Transmit and Receive Arrays for Ultra High Field Parallel Imaging

Gregor Adriany

Center for Magnetic Resonance Research (CMRR), Department of Radiology, School of Medicine, University of Minnesota, Minneapolis, MN 55455

High magnetic fields and parallel imaging are technologies that are synergistic and complementary. Parallel imaging with multi-coil arrays provides a solution to many of the problems encountered with fast acquisitions at high magnetic fields [1, 2]. In turn, high fields are expected to improve parallel imaging performance due to the more complex sensitivity profiles of each coil element and the increased signal-to-noise ratio (SNR) (e.g. [3-5]). At high fields, however, there is also considerable interest in multi-element transmit arrays systems that are capable of similarly high number of independent channels for RF transmission. This interest comes from the fact that High and Ultra High field[1] MR is performed in a frequency regime where the wavelength is on the order of, or smaller then, the dimensions of the human body and head, leading to prominent wave behavior and non-uniform B_1 field patterns. A multi-channel transmit capability with independent phase and amplitude control of its elements can be used to support RF shimming methods that can mitigate these body-induced RF non-uniformities [6-8]. Furthermore such an array immediately can be used for transmit parallel imaging applications [9, 10] and can still be combined with additional receive only coil arrays.

A number of papers comprehensively described the design of receive coils optimized for parallel imaging at clinically used magnetic fields or very high number of receiver channels (e.g. [11-16]).However, there are a number of challenges confronted when designing receive only or transceive coil arrays at ultra high fields. The coil dimensions are no longer small compared to the wavelength; thus coil current phase effects have to be considered. At high fields, sample losses clearly dominate but radiation losses can not be neglected and must be controlled [17, 18]. The strong coupling to the sample at the high frequencies mediates interactions between the separate coils, making it more difficult to electromagnetically decouple them [17].

One design approach that addresses all of these issues simultaneously is the use of transmission lines as building blocks for transceive arrays for high fields. Radiation losses are best addressed by coil designs that incorporate a ground plane or RF shield into the resonance structure. Ultra high field surface coils or receive coil arrays can be built with an RF ground plane in close proximity [19, 20] or a ground plane as an integral part of the resonant structure in the form of transmission line elements [21-25]. Furthermore, the broadband decoupling characteristic of transmission line elements [22] reduces the difficulties of decoupling near neighbor elements.

Our RF front-end accommodates currently 32 independent transmit and receive channels. To evaluate parallel imaging performance, various prototype RF head transmit coils were built from 5 mm to 12 mm thick Teflon material and up to 32 decoupled transmission line elements either in loop of straight line configuration. Our studies indicated that multi-channel parallel imaging coils that can act both as a volume transmitter arrays and multi-channel receiver can be built easily for very high magnetic fields, such as 7 Tesla. In fact, the short wavelength at this high-field magnitude allows the use of stripline transmission line approaches with closely coupled ground conductors, which in turn permit coil arrays where the individual coils can be decoupled from each other easily without having to resort to complex decoupling schemes involving low impedance preamplifiers.

[1] Ultra High Field, since the associated ^{1}H frequencies are in the Ultra High Frequency range (300MHz - 1 GHz).

This transceiver arrangement eliminates the need for the use of separate body or large head coil as a transmitter, thus simplifying the hardware requirements and demands for bore space. This arrangement also permits with ease, the individual control of phase and amplitude of each channel for the transmit mode so that transmit SENSE or RF shimming can be implemented.

Acknowledgement

This work was supported by NIH grant P41 RR08079, EB 00331, EB 00513, CA 76535, W.M. Keck Foundation, and the MIND Institute. The 7 Tesla system acquisition was funded by the Keck Foundation, NSF grant 9907842, and NIH grant S10 RR1395

