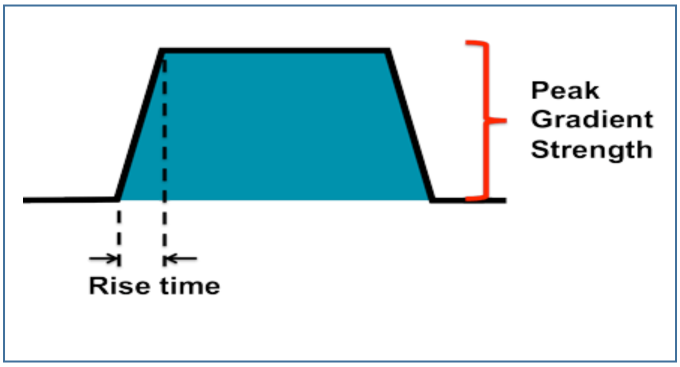
Theoretical Lecture

Gradient specifications & Radiofrequency (RF) Coils

Gradient specifications

Both spatial resolution and imaging speed depend upon good gradient performance, and scanners do differ in their gradient specifications.



Electrical currents are pulsed on and off during imaging, and gradients typically have a trapezoidal waveform as shown in the diagram above from which various measurements are derived.

The first value to look for on the specification sheet is

1- ***Maximum (or peak) gradient strength.*** This is quoted in units of millitesla per meter (mT/m).

- **Most 1.5T to 3.0T superconducting whole body scanners have maximum gradient strengths in the range of 30-45 mT/m.**
- **Lower field (<0.5T) permanent scanners are in the 15-25 mT/m range.**
- **For the best performance concerning peak gradient strength, bigger is better.**

2- ***Rise time***

Unfortunately this is not the case, as we do not live in an ideal world. In reality the gradient needs a little time to reach maximum power and to power down (as seen in figure above). The time it takes to reach maximum power is called: Rise Time. Rise time is measured in milliseconds, and is typically in the range of 0.1-0.3 msec for most scanners.

Slew rate is the speed at which a **gradient** can be turned on and off, and is defined as **the maximum gradient strength** of the gradient divided by the **rise time**.

$$slew\,rate = \frac{peak\ gradient\ strength}{Rise\ Tiime}$$

Slew rates are measured in units of **Tesla per meter per second** (**T/m/s**).

Example:

If the gradient ramps from 0 to peak amplitude of 30 mT/m in 0.5 msec, find the slew rate?

Answer:

$$slew\,rate = \frac{peak\ gradient\ strength}{Rise\ Tiime}$$

$$slew\,rate = \frac{(30-0)mT/m}{0.5\,msec} = 60T/m/s$$

The slew rate influences the minimum attainable Repetition Time (TR) and Time to Echo (TE) for conventional MR imaging.

- ***Repetition Time (TR)*** is the amount of time between successive RF pulses sequences applied to the same slice.
- ***Time to Echo (TE)*** is the time between the delivery of the RF pulse and the receipt of the echo signal.

In the current marketplace, high field superconducting scanners boast slew rates in the 150-200 T/m/s range; superconducting open scanners in the 100-120 T/m/s range; and lower field permanent scanners on the order of 50 T/m/s .

The need for strong gradients and high slew rates depends on your intended scanner use. If cardiac or brain imaging is anticipated, then powerful gradients are mandatory. If the intended scanner use is for orthopedics, however, such demanding gradients may not be required.

Radiofrequency (RF) Coils

The radiofrequency (RF) system includes the set of components for transmitting and receiving the radiofrequency waves involved in exciting the nuclei, selecting slices, applying gradients and in signal acquisition.

Coils are a vital component in the performance of the radiofrequency system figure 1 shows RF coils.

