UTS UNIVERSITY OF TECHNOLOGY SYDNEY

Advanced Transmitarrays and Their Beam Scanning For Future Wireless Communications

by Xuan Wang

Thesis submitted in fulfilment of the requirements for the degree of

Doctor of Philosophy

under the supervision of
Dr Pei-Yuan Qin and Prof. Y. Jay Guo

University of Technology Sydney
Faculty of Engineering and Information Technology

December 2021

Certification of Original Authorship

I, Xuan Wang declare that this thesis, is submitted in fulfilment of the requirements for the award of the degree of DOCTOR OF PHILOSOPHY, in the Faculty of Engineering and Information Technology at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

This research is supported by the Australian Government Research Training Program.

This thesis is the result of a research candidature conducted with Shanghai Jiao Tong University as part of a collaborative Doctoral degree.

Signed: Production Note:
Signature removed prior to publication.

15/12/2021

ABSTRACT

In recent years, transmitarrays have attracted growing attention for many wireless communication systems. Transmitarrays combine both optical and antenna array theories, leading to high gain, high efficiency, low cost and flexible radiation performance. In this thesis, on the basis of the state-of-the-art of transmitarrays, three main contributions are made to meet the challenges that arise from future wireless communications.

The first contribution is the new approach to reduce radar cross section (RCS) of transmitarrays without sacrificing their radiation performance. Phase controllable absorptive frequency-selective transmission (AFST) elements are developed for low RCS transmitarrays, providing absorption-transmission-absorption responses. Moreover, the transmission phase within the transmission band can be controlled by rotating the AFST element. Based on these elements, a low RCS transmitarray has been designed. Compared with a reference transmitarray, the radiation performance of the low-RCS one is almost unchanged. Furthermore, significant RCS reductions have been realized in two absorption bands for wide-angle impinging electromagnetic (EM) waves.

The second contribution is the development of a dual-layer wideband conformal transmitarray at E-band. The dual-layer transmitarray element is designed based on multiple Huygens resonances at different frequencies to achieve both wideband and high efficiency properties. Continuous phase compensation of 360° is achieved, reducing phase errors of the array architecture. Employing the dual-layer Huygens elements, a cylindrically conformal transmitarray at 78 GHz has been designed. The measured results show a peak

realized gain of 26.6 dBi with an aperture efficiency of 35.9 % and 3-dB bandwidth of 20.4 % from 71 to 87 GHz, which can fully cover the E-band spectrum from 71 to 86 GHz.

The third contribution is the development of reconfigurable transmitarrays to achieve 2-dimensional (2-D) beam scanning. A new reconfigurable dual-layer Huygens element is developed. A 1-bit phase compensation with low transmission loss is achieved by controlling two PIN diodes integrated on the element. Compared with many other reconfigurable transmitarray elements using multi-layer structures with metallic vias, the developed reconfigurable Huygens element has a simpler configuration and a simpler biasing network, leading to a very robust design. This particularly facilitates large aperture array at higher frequencies. To validate the design concept, a transmitarray prototype at 13 GHz has been designed. 2-D scanning beams within $\pm 50°$ in E-plane and $\pm 40°$ in H-plane are achieved.

All in all, the developed advanced transmitarrays and their beam scanning represent significant knowledge advance on antenna technologies. They can find wide applications in current and future wireless communication systems.

ACKNOWLEDGEMENTS

First of all, I would like to express my deepest gratitude to my supervisor Dr. Peiyuan Qin for his continuous guidance and support for my PhD study. He has helped me applied for the doctoral candidature at University of Technology Sydney (UTS), which really helped me have the precious opportunity to study at UTS. For my research, Dr. Peiyuan Qin has given me innovative ideas and helpful suggestions. Moreover, his insight into academic frontiers and rigorous academic attitude have deeply inspired and motivated me.

I would like to express my profound gratitude to my co-supervisor Prof. Y. Jay Guo. He has provided me the precious opportunity and invaluable guidance in pursuing my doctoral degree at UTS. Without his support, I would not have the chance to study at UTS. Prof. Guo is always resourceful in providing me insightful and profound suggestions for my research. I am also greatly inspired by Prof. Guo's rigorous academic attitude and his friendly, considerate, and generous nature.

