

THE SCIENCE AND ENGINEERING OF ADVANCED MRI MACHINES



Magnetic resonance imaging (MRI) is a powerful diagnostic tool for generating detailed images of the body using advanced physics and engineering. Here, we'll cover the interplay between the two fields and the RF innovations driving MRI advancements.

Key Physics Concepts in MRI

If you're looking to dive into the nuanced physics behind MRI, there are plenty of resources available. [Here's one](#), in case you need it. For our purposes, here are a couple of key physics concepts to keep in mind when we consider MRI machines from an RF perspective.

MRI Relies on NMR

MRI machines were developed on the principle of proton nuclear magnetic resonance (NMR). Protons are exposed to a large magnetic field that partially polarizes their nuclear spins and then those spins are excited by a fine-tuned RF pulse. The weak signals emitted as the protons relax to their resting energy state makes them detectable.

MRI uses this principle to produce a magnetic field gradient across a tissue of interest, forming a map of the protons present based on the value of the magnetic field in any given location. Proton density differs depending on the tissue type, creating contrast that can be used to develop cross-sectional images. The charge radius of a proton is approximately 1 femtometer, about 25 trillion times smaller than a golf ball. NMR enables us to gather diagnostic information, non-invasively, from subatomic particles.

Resonant Frequency Varies with Magnetic Field Strength

The strength of the magnetic field dictates the energy a proton gains when excited by an RF pulse. When that proton relaxes, it releases a signal that the MRI system can detect by design.

Certain materials have a designated Larmor frequency, which represents the frequency detected in a 1T field. This value is essential for tuning MRI machines to the correct RF energy for imaging specific tissues and nuclei at different field strengths, as demonstrated in Table 1.

Particle	MHz/T	MHz vs Field Strength (T)				
		0.1T	1T	2T	3T	10T
<i>Hydrogen Atom: Proton</i>	42.5781	4.25781	42.5781	85.1562	127.7343	425.781
<i>Carbon-13: 13C</i>	10.71	1.071	10.71	21.42	32.13	107.1

Table 1: Larmor frequency of common particles at different magnetic field strengths

MRI from an RF Perspective

MRI technology relies heavily on precise RF systems to generate and detect signals essential for imaging. The interplay between magnetic field strength, coil design and amplifier performance is crucial for achieving high-resolution images.

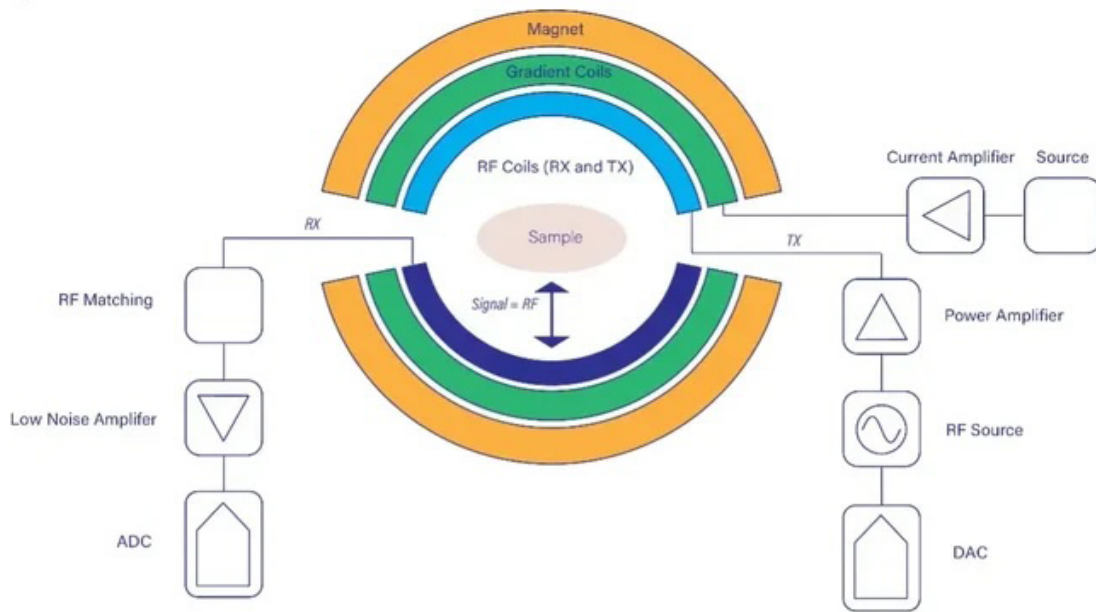


Figure 1: Major RF components in an MRI system

MRI machines leverage large superconducting magnets to establish the magnetic field and partially polarize protons. Gradient coils make it possible to fine tune the magnetic field in the x, y and z directions.

Field strength and the particle strength determine the frequencies the system can detect. Adjusting the magnetic field locally enables the system to use signal processing to determine where in the tissue sample a signal came from and build images accordingly.

For high precision, gradient coil current amplifiers must supply the coils with very consistent electrical signals. To maintain that consistency, it's useful to have supercapacitor modules for backup energy.

Transmit coils, also known as volume coils, send pulses that excite the protons in the magnetic field to a higher energy state. [High power amplifiers](#) enable this function, and to reduce losses, it's beneficial to position them close to the transmit coils. Receive coils, also known as body coils, are responsible for detecting those weak signals produced by the protons when they relax. Depending on the particles of interest and the magnetic field strength, receive coils must be tuned to the relevant Larmor frequency.

Since the receive coils are detecting such weak signals, signal-to-noise ratio (SNR) is critical for resolving image details. The following factors drive SNR in MRI machines:

- **Magnetic Field Strength:** The relationship between SNR and field strength is nearly direct.
- **Temperature:** When practical, cooling preamplifiers with liquid nitrogen can reduce noise.
- **Preamplifier Noise:** The noise figure (NF) of the low noise amplifier (LNA) quantifies how much noise the amplifier adds to the signal relative to an ideal amplifier. A lower NF in the RF receiving system indicates better performance.
- **Coil Design:** Placing the receive coil close to the region of interest (ROI) improves SNR and, by extension, image quality.

MRI Field Strength Trends Both Higher and Lower to Support Advances in Care

MRI technology spans a wide range of magnetic field strengths, and that range is trending wider. From low-field portable systems to ultra-high-field machines for advanced diagnostics, optimizing performance requires balancing trade-offs in design, functionality and safety.

Low Field Strength for Portable MRI

By design, MRI machines require a controlled environment for proper function, however MRI scans can be physically demanding for critically ill patients. Technological development is moving this diagnostic service to where patients are through point of care (POC) MRIs.

Designing for portability requires additional consideration for size, weight, power, cost and field strength. Portability lends itself to very low fields (e.g., under 1T), which can degrade SNR. Improving coil and amplifier design presents a critical opportunity to compensate for that. Since frequency varies with field strength, RF components should be optimized for a lower frequency range.

High Field Strength for Very High-Resolution MRI

On the other end of the spectrum, applications in neurology benefit from very high field strength (e.g., 10T) for better diagnostics and patient monitoring. Here, frequency increases to approximately 425MHz. Engineers face technical difficulties with RF field uniformity, which places additional emphasis on improving RF and gradient coil design. There are general safety questions too. Is it safe to use such a strong magnetic field for MRI? What happens when there's a patient with an "MRI safe" implant that's not rated for such a strong field strength?

For more on MRI, watch our recent webinar, [Components for Advancing MRI Technologies](#), where we review the basic operating principles that make MRI possible and where the technology is achieving key breakthroughs.

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