EQUIPMENT TECHNIQUES OF MAGNETIC RESONANCE IMAGING

3.ST STAGE

LECTURE 2- THEORY

RADIO-FREQUENCY SYSTEM

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Radiofrequency System

One of the major component of the MRI scanner is the RF system. The purpose of the RF system is to transmit and receive electromagnetic radiation during image acquisition. Radiofrequency transmit and receive signal, which excite and detect the MR coils.

- They one of the most important components that affects image quality and obtaining clear images of the human body.

Specific resonant **(Larmor frequency):**

The Larmor frequency scales directly with main magnetic field strength (**Bo**), and for clinical MRI lies in the range of tens to hundreds of MHz. These frequencies are part of the electromagnetic spectrum commonly used for radio transmission.

Field Strength	Operating Frequency (MHz)	Assigned Range in US
0.3T	12.8	Maritime mobile
0.5T	21.3	Shortwave "ham" radio (15 m band)
1.0T	42.6	Land mobile
1.5T	63.9	Analog TV Channel 3 (USA)
3.0T	127.8	Civil aviation
7.0T	298.2	Mobile satellite

Table 1: The electromagnetic spectrum used in NMR corresponds to "radio waves" used in commercial communications.

Functions of radiofrequency (RF) coils

- RF-coils may serve as transmitters, receivers, or both.

1. RF Transmit Coils

The transmitter has to generate RF pulses with appropriate center frequencies, bandwidths, amplitudes and phases in order to excite nuclei within the desired slices or slabs.

RF-coils generate an oscillating/rotating magnetic field (denoted $\mathbf{B_1}$) that is perpendicular to the static main magnetic field ($\mathbf{B_0}$). If the oscillation of $\mathbf{B_1}$ closely matches the natural precession of nuclear spins near the Larmor frequency, energy is deposited into the spin system causing a change in its net alignment.

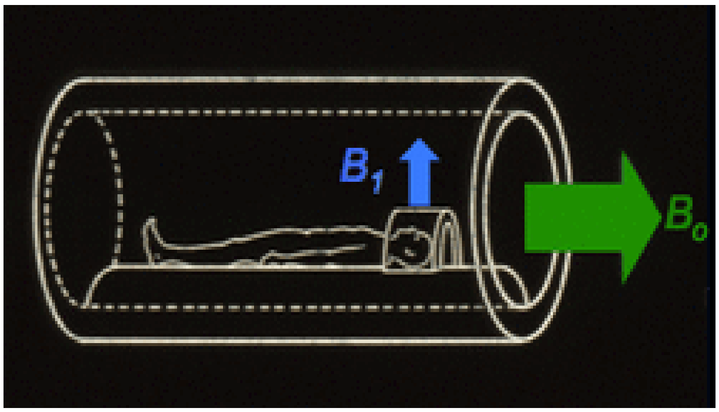


Figure1: The B_1 RF-field is perpendicular to B_0

The **B1** field is generated by the transmit RF-coil in response to a powerful current generated by the scanner's transmit circuitry. $\mathbf{B_1}$ is typically turned on for only brief periods of time (a few millisecond), called "**RF-pulses**." By adjusting the magnitude or duration of these $\mathbf{B_1}$ pulses, the nuclear spin system can be rotated by variable flip angles, such as 90° or 180°.

To stimulate the NMR spin system, an RF-coil must produce a time-varying excitation field $B_1(t)$ with the following characteristics:

1. $B_1(t)$ must have components that rotate near the resonant frequency (ω_o), and
2. $B_1(t)$ must have components perpendicular to the static magnetic field (B_0)

Figure 2:Transmit-receive head coil

The aim of the transmit coil is to transfer energy to the hydrogen nuclei. The most efficient way to do this is to generate a field that oscillates at the Larmor frequency but also rotates directed perpendicularly to the main magnetic field (B_0) in the same orientation as the spins.

