SAWA UNIVERSITY

Equip. Techniques of MRI

Radio Frequency System

جامعة ساوة

كلية التقنيات الصحية والطبية

قسم تقنيات الأشعة والسونار

المرحلة الثالثة

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The Radio Frequency (RF) system in MRI plays an integral role in both stimulating the tissue and receiving the signals necessary to produce detailed images. Here's a deeper look into various aspects of the RF system in MRI:

1. **Principles of RF in MRI**

- **Larmor Frequency:** The Larmor frequency is determined by the strength of the external magnetic field (B_0) and the gyromagnetic ratio (γ) of hydrogen protons, which is a constant. The relationship is given by:

$$f = \gamma \cdot B_0$$

Where f is the Larmor frequency, γ is the gyromagnetic ratio (for hydrogen protons, it is approximately 42.58 MHz/Tesla), and $B0$ is the magnetic field strength.

- **Excitation:** The RF pulses are transmitted at the Larmor frequency, causing protons to absorb energy and shift their alignment. This process flips the net magnetization from its equilibrium along the z-axis (parallel to B_0) into the transverse plane (xy-plane).

2. RF Pulse Sequences

The RF system is responsible for delivering precise pulse sequences. These sequences consist of RF pulses that are carefully timed and combined with gradient magnetic fields to create images with different contrast and resolution.

90° and 180° Pulses:

- A **90° pulse** flips the magnetization from the longitudinal axis (along B_0) into the transverse plane, creating transverse magnetization that is detectable.
- A **180° pulse** is used in spin-echo sequences to refocus dephased spins, which improves signal quality by eliminating inhomogeneities in the magnetic field.

Common Pulse Sequences:

a. Spin-Echo (SE): Uses a 90° pulse followed by a 180° refocusing pulse to produce T1- and T2-weighted images. The time between the 90° pulse and the signal measurement is the Echo Time (TE), while the time between successive 90° pulses is the Repetition Time (TR).

b. Gradient-Echo (GRE): Does not use a 180° pulse, relying instead on gradient fields to refocus the signal. GRE sequences are faster but more sensitive to magnetic field inhomogeneities.

c. Inversion Recovery (IR): Begins with a 180° pulse to invert the net magnetization, followed by a 90° excitation pulse at a set time to create strong T1 contrast (e.g., STIR for fat suppression).

3. RF Safety in MRI: Specific Absorption Rate (SAR)

- RF energy absorbed by the body is converted to heat, and the rate at which this energy is absorbed is referred to as the Specific Absorption Rate (SAR).
- SAR is expressed in watts per kilogram (W/kg) and is carefully monitored to prevent excessive heating of tissue.

The SAR depends on several factors:

- The strength of the magnetic field (B_0).The type of -
- RF pulse sequence (longer pulse sequences may increase SAR).
- The patient’s body weight and surface area.

Safety Standards:

Regulatory bodies, such as the U.S. FDA, limit SAR values in MRI to avoid tissue heating. In the U.S., the SAR is limited to 4 W/kg over the whole body for 15 minutes of scanning, or 8 W/kg for localized areas (such as the head).

4. RF Shielding and Interference

MRI scanners are highly sensitive to external RF interference (e.g., from cell phones or radio signals). To prevent this, MRI rooms are constructed as Faraday cages, which block external RF signals from entering the scanner environment.

RF Leakage: Any leak in the shielding can lead to noise artifacts in the image, reducing image quality.

Transmitter coils

are a crucial part of the Radio Frequency (RF) system, responsible for generating and delivering RF pulses that excite the hydrogen nuclei within the body. These coils create a rotating magnetic field (referred to as the B1 field) perpendicular to the main static magnetic field (B_0), temporarily altering the alignment of the protons and enabling signal detection.

