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SY06-01

Parallel Transmit and its Applications

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Despite the signal-to-noise ratio (SNR) benefits engendering higher spatiotemporal resolutions, MRI at ultra-high field (≥ 7T) has remained mostly an investigational device for research institutes. The key obstacle probably has been the inherent radiofrequency (RF) field inhomogeneity caused with the increase of the Larmor frequency, thus the decrease of the wavelength of the RF pulses, causing standing wave effects, SNR and contrast losses as well as severe signal dropouts. Beyond doubt, the most promising technology to address this fundamental problem has been parallel transmission, now proposed 15 years ago [1]. It consists of placing around the head of the subject several RF transmitters that can be controlled independently in amplitude and phase and with different temporal variations. By interference and via sophisticated pulse design algorithms, the flip angle can then be made effectively homogeneous over volumes such as the human brain at 7T. But likewise, despite its power and versatility, the technology has failed to be embraced in routine practice because of a cumbersome and time-consuming workflow. Before a scan of clinical use could be conducted, a series of subject-based measurements and calibrations indeed needed to be performed: field map (B_1^+, B0) measurements, data transfer, data analysis and online pulse design calculations. These steps cumulate 10-15 minutes, require know-how and expertise and are prone to human and technical errors, overall resulting in an unacceptable cost for clinical use in routine. To circumvent the problem, calibration-free (Universal) pulses were proposed [2]. They consist of designing, offline, RF pulses to mitigate the RF field inhomogeneity problem while being robust versus intersubject variations. Field maps are first acquired on a series of volunteers representative of a certain population (e.g. adult). The pulse design then is sequence specific and minimizes the average flip angle normalized root mean square error over the database subjects. Specific absorption rate (SAR) and hardware (peak and average power) are handled exactly the same way as in subject-based pulse designs. After plugging the solutions into the sequences, the MRI exam can be conducted exactly in the same way as in single-channel mode, without any time/stress penalty for the user. Parallel transmission becomes plug and play.

This talk will focus on the universal pulse results obtained at NeuroSpin-CEA. To date, the plug and play universal pulse approach has been developed for 6 pillar sequences at 7T (GRE3D, GRE2D, MPRAGE, TSE, MP-FLAIR, DIR) and for a workhorse commercial coil. The in vivo tests cumulate close to 50 volunteers at 4 different sites, without any failure. Simulations and retrospective controls based on subject-based measured field maps (not included in the pulse design database) reveal a B_1^+ inhomogeneity performance better than the one measured at 3T in the CP mode, bringing parallel transmission one step closer to use in clinical routine.

