Al-Mustaqbal University
College of Engineering and Technical Technologies
Biomedical Engineering Department

Subject: Biomedical Instrumentation Design_II.

Class (code): 5th (MU0115103)

Lecture: 5

BMID_II

1

MRI Design: 27. Gradient Functions

- Gradients are coils that alter the magnetic field strength of the magnet in a controlled and predictable way. They add to or linearly subtract from the existing field so that the magnetic field strength at any point along the gradient is known.

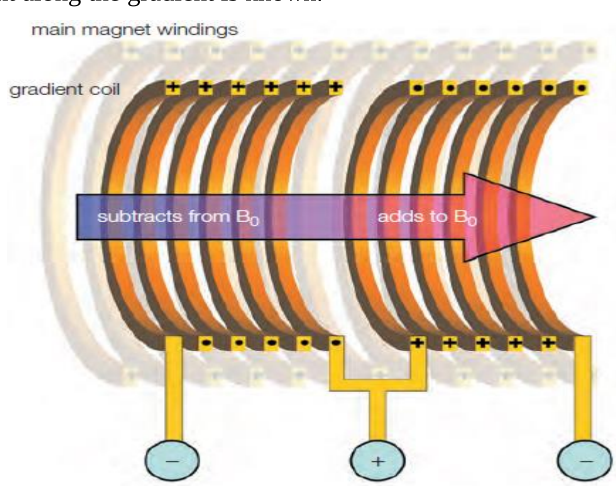
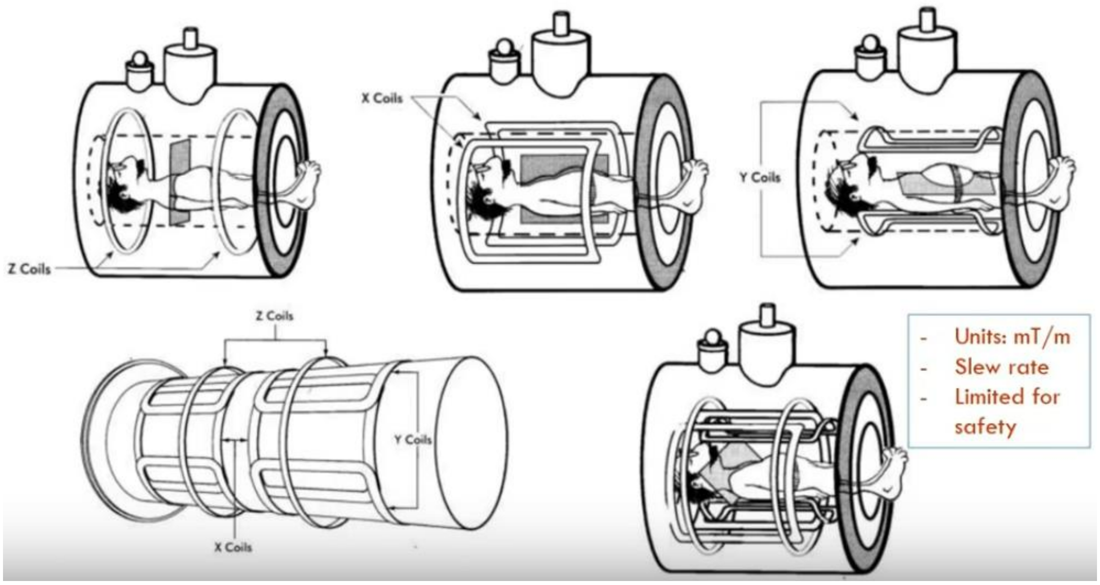


Figure 27.1 A gradient coil.

