ABSTRACT

The advancement of MRI as a radiological instrument has been associated with a constant drive towards higher magnetic field strengths resulting in higher operational frequencies. More powerful magnets bring the promise of enhanced signal to noise ratio, exquisite resolution, and reduced scan times. At the same time however, MRI at higher frequencies adds significant engineering complexities to the MRI experiment, most notably in designing safe, versatile, and high-performance radio frequency (RF) coils.

In this work, computational and theoretical electromagnetic analysis of several RF coils used in MRI are presented at Larmor frequencies that range between 64 and 470 MHz representing clinical imaging at 1.5:11 Tesla. The electromagnetic interactions with phantoms and anatomically detailed head models, including a developed high-resolution human head mesh, are studied at different field strengths. The electromagnetic computational tool of choice in this work was the finite difference time domain (FDTD) method. Combined with measurements using an 8 Tesla MRI system, currently the most powerful clinical magnet in the world and a 1.5 Tesla system, the FDTD method is utilized to study, analyze, and eventually design RF coils. Innovative Engineering approaches using phased array techniques are presented to improve

the performance of RF head coils in terms of transverse magnetic field uniformity and reduction of specific absorption rate for operation at 4.7 and 8 Tesla. Novel analytical derivations are presented to explain the source of the MR signal. The combination of the analytical derivations, FDTD modeling, experiments. and infrared imaging gives a new prospective onto the electromagnetics associated with low and high field clinical imaging.

For my Mother, my Father, Nevine, Daniel, and the Truth

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my Advisor Professor Robert Lee for granting me the opportunity to work on this great project. There are not enough words that would describe my appreciation toward Rob. His support, patience, and close guidance have been invaluable throughout my career and my life. Special thanks go to Professor Pierre-Marie Robitaille for his support to me throughout my studies. I would like also to acknowledge Dr. Robitaille for building the 8 Tesla system here at The Ohio State University (OSU), a cornerstone for a significant portion of the work done in this dissertation. I would like to thank Dr. Brian Baertlein for his technical help and encouragement throughout this work. I would like to thank aforementioned three professors for guiding my dissertation.

In the Department of Radiology at OSU, special thanks go to Dr. Donald Chakeress for his support and providing me the opportunity to complete this work during my stay at the Department of Radiology. In the same department, I want to thank my friends Ryan Gilbert, Dr. Alayar Kangarlu, Dr. Amir Abduljalil, Professor Petra Schmalbrock, Chad Mitchel, Chastity Diane Shaffer Whitaker, and Trong-kha Truong. I would like to acknowledge Petra and Chad for obtaining 8 Tesla images and field maps in Chapter 6, and Amir for his assistance in obtaining experimental data in Chapters 4 and 6. I would also like to acknowledge Hui Zhu and Brian Baertlein for their assistance in developing the anatomically detailed human head model. I am also grateful to Brian for providing some of the analytical results in Chapters 4 and 6. I would also like to thank all my friends who were or currently are at the ElectroScience Laboratory, especially Kwan-ho Lee, Simon Lee, Kishore Rama Rao, Hyunjun Kim, Ajith Gunatilaka, Do-Hoon Kwon, and Rodney Slone for their help.

Finally, I would like to express my special appreciation to my supportive mother and father for their encouragement and to my loving wife for her support.

The Cray C-90 and the Compaq-Dec at the Aeronautical Systems Command Major Shared Resource Center of the Wright Patterson Air Force Base was used to generate some of the the numerical results for this dissertation.