References

1. Sodickson, D.K. and W.J. Manning, *Simultaneous acquisition of spatial harmonics (SMASH): fast imaging with radiofrequency coil arrays.* Magn Reson Med, 1997. 38(4): p. 591-603.
2. Pruessmann, K.P., et al., *SENSE: sensitivity encoding for fast MRI.* Magn Reson Med, 1999. 42(5): p. 952-62.
3. Wiesinger, F., K.P. Pruessmann, and P. Boesinger. *Inherent limitations of the reduction factor in parallel imaging as a function of field strength*. in *Proc. 10th ISMRM*. 2002. Honolulu,Hawaii, USA.p.191
4. Ledden, P.J. and J.H. Duyn. *Ultra-high Frequency Array Performance: Predicted Effects of Dielectric Resonance*. in *Proc.10th ISMRM*. 2002. Honolulu,Hawaii,USA.p.324
5. Adriany, G., et al. *Transceive Stripline Arrays for Ultra High Field Parallel Imaging Applications*. in *Proc. 11th ISMRM*. 2003. Toronto,Canada. p. 474
6. Vaughan JT; RF Coil for Imaging System. US Patent 6,633,161 (2003).
7. Boskamp, E.B. and R.F. Lee. *Whole Body LPSA transceive array with optimized transmit homogeneity*. in *Proc. ISMRM*. 2002. Honolulu,Hawaii, USA.
8. Vaughan, J.T., et al., *An Efficient High Frequency Body Coil for High Field MRI.* Magn Reson Med, 2004. in press.
9. Katscher, U., et al., *Transmit SENSE.* Magn Reson Med, 2003. 49(1): p. 144-50.
10. Zhu, Y., *Parallel excitation with an array of transmit coils.* Magn Reson Med, 2004. 51(4): p. 775-84.
11. Griswold, M.A., et al., *A multicoil array designed for cardiac SMASH imaging.* Magma, 2000. 10(2): p. 105-13.
12. Weiger, M., et al., *Specific coil design for SENSE: a six-element cardiac array.* Magn Reson Med, 2001. 45(3): p. 495-504.
13. de Zwart, J.A., et al., *Design of a SENSE-optimized high-sensitivity MRI receive coil for brain imaging.* Magn Reson Med, 2002. 47(6): p. 1218-27.
14. de Zwart, J.A., et al., *Signal-to-noise ratio and parallel imaging performance of a 16-channel receive-only brain coil array at 3.0 Tesla.* Magn Reson Med, 2004. 51(1): p. 22-6.
15. McDougall, M.P., S.M. Wright, and D.G. Brown. *A 64 Channel Planar RF Coil Array for Parallel Imaging at 4.7 Tesla*. in *Proc. 11th ISMRM*. 2003. Toronto, Canada. p.472
16. Hardy, C.J., et al. *Real time Large FOV MRI with a massively Parallel 32 Channel MRI System and Detector Array*. in *Proc. 11th ISMRM*. 2003. Toronto,Canada.p.471
17. Keltner, J.R., et al., *Electromagnetic fields of surface coil in vivo NMR at high frequencies.* Magn Reson Med, 1991. 22(2): p. 467-80.
18. Vaughan, J.T., et al., *7T vs. 4T: RF power, homogeneity, and signal-to-noise comparison in head images.* Magn Reson Med, 2001. 46(1): p. 24-30.
19. Ong, K.C., et al., *Radiofrequency shielding of surface coils at 4.0 T.* J Magn Reson Imaging, 1995. 5(6): p. 773-7.
20. Adriany, G., et al. *Shielded Surface Coils and Halfvolume Cavity Resonators for Imaging and Spectroscopy Applications at 7 Tesla*. in *8th ISMRM*. 2000. Denver.
21. Vaughan, J.T., et al. *High Frequency Surface Coils for Clinical NMR Imaging and Spectroscopy*. in *Proc. Society for Magnetic Resonance in Medicine*. 1993. New York, NY, USA.
22. Lee, R.F., et al., *Planar strip array (PSA) for MRI.* Magn Reson Med, 2001. 45(4): p. 673-83.
23. Zhang, X., K. Ugurbil, and W. Chen, *Microstrip RF surface coil design for extremely high-field MRI and spectroscopy.* Magn Reson Med, 2001. 46(3): p. 443-50.
24. Zhang, X., K. Ugurbil, and W. Chen, *A microstrip transmission line volume coil for human head MR imaging at 4T.* J Magn Reson, 2003. 161(2): p. 242-51.
25. Adriany, G., et al., *Transmit and Receive Transmission Line Arrays for 7 Tesla Parallel Imaging.* Magn. Reson. Med., 2004 ,accepted for publication.