2

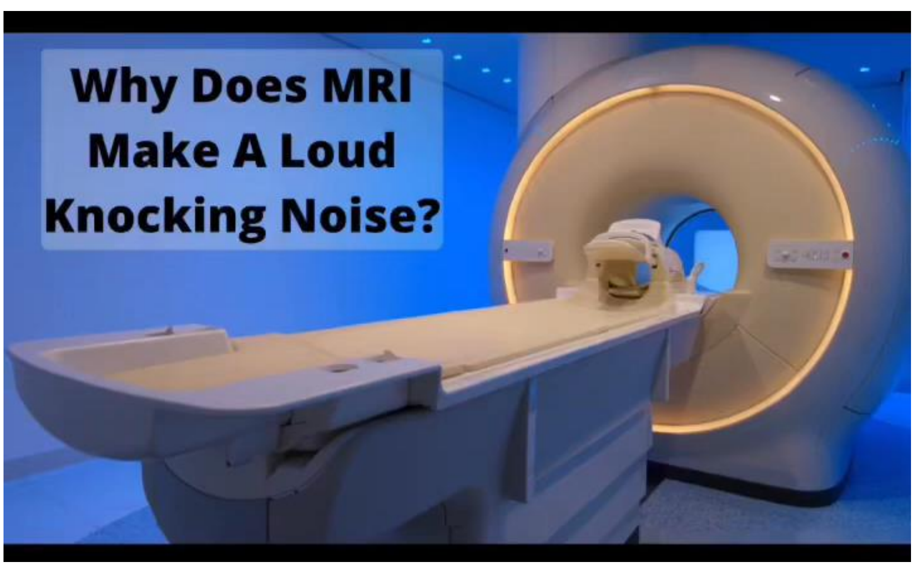
MRI Design: 27. Gradient Functions



- Units: mT/m
- Slew rate
- Limited for safety

3

MRI Design: 27. Gradient Functions



4

MRI Design: 27. Gradient Functions

› At magnetic isocentre (the centre of all three gradients), the field strength remains unchanged even when the gradient is switched on.

› At a certain distance away from isocentre, the field strength either increases or decreases.

› The magnitude of the change depends on the distance from isocentre and the strength

› The slope of the gradient signifies the rate of change of the magnetic field strength along its length.

› Larger gradient coil currents create steeper gradients, so that the change in field strength over distance is greater. The reverse is true of smaller currents.

› The polarity of the gradient determines which end of the gradient produces a higher field strength than isocentre (positive) and which a lower field strength than isocentre (negative).

5

MRI Design: 27. Gradient Functions

› The *polarity* of the gradient is determined by the *direction of the current* flowing through the coil. As coils are circular, current either flows clockwise or anticlockwise.

› The *maximum amplitude* of the gradient determines the maximum achievable resolution. Therefore, if at least one (and sometimes all three) gradients are steep, small voxels are achieved.

› The maximum speeds at which gradients can be switched on and off are called the rise time and slew rate. Both of these factors determine the maximum scan speeds of a system.

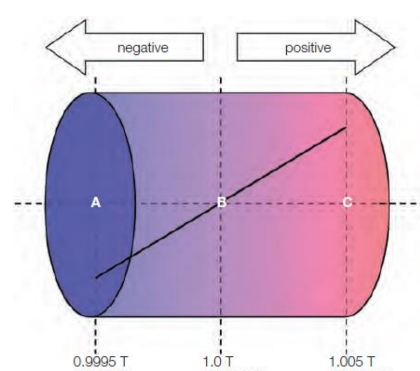


Figure 27.2 Gradients and changing field strength.

6

MRI Design: 27. Gradient Functions

› The precessional frequency of the magnetic moments of nuclei is proportional to the magnetic field strength experienced by them (as stated by the Larmor equation).

› The frequency of signal received from the patient can be changed according to its position along the gradient.

› The precessional phase is also affected, as faster magnetic moments gain phase compared with their slower neighbours.

Table 27.1 Frequency changes along a linear gradient.

