New Developments in MR Hardware

Boris Keil
keil@nmr.mgh.harvard.edu

Cardiac Magnetic Resonance Imaging (MRI) has seen tremendous advances in the past decade toward improved sensitivity and reduced scan-time in clinical and research imaging examinations. While gradient performance improvements in strength and slew-rate played an important role in terms of acquisition speed, magnetic field strength and well-crafted detector geometries have always been critical for maximizing the sensitivity of the cardiac MR experiment.

Cardiac Receive Array Coils

Array coils have proven highly valuable for increasing images sensitivity in cardiac MRI examination. The major advantage of detection with coil arrays originates form the ability to reconstruct under-sampled *k*-space data and thus significantly speed up the MR image encoding process. These parallel imaging reconstruction techniques [1–5] effectively uses the additional spatial information contained in the signal intensity and phase profiles of the array elements to allow reconstruction of the image from under-sampled *k*-space data sets. In these methods, the image encoding is shared between the array coil and the gradient encoding steps. The benefits of acquisition speed and high temporal resolution are frequently used to reduce breath-hold duration and increase comfort for patients with advanced cardiac disorders. The improvements in temporal resolution have increased frame rates in cardiac cine imaging, allowing a better examination of cardiac morphology, wall motion abnormalities, and valve diseases. Spatial and temporal resolution improvements have contributed to more accurate assessments of cardiac function and myocardial perfusion.

Much effort has therefore been placed in optimal coil design in order to reduce noise enhancement during parallel image reconstruction (g-factor). The coil element arrangement differs from overlapped coil elements (canceling out the mutual inductance) [6], to total gapped arrays [7], or where elements are overlapped in S-I direction but have gaps in L-R direction [8]. The early success from cardiac array has led to commercial array coils with up to 32 channels. Coils with up to 128 channels have been established in experimental settings [6,9].

Transmit Coils

Cardiac MRI examinations at 1.5T or 3T field strength commonly use the scanner's integrated quadrature birdcage coil for excitation. However, at 3-Tesla the body coil's excitation profile shows already field variation throughout the subject's body. Non-uniformity in the transmit field (B_1^+) can cause signal dropouts, contrast losses, or shading in the organ of interest. Up to 63% B_1^+ field variation has been shown in the entire left-ventricular volume, when using a 3T body coil transmitter [10]. The constrains in achieving B_1^+ field homogeneities at higher field strength (e.g. 7 Tesla) are so destructive, that traditional birdcage body coils are no longer used for transmit. There are several major engineering challenges associated with coil instrumentation at ultra-high fields, which deal with the increased dissipative losses in conductive tissue, effects arising from the short RF wavelength in biological tissue (~13cm at 7T, 300MHz). To reduce those unwanted electro-dynamic effects at ultra-high fields, multi-channel transmission systems has been introduced for independent control of amplitude and phase of each transmit channel in order to homogenously "shape" the excitation profile in a locally selected field-of-view. So far, various design alterations have been developed for dedicated ultra-high-field cardio MRI, which includes classical loops elements [11], strip line elements [12], or radiative antenna elements. Array configurations utilizing from 4 to 32 independent transmit/receive elements have been successfully established in research settings [13]. Even concepts, where multiple transmit amplifiers were placed adjacent to the coil elements have been shown promising results [14].

References:

[1] D. K. Sodickson, W. J. Manning, Simultaneous acquisition of spatial harmonics (SMASH): fast imaging with radiofrequency coil arrays, Magn. Reson. Med. 38 (1997) 591–603.

[2] K. P. Pruessmann, M. Weiger, M. B. Scheidegger, P. Boesiger, SENSE: sensitivity encoding for fast MRI, Magn. Reson. Med. 42 (1999) 952–962.

[3] M. A. Griswold, P. M. Jakob, R. M. Heidemann, M. Nittka, V. Jellus, J. Wang, B. Kiefer, A. Haase, Generalized autocalibrating partially parallel acquisitions (GRAPPA), Magn. Reson. Med. 47 (2002) 1202–1210.

[4] P. Kellman, F. H. Epstein, E. R. McVeigh, Adaptive sensitivity encoding incorporating temporal filtering (TSENSE), Magn. Reson. Med. 45 (2001) 846–852.

[5] F. A. Breuer, P. Kellman, M. A. Griswold, P. M. Jakob, Dynamic autocalibrated parallel imaging using temporal GRAPPA (TGRAPPA), Magn. Reson. Med. 53 (2005) 981–985.

[6] M. Schmitt, A. Potthast, D. E. Sosnovik, J. R. Polimeni, G. C. Wiggins, C. Triantafyllou, L. L. Wald, A 128-channel receive-only cardiac coil for highly accelerated cardiac MRI at 3 Tesla, Magn. Reson. Med. 59 (2008) 1431–1439.

[7] T. Lanz, P. Kellman, M. Nittka, A. Greiser, M. A. Griswold, A 32 Channel Cardiac Array Optimized for Parallel Imaging, Proceedings of the 10th Annual Meeting of ISMRM, Seattle, (2006) p. 2578.

[8] Y. Zhu, C. J. Hardy, D. K. Sodickson, R. O. Giaquinto, C. L. Dumoulin, G. Kenwood, T. Niendorf, H. Lejay, C. A. McKenzie, M. A. Ohliger, N. M. Rofsky, Highly parallel volumetric imaging with a 32-element RF coil array, Magn. Reson. Med. 52 (2004) 869–877.

[9] C. J. Hardy, R. O. Giaquinto, J. E. Piel, K. W. Rohling, L. Marinelli, D. J. Blezek, E. W. Fiveland, R. D. Darrow, T. K. F. Foo, 128-channel body MRI with a flexible high-density receiver-coil array, J. Magn. Reson. Imaging 28 (2008) 1219–1225.

[10] K. Sung, K. S. Nayak, Measurement and characterization of RF nonuniformity over the heart at 3T using body coil transmission, J. Magn. Reson. Imaging 27 (2008) 643–648.

[11] M. A. Dieringer, W. Renz, T. Lindel, F. Seifert, T. Frauenrath, F. von Knobelsdorff-Brenkenhoff, H. Waiczies, W. Hoffmann, J. Rieger, H. Pfeiffer, B. Ittermann, J. Schulz-Menger, T. Niendorf, Design and application of a four-channel transmit/receive surface coil for functional cardiac imaging at 7T, J. Magn. Reson. Imaging 33 (2011) 736–741.

[12] S. Maderwald, S. Orzada, R. Duensing, L. C. Schäfer, A. K. Bitz, I. Brote, O. Kraff, J. M. Theysohn, M. E. Ladd, S. C. Ladd, H. H. Quick, 7T Human in vivo Cardiac Imaging with an 8-Channel Transmit/Receive Array, Proceedings of the 17th Annual Meeting of ISMRM, Honolulu, (2009) p. 822.

[13] A. Gräßl, W. Renz, F. Henzel, T. Frauenrath, H. Pfeiffer, W. Hoffmann, P. Kellman, C. Martin, T. Niendorf, Design, Evaluation and Application of a Modular 32 Channel Transmit/Receive Surface Coil Array for Cardiac MRI at 7T, Proceedings of the 20th Annual Meeting of ISMRM, Melbourne, (2012) p. 305.

[14] J. T. Vaughan, C. J. Snyder, L. J. DelaBarre, P. J. Bolan, J. Tian, L. Bolinger, G. Adriany, P. Andersen, J. Strupp, K. Ugurbil, Whole-body imaging at 7T: preliminary results, Magn. Reson. Med. 61 (2009) 244–248.