Al-Mustaqbal University College
Biomedical Engineering Department

Subject: Biomedical Instrumentation Design.

Class (code): 5th (BME515)

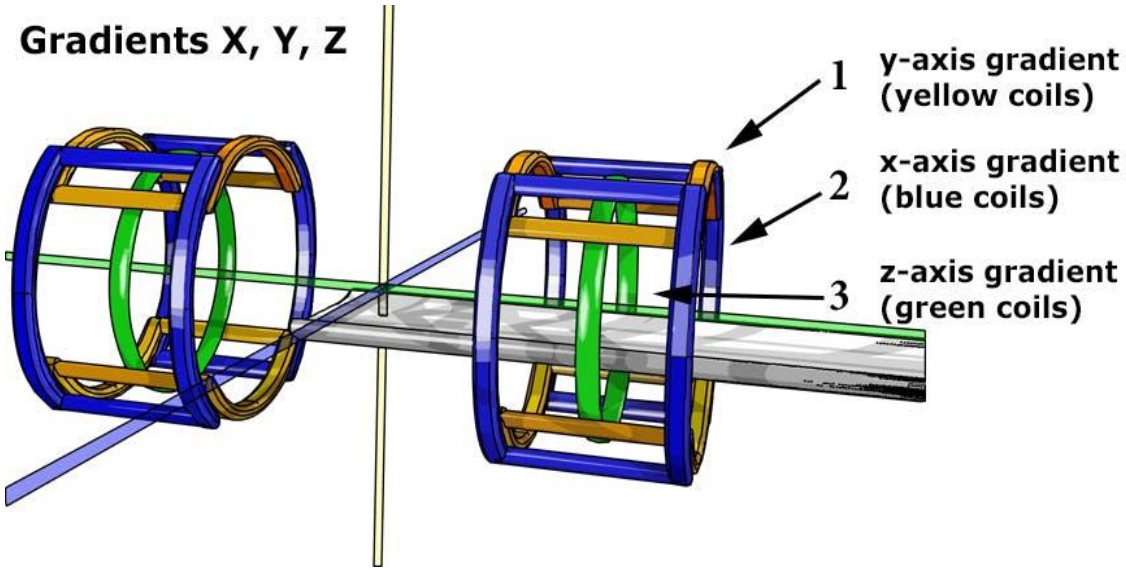
Lecture: *4*

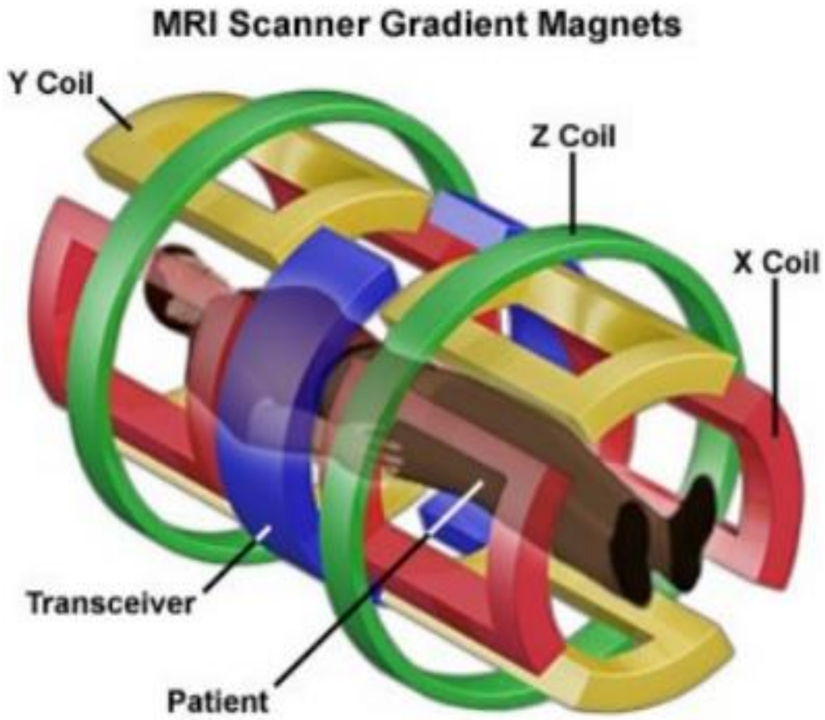
MRI DESIGN: Gradient Coils and Slice Selection