Position along gradient	Field strength (gauss)	Larmor frequency (MHz)
isocentre	10000	42.5700
1 cm negative from isocentre	9999	42.5657
2 cm negative from isocentre	9998	42.5614
1 cm positive from isocentre	10001	42.5742
2 cm positive from isocentre	10002	42.5785
10 cm negative from isocentre	9990	42.5274

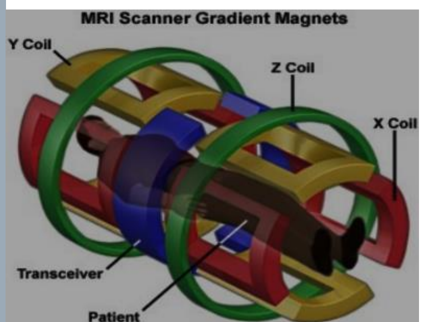
MRI Design: 27. Gradient Functions

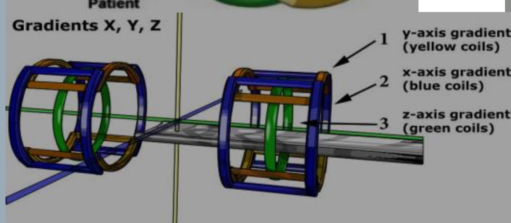
› Three orthogonal sets of gradient coils situated within the bore of the magnet are used to **encode** the MR signal in three dimensions.

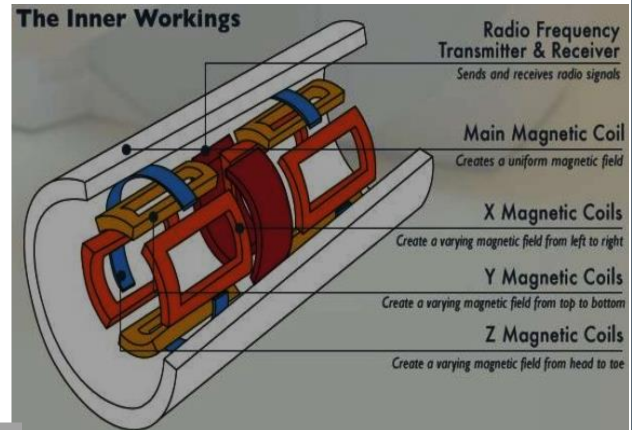
- The *Z gradient* alters the magnetic field strength along the *Z axis.*
- The *Y gradient* alters the magnetic field strength along the *Y axis.*
- The *X gradient* alters the magnetic field strength along the *X axis.*

› The **magnetic isocentre** is the centre of all three gradients.

MRI Design: 27. Gradient Functions



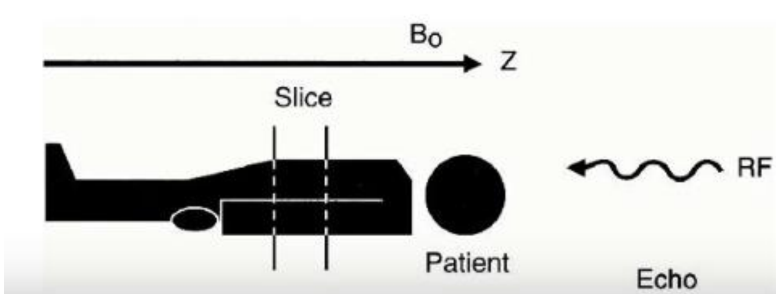




9

MRI Design: 28. Slice Selection

- As a gradient alters the magnetic field strength of the magnet linearly, the magnetic moments of spins within a specific slice location along the gradient have a unique precessional frequency when the gradient is on.
- Transmitting RF at that unique precessional frequency, therefore, selectively excites a slice.



10

MRI Design: 28. Slice Selection

› The precessional frequency of magnetic moments

between slices A and B has changed by 2.6 MHz.

› To excite nuclei in slice A, an RF pulse

of 41.20 MHz must be applied.

