and timing of the gradient pulses. Below is a standard spin echo 2D imaging sequence. There is no slice selection, so the excitation covers the whole object. The phase encode direction is the y direction and the readout is in the x direction. The goal is to keep track of the value of k_x and k_y for each of the ADC samples during the readout. We use our standard formulas for k where γ is 2.675×10^8 [radians/(s T)] but with the simplifying assumption that the gradients are either a constant value or zero. Then;

$$k_x = (\gamma/2\pi)G_x\, t \quad \text{and} \quad k_y = (\gamma/2\pi)G_y\, t \quad .$$



MRI – 2D Imaging

--CZ Cooley, L.L. Wald, May 2013

We are also going to choose our sampling time (ADC dwell time) at this point to be Δt_{RO} (=32us for our laboratory systems). Note this corresponds to a measurement "full" bandwidth of 1/dwell = 31,250 Hz.

Thus, in the SE sequence to the right, we can easily compute the kspace location for the time immediately before the 180 degree pulse. First note that the first green G_x blip is half the length of the second green blip (which is the readout period). Thus at a time just before the 180 pulse, $k_x = (\gamma/2\pi)G_{read}(t_{RO}/2)$ and $k_y = (\gamma/2\pi)G_{PE}\,\tau_{PE}$. We also know how long the readout period is $t_{RO} = N_x\,\Delta t_{RO}$. So for a 128 point readout and our 32us dwell time t_{RO} = 4.096 ms.

Now we need to figure out the kspace location at the time of our first sample point. The 180 degree pulse has a curious effect on the location in kspace. Recall how the 180 "flipped the pancake" of dephased spins. In the phase helix picture, this flipping (really a mirroring) has the effect of flipping a left handed helix into a right handed one (and vice-versa). Thus the 180 pulse takes us from a point in kspace (k_x, k_y) to ($-k_x$, $-k_y$). This doesn't mean much for the k_y encoding, but it means that the second green blip (the one after the 180) will un-wind the helix of the first green blip and the k_x=0 point will be at exactly t=TE. Thus the starting kspace location of the first of the N_x samples is:

$$k_x = -(\gamma/2\pi)G_{read}\,(\Delta t_{RO}/2) \quad \text{and} \quad k_y = -(\gamma/2\pi)G_{PE}\,\tau_{PE}\,;$$

the negative of that immediately before the 180.

Now we know the kspace location of our first sample point. Lets proceed to calculate what value we need for G_{read} . There are several ways to do this, but one is: Since we know the time betwee samples, Δt_{RO} (=32us in our systems), and we know we desire a step size in k_x of Δk_x which we calculated from our FOVx, then we know that the kspace (area) accrued in one sample point needs to be this step size; $\Delta k_x = (\gamma/2\pi)G_{read}\,\Delta t_{RO}$ thus; $G_{read} = 2\pi\Delta k_x/(\gamma\,\Delta t_{RO})$.

Or alternatively, using $\Delta k_x = 1/FOV_x$ then: $G_{read} = 2\pi/(\gamma\,FOV_x\,\Delta t_{RO})$.

During the phase encoding we are going to repeat the sequence over and over with different amplitudes for the red G_y blip. The green readout blips will remain the same in both timing and amplitude for all the acquisitions. Thus each acquisition will fill in a different k_y line of the kspace matrix. Let's start with finding the GPE for the largest blip played out. Call this blip amplitude G_{PE}^{max}. This blip will need to take us to k_y^{max} . This is one of the parameters we have already calculated (based on k_y^{max} = $1/2\Delta y$). From the defination of k we have: $k_y^{max} = (\gamma/2\pi)\,G_{PE}^{max}\tau_{PE}$. Which we can solve;

$$G_{PE}^{max} = (2\pi\,k_y^{max})/(\gamma\,\tau_{PE}) \quad \text{or}$$

$$G_{PE}^{max} = \pi/(\gamma\,\Delta y\,\tau_{PE}) \quad \text{(where we use } 2k_y^{max} = 1/\Delta y)$$