1. Function of Transmitter Coils

- The transmitter coil produces an oscillating magnetic field (B1) at the Larmor frequency, which is determined by the strength of the static magnetic field (B_0) and the type of nuclei being imaged (usually hydrogen).This RF field excites the hydrogen nuclei by tipping them out of alignment with the main magnetic field.
- This process is known as nutation, and it brings the protons from their equilibrium position into the transverse plane, where they are detectable by the receiver coils.
- The transmitter coil determines the flip angle of the protons, which is how far the protons are tilted from the main field. For instance, a 90° pulse tips the net magnetization entirely into the transverse plane, while a 180° pulse inverts it completely.

2. Types of Transmitter Coils

Different types of transmitter coils are used depending on the anatomy being imaged and the system's design. Common types include:

A. Body Coil: This is the most commonly used transmit coil in MRI systems, and it is built into the scanner itself, surrounding the entire patient.It can both transmit RF pulses and receive signals (though often, surface or phased-array coils are used for receiving).The body coil is typically used in whole-body imaging because it provides a uniform B1 field over a large area.

B. Surface Coils (Transmit/Receive Coils): These are smaller coils placed close to the surface of the body, specifically designed for localized imaging (e.g., the head, neck, or extremities).Surface coils can function as both transmitter and receiver coils, though they are primarily used for signal reception due to their proximity to the area of interest, which increases sensitivity.

C. Volume Coils: These coils surround a specific volume of the body and are used when the uniformity of the RF field is required. Examples include the birdcage coil and TEM (Transverse Electromagnetic) coil.The birdcage coil, for example, is often used in brain imaging because of its ability to produce a homogenous RF field within the volume it surrounds.

3. Applications of Transmitter Coils in Imaging

- **Whole-Body Imaging:** The built-in body coil is commonly used for whole-body imaging or imaging large anatomical regions like the torso.
- **Dedicated Imaging:** Surface coils, which often act as both transmit and receive coils, are used in specific regions like the knee, spine, or brain. These coils increase the signal-to-noise ratio (SNR) for detailed imaging of localized areas.
- **High-Field Imaging:** With 3T and higher MRI systems, transmitter coils like birdcage or TEM coils are used for brain imaging or research applications. Their ability to provide homogenous excitation is critical for generating high-quality images in high-field environments.

Receiver Coils

Receiver coils in MRI play a vital role in detecting the weak radiofrequency (RF) signals emitted by hydrogen nuclei after they've been excited by the transmitter coil. These signals, often referred to as Free Induction Decay (FID), are used to generate the high-resolution images that MRI is known for. The performance and configuration of receiver coils significantly impact the signal-to-noise ratio (SNR), which in turn affects the image quality.

1. Function of Receiver Coils

- After the hydrogen nuclei are excited by an RF pulse, they emit signals as they relax back to their equilibrium state. These emitted signals are extremely weak and are detected by the receiver coils.
- The primary job of the receiver coil is to capture these signals with high sensitivity and translate them into electrical signals that the MRI system can process into an image.
- The stronger the received signal (relative to background noise), the better the SNR. A higher SNR produces clearer and more detailed images.

2. Types of Receiver Coils

There are various types of receiver coils, each designed for different applications and anatomical regions. The choice of coil can have a significant impact on the quality of the images obtained.

A. Surface Coils:

- Surface coils are small, localized coils placed directly on or near the body part being imaged.
- They are designed to detect RF signals from superficial tissues close to the coil, providing very high SNR in these areas.
- Surface coils are often used for imaging areas such as the brain, spine, knee, or wrist.

Limitations: Since surface coils are highly localized, they don't capture signals from deeper tissues as effectively, which can limit their use for whole-body or deep tissue imaging.

B. Volume Coils:

- Volume coils, such as the birdcage coil, are larger coils that surround the body or a specific part of the body.
- They provide more uniform signal detection over a larger volume, making them suitable for imaging areas like the torso, abdomen, or head.
- Volume coils generally provide lower SNR than surface coils because they are farther away from the tissue being imaged.
- **Body coils** and **head coils** are common examples of volume coils used for more comprehensive imaging.

