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Multi-beam Antenna Arrays for Base Stations in Cellular Communication Systems

by Maral Ansari

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the degree of

Doctor of Philosophy

under the supervision of Prof. Y. Jay Guo, and
Dr. Negin Shariati Moghaddam

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STATEMENT OF ORIGINALITY

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

To the best of my knowledge, this document has not previously been submitted for qualifications to any other academic institution.

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Maral Ansari
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LIST OF ABBREVIATIONS

ABS	Acrylonitrite Butodiene Styrene
ADS	Advanced Design System
AR	Axial Ratio
BFN	Beamforming Network
BLC	Branch Line Coupler
COW	Cell-On-Wheel
CP	Circularly-Polarization
CPW	Coplanar Waveguide
DFT	Discrete Fourier Transfer
DRGW	Double Ridge gap Waveguide
EDT	Electronic downtilt
EM	Electromagnetic
FFT	Fast Fourier Transfer
FCSIW	Folded C-type Substrate Integrated Waveguide
FR1	Frequency Range1
FR2	Frequency Range2
FTBR	Front-to-Back Ratio
HFSS	High-Frequency Structure Simulator
HIS	High Impedance Surface
HP	Horizontal Polarization
HPBW	Half-Power Beamwidth
LEO	Low Earth Orbit
LP	Linearly-Polarization
LTCC	Low Temperature Co-fired Ceramic
MD-FFT	Multi-dimensional Discrete Fourier Transfer
ME-dipole	Magneto-Electric Dipole
MIMO	Multiple-Input Multiple-Output
Mm-wave	Millimeter-wave
PCB	Printed Cicuit Board
PD	Power Divider

PIM	Passive Intermodulation
PMC	Perfect Magnetic Conductor
PMSL	Packaged Microstrip Lines
PPW	Parallel Plate Waveguide
PRGW	Printed Ridge Gap Waveguide
PS	Phase Shifter
PTFE	Polytetrafluoroethylene
RF	Radio Frequency
RHMSIW	Ridge Half Mode Substrate Integrated Waveguide
RI	Refractive Index
RL	Return Loss
RMSE	Root-Mean-Squared-Error
RSIW	Ridge Substrate Integrated Waveguide
SINR	Signal to Interference and Noise Ratio
SISL	Substrate Integrate Suspended Line
SIW	Substrate Integrated Waveguide
SLL	Sidelobe Level
TDD	Time-Division-Duplex
TE	Transverse-Electric
TEM	Transverse-Electromagnetic
TM	Transverse-Magnetic
UWB	Ultra-Wideband
VP	Vertical Polarization
XPD	Cross Polarization Discrimination
XPS	Extruded Polystyrene Sheets
1D	One-dimensional
2D	Two-dimensional
3D	Three-dimensional
4G	Fourth Generation
5G	Fifth Generation
6G	Sixth Generation

Abstract

Multi-beam antennas will play an increasingly important role in future communications systems such as the fifth generation (5G) and sixth generation (6G) cellular systems. There will also be a shift to higher frequencies where more spectrum is available to accommodate wide-band high data rate systems. These factors will cause shifts in the technologies used in implementing advanced communications systems. Multi-beam antenna implemented with conventional network techniques are approaching physical limitations due to increasing losses and complexity. Quasi-optical techniques for implementing multi-beam antenna such as Luneburg lenses should be an attractive alternative.

In this thesis, some of the advantages and limitations of these opposing technologies using as examples firstly, a multi-beam antenna implemented using a Butler matrix feed network which is approaching high frequency limitations of loss and complexity and secondly, a multi-beam antenna based on a spherical Luneburg lens implemented with an artificial dielectric material which is approaching low frequency limitations of excessive size, weight and anisotropy is explored. In the case of Butler matrix networks, control of beamwidth and sidelobes is studied as are implementation details such as network crossovers. In the case of Luneburg lenses, the effects of an economical layered construction and the characteristics of the artificial dielectric are examined in detail. Two prototype Butler matrix fed arrays and two prototype spherical Luneburg lenses were designed, manufactured and tested. The results of these tests are described in the text.

An important qualitative difference between these two technologies is that to implement a two-dimensional (2D) beam space with beamforming networks requires a 2D array of networks. To provide dual polarization as is almost universally required in communications systems, all the hardware must be duplicated. The spherical lens solution naturally provides these capabilities with no duplication. In addition, the ohmic losses can be very low. These capabilities are explored in detail and simple construction methods for the artificial dielectric are presented that avoid the anisotropy that can mar such designs.

In current advanced 5G antennas with 2D arrays using multiple-input and multiple-output (MIMO) where multipath propagation is exploited to enhance capacity are being used in preference to multi-beam antennas. Such systems require a separate radio for each array element. The high power consumption is seen as a disadvantage of such systems as is the high cost. The move to higher frequencies where propagation characteristics make MIMO less advantageous will likely lead to a trend to wider use of multi-beam antennas.