MR Technology to 4T

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After fifteen years of development, Magnetic Resonance (MR) technology for human imaging and spectroscopy is reaching a refined state with FDA approved 3T clinical products from Siemens, GE, and Philips. Bruker has cleared CE approval with a 4T system.Varian supports a 4T system platform as well. Shielded magnets are standard at 3T from GE, Oxford, Magnex, and IGC. A shielded 4T whole body magnet is available from Oxford. Stronger switched gradients and dynamic shim coils, desired at any field, areespecially useful at higher static magnetic fields B0. In addition to the higher currents required for higher resolution slice or volume selection afforded by higher SNR, whole body gradient coils will be driven at increasing slew rates to meet the needs of new cardiac applications and other requirements. For example 3T and 4T systems are now being equipped with 2kV, 500A gradient coils and amplifiers capable of generating 4G/cm in 200msec, over a 67+/-cm bore diameter. High field EPI applications require oscillation rates at 1 kHz and higher.To achieve a benchmark 0.2 ppm shim over a 30cm sphere in a high field magnet, at least four stages of shimming need to be considered. 1) A good high field magnet will be built to a homogeneity spec. falling in the range of 100 to 150 ppm over this 30cm spherical "sweet spot". 2) Most modern high field magnets will also have superconducting shim coils capable of finding 1.5 ppm by their adjustment during system installation. 3) Passive ferro-magnetic shimming combined with 4) active, high order room temperature shim coils (as many as five orders are now being recommended) will accomplish 0.2 ppm over the 30cm sphere, and 0.1 ppm over a human brain in even the highest field magnets for human studies. Safety concerns for strong, fast gradients at any B0 field include acoustic noise and peripheral nerve stimulation. One or more of the mechanical decoupling methods may lead to quieter gradients. Patient positioning relative to asymmetric or short gradient coils may limit peripheral nerve stimulation at higher slew rates. Gradient designs combining a short coil for local speed and strength with a longer coil for coverage are being developed for 3T systems. Local gradients give another approach to maximizing performance over a limited region while keeping within the physiologically imposed dB0/dt performance limits.

The radiofrequency (RF) subsystem consisting of an RF power amplifier, an RF front end, and RF coils is more challenging at 3T and 4T compared to lower fields. The RF power amplifier has a peak power rating of 35kW at 3T (128MHz) and an RF front end rated accordingly. The transmit RF front end consists of transmit receive switches, an RF power monitor, and possibly RF quadrature hybrids or power splitters required to drive a large, homogeneous transmit (body) coil. The receiver front end consists of multi-channel (typically eight) decoupling preamplifiers to support phased array and parallel array receiver coils. Most imaging at 3T is conducted with either a transmit and receive head coil, or with a body coil transmitter and an array coil receiver designed specifically for head, body, or limb applications. The transmit coils are typically of conventional high pass or band pass, shielded bird cage design. These coils however are aggressively shortened and have highly distributed capacitance;both strategies to improve elevate the frequency and improve the efficiency of this design. Evenso, RF pulse protocols are increasingly power limited at 3T compared to lower fields. While TEM body coils have been successfully tested on a number of Bruker and Varian systems at 4T, these systems are not yet configured with RF power amps and front ends for the full range of body applications. RF safety for NMR applications is power rather than frequency dependent. While the power loss density and resultant thermal heating become increasingly non uniform with frequency in the human body, conservative (safe) FDA guidelines dictate the same SAR thresholds for all field strengths. Whereas whole body imaging at these field strengths was thought to be not possible as recently as three years ago, convincing data now suggests that the very best head and body imaging to date will be conducted at 3T, and possibly 4T or higher in the near future.