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

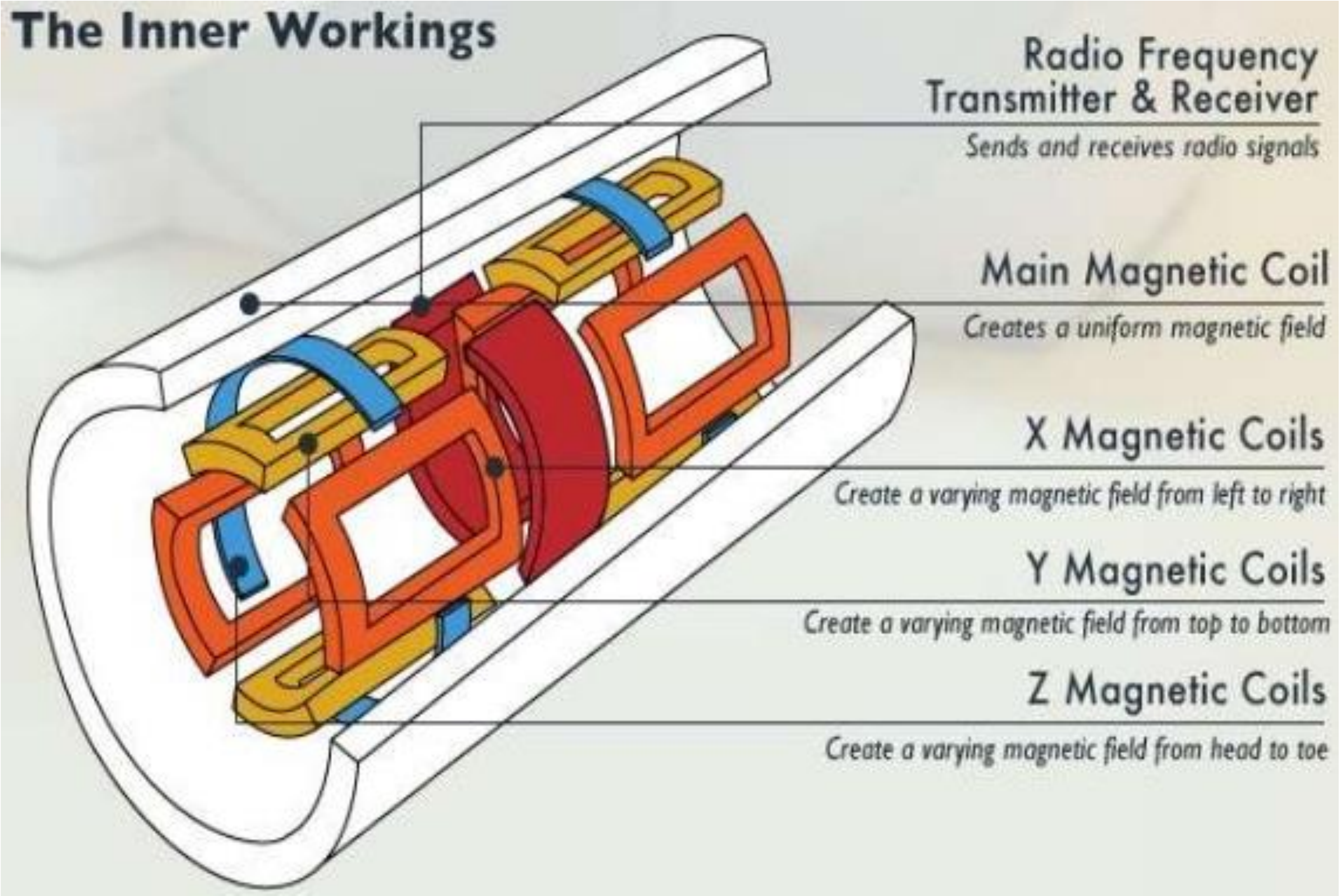
- The *Z gradient* alters the magnetic field strength along the *Z axis*.
- The *Y gradient* alters the magnetic field strength along the *Y axis*.
- The *X gradient* alters the magnetic field strength along the *X axis*.

