HAWAII CENTER FOR ADVANCED COMMUNICATIONS

Development of Metamaterials for Wideband Antenna Applications

Ph.D. Dissertation Defense

Presented By: Jodie Bell

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Supervisory Committee:

Dr. Magdy Iskander, Chair

Dr. Luis Elias

Dr. Wayne Shiroma

Dr. David Yun

Dr. Zhengqing Yun

Abstract

Many low-profile broadband antennas that operate in the relatively low frequency ranges desired for certain mobile RADAR and electronic warfare (EW) applications radiate in a bi-directional manner. Thus an ultrawideband and low-profile ground plane is clearly necessary to back these antennas and provide for enhanced performance while meeting the design specifications. To achieve the desired performance with minimal limitations it is logical to lean towards a hybrid design that implements a combination of more than one ground plane option. With a hybrid approach ultrawideband operation can be achieved in a low-profile package.

This dissertation presents the design and analysis of a low-profile ultrawideband hybrid EBG/ferrite structure. The hybrid structure consists of a mushroom type EBG structure implemented with a slab of absorbing ferrite material resting on the conductive backing of the structure. Reflectivity and phase simulation analyses indicate that the hybrid structure offers ultrawideband operation beginning in the hundreds of megahertz with one design variation offering an operational bandwidth exceeding 40:1 starting at 120MHz. Simulation analysis of the hybrid structure implemented with Raytheon's ultrawideband long slot array antenna further validates the ultrawideband performance of the hybrid structure. An equivalent circuit model of the hybrid structure was developed to provide a more in-depth understanding of the operation of the structure in regards to its geometry and material properties. It is shown that unlike the equivalent circuit models developed for traditional mushroom type EBG structures, the equivalent circuit model for the hybrid structure contains a resistance representing the permeability losses due to the ferrite layer. Additionally, it is shown that both the inductive and resistive equivalent circuit components are frequency dependent and depend on the frequency dependent characteristics of the ferrite. Experimentally testing the hybrid structure using a free space method would require the fabrication of an unreasonably large structure. Therefore, a TEM cell was designed and fabricated to experimentally test the performance of the hybrid structure. It is shown that experimental results of the reflectivity and phase analyses show good correlation with the simulated results. An important attribute of the mushroom type EBG structure is its ability to provide surface wave suppression. Experimental analysis of the surface wave suppression capabilities of the hybrid structure indicate suppression of at least 20dB across the band and suppression exceeding 60dB in the "EBG structure" region of operation compared to an electric conductor. Thus the implementation of this hybrid EBG/ferrite structure as a ground plane will allow for the practical and effective implementation of new highly sophisticated ultrawideband antenna systems.

Journal Publications:

J. M. Bell and M. F. Iskander, *Equivalent Circuit Model of an Ultrawideband Hybrid EBG/Ferrite Structure*, IEEE Antennas and Wireless Propagation Letters, accepted for publication April 2008.

J. M. Bell and M. F. Iskander, *Experimental Analysis of an Ultrawideband Hybrid EBG/Ferrite Ground Plane*, IEEE Transactions on Instrumentation and Measurement, accepted for publication March 2008.

J. M. Bell and M. F. Iskander, *Effective Propagation Properties of an Enhanced Hybrid EBG/Ferrite Ground Plane*, IEEE Antennas and Wireless Propagation Letters, vol. 7, pp. 74-77, 2008.

J. M. Bell, M. F. Iskander, and J. J. Lee, *Ultrawideband Hybrid EBG/Ferrite Ground Plane for Low-Profile Array Antennas*, IEEE Transactions on Antennas and Propagation, vol. 55, pp. 4-12, January 2007.

W. W. G. Hui, J. M. Bell, M. F. Iskander, and J. J. Lee, *Low-Cost Microstrip-Line-Based Ferrite Phase Shifter Design for Phased Array Antenna Applications*, IEEE Antennas and Wireless Propagation Letters, vol. 6, pp. 86-89, 2007.