C. Phased Array Coils:

- Phased array coils consist of multiple small coil elements that work together to cover a larger area while maintaining high SNR.
- Each coil element in the array detects signals from a specific region, and the signals from all the elements are combined to create a complete image.
- Phased array coils are commonly used for spine, abdominal, and pelvic imaging because they provide good coverage of large areas while still offering high SNR.
- **Advantages:** Phased array coils improve image quality by allowing for parallel imaging techniques, which can reduce scan times without losing resolution.

D. Quadrature Coils:

- Quadrature coils use two receiver coils placed orthogonally (at 90° to each other) to detect the signal. This improves the efficiency of signal detection because signals from both orientations are captured.

- Quadrature detection increases SNR compared to single-coil systems and is often used in conjunction with other coil designs.

E. Loop Coils:

- Loop coils are simple circular or oval coils that are placed near the body part of interest. They are often used for imaging small structures like the knee, wrist, or brain.
- They are compact and provide high SNR when placed close to the area being imaged.

Surface coils

a type of MRI receiver coil designed to detect signals from specific, localized regions of the body with high sensitivity. These coils are placed directly on or very near the anatomical region being imaged and are commonly used in clinical and research settings to improve the signal-to-noise ratio (SNR) for structures close to the surface, such as the brain, spine, joints, or other superficial tissues.

1. Function of Surface Coils

- Surface coils act as receivers for the RF signals emitted by the excited hydrogen nuclei in the tissue. These coils do not transmit RF pulses; instead, they capture the faint signals emitted by protons as they relax back to their equilibrium state after excitation.
- Surface coils are particularly useful for localized imaging, where high SNR is needed, such as in imaging small anatomical regions like the spine, brain, or joints.

2. Applications of Surface Coils

- **Neuroimaging:** Surface coils are frequently used in brain imaging to capture high-resolution images of superficial brain structures like the cortex. In specialized settings, they can also be used for imaging cranial nerves or small brainstem regions.
- **Spinal Imaging:** For spine imaging, especially in regions like the cervical or lumbar spine, surface coils are often used to enhance SNR for detailed images of the vertebrae, spinal cord, and surrounding tissues.

- **Musculoskeletal Imaging:** Surface coils are widely used in imaging joints (e.g., knee, elbow, wrist), tendons, and ligaments, where high resolution and SNR are required to identify small anatomical structures and potential injuries (e.g., ligament tears or cartilage damage).
- **Breast Imaging:** Dedicated surface coils are used in breast MRI to provide high-resolution images of breast tissue, aiding in the detection of small tumors or abnormalities.
- **Cardiac Imaging:** Surface coils can also be used for cardiac imaging, where they are positioned over the chest to capture detailed images of the heart and surrounding structures.

Volume RF coils

are a type of MRI coil designed to surround the body or a body part, providing more uniform signal transmission and reception across a larger region. Unlike surface coils, which focus on small, localized areas, volume coils can cover larger anatomical regions with consistent sensitivity, making them ideal for imaging the brain, torso, abdomen, or even the entire body.

Applications of Volume RF Coils:

- **Brain Imaging:** Volume coils, particularly birdcage coils, are widely used in neuroimaging. They provide uniform coverage of the head, making them ideal for detecting structural abnormalities, brain lesions, or functional brain mapping.
- **Whole-Body Imaging:** The integrated body coil is commonly used in whole-body scans, particularly for assessing systemic conditions such as metastatic cancer or whole-body fat and muscle distribution.
- **Cardiac Imaging:** Volume coils are used in cardiac MRI to capture the heart and surrounding vasculature. They provide consistent signal coverage over the entire chest area.
- **Abdominal and Pelvic Imaging:** Volume coils are employed in the imaging of large internal organs like the liver, kidneys, and pelvis. The uniform excitation and reception over a large area help in generating clear images of deep structures.

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