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





MRI DESIGN: Gradient Coils and Slice Selection



MRI DESIGN: Gradient Coils and Slice Selection

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

- 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

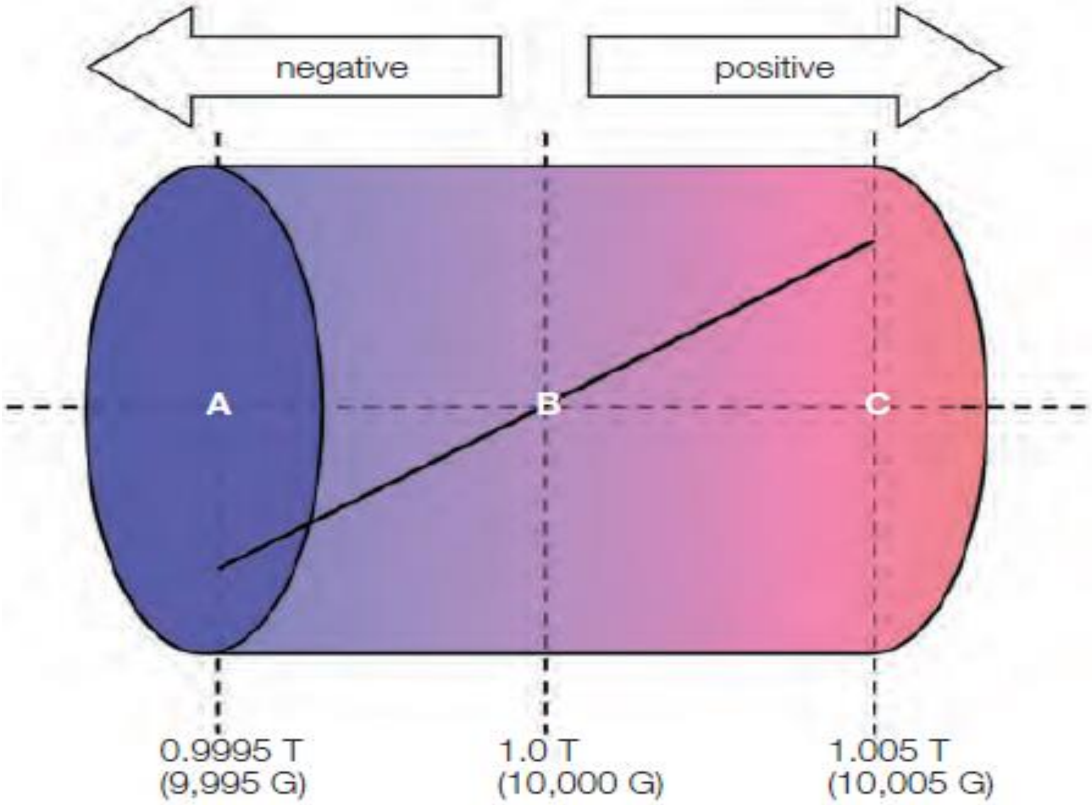


Figure 27.2 Gradients and changing field strength.

MRI DESIGN: Gradient Coils and Slice Selection

- 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.