I am deeply grateful to my supervisor Prof. Ronghong Jin at Shanghai Jiao Tong University (SJTU) for providing me the opportunity to study as a joint PhD student at UTS and SJTU. He has given me continuous and solid support throughout my whole PhD study.

I would like to thank my collaborator Dr. Anh Tuyen Le and Dr. Hao Zhang for their valuable help on my work, support with experiments, and advice on papers.

I would like to thank Prof. Trevor Bird and Prof. Richard W. Ziolkowski for their guidance and encouragement during my PhD study. I would like to thank Prof. Yanhui Liu and Prof. Zheng Li for their valuable suggestions on my work and advice on papers. My sincere thanks also go to other members at Global Big Data Technologies Centre (GBDTC), especially, Dr. Stanley Chen, Dr. Ting Zhang, Dr. He Zhu, Dr. Wei Lin, Dr. Can Ding, Miss Lizhao Song, Miss Maral Ansari, Mr Yubo Wen, Mr Ming Li, and Mr Yuenian Chen for their kind help and support.

I am also thankful to the University of Technology Sydney for giving me the opportunity to pursue my PhD studies by granting me scholarships to cover my tuition fee and living expenses. I also acknowledge the handwork put in by the School of Electrical and Data Engineering staff to provide efficient admin and academic support to the research students.

In the end, I would like to express my forever thanks to my parents for their unconditional love, unreserved support and encouragement throughout my life.

LIST OF PUBLICATIONS

Journal Articles

1. **X. Wang**, P. -Y. Qin, and R. Jin, ”Low RCS Transmitarray Employing Phase Controllable Absorptive Frequency-Selective Transmission Elements,” *IEEE Transactions on Antennas and Propagation*, vol. 69, no. 4, pp. 2398-2403, Apr. 2021.
2. **X. Wang**, P.-Y. Qin, A. T. Le, H. Zhang, R. Jin, and Y. J. Guo, ”Beam Scanning Transmitarray Employing Reconfigurable Dual-Layer Huygens Element,” *IEEE Transactions on Antennas and Propagation*. (Under review)

Conference Articles

1. **X. Wang**, P.-Y. Qin, and Y. J. Guo, ”1-Bit Reconfigurable Huygens Element for Beam-Steering Transmitarrays,” *26th International Symposium on Antennas and Propagation (ISAP)*, 2021, pp. 1-2, doi: 10.23919/ISAP47258.2021.9614579.
2. **X. Wang**, P.-Y. Qin, C. Ding and R. Jin, ”Low RCS Transmitarray Using Phase Controllabe Rasorber,” *2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI)*, 2021, pp. 161-162, doi: 10.1109/APS/URSI47566.2021.9704697.

Contents

LIST OF FIGURES

List of Tables

LIST OF ACRONYMS

2-D	2-Dimensional
3-D	3-Dimensional
5G	Fifth Generation
6G	Sixth Generation
AFST	Absorptive Frequency-Selective Transmission
AMC	Artificial Magnetic Conductor
BW	Bandwidth
CP	Circular-Polarization
DC	Direct Current
EM	Electromagnetic
FPGA	Field-Programmable Gate Array
FSR	Frequency-Selective Rasorber
FSS	Frequency-Selective Surface
Gbps	Gigabits-Per-Second
IDC	Insulation-Displacement Contact
LED	Light-Emitting Diode
LP	Linear-Polarization
MEMS	Micro-Electro-Mechanical System
M-FSS	Multilayer-Frequency-Selective Surface
mm-wave	Millimeter Wave
MVG	Microwave Vision Group

PCB	Printed Circuit Board
PEC	Perfect Electric Conductor
RCS	Radar Cross Section
RF	Radio Frequency
RTA	Reconfigurable Transmitarray
RTE	TE^y Plane Wave
RTM	TM^y Plane Wave
SLL	Side Lobe Level
Tbps	Terabits-Per-Second
THz	Terahertz
UAV	Nnmanned Aerial Vehicles
USB	Universal Serial Bus
VNA	Vector Network Analyzer