# Dielectric Resonator Antennas: From Multifunction Microwave Devices to Optical Nano-antennas

by

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# Contents

# Abstract

Since a cylindrical dielectric resonator antenna (DRA) was firstly proposed by Long et al. in the 1980s, extensive research has been carried out on analyzing DRA shapes, characterizing the resonant modes, improving their radiation characteristics with various excitation schemes. Compared with conventional conductor-based antennas, DRAs have attractive features such as small size, high radiation efficiency and versatility in their shape and feeding mechanism.

Importantly, various orthogonal modes with diverse radiation characteristics can be excited within a single DRA element. These modes can be utilized for various requirements, which makes the DRA a suitable potential candidate for multifunction applications. Based on this principle, this thesis presents different multifunction designs: Firstly a cross-shaped DRA with separately fed broadside circularly polarized (CP) and omnidirectional linearly polarized (LP) radiation patterns and, secondly, a multifunction annular cylindrical DRA realizing simultaneously omnidirectional horizontally and vertically polarized radiation patterns with low cross-coupling. The evolution, design process and experimental validation of these two antennas are described in details in the thesis.

The second part of the thesis dramatically scales down DRA to shorter wavelengths. Inspired by the fact that DRA still exhibits high radiation efficiency (>90%) in the millimetre wave range, while the efficiency of conventional metallic antenna degrades rapidly with frequencies, this thesis proposes the concept of nanometer-scale DRA operated in their fundamental mode as optical antennas. To validate the concept, optical DRA reflectarrays have been designed and fabricated. Although the zeroth-order spatial harmonic reflection is observed in the measurement due to the imperfect nanofabrication, the power ratio of deflected beam to the specular component of reflection amounts to 4.42, demonstrating the expected operation of the reflectarray. The results strongly support the concept of optical DRA and proposes design methods and strategies for their realization. This proof of concept is an essential step for future research on nano-DRA as building block of emerging nano-structured optical components.

# Statement of Originality

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Date

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# Conventions

## Typesetting

This thesis is typeset using the LaTeX2e software. WinEdt build 5.5 was used as an effective interface to LaTeX.

## Referencing

Referencing and citation style in this thesis are based on the Institute of Electrical and Electronics Engineers (IEEE) Transaction style.

## Units

The units used in this thesis are based on the International System of Units (SI units).

## Prefixes

In this thesis, the commonly used numerical prefixes to the SI units are ″p″ (pico, $10^{-12}$), ″n″ (nano, $10^{-9}$), ″$\mu$″ (micro, $10^{-6}$), ″m″,(milli,$10^{-3}$), ″k″(kilo, $10^{3}$), ″M″(mega, $10^{6}$), ″G″(giga, $10^{9}$), and ″T″(tera, $10^{12}$).

## Spelling

The Australian English spelling is adopted in this thesis.

# Abbreviations

| | |
|---|---|
| **AR** | Axial Ratio |
| **BAN** | Body-Area Network |
| **CP** | Circularly Polarized |
| **CPW** | Coplanar Waveguide |
| **DR** | Dielectric Resonator |
| **DRA** | Dielectric Resonator Antenna |
| **DWM** | Dielectric Waveguide Model |
| **EBG** | Electromagnetic Band Gap |
| **ECC** | Envelope Correlation Coefficient |
| **EM** | Electromagnetic |
| **FEM** | Finite-Element Method |
| **HD** | High Definition |
| **HEM** | Hybrid Electric and Magnetic |
| **HFSS** | High Frequency Structural Simulator (a commercial simulation software) |
| **HMSIW** | Half-mode Substrate Integrated Waveguide |
| **HP** | Horizontally Polarized |
| **LHCP** | Left-Hand Circularly Polarized |
| **LP** | Linearly Polarized |
| **MEG** | Mean Effective Gain |
| **MIMO** | Multiple-Input Multiple-Output |
| **MMW** | Millimeter Wave |

**MNG-TL** Mu-Negative Transmission Line

**PCB** Printed Circuit Board

**PEC** Perfect Electric Conductor

**PIFA** Planar Inverted-F Antenna

**RHCP** Right-Hand Circularly Polarized

**SIW** Substrate Integrated Waveguide

**SPP** Surface Plasmon Polariton

**TE** Transverse Electric

**TM** Transverse Magnetic

**VP** Vertically Polarized

**WPAN** Wireless Personal Area Network

**XPR** Cross-polarization Power Ratio

# Author Publications

## Journal

[1] L. Zou and C. Fumeaux, ”A cross-shaped dielectric resonator antenna for multi-function and polarization diversity applications,” *IEEE Antennas Wireless Propag. Lett.*, vol. 10, pp. 742-745, Jul. 2011.

[2] L. Zou, D. Abbott, and C. Fumeaux, ”Omnidirectional cylindrical dielectric resonator antenna with dual polarization,” *IEEE Antennas Wireless Propag. Lett.*, vol. 11, pp. 515-518, 2012.

[3] L. Zou, W. Withayachumnankul, C. Shah, A. Mitchell, M. Bhaskaran, S. Sriram, and C. Fumeaux, ”Dielectric resonator nanoantennas at visible frequencies,” *Opt. Express*, vol. 21, no. 1, pp. 1344-1352, Jan. 2013.

## Conference

[1] L. Zou and C. Fumeaux, ”High-permittivity cross-shaped dielectric resonator antenna for circular polarization,” in *Int. Conf. Electromagn. Adv. App (ICEAA)*., Sep. 2010, pp. 1-4.

[2] L. Zou and C. Fumeaux, ”Cross-shaped dielectric resonator antenna for circular polarization with symmetric radiation patterns,” in *Twelfth Australian Symposium on Antennas*, Feb. 2011.

[3] L. Zou and C. Fumeaux, ”Horizontally polarized omnidirectional dielectric resonator antenna,” in *Asia-Pacific Microwave Conference (APMC), 2011*, Dec. 2011, pp. 849-852.

[4] L. Zou and C. Fumeaux, ”Mutual coupling reduction in a multi-mode multi-function dielectric resonator antenna,” in *International Symposium on Antennas and Propagation (APS)*, Jul. 2012. pp. 1-2.

[5] L. Zou, W. Withayachumnankul, C. Shah, A. Mitchell, M. Bhaskaran, S. Sriram, and C. Fumeaux, ”Optical reflectarray based on dielectric resonator antennas,” in *Australian Nanotechnology Network (ANN) 2012 Early Career Symposium*, Dec. 2012.

[6] L. Zou, W. Withayachumnankul, C. Shah, A. Mitchell, M. Bhaskaran, S. Sriram, and C. Fumeaux, ”Optical dielectric resonator antenna reflectarray,” in *Thirteenth Australian Symposium on Antennas*, Feb. 2013.

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