2. Receive Coils

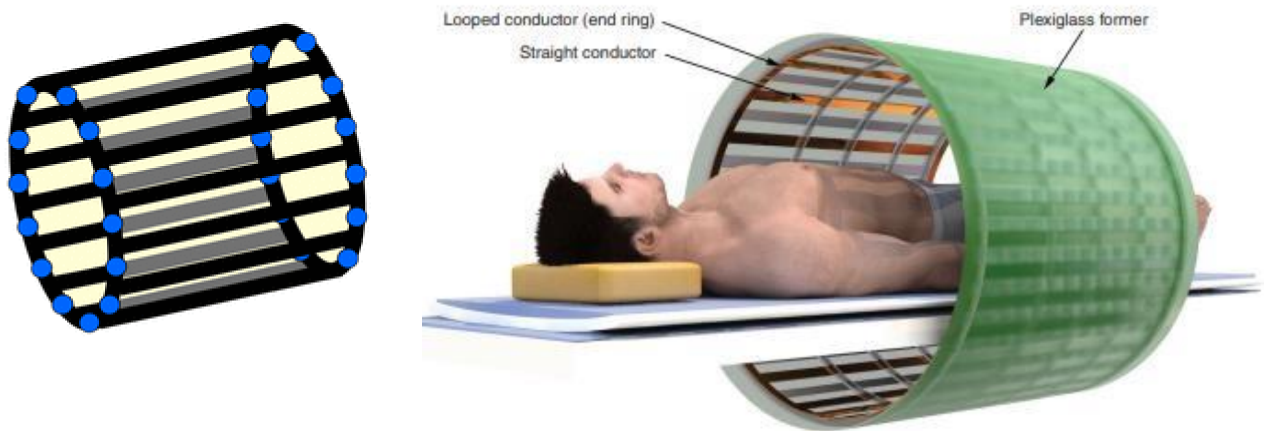
The aim of the RF receive system is to receive MR signal returning from the patient at time TE

RF-coils are responsible for detecting the MR signal. The oscillating net magnetic flux from the excited spin system can be captured by the coil in which an induced electric current is generated. This current is then amplified, digitized, and filtered to extract frequency and phase information.

Birdcage Coils

the main RF transceiver is colloquially known as the body coil and typically features what is known as a birdcage design.

The birdcage coil (Figure 3) is the most commonly used RF-transmit device used in clinical MRI today.



A- Birdcage coil design with two end rings, multiple legs/rungs, and double capacitors.

B-The RF transmit coil. This is a birdcage resonator coil consisting of two end rings linked by a symmetrical array.

Figure 3: Birdcage coil

As shown in Figure 3, there are two large circular conductive loops (known as end-rings) located at each end of the structure, and these are connected along the length of the magnet bore by an even number of straight copper strips. The end-rings must be larger than the circumference of the patient bore, greater than 70 cm in diameter, and the length of the coil is typically around 50 cm in length. This is desirable to achieve a large FOV (field of view) , such as is required in abdominal imaging.

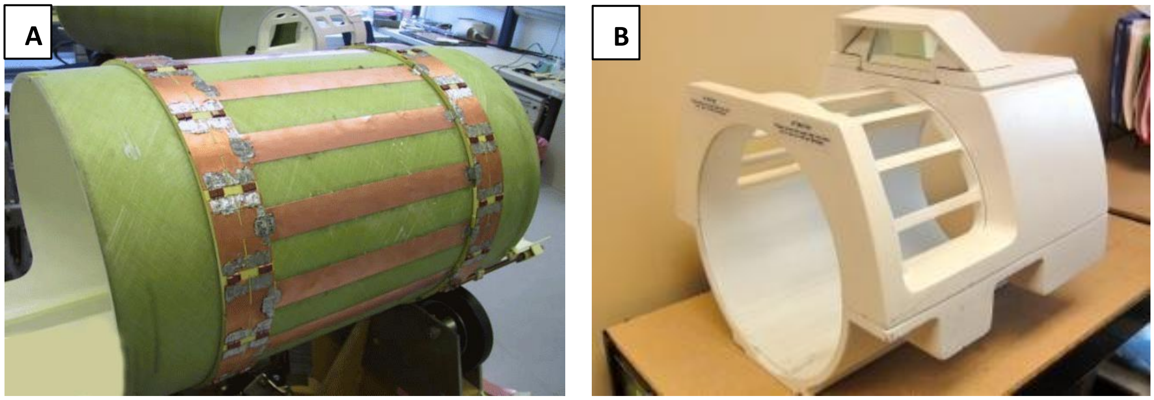


Figure 4: A- RF-body coil with birdcage design , B- Quadrature head coil with birdcage design.

Types of Radiofrequency Coils

There are basically two types of RF coils:

1. volume coils
2. surface coils.

Volume RF Coils

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. Volume coils need to have the area of examination inside the coil. They can be used for transmit and receive, although sometimes they are used for receive only.

Figure 4: shows two volume coils (a) Head coil (b) Knee coil

Most clinical applications volume coil is built to perform whole-body imaging, and smaller volume coils have been constructed for the head and other extremities. These coils are requiring a great deal of RF power because of their size, so they are often driven in quadrature in order to reduce by two the RF power requirements. Figure 4 shows two volume coils. The head coil is a transmit/receive coil; the knee coil is receive only.

Surface coils

Surface coils have very high RF sensitivity over a small area of interest. As the name already implies, surface coils are placed over or around the surface of the anatomy of interest to the patient directly such as the temporo-mandibular joint, the orbits or the shoulder. The coil consists of single or multi-turn loops of copper wire. They have a high Signal to Noise Ratio (SNR) and allow for very high-resolution imaging because their small field of view and hence they only detect noise from the region of interest.