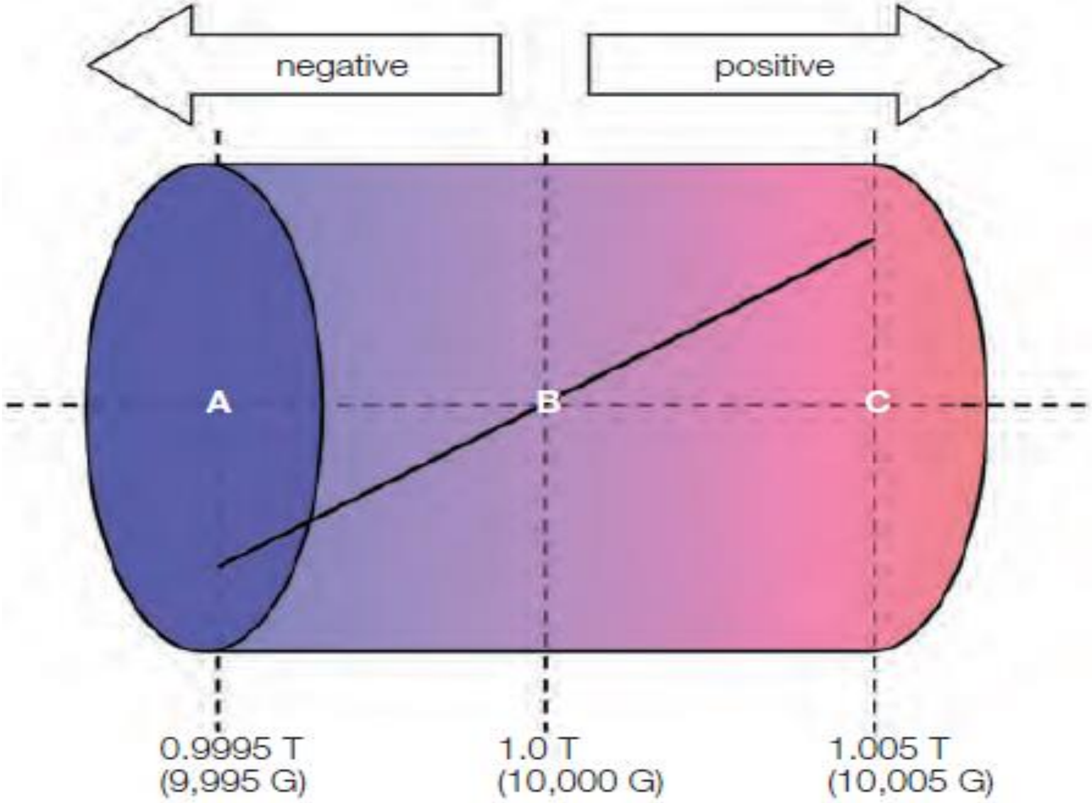


Figure 27.2 Gradients and changing field strength.

MRI DESIGN: Gradient Coils and Slice Selection

› 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).

› 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.

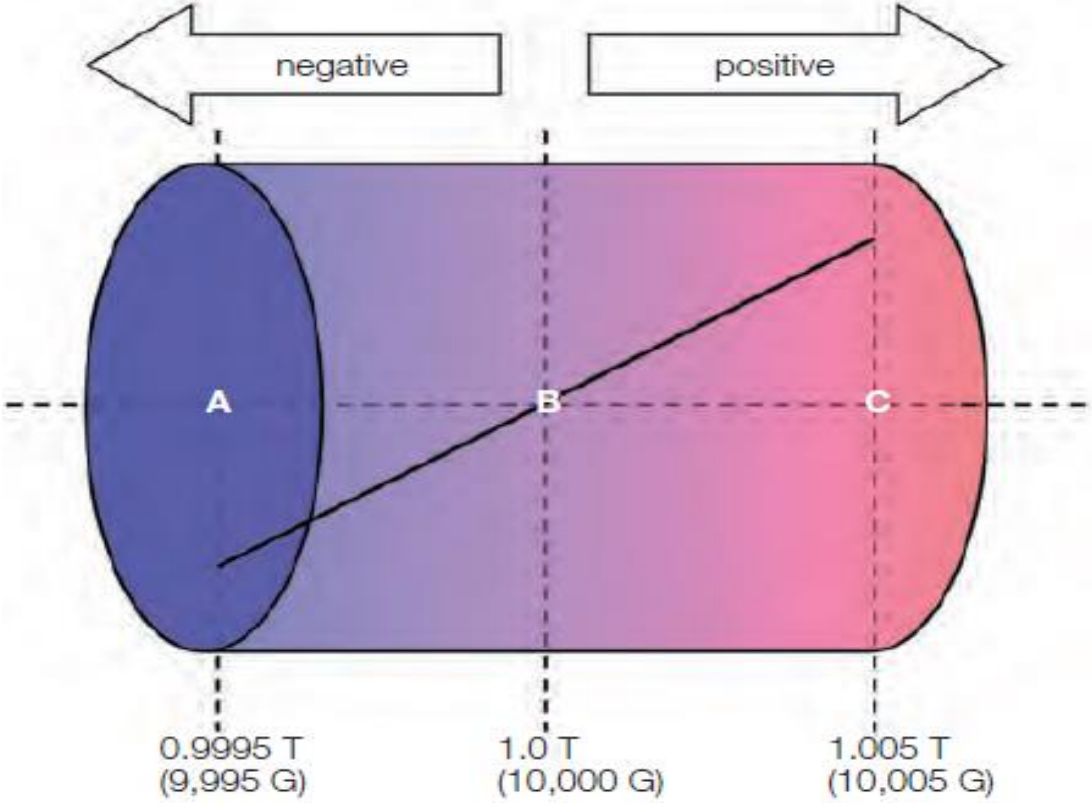


Figure 27.2 Gradients and changing field strength.

MRI DESIGN: Gradient Coils and Slice Selection

› 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.