J. M. Bell and M. F. Iskander, *A Low-Profile Archimedean Spiral Antenna Using an EBG Ground Plane*, IEEE Antennas and Wireless Propagation Letters, vol. 3, pp. 223-226, 2004.

Book Chapter:

M. F. Iskander, J. M. Bell, N. Celik, W. C. Kim, and Z. Q. Yun, *Antenna Array Technologies for Advanced Wireless Systems* in Modern Antenna Handbook, edited by C. A. Balanis, John Wiley & Sons, July 2008.

Patents:

W. C. Kim, J. M. Bell, and M. F. Iskander, *Coplanar Waveguide Continuous Transverse Stub (CPW-CTS) Antenna for Wireless Communications*, United States Patent #7,079,082, July 2006.

J. M. Bell and M. F. Iskander, *Hybrid Electromagnetic Band-Gap (EBG)/Ferrite Ultrawideband Ground Plane for Low-Profile Uni-Directional Antennas*, United States Patent disclosure submitted May 2006.

Conference Publications:

M. F. Iskander, Z. Q. Yun, N. Celik, J. M. Bell, and W. C. Kim, *Antenna Arrays and Propagation Models for Advanced Wireless Systems*, International Conference on Electromagnetics in Advanced Applications, pp. 79-84, September 2007.

J. M. Bell, M. F. Iskander, and J. J. Lee, *Ultrawideband Hybrid EBG/Ferrite Ground Plane for Low-Profile Array Antennas*, IEEE AP-S International Symposium, pp. 1313-1316, June 2007.

J. M. Bell, M. F. Iskander, and J. J. Lee, *Ultra-Wideband and Low-Profile Hybrid EBG/Ferrite Ground Plane for Airborne Foliage Penetrating Radar*, IEEE AP-S International Symposium & USNC/URSI National Radio Science Meeting & AMEREM Meeting, pp. 369-372, July 2006.

W. W. G. Hui, J. M. Bell, M. F. Iskander, and J. J. Lee, *Low-Cost Microstrip-Based Ferrite Phase Shifter Utilizing Circular Polarization*, IEEE AP-S International Symposium & USNC/URSI National Radio Science Meeting & AMEREM Meeting, pp. 4805-4808, July 2006.

J. M. Bell, W. W. G. Hui, M. F. Iskander, and J. J. Lee, *Low-Cost Nonplanar Microstrip-Line Ferrite Phase Shifter Utilizing Circular Polarization*, IEEE/ACES International Conference on Wireless Communications and Applied Computational Electromagnetics, pp. 233-236, April 2005.

C. S. Suh, J. M. Bell, K. S. Ching, T. A. Heffner, W. W. G. Hui, G. S. Shiroma, C. Song, R. K. Sorensen, and W. A. Shiroma, *An Investigation of Grounding Techniques in Microwave Amplifiers*, IEEE Topical Conference on Wireless Communication Technology, pp. 170-171, October 2003.

Biography

Jodie Bell received the B.S. degree in electrical engineering from North Carolina State University in 2002 and the M.S. degree in electrical engineering from the University of Hawai'i in 2004, where he is currently working towards the Ph.D. degree in electrical engineering. In 2003, he joined the Hawai'i Center for Advanced Communications (HCAC) at the University of Hawai'i, where he conducts research in the area of electromagnetics. His research interests include antennas and wave propagation as well as computational electromagnetics. While working with the HCAC he has worked on various research projects including ultrawideband low-profile phased array antenna systems, low-cost microstrip-line ferrite phase shifters, stray-field coil drier systems for ceramics, and IED (improvised explosive device) and UXO (unexploded ordinance) detection and discrimination systems. From his research, Jodie has published several papers through the Institute of Electrical and Electronics Engineers (IEEE). Mr. Bell was a recipient of the Achievement Rewards for College Scientists (ARCS) Scholarship Award in 2006/2007 and 2007/2008.