KEY TECHNOLOGIES FOR ADVANCED CELLULAR BASE STATION ANTENNAS

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Certification of Original Authorship

I, Haihan Sun, declare that this thesis, is submitted in fulfilment of the requirements for the award 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.

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List of Publications

Peer-Reviewed Journal Papers

1. **H. Sun**, C. Ding, B. Jones, and Y. J. Guo, "A wideband base station antenna element with stable radiation pattern and reduced beam squint," *IEEE Access*, vol. 5, pp. 23022 – 23031, 2017.
2. **H. Sun**, H. Zhu, C. Ding, and Y. J. Guo, "Wideband planarized dual-linearly-polarized dipole antenna and its integration for dual-circularly-polarized radiation," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, pp. 2289 – 2293, Dec. 2018.
3. **H. Sun**, C. Ding, H. Zhu, B. Jones, and Y. J. Guo, "Suppression of cross-band scattering in multiband antenna arrays," *IEEE Transactions on Antennas and Propagation*, vol. 67, pp. 2379 - 2389, Jan. 2019.
4. C. Ding, **H. Sun**, R. W. Ziolkowski, and Y. J. Guo, "Simplified tightly-coupled cross-dipole arrangement for base station applications," *IEEE Access*, vol. 5, pp. 27491 – 27503, 2017.
5. T. S. Bird, V. Lingasamy, K. T. Selvan, and **H. Sun**, "Improved finite-range gain formula for open-ended rectangular waveguides and pyramidal horns," *IET Microwaves, Antenna & Propagation*, vol. 14, issue 14, pp. 2054 – 2058, 2017.
6. C. Ding, **H. Sun**, R. W. Ziolkowski, and Y. J. Guo, "A dual-layered loop array antenna for base stations with enhanced cross-polarization discrimination (XPD)," *IEEE Transactions on Antennas and Propagation*, vol. 66, pp. 6975 - 6985, Dec. 2018.
7. H. Zhu, **H. Sun**, B. Jones, C. Ding, and Y. J. Guo, "Wideband dual-polarized multiple beam-forming antenna arrays," *IEEE Transactions on Antennas and Propagation*, vol. 67, pp. 1590 – 1604, Dec. 2018.
8. **H. Sun**, H. Zhu, C. Ding, B. Jones, and Y. J. Guo, "Choking techniques for scattering suppression in multi-band base station antenna arrays," *IEEE Transactions on Antennas and Propagation*. (Under review)
9. **H. Sun**, B. Jones, C. Ding, and Y. J. Guo, "A method to enhance the bandwidth and reduce the size of dual-polarized antennas," *IEEE Transactions on Antennas and Propagation*. (Under review)

Peer-Reviewed Conference Papers

1. **H. Sun**, C. Ding, Y. J. Guo, and R. Mittra, "A wideband dipole antenna based on a non-uniformly segmented structure," *European Conference on Antennas and Propagation (EuCAP)*, 2017.
2. **H. Sun,** C. Ding, T. Yang, Y. J. Guo, and P. Q, "A wideband base station antenna with stable radiation pattern," *Australian Microwave Symposium (AMS)*, ***Best Student Paper***, 2018.
3. **H. Sun**, C. Ding, and Y. J. Guo, "A novel dual-polarized planar antenna," *IEEE International Symposium on Antennas and Propagation (APS)*, ***Honourable Mention in Student Paper Competition***, 2018.
4. **H. Sun**, C. Ding, and Y. J. Guo, "A wideband base station antenna with reduced beam squint," *European Conference on Antenna and Propagation (EuCAP)*, 2018.
5. **H. Sun**, C. Ding, T. S. Bird, and Y. J. Guo, "A base station antenna element with simple structure but excellent performance," *Australian Microwave Symposium (AMS)*, 2018.
6. **H. Sun**, C. Ding, H. Zhu, B. Jones, and Y. J. Guo, "Suppression of cross-band scattering in multi-band base station antenna arrays," *Australian Symposium on Antennas (ASA)*, ***Student Prize for Best Oral Presentation***, 2019.
7. C. Ding, **H. Sun**, Y. J. Guo, P. Qin, and Y. Yang, "Beamwidth control of base station antennas employing reflectors and directors," *International Symposium on Antennas and Propagation (ISAP)*, 2015.
8. D. Guan, C. Ding, **H. Sun**, and F. Yuan, "Wide-band SIW cavity-backed circular polarized array antennas with sequential rotation technique," *International Conference on Electromagnetics in Advanced Applications (ICEAA)*, 2016.
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10. C. Ding, **H. Sun**, Y. J. Guo, and R. W. Ziolkowski, "A general design and optimization method of tightly-coupled cross-dipoles for base station," *European Conference on Antenna and Propagation (EuCAP)*, 2018.