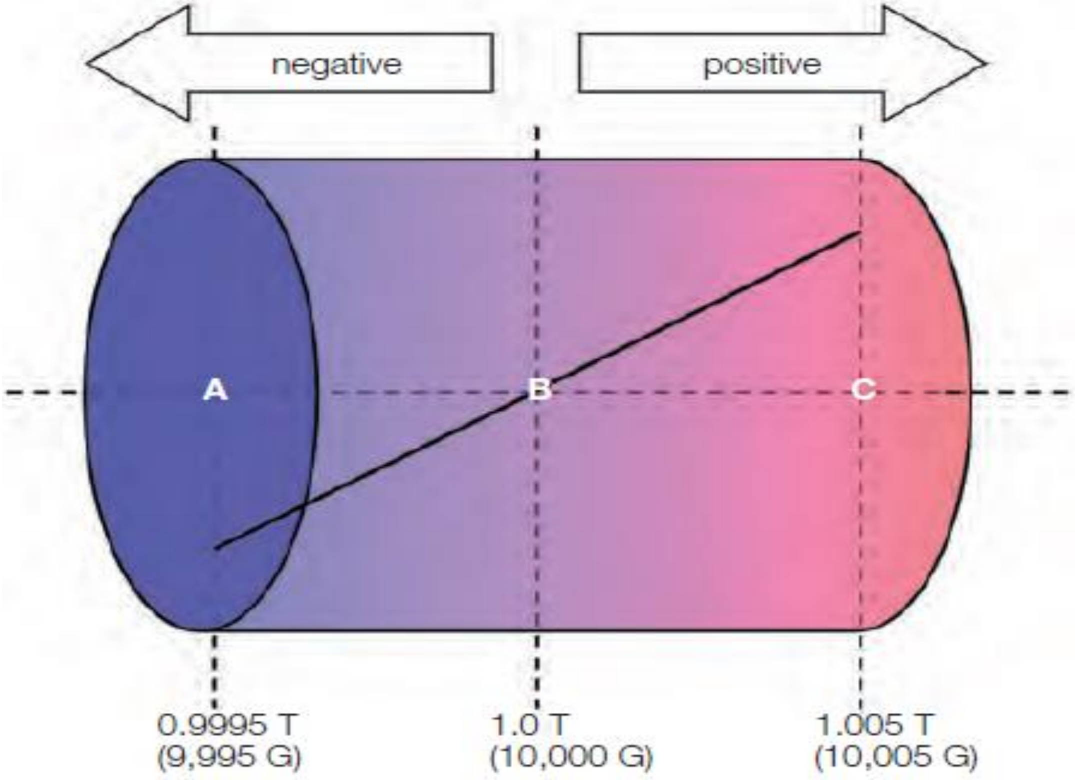


Figure 27.2 Gradients and changing field strength.

MRI DESIGN: Gradient Coils and Slice Selection

› 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: Gradient Coils and 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.
- The gradient used for each task depends on the plane of the scan and on which gradient the operator selects to perform frequency or phase encoding.
- • Slice selection – locating a slice in the scan plane selected.
- • Spatially locating signal along the short axis of the image. This is called phase encoding.
- • Spatially locating signal along the long axis of the image. This is called frequency encoding.

MRI DESIGN: Gradient Coils and 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.
- To excite nuclei in slice B, an RF pulse of 43.80 MHz must be applied.

