

Terahertz Reflectarrays

by

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Thesis submitted for the degree of

Doctor of Philosophy

in

School of Electrical and Electronic Engineering,
Faculty of Engineering, Computer and Mathematical Sciences
The University of Adelaide, Australia

2015

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Abstract

REFLECTARRAY, the concept combining the principles of phased arrays and geometrical optics, can produce predesigned radiation characteristics without requiring a complicated feeding network. A free-space excitation is used to illuminate reflectarrays with passive resonant elements made of metal and dielectric structures, whose individual reflection phase is dependent on the size and geometry of a radiating resonator. Reflectarrays offer the advantages of flat profile and high efficiency, and therefore various reflectarray structures have been intensively realised in the microwave region. With the development of integrated circuit lithography processes, the application of the reflectarrays has been extended to the infrared and even to the visible light regions. However, the realisation of the reflectarrays that can manipulate beams in the terahertz regime still remains largely under-explored, because of the high intrinsic material loss and due to the challenges associated with measurement technology in this frequency range. In recent years, owing to emerging solid-state sources and detectors in the terahertz spectrum, high-gain antennas have become intensively required for constructing terahertz wireless networking or imaging systems. Low-loss terahertz reflectarray antennas thus promise attractive potential for enabling the manipulation of terahertz radiation. This thesis will first introduce the background of terahertz technology, approaches for manipulating terahertz radiation, and fundamental theories for reflectarray design. Following the introductory chapters, the core of the thesis shows how several terahertz reflectarrays have been designed, fabricated, measured and analysed for the aim of (**Part I**) beam deflection with polarisation independence, (**Part II**) beam splitting with polarisation dependence, and (**Part III**) broadband operation:

Part I involves a terahertz reflectarray that is composed of resonant microstrip gold patches on a dielectric substrate. The relation between the patch size and the reflection phase is analysed for a realisation at 1 THz. A subarray is then configured based

on a progressive and cyclic phase distribution to deflect an incident beam into a pre-designed angle off the specular direction. Both the numerical simulation and the experimental measurement verify that the proposed reflectarray can efficiently deflect the incident TM and TE polarised waves into the same desired direction at an operation frequency.

Part II focuses on reflectarray designs that can split an incident beam into two different directions with polarisation dependence. In the first realisation, two sets of orthogonal strip dipoles are arranged into interlaced triangular lattices, whereas the second realisation is based on metallic wire grids patterned into square layout with variable lengths backed with wire-grid ground layer. Both configurations of reflectarrays can separate the two polarisation components into different designed directions by deflection or transmission. The designs are realised for experimental validation, and the corresponding measurements are performed in a terahertz time-domain spectroscopy system. The measurement results verify the designs and show acceptable efficiency and high polarisation purity of these polarisation beam-splitters.

Part III concerns the design of novel radiating resonators for broadband reflectarrays. Three parallel elliptical dipoles with variable lengths are proposed to enable broadband operation. A reasonably linear phase response with a wide enough range is obtained by the proposed configuration while the phase curves for different frequencies are nearly parallel each other over a wide frequency range. The simulated field distributions and radiation patterns at different frequencies in the terahertz range demonstrate that the designed reflectarray can perform as expected in a wide frequency band.

These original designs along with corresponding experimental validations offer a first demonstration of reflectarray in the terahertz regime, with antennas composed of metal-dielectric resonators. This is an important progress in expanding approaches for terahertz wave manipulation. The designed reflectarrays with different structures can be utilised as high-efficiency components for advancing the technologies of high-speed communications and high-resolution imaging in the terahertz range.

Statement of Originality

I certify that this work contains no material that has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Date

Acknowledgments

I would like to take the opportunity to express my gratitude to all those people whose support, skills, friendship and encouragement has helped me to complete this thesis successfully.

First of all, I would like to convey my special thanks to my principal supervisor **Prof Christophe Fumeaux** for accepting me as a Ph.D candidate in 2011 and guiding me throughout my candidature. His extensive experience and comprehensive knowledge in the antenna area have offered me invaluable advice in my research. Reviewing manuscripts with his enlightening questions and critical comments always challenged me. However, these hard times eventually turned out as a productive Ph.D journey. I am grateful to have meetings with him every week from where many creative ideas were inspired, revised and realised. Dear Christophe, I am so appreciated to have your time, concerns, contributions, passions, and quick replies on each publication including this thesis. It was your warm encouragement that kept me going when times were tough.

My sincere gratitude definitely goes to my co-supervisor and supportive colleague **Dr Withawat Withayachumnankul**, an outstanding scholar with passionate personalities at the University of Adelaide. He was very generous with his time and knowledge and assisted me in each step to complete the thesis. I still remember some words from his email saying “trust me that everything is going to be fine” just before my departure from Beijing to Adelaide in 2011. Since my first day of this journey, his generous patience and extensive knowledge in the terahertz area have made me feel free to knock his office door or just write an email for intellectual supervision at any time. Long-hours discussion with him on different research issues, inspirations from him on our weekly meetings, and his constructive comments on each publication guaranteed the completion of the thesis.

In particular, I would like to take the opportunity to express my deep gratitude to **Prof Zhonglei Mei**, an outstanding professor of the Lanzhou University. He was a passionate and humorous teacher during my Bachelor study, and the great supervisor of my Master research. He has been not only my spiritual mentor, but also a dear friend.

Acknowledgments

I must show my gratitude to Functional Materials and Microsystems Research Group of RMIT University. All prototypes presented in the thesis were fabricated by this group. Sincere thanks to Dr Madhu Bhaskaran, Dr Sharath Sriram, Hakan Menekse, Aditi Upadhyay, and Philipp Gutruf for providing me these delicate samples with excellent performance.