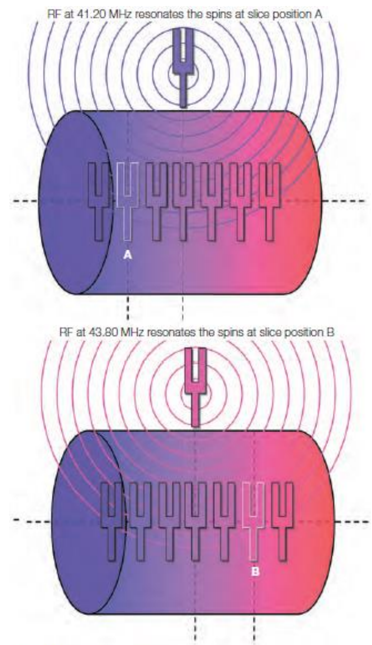


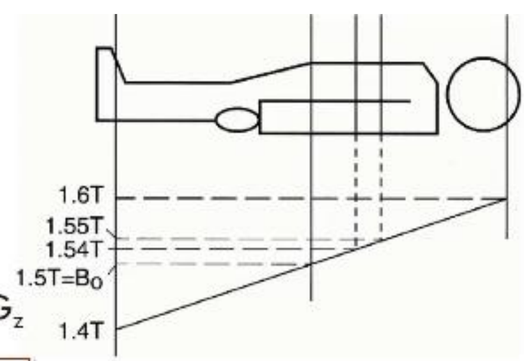
Figure 28.1 Slice selection.

11

MRI Design: 28. Slice Selection

- Larmor equation:

$$\omega_o = \gamma B_0$$



- Larmor equation with gradient G_z

$$\omega_o(z) = \gamma(B_0 + G_z \cdot z)$$

  - Larmor frequency depends on location
  - Send RF pulse with desired frequency range to excite a slice !

12

MRI Design: 28. Slice Selection

- The scan plane selected determines which gradient performs slice selection.
- In a superconducting system the following usually apply:

- The Z gradient selects axial slices, so that nuclei in the patient's head spin at a different frequency to those in the feet.
- The Y gradient selects coronal slices, so that nuclei at the back of the patient spin at a different frequency to those at the front.
- The X gradient selects sagittal slices, so that nuclei on the righthand side of the patient spin at a different frequency to those on the left.

- A combination of any two gradients selects oblique slices.

13

MRI Design: 28. Slice Selection

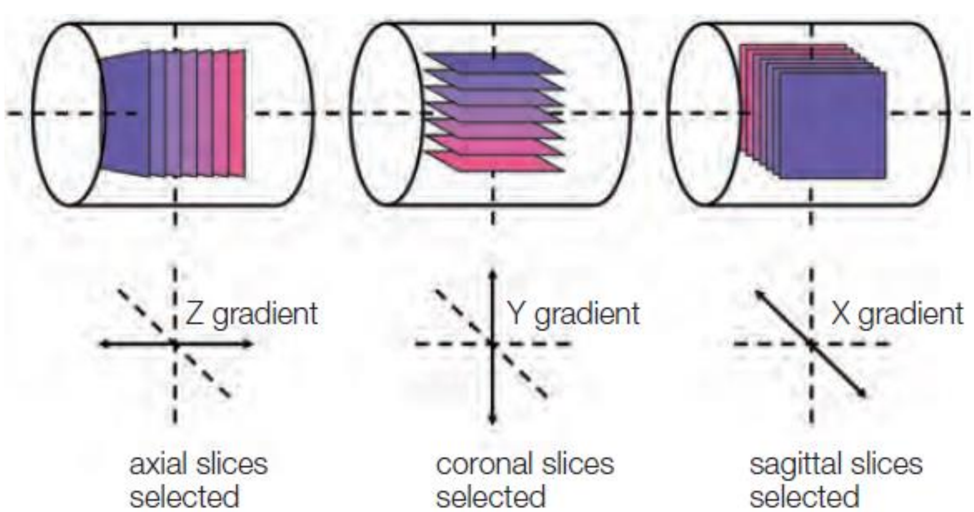
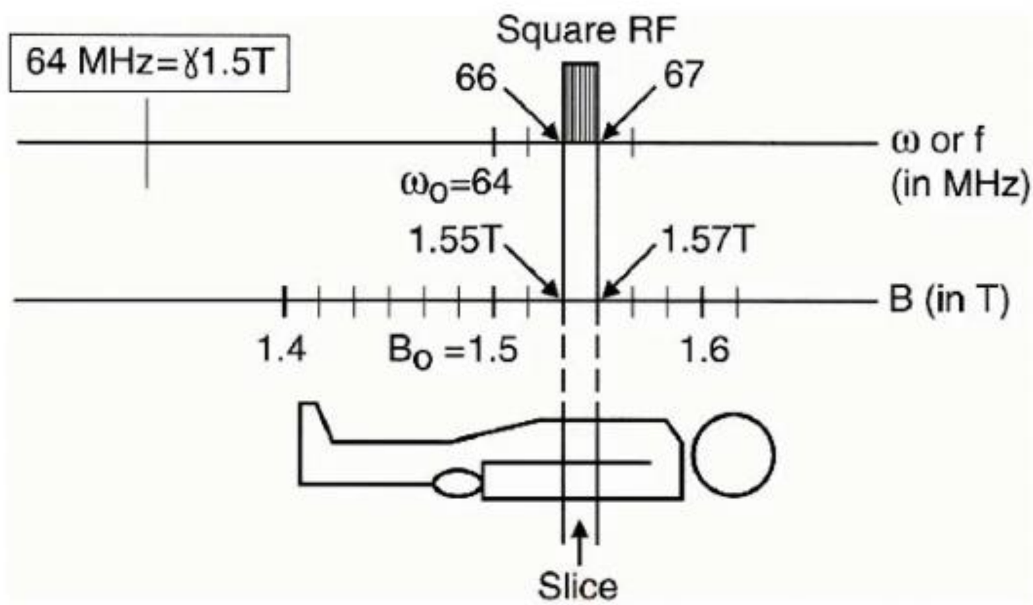


