System Integration and Console

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Introduction: An MR system is fundamentally a device that allows one to polarize, excite, manipulate, detect, and analyze nuclear spins based on the physics of NMR (Nuclear magnetic Resonance). During the prior lectures in this series you have heard in detail about the major system components that enable us to perform the MR experiment and create an image. From an MR Physics perspective, each subsystem is responsible for a particular function in the MR experiment:

- Magnets and Shims polarize the nuclear spins, creating “Longitudinal Magnetization” with precise Larmor frequency
- RF transmit subsystem manipulates the spin system, creating “Transverse Magnetization” that is then detected by RF receive subsystem.
- Gradients generate the spatial dependence that enables localization (imaging) of the detected spins
- Understanding Magnet/Gradient/RF/Device interactions enables the various subsystems to operate together properly, and understanding of interactions with the human body enables operation of the MR system in a safe and effective manner

This lecture will discuss integration of the various subsystems into a fully working MR imaging system. For purposes of this lecture, the “Console” will include the system and software components necessary to integrate the subsystems described in previous lectures into a fully operational system.

Pulse sequences and system control

The incredible ability of MR to gather so much information about structure, function, biophysics parameters, and biochemistry derives from careful manipulation of the MR spin systems by the gradient and RF fields as defined by pulse sequences. These sequences, which define when and how the gradients and RF pulses are applied, are developed on a controlling computer and then played out on the gradient and RF hardware by sequencers including digital-to-analog conversion. Some factors to consider are timing accuracy and synchronization, dynamic range, linearity, precision, waveform flexibility, and the range of system parameters that can be controlled. The precise control of these parameters is essential to achieve desired pulse sequence control and avoid imaging artifacts. Real-time feedback and control, such as the use Navigators or other external data to perform on-the-fly sequence modifications, introduces additional system architecture requirements.

MR Safety monitoring

Standards of MR safety relating to dB/dT and SAR are well established for human MR scanning. While individual subsystems (gradients and RF) are commonly engineered with power levels that could exceed the safe operating limits, the scanner software and hardware are designed to limit the operation of the system to stay within such limits. A combination of both software monitoring (based on predictive models) and hardware monitoring (based on measured power levels) are commonly used to ensure that patient protections are ensured.

Physiological monitoring

With ongoing refinement of MR applications to reduce artifacts from physiological motion (respiration, flow, motion) it is increasingly common to monitor the patient and to feed the patient information back to the MR system. This monitoring may be based on devices or on observation of monitoring MR signals, or Navigators and may be used for gating, triggering, or prospective or retrospective motion correction. Commonly monitored signals include:

- Respiratory monitoring
- Cardiac monitoring
- Peripheral pulse monitoring
- Subject motion, (especially head motion)

Spin detection and the RF receiver system

The RF receiver system is responsible for detecting the very weak signals emitted by the MR spins and converting them to a stored digital signal for further processing. The signal emitted by the spins is initially detected by RF receiver coil(s), amplified by preamplifiers and amplifiers and then digitized by the receiver and then saved in memory for further processing. Traditional early receiver architectures used relatively low bandwidth A/D converters and relied on analog demodulation of the received analog signal to near baseband (zero frequency). Since about 1990 the benefit of digital receivers, which sample the MR signal at a non-zero baseband has become evident, and the evolution and miniaturization of digital electronics has led to universal adoption of digital receivers. Important considerations in the receive coils and electronics include include coil geometry, tuning, bandwidth, Q (quality factor) and noise figure, digitization rate, and dynamic range. Also of increasing importance is the question of how rapidly data can be acquired and processed.

Image reconstruction and display

As MR data is acquired it is commonly saved initially to bulk memory (RAM), which is a relatively fast operation, with the intent that subsequent processing will be fast enough to avoid filling this memory and needing to save the data to disk (slow process). In practice, new MR imaging methods and increasing channel counts continually push the limits of the available reconstruction power. Some factors to consider include data storage capacity, transfer bandwidth, data processing speed, programming environment, and flexibility for real-time analysis and feedback to the subject and/or MR system.