

Toward 10.5T MRI

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Target audience – Engineers, Physicists, Biomedical Researchers

Purpose – The objective of this work is to develop and apply the world's highest field strength, whole-body MRI system for biomedical research of the human body in health, disease, and therapeutic intervention. Due to the better than linear proportion of signal-to-noise to field strength, this system has the inherent potential of being the most powerful instrument yet, for non-invasive investigation, In-vivo.

Methods – Because the 450 MHz Larmor wavelength of the energy stimulating and receiving the nuclear magnetic signal response in high water content human tissues is on the order of 7cm, conventional MRI technology and methods used at lower field strengths and frequencies will not realize the full potential of this system. RF field non-uniformities and losses associated with current approaches will compromise both the success and the safety of 10.5T studies. New solutions to these short-wave problems must be found to realize the full benefit of this MRI at this unprecedented field strength. These new solutions for RF technology for MRI at 10.5T are the topic of this work.

The system will be built around an Agilent superconducting solenoid wound of 433 km of NbTi wire and weighing 110 tons. The magnet will be shielded with 650 tons of welded steel plate. The backend console of this system as well as the resistive magnet shims and gradients will be supplied by Siemens. The RF front-end however are being developed in-house by the approaches outlined in this abstract. The finite difference time domain (XFDTD, Remcom) simulations of fields shown in Fig 2 illustrate the challenges of RF transmit and receive functions, already known at 7T and significantly increased at 10.5T. The calculations result from a conventional, free-space uniform, circularly polarized RF transmit field at 300 MHz for the 7T simulations and at 450 MHz for 10.5T. B1 and E field nonuniformities at both frequencies result from short-wave interference patterns in the anatomy. SAR gradients are similarly nonuniform. Thermal contours, resulting from highly inhomogeneous electrodynamic, thermodynamic, and physiodynamic properties of the anisotropic anatomy are even more problematic to predict and to monitor. Clearly new solutions are required for RF excitation, control and monitoring at these highest field strengths. [1] To efficiently explore new RF coil designs and RF excitation methods, XFDTD solvers by REMCOM, State College, PA, and SEMCAD, Zurich, were used to model the circuits and the Duke male atlas was used for the anatomic load. Numerous transmit and receive coils were modeled, both conventional circularly polarized birdcage and TEM designs and new 2D and 3D, multi-channel TEM and loop array designs.

Results- As predicted in Figure 2, whole-body transmit coils of conventional, circularly polarized design resulted in highly inhomogeneous excite fields rendering these designs and methods unusable. However the fields generated by arrays of independently controlled (B1 shimmed) TEM and loop arrays generated more uniform excite fields. The designs with higher numbers of independent coil elements distributed in x, y, and z (3D) fared produced the best results, with the TEM elements measuring greater efficiency than the loop element counterparts. As with the B1+ fields, SAR contours were more controllable and therefore more uniform with 3D coils of higher element count. The most efficient candidates for 10.5T head and body coils found by investigative modeling have been built and tested at 7T, and are now being constructed for 10.5T. The prototype head and body coils are shown in Figures 3 and 4 respectively. By fitting TEM elements more closely to the body, a factor of six or more in RF transmit efficiency and similar SNR gains can be had. This design also includes on-board, channel dedicated power amplifiers, T/R switches, preamplifiers, and innovative new automatic tune and match circuitry. Two approaches for feedback driven tune and match have been developed and successfully tested. The coil of Figure 3 has demonstrated the feasibility of driving a multi-channel TEM coil with in-bore, 1kW amplifiers, B1 shimming, PIN capacitive matrix switched tuning and matching, in a 7T magnet. An electromechanical approach employed in the body coil shown in Figure 4 uses linear piezo motors to drive tune and match stubs in each element. This "clam shell" design has become our workhorse at 7T and shows great promise for 10.5 T as well. [2][3] Head imaging at 10.5T can be performed by the same approaches.

Conclusions - New RF technology and methods for MRI at ultra-high fields are demonstrated at 7T and being developed further for use at 10.5T.

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References- [1] Vaughan JT, DelaBarre L, Snyder C, Tian J, Akgun C, Shrivastava D, Olson C, Adriany G, Strupp J, Andersen P, Gopinath A, Van de Moortele P-F, Garwood M, Ugurbil K. "9.4T human MRI: preliminary Results" Magn Reson Med 2006;56:1274-1282
 [2] Snyder CJ, DelaBarre L, Metzger GJ, van de Moortele PF, Akgun C, Ugurbil K, Vaughan JT. Initial results of cardiac imaging at 7 Tesla. Magn Reson Med. 2009 Mar;61(3):517-24.
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Fig1. 10.5T, 88cm diameter superconducting magnet for human MRI. This magnet is built, tested at field, and is in route for delivery in December 2013.

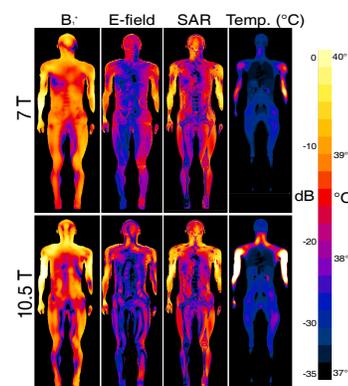


Fig 2. Numerical calculations of the B1 field, E-Field, SAR and temperature contours in a human body for MRI at 7T (top row) and 10.5T (bottom row).

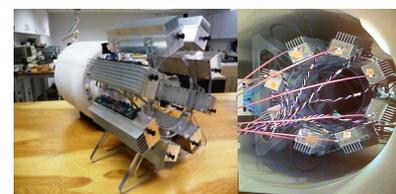


Fig. 3. An eight channel TEM head coil is also shown, with eight dedicated, 1kW each power amplifiers.

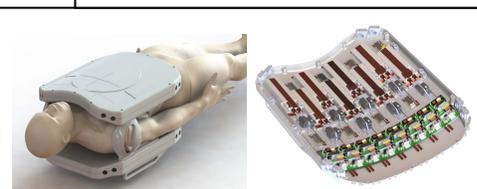


Fig. 4. Efficient TEM "clam shell" coil including elements distributed in x,y,z. Each element includes channel dedicated power amplifier, T/R switch, preamp and auto-tuning +matching circuits.