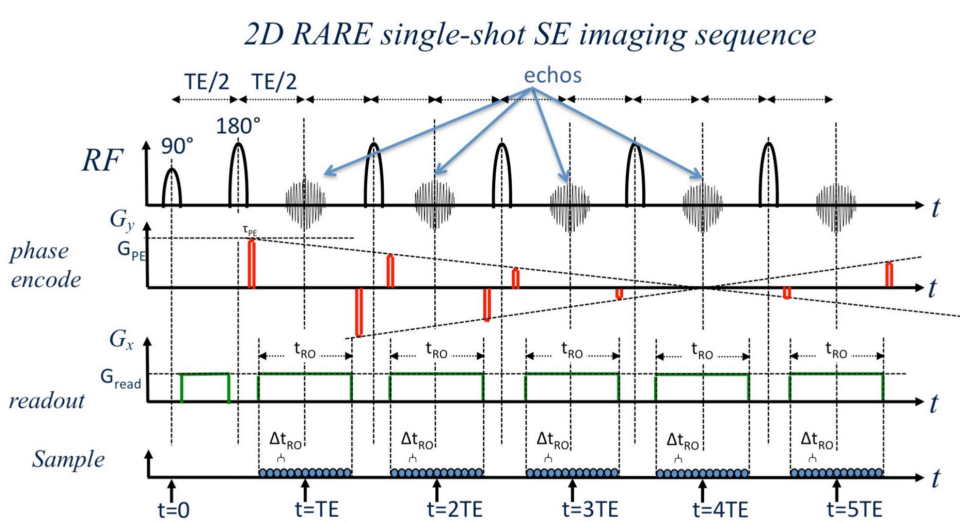
So we need to vary this blip's amplitude from + G_{PE}^{max} to - G_{PE}^{max} in N_y equal steps.

Playing out the basic SE sequence For an N_x x N_y matix, we will play out the basic SE pulse train shown in the figure above N_y times to get all the k_y lines we need. Each time we will change the amplitude of the red Phase Encode blip from + G_{PE}^{max} to - G_{PE}^{max} in N_y equal steps. Each repetition yields a vector of N_x kspace points (one row in the kspace matrix). If the time between repetitions is TR (which stands for "time to repetition"), this image will take a total of imaging time = TR*N_y to acquire. So for our N_y=128 matrix and TR=2s, this is 256s or 4min 16s. Note the subject has to hold still for this time. Not a problem in our class, but an enormous problem in medicine.

Converting to integer indexed matrix. MatLab, of course, does not want the matrix indexed by k_x and k_y, but by integers representing them. Simple, we just load our measured readout sample points for the acquisition shown in the figure into a vector indexed by the integer index u, which ranges from 0 to N_x - 1. Remember we vary the phase encode gradient blip's amplitude from + G_{PE}^{max} to - G_{PE}^{max} in N_y equal steps and we set the readout gradient amplitude G_{read} properly so we know that this matrix will correspond to the proper kspace matrix to give the desired FOV_x and FOV_y and image resolution Δx and Δy. We index each of the readout samples with the integer index v, starting with v=0 up until v= N_y -1 so as we load out readout vectors into the kspace matrix; k[u, v] . This will put the center of kspace at index [N_x/2, N_y/2], which is the usual convention. Its also usual to make sure N_x and N_y are even integers.

Faster imaging As noted above, MR imaging is not fast if you have to laboriously step through kspace one line at a time and the time between lines is a second or more. One solution to this problem is to take multiple lines after each excitation. We have been talking about the spin echo refocusing the magnetization and then after it comes together to produce the echo it just dephases again. Why not play a second 180 pulse and refocus it again. If the amplitude of the echo diminishes slowly, we can do this literally dozens of times!. E.g. if we do 64 echos, we have just speed up the imaging by 64x !! So for a matrix size of N_y=64 the image is done in one shot. If the read period is ~4ms, the TE period must be about 6ms so the total sequence time is about (N_y + ½)*TE= 387ms.

The sequence for doing this is shown below. Basically its just the same sequence with multiple refocusing pulses. But since we want a different line of kspace for each echo, we have applied a different phase encode blip before each readout. Note we undo the effect of this blip at the end of the readout. Thus after the end of the period before the next 180 we are back to k_y=0. Then after the next 180 we do the same thing with a slightly smaller bipolar blip pair. Note the 4th



MRI – 2D Imaging

--CZ Cooley, L.L. Wald, May 2013

echo is at k_y=0 and to get a full N_y = 7 matrix we would need 2 more echos (not shown). In this case we had an odd # k_y samples, a little unusual. Note the readout is the same as for the basic SE (just repeated).

Prelab problem #1:

In our lab we will image mainly in the xz plane using x as the readout and z as the phase encode direction. Find the gradient strengths G_{read}, G_{PE}^{max} needed for a 2.56cm x 2.56cm field of view (FOV_x, FOV_z) and a matrix of 128 x 128. Assume the readout dwell time (Δt_{RO}) is 32 us and the phase encode length (τ_{PE}) is 2ms. Also, x is the readout direction and z is the phase encode direction.