Investigation of High-Performance Millimetre-Wave and Terahertz Beam-Shaping Devices for Next Generation Communication Systems

by Jianfeng Zhu

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under the supervision of
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CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Jianfeng Zhu declare that this thesis, is submitted in fulfilment of the requirements award of the Doctoral Degree, in the School of Electrical and Data Engineering, Faculty of Engineering and Information Technology at the University of Technology Sydney.

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

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of the requirements for a degree at any other academic institution except as fully acknowledged within the text. This thesis is the result of a Collaborative Doctoral Research Degree program with Beijing University of Posts and Telecommunications.

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Published and Under Review Papers Related to This Thesis

[1] **J. Zhu,** Y. Yang, D. McGloin, R. Unnithan, S.Li, S. Liao, and Q. Xue, "3-D Printed Planar Dielectric Linear-to-Circular Polarization Conversion and Beam Shaping Lenses Using Coding Polarizer," ***IEEE Transactions on Antennas and Propagation,*** vol. 68, no. 6, pp. 4332-4343, June 2020, doi: 10.1109/TAP.2020.2972625. **[Chapter 2, Section 2.2]**

[2] **J. Zhu,** Y. Yang, D. McGloin, S. Liao and Q. Xue, "Sub-Terahertz 3-D Printed All-Dielectric Low-Cost Low-Profile Lens-Integrated Polarization Beam Splitter," ***IEEE Transactions on Terahertz Science and Technology.*** vol. 11, no. 4, pp. 433-442, July 2021, doi: 10.1109/TTHZ.2021.3064209. **[Chapter 2, Section 2.3]**

[3] **J. Zhu,** Y. Yang, D. McGloin, S. Liao and Q. Xue, "3-D Printed All-Dielectric Dual-Band Broadband Reflectarray with a Large Frequency-Ratio," ***IEEE Transactions on Antennas and Propagation***, early access doi: 10.1109/TAP.2021.3076528. **[Chapter 2, Section 2.4]**

[4] **J. Zhu**, Y. Yang, S. Li, S. Liao, and Q. Xue, "Single-Ended-Fed High-Gain LTCC Planar Aperture Antenna for 60 GHz Antenna-in-Package Applications," ***IEEE Transactions on Antennas and Propagation***, vol. 67, no. 8, pp. 5154-5162, Aug. 2019 **[Chapter 3, Section 3.2]**

[5] **J. Zhu,** Y. Yang, C. Chu, S. Li, S. Liao, and Q. Xue, "Low-Profile Wideband and High-Gain LTCC Patch Antenna Array for 60 GHz Applications," ***IEEE Transactions on Antennas and Propagation***, vol. 68, no. 4, pp. 3237-3242, April 2020. **[Chapter 3, Section 3.2]**

[6] **J. Zhu,** Y. Yang, D. McGloin, S. Liao and Q. Xue, "Dual-Band Dual-Sense Circularly Polarized High Gain Antenna with a Single Linearly-Polarized Feed,"

submitted to ***IEEE Transactions on Antennas and Propagation,*** **[Chapter 4, Section 4.2]**

[7] **J. Zhu,** Y. Yang, S. Liao, and Q. Xue, "Large Frequency-Ratio, High Aperture Reuse efficiency, Dual-Band Antenna for Millimeter-Wave and Sub-6 GHz Applications," submitted to ***IEEE Antennas and Wireless Propagation Letters (Major revision)*** **[Chapter 4, Section 4.3]**

Abstract

The shortage of global bandwidth has motivated the exploration of the underutilized millimetrewave (mm-wave) and terahertz (THz) spectrum for future broadband communication networks. Nevertheless, one of the fundamental challenges is the huge propagation loss. To tackle this problem, antennas at the front-end of transceivers should be capable of shaping the mm-wave/THz wavefront to achieve high-directivity radiation and large spatial coverage. Meanwhile, the print circuit board (PCB) cannot fully satisfy the demand due to the deterioration of electrical performance at high frequencies. Therefore, new fabrication technologies need to be exploited to build highly-efficient and highly-integrated mm-wave/THz beam shaping devices. In this thesis, taking advantage of PCB, 3-D printing, and low-temperature co-fire ceramics (LTCC), beam shaping devices including lenses, reflectarrays, antennas operating in the mm-wave and low THz region are proposed for next-generation communication systems applications. The main contents are as follows:

1. 3-D printed polarization manipulation and beam-shaping devices. First, we present a new 3-D printed lens, which achieves linear to circular polarization conversion and beam collimation in transmission mode simultaneously with a planar configuration. Next, we demonstrate a 3-D printed THz Fresnel-Rochon prism, which has the potential to replace conventional expensive prism. Finally, a new all-dielectric broadband dual-band reflectarray operating in K-band and V-band is demonstrated using low-cost 3-D printing. To the best of our knowledge, this is the first type of all dielectric reflectarray that has ever been reported.

2. Highly-integrated and high gain LTCC antenna array for 60-GHz antenna-in-package applications. Firstly, single-ended-fed planar aperture antennas fabricated using LTCC technology are demonstrated, which not only inherits the merits of the aperture antennas but also exhibits advantages of low-profile and compact size. Then, we demonstrate a low-profile wideband and high gain patch antenna array. The antenna achieves good radiation performances, which are comparable to those of the differential-driven patch antenna without a differential feeding network.

3. Dual-band beam-shaping antennas. First, a new kind of dual-band high gain antenna is proposed by folding a reflectarray into a Fabry-Perot cavity. The high gains of the two bands are achieved by exploiting the collimating reflectarray and Fabry-Perot resonant principles, respectively. Next, an aperture-shared dual-band antenna is proposed by integrating a high-band Fabry-Perot cavity antenna into a low-band patch antenna. Because of the FP resonance, the antenna can achieve a peak gain of 16 dBi at 28 GHz band without a feeding network.

Keywords: Millimetre-wave, THz, beam shaping, polarization, 3-D printing, LTCC

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