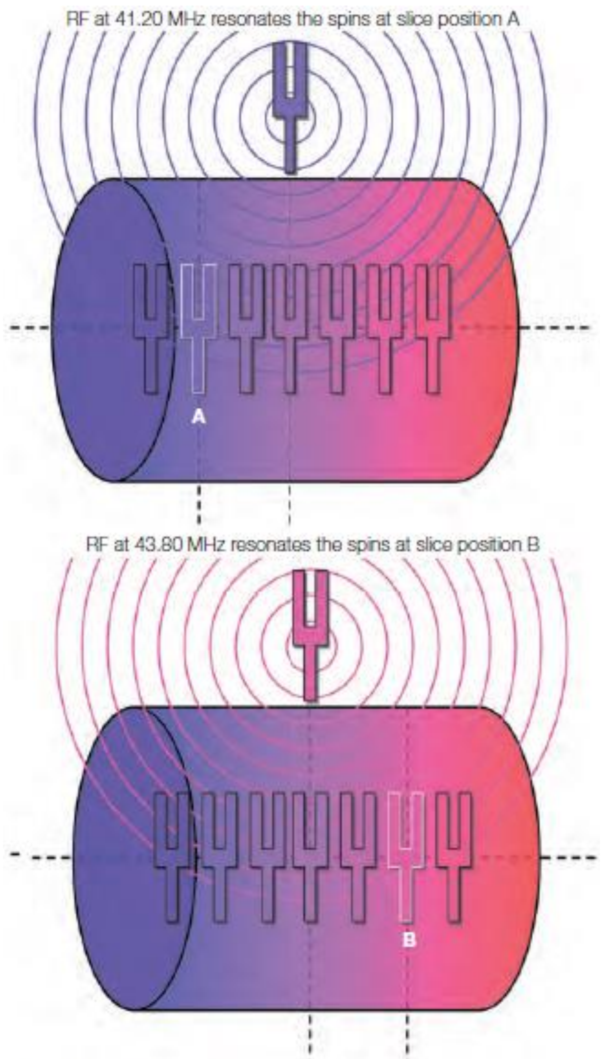


Figure 28.1 Slice selection.

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- 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.

MRI DESIGN: Gradient Coils and Slice Selection

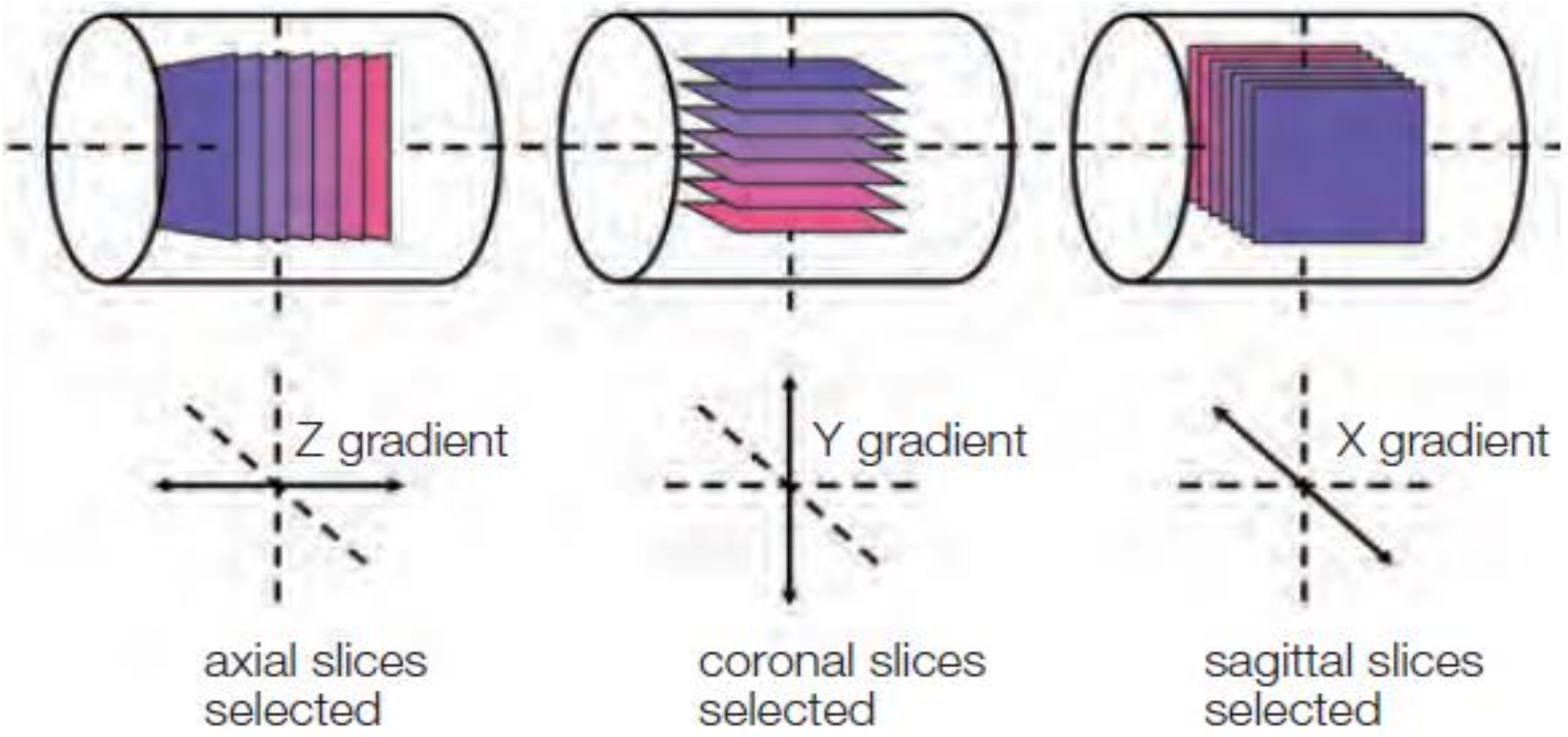


Figure 28.2 Using X, Y and Z gradients to select slices.