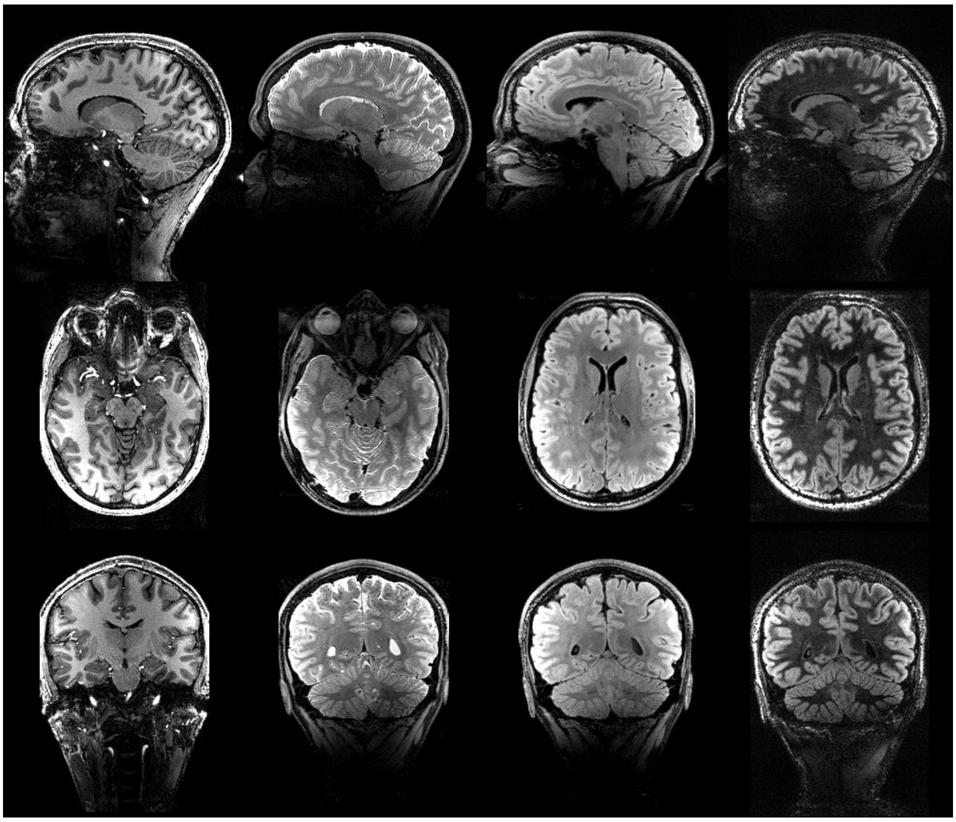

Figure 1. From left to right: MPRAGE, TSE, Magnetization-Prepared FLAIR, DIR images at 7T on one volunteer using the Circularly-Polarized standard mode of excitation (CP) versus calibration-free universal pulses (UP). The images obtained with Universal Pulses are virtually RF field inhomogeneity artefact free.

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Keywords: Parallel transmission, Ultra-high field, Brain, RF field inhomogeneity, Plug and play

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RF Coil Development for 7T High Field MRI

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In the past decade, an increased number of high field MR imaging systems, such as 7T and 9.4T, have been installed and used for human studies, due to their high image SNR and resolution, improved image contrast and large spectral dispersion. To fully realize the capability of high field systems, optimizing the design of large-size, homogenous RF coils is a critical factor, which allows us to visualize fine anatomical details, better functional and metabolic information for neural, cognitive science research and clinical medicine. However, a major challenge is the high frequency wave behavior of the B1+/B1- fields in the conductive and high dielectric samples (such as human body) which causes inhomogeneous RF signal distribution. High-field problems can be mitigated by developing the RF technology of transmit and receive array coils. With a guidance of 3D electromagnetic (EM) simulation approach combined with the RF circuit analysis method, we have designed and constructed several transceiver array coils in a 7T whole-body system, optimizing the geometric size of array structures, values of the distributing capacitors and employing new decoupling methods, etc. The phased-array loop coils, microstrip transmission line (MTL) array, monopolar and dipole-array coils were constructed and evaluated based on their S-parameter properties and lab measurement results. The simulated B_1^+ and E field distribution patterns, accelerating capabilities for parallel imaging, global and local peak SAR (specific absorption rate) values of the coils were analyzed and estimated for better MR image quality and meeting the safety guideline for human subjects.

As an example, an eight-channel transmit/receive (Tx/Rx) loop array head coil was designed and constructed at 7T with a recently-proposed induced current compensation or elimination (ICE) decoupling method. 8 narrow loop elements were built as ICE decoupling elements and placed between 8 individual Tx/Rx coil elements. This ICE-decoupled array coil demonstrated its feasibility and robustness for homogeneous human head imaging at 7T. Images of both water phantom and human brain were acquired and g-factor maps were measured to evaluate the coil property. Compared with the conventional capacitive-decoupled loop-array coil, the ICE-decoupled array coil demonstrated improved parallel imaging ability, higher image SNR near peripheral brain regions and better mechanical strength between coil elements. The experimental results indicate that the transceiver array design with the ICE decoupling technique might be a promising solution when flexible coil arrays are needed for human head and/or body imaging at high fields.