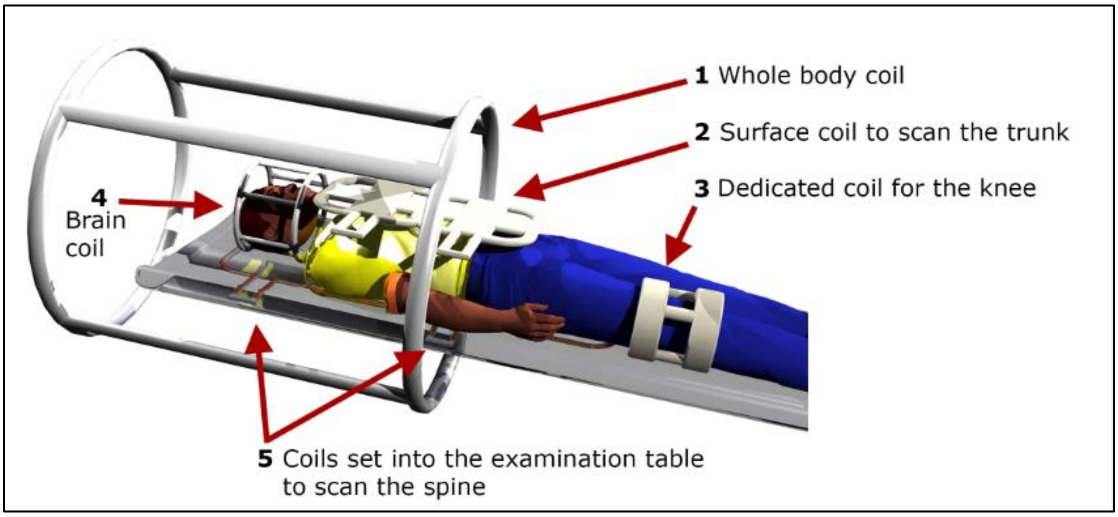


Figure1: RF coils.

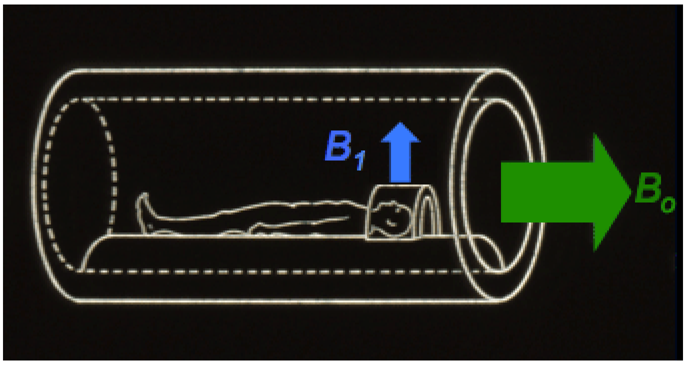
RF coils are RF produces magnetic field perpendicular to the main magnetic field. It should be close to the imaging part.

RF coils made for:

a) Receive only.
b) Transmit only.
c) Transmit and receive.

Sending and Receiving Coils

RF-coils generate an oscillating/rotating magnetic field (denoted B_1) that is perpendicular to the static main magnetic field when employed as transmitters (B_o). Energy is deposited into the spin system if the oscillation of B_1 closely matches the natural precession of nuclear spins near the Larmor frequency, causing a change in its net alignment. The transmit RF-coil produces the B_1 field in response to a strong current provided by the scanner's send circuitry. B_1 is normally turned on for only a few milliseconds at a time, known as "RF-pulses." The nuclear spin system can be rotated by variable flip angles, such as 90^o or 180^o, by modifying the size or length of these B_1 pulses.



RF-coils are responsible for detecting the MR signal when employed as receivers. The coil in which an induced electric current is created can capture the oscillating net magnetic flux from the excited spin system. To extract frequency and phase information, the current is amplified, digitized, and filtered. RF receive-only coils are now commonly arranged in large arrays for use in parallel imaging applications.

Types of RF coils includes (Figure 2).

- Volume coil (include Body coil, Head coil and knee coil).
- Surface coil.
- Phased array coils.

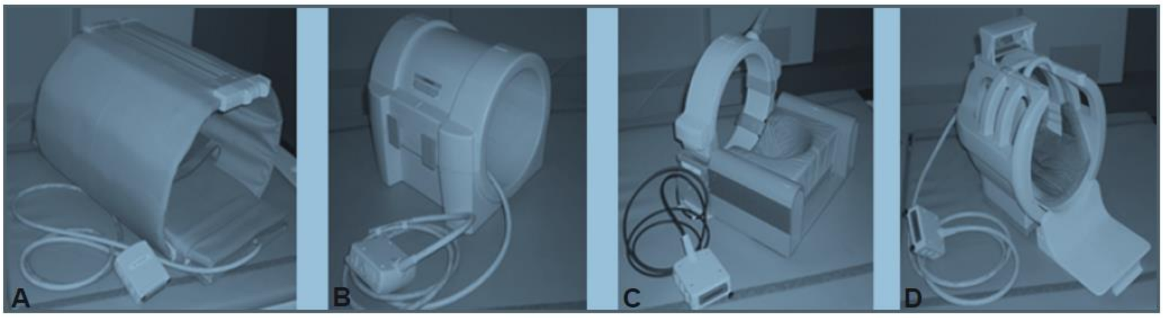


Figure2: (A) Body coil, (B) Knee coil, (C) Head and shoulder coil, and (D) Head coil

The sending coil of an MRI system is usually built into the bore of the magnet, while the receiving coil is located on the patient table (Figure 3).

- Precise positioning of the patient within the sending coil is necessary to ensure that the anatomy of interest appears in the image.
- In most imaging units it is difficult to visualize patient position after the patient has entered the bore of the magnet. Therefore, a positioning system is used that involves the use of external markers or a patient table indexing scale.
- Under some circumstances, the use of separate sending and receiving coils may be eliminated.