Figure 28.2 Using X, Y and Z gradients to select slices.

14

MRI Design: 28. Slice Selection



15

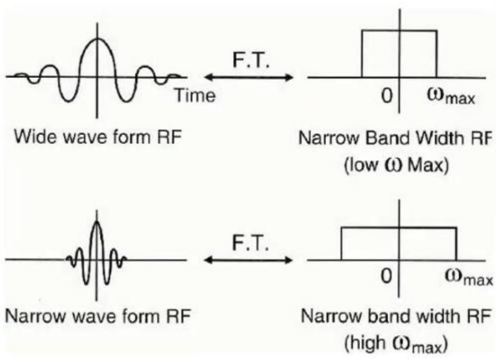
MRI Design: 28. Slice Selection

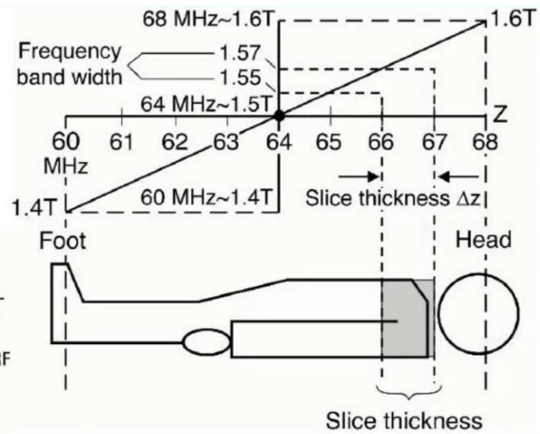
- In order to attain ***<u>slice thickness</u>***, a range of frequencies must be transmitted to produce resonance across the whole slice (and therefore to excite the whole slice).
- A bandwidth of RF is transmitted, and called the transmit bandwidth.
- The slice thickness is determined by the slope of the slice select gradient and the transmit bandwidth.
  - Thin slices require a steep slope or a narrow transmit bandwidth, and improve spatial resolution.
  - Thick slices require a shallow slope or a broad transmit bandwidth, and decrease spatial resolution.
- The slice gap or skip is the space between slices. Too small a gap in relation to the slice thickness can lead to an artefact called **cross-talk**.

16

MRI Design: 28. Slice Selection

- Slice definition
  - Slice location
  - Slice thickness
  - Slice profile





17

MRI Design: 28. Slice Selection

› The slice select gradient is always switched on during the delivery of the RF excitation pulse in the pulse sequence. It is switched on in the positive direction.