Keywords: High field, RF array coil, Decoupling, Transceiver, EM simulation

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SY06-03

Pushing the limit of in vivo diffusion tensor imaging

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Diffusion imaging has become the pillar of modern MRI imaging, and is being widely used in routine diagnostic imaging and research imaging. Not only diffusion weighted imaging has been proven to provide superior sensitivity in detection of various diseases such as stroke and tumor, diffusion imaging combined varying diffusion gradients application strategies and hence the diffusion models is by far the best non-invasive method to probe tissue microstructures in vivo.

There are many factors may impact the extent to which the tissue microstructures may be resolved, such as image resolution, susceptibility distortion, SNR, etc. However, if we take a look at the needs from the system level, these requirements come down to 3 parts: 1) gradient performance and stability; 2) receiver coil; 3) pulse sequence design.

Gradient performance. With the advance of gradient amplifier design, 80/200 has become the hallmark of commercial 3.0T clinical scanner. While wide bore is now the standard of 3.0T MRI, GE has used a revolutionized design called super G gradient. It allows simultaneous gradient strength of 80mT/m and slew rate of 200mT/m/s to be achieved. The gradient stability is also important for achieving high resolution diffusion imaging, as with the application of diffusion gradients, the system will become highly sensitive to the scan table movement. It would be hard to imagine high resolution images with a shaking scan table during the scan.

Receiver coil. Higher number of receiver coil elements allows higher level of image SNR. However, the limiting factor of increasing the coil elements is the coupling between different neighboring elements: to avoid the signal coupling, either the coil elements need to be separate apart or the coil elements need to be compact in dimension. However, if the coil elements are placed apart, the space around the skull will limit the number of coil elements possible; compact coil elements are also undesirable for imaging due to image homogeneity. A new coil design resolved this issue by eliminating the coupling effects to a large extent. Another innovative design that may improve the susceptibility distortion is the local shimming within the receiver coil, which will largely improve the shimming within the FOV.

The third and perhaps most predominant factor for high resolution diffusion imaging is the use of advanced imaging method. Conventional single shot EPI acquisition is intrinsically limited by the spatial resolution achievable. The use of multi-shot acquisition combined with the ability of phase inconsistency correction between shots is the key for improving the image resolution. Multi-shot acquisition can be either performed alone the phase encoding direction or the frequency readout direction.

In this introduction, an imaging effort combing the above three improvements conducted in one of the earliest available GE premier MR scanner is presented. With the efforts of microstructure imaging via diffusion tensor imaging in the hippocampus.

Keywords : Diffusion tensor imaging, PSD, Neuro, Engineering

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SY06-04

Magnetic field monitoring system development and applications

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The increased technological development of the Magnetic Resonance Imaging (MRI) systems has made possible to achieve new frontiers of anatomical and functional imaging and applications. The subject of this work is to develop a magnetic field monitoring (MFM) system, capable of measure the time evolution of the magnetic field during a MRI procedure. The measured MFM signals are used to retrospectively correct image artifacts that are originated by field inhomogeneity. The developed magnetic field monitoring system, consist of four probes connected to a RF chain that enable transmission and reception. The construction of the MFM probes is a methodical process, mainly because of the requirements that the probes should have, which are: enough signal-to-noise-ratio (SNR) and a long lifetime signal. Simulations were used to find the optimal size that would reduce the field inhomogeneity inside the ellipsoid.

Each MFM probe is excited to acquire a free induction decay (FID) signal. The MFM system was used to monitor the gradient fields during an echo planar imaging (EPI) procedure. The information of the k-space trajectory was used to correct the ghosting artifacts by applying a gridding reconstruction. The MFM system was also used to correct the main magnetic field (B_0) phase drift from temperature maps, measured with proton resonance frequency shift (PRFS). Temperature maps were acquired for an agar phantom and also in the brain of a female volunteer. The phantom was heated with a hyperthermia system that was developed to induce RF heating.

In conclusion, a magnetic field monitoring system was developed, and used to measured field variations over time, the first application was the correction of the ghosting artifacts produced in an EPI image, and the second application was the B_0 phase drift correction for temperature maps acquired with the PRFS method.

Keywords : Magnetic Resonance Imaging, Magnetic field monitoring, Temperature mapping, EPI