During the time of my Ph.D study I received plentiful support and help from my friends and colleagues in the Applied Electromagnetics Group at the University of Adelaide, Dr Thomas Kaufmann, Dr Longfang Zou, Dr Shifu Zhao, Dr Zhi Xu, Dr Ali Karami Horestani, Dr Pouria Yaghmaee, Dr Zahra Shaterian, Weixun Wu, Amir Ebrahimi, Shengjian (Jammy) Chen, Chengjun Zou, Nghia Nguyen, Sree Pinapati, Wendy Suk Ling Lee, Andrew Udina, and Fengxue Liu. I enjoyed the time of our group meetings with critical questions, which has made me more professional in presenting my work. Great thanks also go to people at the Adelaide T-ray Group, Prof Derek Abbott, Daniel Headland, Dr Benjamin S.-Y. Ung, Dr Jining (Andrew) Li and Mr Henry Ho for their lab training and experimental support to my measurements.

I am grateful to the School of Electrical and Electronic Engineering whose financial support for attending several high-quality international conferences in which I presented my papers and built up connections with the participants. I also gratefully acknowledge the staff of the school, IT officers, and Workshop colleagues for giving me all necessary assistance during my studies. My appreciation is also given to the University of Adelaide for Adelaide University China Fee Scholarship (AUCFS) covering my international tuition fees and to China Scholarship Council (CSC) for the State Scholarship covering my living stipend here. These scholarships have set me free from financial pressures and made the thesis possible. My heartfelt gratitude especially to the Lanzhou University where my Bachelor and Master degrees were issued in 2003 and 2011, respectively. Fundamental knowledge in various subjects and basically electromagnetic theories I learned in the Lanzhou University have been the solid basement of the thesis and also of my future research career.

I cannot go without mentioning my pastor Mr Chris Ambrose along with his lovely wife Mary Ambrose. Blessed by the God with grace and mercy, I was welcomed and loved by this spiritual family since the moment I stepped into the Maylands Church of Christ for the first time. Blessings from the God and loves from my Christian siblings supported me to go through these tough time. Sincere thanks also go to my friends.

Their patience, tolerance and friendship can always make me relaxed from my work, either through enjoying a meal together and a calling chat, or even a long-trip travel.

And finally, but not least, my warmest thanks goes to my whole family, who have been an important and indispensable source of spiritual support. Endless love, continuous encouragement, and spiritual support from my parents always accompany me in my ups and downs. Love and support from my dear brothers and sister always comfort me. I have learned so much from them about how to fulfill a life with passion, love and kindness. My endless appreciation goes to my dear husband Mr Yuming Zhu. His unconditional love and infinite support provided me the energy to attain my study.

Thesis Conventions

The following conventions have been adopted in this Thesis:

Typesetting

This document was compiled using L^AT_EX2_ε. TeXnicCenter was used as text editor interfaced to L^AT_EX2_ε. Adobe Illustrator CS2 was used to produce schematic diagrams and other drawings.

Spelling

Australian English spelling conventions have been used, as defined in the Macquarie English Dictionary (A. Delbridge (Ed.), Macquarie Library, North Ryde, NSW, Australia, 2001).

Referencing

The Harvard style is used for referencing and citation in this thesis.

System of Units

The units comply with the international system of units recommended in an Australian Standard: AS ISO 1000-1998 (Standards Australia Committee ME/71, Quantities, Units and Conversions 1998).

Publications

Journal Articles

- NIU T. M., WITHAYACHUMNANKUL W., UNG B. S.-Y, MENEKSE H., BHASKARAN M., SRIRAM S., & FUMEAUX C. (2013). Experimental demonstration of reflectarray antennas at terahertz frequencies, *Optics Express*, **21**(3), pp. 2875–2889.
- NIU T. M., WITHAYACHUMNANKUL W., UPADHYAY A., GUTRUF P., ABBOTT D., BHASKARAN M., SRIRAM S., & FUMEAUX C. (2014). Terahertz reflectarray as a polarizing beam splitter, *Optics Express*, **22**(13), pp. 16148–16160.
- NIU T. M., UPADHYAY A., WITHAYACHUMNANKUL W., HEADLAND D., ABBOTT D., BHASKARAN M., SRIRAM S., & FUMEAUX C. (2015). Polarization-dependent thin-film wire-grid reflectarray for terahertz waves, *Applied Physics Letters*, **107**(3), 031111.

Conference Articles

- NIU T. M., WITHAYACHUMNANKUL W., UNG B. S.-Y, MENEKSE H., BHASKARAN M., SRIRAM S., & FUMEAUX C. (2012). Design and implementation of terahertz reflectarray, *2012 37th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, Wollongong, Australia, pp. 1–2.
- NIU T. M., WITHAYACHUMNANKUL W., ABBOTT D., & FUMEAUX C. (2014). Design of polarization-dependent reflectarray for terahertz waves, *2014 International Workshop on Antenna Technology: "Small Antennas, Novel EM Structures and Materials, and Applications"(iWAT)*, Sydney, Australia, pp. 205–207. (Best Student Paper Award)
- NIU T. M., WITHAYACHUMNANKUL W., ABBOTT D., & FUMEAUX C. (2014). Terahertz reflectarray for bidirectional beam splitting, *2014 39th International Conference on Infrared, Millimeter, and Terahertz Waves (IRMMW-THz)*, Tucson, AZ, USA, pp. 1–2.
- NIU T. M., WITHAYACHUMNANKUL W., & FUMEAUX C. (2015). Terahertz broadband reflectarray with parallel elliptical dipoles, *2015 IEEE 4th Asia-Pacific Conference on Antennas and Propagation (APCAP)*, Bali Island, Indonesia, pp. 102–104.

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