MRI DESIGN: Gradient Coils and 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).

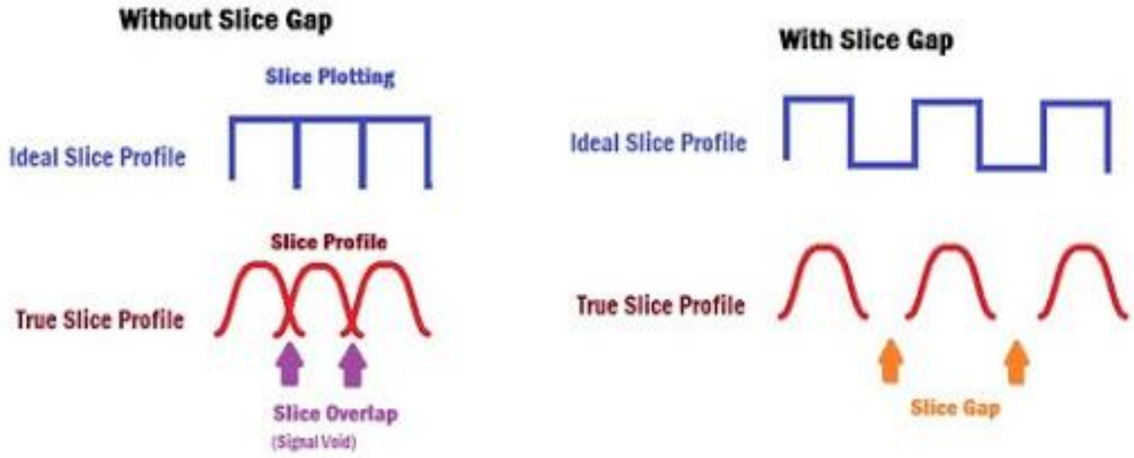
- A bandwidth of RF is transmitted and called the transmit bandwidth.

- 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 artifact called **cross-talk**.