To my parents

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List of Abbreviations

AR	Axial Ratio
BSA	Base Station Antenna
CP	Circularly-Polarized
GLL	Grating Lobe Level
FBR	Front-to-Back Ratio
HB	High Band
HPBW	Half-Power Beamwidth
ICD	Isolated Cross-Dipole
LB	Low Band
LHCP	Left-Handed Circular Polarization
LP	Linearly-Polarized
ME-dipole	Magneto-Electric Dipole
MIMO	Multiple-Input Multiple-Output
PDR	Power Division Ratio
RHCP	Right-Handed Circular Polarization
SLL	Side Lobe Level
TCCD	Tightly-Coupled Cross-Dipole
XPD	Cross Polarization Discrimination
3G	Third Generation of Cellular Mobile Communications
4G	Fourth Generation of Cellular Mobile Communications
5G	Fifth Generation of Cellular Mobile Communications

Abstract

Cellular base station antennas (BSAs) are critical components in mobile communication systems. As the cellular mobile communication systems evolve rapidly to the fifth generation (5G), BSAs that can simultaneously support different standards and have high data capacity are in high demand. Multi-band arrays and multi-beam arrays are good solutions, but they place additional stringent requirements on the antennas. Firstly, high performance characteristics of antenna elements are required. Secondly, cross-band scattering, which is a long-existing issue in multi-band antenna arrays, needs to be suppressed to maintain the performance and stability of antenna systems. Thirdly, for multi-beam antenna arrays, they are desired to have wide operating bandwidth and consistent patterns with low side-lobe levels. All of these are difficult to achieve. This thesis addresses the challenges mentioned above by making three main contributions.

The first contribution is the improvement of the base station antenna elements. Three configurations have been thoroughly studied, including square-dipole-array, cross-dipole and dual-dipole configurations. Different methods are investigated to enhance bandwidth, stabilize radiation patterns, or minimize beam squint, and the outcomes of these are implemented in antenna designs. In addition, circuit models of feed networks are proposed to facilitate wideband impedance matching. Two antennas featuring planarized configurations are designed for the ease of system integration. In total, eight antenna elements have been designed, fabricated and tested to achieve the desired wideband radiation performances.

The second contribution is the development of new approaches to minimize cross-band interference in multi-band BSA arrays. Chokes that can minimize scattering currents are implemented in the antenna designs. The working principles and capabilities of suppressing scattering of three different types of chokes are analyzed. Based on these techniques, two dual-band antenna arrays have been designed. Experimental results verify that cross-band scattering is suppressed and both arrays have stable radiation patterns across wide operating bandwidths. The techniques presented for suppressing cross-band scattering guarantee the co-existence of antennas for different services, and facilitate the evolution of communication standards.

The third contribution is the development of multi-beam antenna arrays to increase system capacity with a wide coverage area. Cross-dipoles with a compact configuration

and stable radiation performances are chosen as array elements. Wideband beam-forming networks formed by Butler matrices and power dividers are used to provide correct phase increments and power levels for elements. Three-beam antenna arrays have been designed with required beamwidth and crossover level. The proposed designs can be used in a wide range of LTE base stations to increase system capacity.