The disadvantage :

- They lose signal uniformity very quickly when you move away from the coil and include limited FOV and positioning because the surface coil is smaller than the head or body probe, it has a smaller sensitive volume, which results reduced field of view (FOV). This is acceptable if only a small region of anatomy is to be imaged.
- Surface coils make poor transmit coils because they have poor RF homogeneity, even over their region of interest.

In case of a circular surface coil, the depth penetration is about half its diameter. Figure 5 shows a few examples of surface coils.

Figure 5: few examples of surface coils.

Phased Array Coils

Phased array coils consist of multiple surface coils with small diameter which are combined (coil elements in phased array) to record the signal simultaneously and independently, so a greater level can be explored. We can say that array coil systems are collections of small surface coils whose signals may be combined but generally feed into independent receiver circuitry. By combining multiple small coils into large arrays it is possible to obtain the best of both — high signal-to-noise ratio (SNR) and large fields of view. Surface coils have the highest signal-to-noise ratio than that delivered by one large diameter but have a limited sensitive area. In other words, a small diameter coil obtains a better signal with a higher signal-to-noise ratio than a coil with a large diameter. Small-diameter surface coils near the patient have high sensitivity but limited anatomical coverage. The use of phased array coils allows the decreasing of the number of signal averages, which shortens the scan time by high SNR and resolution. However its sensitive volume is lower. When several small coils are combined (coil elements in phased array) to record the signal simultaneously and independently, a greater level can be explored. Thanks to the geometry of the coils and the lack of noise correlation recorded by the different elements in the phased array, the signal obtained will have a better signal-to-noise ratio than that delivered by one large coil.

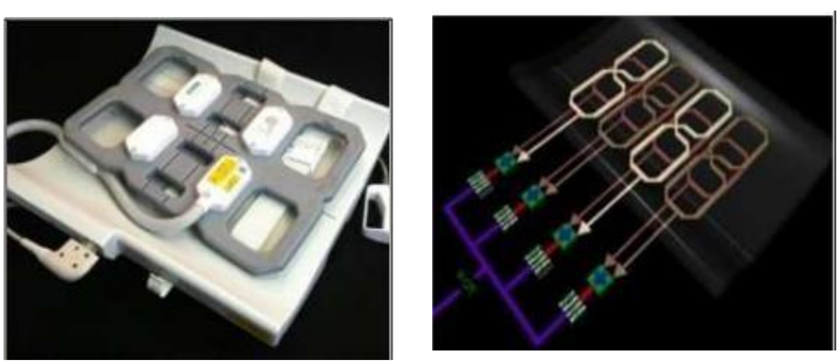


Figure 6: Spine Array coil

Quadrature Coils

The quadrature coil consists of two coils, which are placed at right angles to one another that mean oriented 90 degrees relative to each other. Therefore, the MRI signals received by each, coil is 90 degrees out of phase with each other. The advantage of this design is that they produce √2 more signal than single loop coils. The quadrature coil operates in the circular polarization circularization mode. Nowadays, most volume coils are Quadrature coils. The coils shown in Figure 6 are Quadrature coils. The QD Body Array coil is a volume coil, while the Spine Array coil is a surface coil. Phased Array coils produce in average √2 more signal than Quadrature coils. Today most MRI systems come with Quadrature and phased array coils.

Radiofrequency (RF) Shielding

Radiofrequency (RF) shielding of an MR scanner is mandatory and serves two functions:

1) To prevent extraneous electromagnetic radiation from contaminating/distorting the MR signal.
2) To prevent electromagnetic radiation generated by the MR scanner from causing interference in nearby medical devices.

1. What is the primary function of the RF system during image acquisition?

- A) To maintain the stability of the static magnetic field
- B) To provide spatial localization using gradient slopes
- C) To transmit and receive electromagnetic radiation
- D) To cool the internal components of the gantry
- E) To digitize the final image for display

2. The B_1 field generated by the RF-coil must be:

- A) Parallel to the static field B_0
- B) At a 45-degree angle to B_0
- C) Perpendicular to the static field B_0
- D) Zero during the excitation phase
- E) Constant and non-oscillating

3. Which of the following is a characteristic of Volume RF Coils?

- A) They provide very high sensitivity over a tiny area
- B) They lose signal uniformity very quickly with depth
- C) They provide a homogeneous RF field inside the coil
- D) They are always placed directly on the patient's skin
- E) They cannot be used for transmitting RF

4. Phased array coils are essentially a collection of:

- A) Large volume coils connected together
- B) Small surface coils used independently/simultaneously
- C) Gradient coils designed for RF transmission
- D) Insulated wires used for cooling
- E) Magnet shims used to fix B_0

5. Which of these coils is described as a surface coil in the text?

- A) QD Body Array coil
- B) Spine Array coil
- C) Birdcage head coil
- D) Main magnet bore
- E) RF shielding room