MRI DESIGN: Gradient Coils and Slice Selection



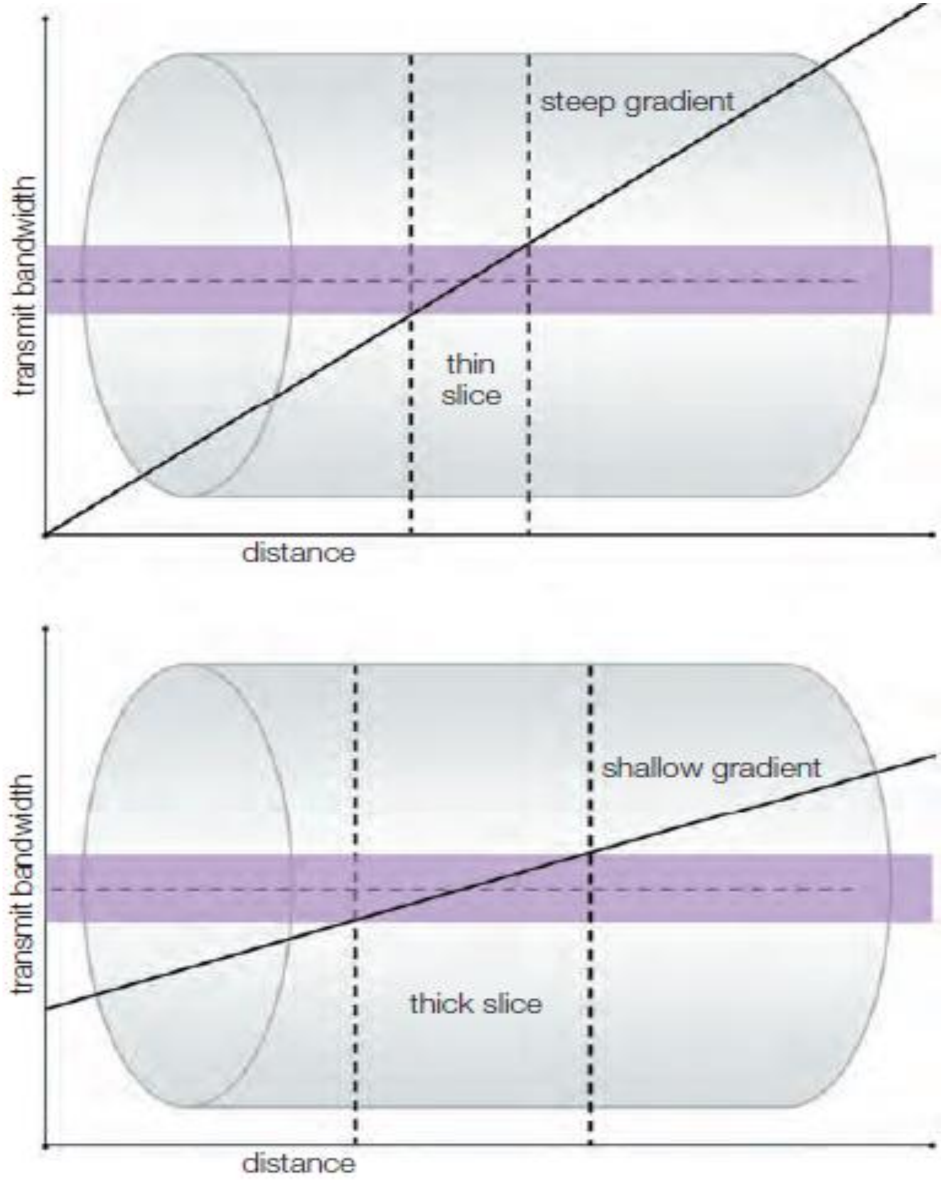


Figure 28.3 Transmit bandwidth, gradient slope and slice thickness

MRI DESIGN: 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.
- 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.

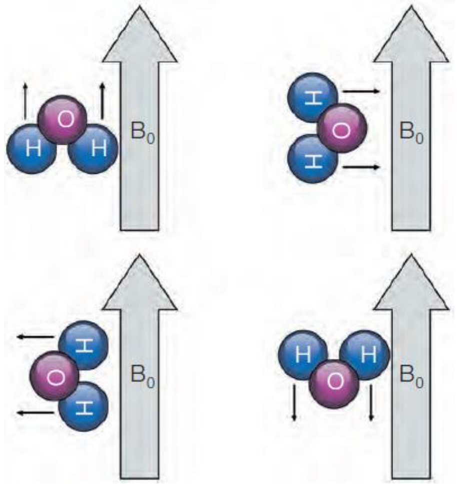


Figure 50.1 Tumbling of water molecules.

MRI DESIGN: Contrast Agents

- Molecules that tumble with a frequency at or near the Larmor frequency have more efficient T1 recovery times than other molecules.

- 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.

MRI DESIGN: Contrast Agents

- Gadolinium (Gd): T1 enhancement agent.

- Paramagnetic agent that has seven unpaired electrons and the ability to allow rapid exchange of bulk water to minimize the space between itself and water within the body.

- It 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.

MRI DESIGN: Contrast Agents

- Gadolinium has proven invaluable in imaging the central nervous system because of its ability to pass through breakdowns in the blood-brain barrier (BBB).

- Clinical indications for gadolinium include:

- • tumors; • infection; • arthrography;

- • post-operation lumbar disc; • breast disease; • vessel patency and morphology.

MRI DESIGN: Contrast Agents

- Iron oxide: as T2 enhancement agents.
- Iron oxides shorten 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.
- Iron oxide is taken up by the reticuloendothelial system and excreted by the liver, so that normal liver is dark and liver lesions are bright on T2 weighted images.
- Iron oxide is mainly used in liver and biliary imaging.

MRI DESIGN: Contrast Agents

- Other contrast agents

- barium, ferromagnetic agents, and fatty substances are used as gastrointestinal contrast agents which are used for bowel enhancement.

- However, due to constant peristalsis, these agents enhance bowel motion artefacts more often than enhancing pathological lesions.

- The use of anti-spasmodic agents helps to retard peristalsis to decrease these artefacts.

- Other agents include helium, which is inhaled and assists in the evaluation of lung perfusion.