› The slice select gradient is also applied during the 180° pulse in spin echo sequences so that the RF rephasing pulse can be delivered specifically to the selected slice.

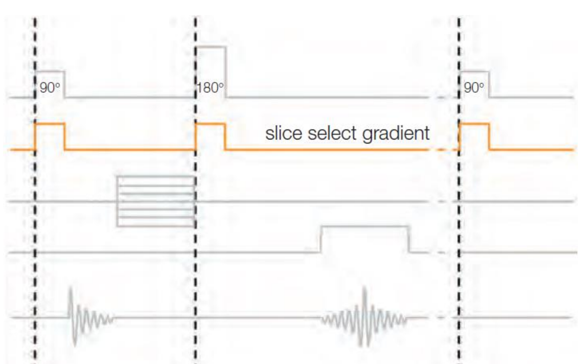


Figure 28.4 Timing of slice selection in a spin-echo pulse sequence.

18

MRI Design: 50. Contrast Agents

- In order to increase the contrast between pathology and normal tissue, enhancement agents may be introduced that selectively affect the T1 and T2 relaxation times in tissues.
- Both T1 recovery and T2 decay are influenced by the magnetic field experienced locally within the nucleus.
- The local magnetic field responsible for these processes is caused by:
- • the main magnetic field;
- • fluctuations as a result of the magnetic moments of nuclear spins in neighbouring molecules.

19

MRI Design: 50. Contrast Agents

- These molecules rotate or tumble, and the rate of rotation of the molecules is a characteristic property of the solution. It is dependent on:
- magnetic field strength;
- viscosity of the solution;
- temperature of the solution

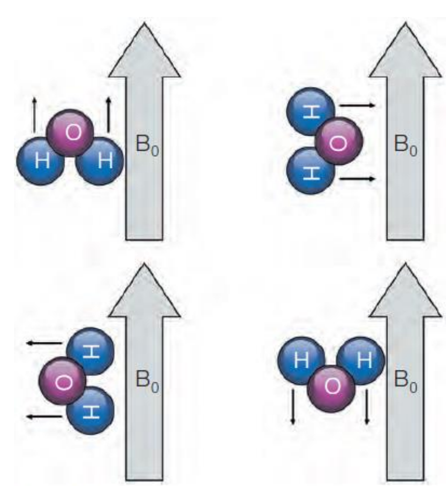


Figure 50.1 Tumbling of water molecules.

20

MRI Design: 50. Contrast Agents

- The excited protons are affected by nearby excited protons and electrons (dipole-dipole interaction).
- If a tumbling molecule with a large magnetic moment, such as gadolinium, is placed in the presence of water protons, local magnetic field fluctuations occur near the Larmor frequency.
- T1 relaxation times of nearby protons are therefore reduced, and so they appear bright on a T1-weighted image.
- This effect on a substance whereby relaxation rates are altered is known as relaxivity.

21

MRI Design: 50. Contrast Agents

- Gadolinium (Gd) is a paramagnetic agent that has a large magnetic moment, and when it is placed in the presence of tumbling water protons, fluctuations in the local magnetic field are created near the Larmor frequency.
- The T1 relaxation times of nearby water protons are therefore reduced, resulting in an increased signal intensity on T1-weighted images.
- Thus, Gadolinium is known as a T1 enhancement agent.
- Clinical indications for gadolinium include: • tumurs; • infection; • arthrography; • post-operation lumbar disc; • breast disease; • vessel patency and morphology.

22

MRI Design: 50. Contrast Agents

- Iron oxides shorten the relaxation times of nearby hydrogen atoms and, therefore, reduce the signal intensity in normal tissues.
- This results in a signal loss on proton density-weighted or heavily T2-weighted images. Super-paramagnetic iron oxides are known as T2 enhancement agents.
- Iron oxide is taken up by the reticuloendothelial system and excreted by the liver so that the normal liver is dark and liver lesions are bright on T2-weighted images.

23