Chapter 7 – Magnetic Resonance Imaging

Review of last lecture

RF excitation with different “flip angles”

Figure: flip angles

So far, we talked about excitation and relaxations.

Figure: Excitation and relaxations

In MRI data acquisition, we repeat excitation-relaxation-acquisition processes multiple times to generate an image.

Of cause, we do not simply "repeat" but we do change "something" in each repetition. "Something" allows us to resolve spatial information

7.7 Linear magnetic gradient fields (G_x, G_y, G_z)

The gradient fields allow "spatial localization". The word "imaging" in MRI has become possible with these gradients.

Before MRI, people used B_0 and B_1 to perform NMR experiments which do not give any spatially localized information. A whole sample was treated to be uniform in NMR.

Gradient fields are relatively small magnetic fields that produce linearly increasing or decreasing magnetic field in an axis.

The direction of the gradient fields is still in B_o direction.

Figure: Gradient along an axis ($\pm x$, $\pm y$, $\pm z$)

$$e.g.\ \mathbf{B} = (\mathrm{B_o} + \mathrm{G}_x x)\hat{\mathrm{k}}$$

We can change the gradient fields over time and control the amplitude of the gradient fields.

Q: What happens if we have a gradient field on?

Figure: Example of resonance frequency change from G field

The resonance frequency of the spins become a function of *x*-position

$$\omega(x) = \gamma(B_o + G_x x) = \omega_o + \gamma G_x x$$

If we have a 20 cm object and 1 G/cm, the frequency difference in the object becomes

Q: What happens if we change a gradient field over time?

Figure: Example of spin phase change from a G field change

If we include B_o field and all three gradients, the total magnetic field becomes

$$\mathbf{B}(\mathbf{r}) = \mathbf{B}(x, y, z) = (B_o + G_x x + G_y y + G_z z)\mathbf{k}$$

$$\omega(\mathbf{r}) = \omega(x, y, z) = \gamma(B_o + G_x x + G_y y + G_z z)$$

Important! Gradients change B-field in the direction of *z* (*i.e.* $\hat{\mathbf{k}}$ direction). G_x and G_y do not mean that B fields in *x* and *y* directions. It means that *z* directional B-field are linearly changing in *x* and *y* axis. Does it mean sense to you?

Q: What about B_1 field?

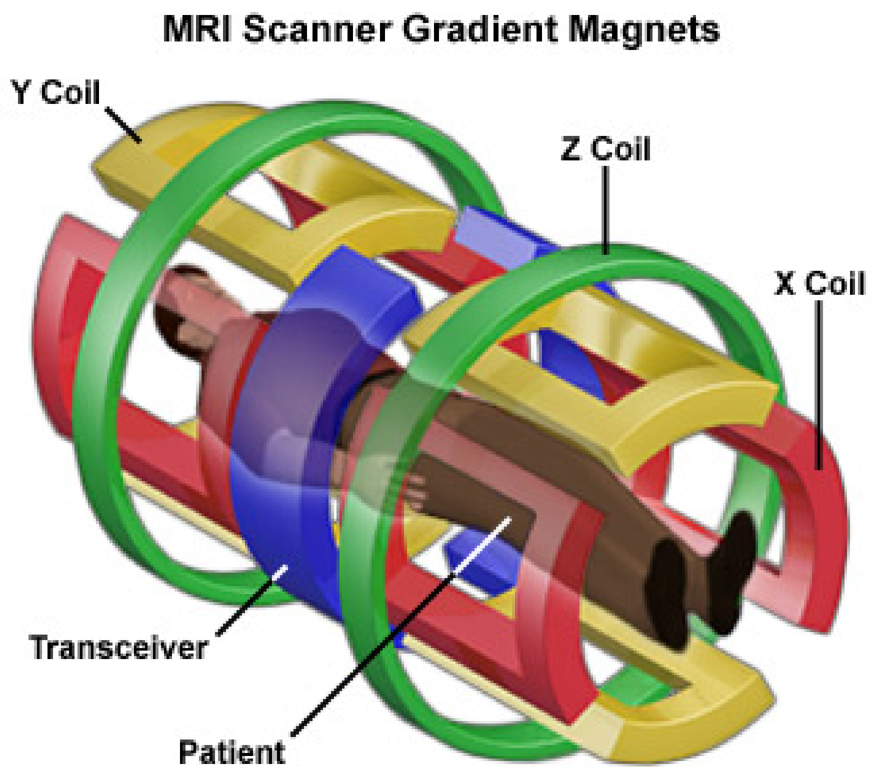

Figure: Gradient coils

A paired loop coil generates z-gradient whereas two sets of paired saddle coils generates x- (or y-) gradient that offsets the main magnetic field (B_o).

Gradient cannot change the magnetic field instantaneously. If there is a change in magnetic field, it produces transient eddy current which induces the opposite polarity magnetic field. This eddy-current induced field distorts the original gradient field. One solution is to change the magnetic field slowly to minimize the effect but we need to have fast changing gradients to be most efficient. Hence pre-emphasis circuits have been introduced which estimate the distortion field and pre-compensate it by producing additional field.

Figure 15: pre-emphasis

Commercially available gradient system (human) has

- maximum 4 G/cm (40 mT/m)
- slew rate of 15-20 G/cm/ms (150-200 mT/m/ms).

This means over a head (~20 cm), it produces 80 G (much smaller than B_0). In 1 ms, the gradients can slew up to 20 G/cm (higher than the G_{max}).

Peripheral nerve stimulation: Max slew rate is limited by peripheral nerve stimulation which gives uncomfortable experience during the scan.

A higher slew rate system can be used for a head-only gradient system

In animal systems, one can have much stronger and faster gradient systems (x10).

7.8 2D imaging basics

Spatial localization is necessary for MRI. The simplest approach is acquiring data slice by slice instead of a full 3D object. This can be achieved by using a slice selective RF excitation.

Let's say we applied a z gradient. Then the resonance frequency of each position along z-axis becomes different.

Slice selection for 2D imaging

Figure: slice selective excitation

- Basic procedure of 2D imaging

1) Selectively excite a slice

2) Change G_x and G_y and record FID.

3) Wait for recovery (Why?)

4) Repeat the measurement