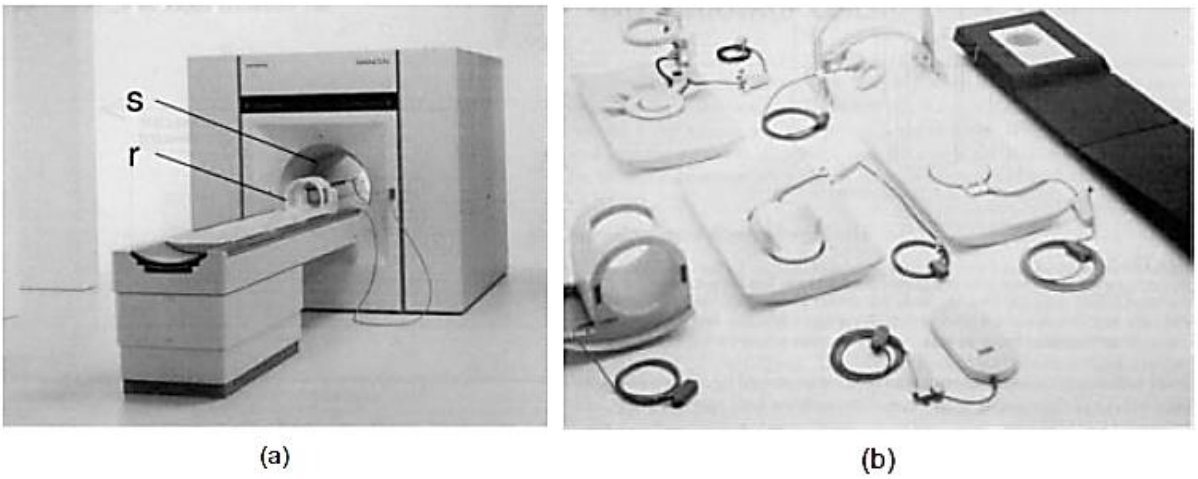


Figure 3: (a); The radio-frequency (RF) coil for sending is usually located within the bore of the magnet, while the RF coil for receiving is located on the patient table. **(b);** a set of RF "surface coils" for imaging various body parts. (Courtesy of Siemens Medical Systems.)

- The same coil may send and receive radio waves in the same fashion as radio antennas may be both senders and receivers.
- There is some interest in eliminating the in-bore sending coil to provide more room in the bore to help alleviate claustrophobic effects in patients.
- Alternately, deletion of the in-bore coil would allow a reduction in bore size that could resolve some of the design problems inherent in MRI magnet construction.

Volume RF coils

Volume coils are the transmit and receive radiofrequency coils which are used to both transmit and receive the radiofrequency signal in MRI.

The design of a volume coil is to provide a homogeneous RF field inside the coil which is highly desirable for transmit, but is less ideal when the region of interest is small. The large field of view of volume coils means that by receiving the noise that they receive from the whole body, not just the region of interest.

The main body coil transmits RF to the patient, and it will typically be circularly polarized (generating a field rotating at the Larmor frequency) and be driven in quadrature (figure 4).

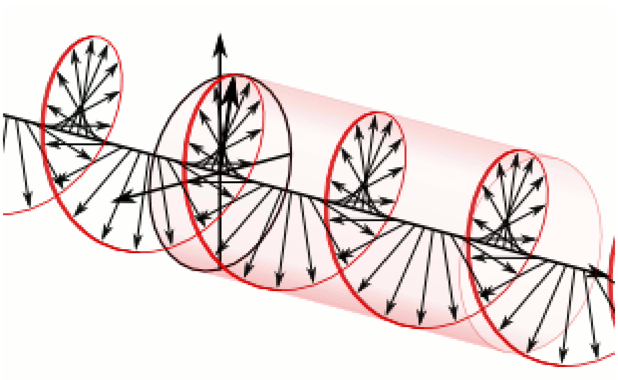


Figure 4: circular polarization; circular polarization of an electromagnetic wave is a polarization state in which, at each point, the electromagnetic field of the wave has a constant

The body coil is also often able to act as a receiver, and allows large volumes of the body and multistation whole body imaging (i.e. images of different sections of the body which are joined together to give a whole body image) to be achieved.

Body coil; which is a volume coil built into the bore of the magnet which transmits the radiofrequency for most examinations. It transmits RF and receive MR signal, e.g. chest, abdomen .

Smaller homogeneous volume coils include head coils (Head coil is used for brain imaging, and it transmits and receives the signal) and knee coils, there is a range of designs, including birdcage designs.

Questions:

1- Define slew rate and write its equation?
2- Calculate the slew rate if the gradient slope from 0 to 50 mT/m in 0.5 msec?
3- What is the important values of the gradient specification sheet?
4- Define radio frequency system (RF) system?
5- How the transmit RF coil work?
6- What are the types of RF coils according to imaging part?
7- Define body coil and how it built?
8-