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

by

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Contents

Chapter 1. Introduction 1
  1.1 Introduction and motivation ........................................... 2
  1.1.1 Motivation - Multifunction and diversity DRA ..................... 3
  1.1.2 Motivation - Optical DRA ........................................... 4
  1.2 Objectives of the thesis ................................................. 4
  1.3 Statement of original contributions ................................... 6
  1.4 Overview of the thesis .................................................. 9

Chapter 2. Rectangular and cylindrical dielectric resonator antenna 13
  2.1 Introduction ............................................................ 14
  2.2 Modes of DR ............................................................ 15
  2.3 Rectangular dielectric resonator antenna ............................ 16
    2.3.1 Resonant frequency of the fundamental TE_{111} mode ........... 17
2.3.2 Radiation Q-factor of the fundamental TE_{111} mode ....... 20
2.3.3 Methods for excitation of the fundamental TE_{111} mode .... 21
2.4 Cylindrical dielectric resonator antenna ......................... 26
  2.4.1 Field distribution, resonant frequency and Q-factor of funda-
  mental modes ............................................. 27
  2.4.2 HEM_{11,\delta} and TM_{01,\delta} mode excitation methods ............ 29
  2.4.3 TE_{01,\delta} mode excitation method .......................... 33
2.5 Conclusion .............................................. 34

Chapter 3. Circularly polarized dielectric resonator antenna ... 35
  3.1 Introduction ............................................ 36
  3.2 Circularly polarized DRA configuration ............................ 37
    3.2.1 DR design ........................................ 38
    3.2.2 Feeding network design ................................ 41
  3.3 Experimental results ..................................... 41
  3.4 Radiation pattern improvement ............................... 45
  3.5 Conclusion .............................................. 47

Chapter 4. Multifunction and diversity dielectric resonator anten-
a .......................................................... 51
  4.1 Introduction ............................................ 52
  4.2 Multifunction DRA design .................................. 53
    4.2.1 Antenna structure .................................... 53
    4.2.2 Excitation of the TE_{111} mode from Port 1 ............... 54
    4.2.3 Excitation of the Quasi-TM_{111} mode from Port 2 .......... 55
    4.2.4 Integrating two ports into a common volume ............... 56
    4.2.5 Feeding network of Port 1 for broadside circular polariza-
    tion ...................................................... 59
    4.2.6 Impedance bandwidth optimization of Port 2 ................ 60
  4.3 Antenna performance ..................................... 62
    4.3.1 S parameters ........................................ 62
    4.3.2 Axial ratio .......................................... 63
    4.3.3 Radiation patterns and gain ............................ 64
    4.3.4 Diversity .......................................... 67
  4.4 Conclusion .............................................. 73
Chapter 5. Horizontally polarized omnidirectional DRA

5.1 Introduction .......................................................... 76
5.2 HP DRA design ...................................................... 78
  5.2.1 Excitation of the TE$_{01\delta}$ mode ......................... 78
  5.2.2 Bandwidth enhancement by addition of an air gap .......... 79
  5.2.3 Feeding structure optimization ............................ 82
5.3 Fabrication ......................................................... 83
5.4 Experimental results ............................................. 84
5.5 Conclusion .......................................................... 88

Chapter 6. Horizontally and vertically polarized omnidirectional DRA

6.1 Introduction .......................................................... 90
6.2 Dual polarized DRA design ....................................... 91
  6.2.1 DR design ...................................................... 92
  6.2.2 Excitation of TE$_{01\delta}$ Mode ............................ 94
  6.2.3 Excitation of the TM$_{01\delta}$ mode ......................... 98
6.3 Antenna performance ............................................. 99
  6.3.1 S parameters .................................................. 99
  6.3.2 Radiation pattern and gain ................................ 100
  6.3.3 Diversity ...................................................... 101
6.4 Conclusion .......................................................... 103

Chapter 7. On the scaling of DRAs from microwave towards visible frequencies

7.1 Introduction .......................................................... 106
7.2 Approaches for electromagnetic modeling of metal .............. 108
  7.2.1 Classical skin-effect model ................................ 108
  7.2.2 Modified relaxation-effect model ......................... 108
  7.2.3 Drude model .................................................. 109
7.3 A scalable DRA model ............................................. 111
7.4 DRA scaling behaviour .......................................... 112
7.5 Computational accuracy and expenditure ......................... 114
7.6 Excitation of the fundamental mode at optical frequency range . 117
7.7 Conclusion .......................................................... 117
Chapter 8. Optical reflectarray of dielectric resonator nano-antennas

8.1 Introduction ......................................................... 122
8.2 Optical DRA reflectarray design ................................. 123
  8.2.1 Design principle .............................................. 124
  8.2.2 TiO$_2$-Silver DR array model ............................. 124
  8.2.3 Six-element DRA reflectarray ............................ 127
  8.2.4 Four- and nine-element DRA reflectarray ............... 128
8.3 Fabrication ......................................................... 130
8.4 First prototypes measurement and discussion .............. 132
8.5 Silver properties measurement ................................. 136
8.6 Improved design of optical DRA reflectarray ............... 137
8.7 Second prototypes measurement and discussion ............ 138
8.8 Dissipation loss in optical DRs ............................... 140
  8.8.1 Simulation .................................................... 141
  8.8.2 Measurement ............................................... 142
8.9 Comparison with grating reflector ............................ 144
8.10 Conclusion ......................................................... 145

Chapter 9. Conclusion and future work ........................... 147

9.1 Conclusion ......................................................... 148
9.2 Future work ....................................................... 152

Bibliography .......................................................... 155
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

This work contains no material that has been accepted for the award of any other degree or diploma in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

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Signed

Date
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Conventions

Typesetting

This thesis is typeset using the \texttt{LATEX2e} software. WinEdt build 5.5 was used as an effective interface to \texttt{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, $10^{-9}$), "µ" (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

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

**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


Conference


List of Figures

1.1 The tree diagram of the thesis ........................................... 10
2.1 Geometry of rectangular DR on a ground plane ....................... 17
2.2 Normalized resonant frequency of the $\text{TE}_{111}^x$ mode of a rectangular DR ($\varepsilon_r=10$) with different aspect ratio $C = L/b$ and $D = W/b$ .......... 20
2.3 Near and far field of $\text{TE}_{111}$ mode .................................. 22
2.4 Probe coupling to a rectangular DR ...................................... 22
2.5 Microstrip line coupling to a rectangular DR .......................... 23
2.6 Slot aperture coupling to a rectangular DR ............................. 24
2.7 Coplanar waveguide coupling to a rectangular DR ................... 24
2.8 SIW structure and field distribution .................................... 25
2.9 HMSIW structure and field distribution ................................ 26
2.10 SIW fed rectangular DRA ................................................ 26
2.11 Field distribution of three fundamental modes in a cylindrical DR . 27
2.12 Radiation patterns of three fundamental modes of a cylindrical DR . 28
2.13 (a) $k_0\alpha$ and (b) Q-factor of the $\text{HEM}_{11\delta}$, $\text{TM}_{01\delta}$ and $\text{TE}_{01\delta}$ modes of a cylindrical DR with $\varepsilon_r=10$ ...................... 29
2.14 Probe coupling to a cylindrical DR .................................... 30
2.15 Microstrip line coupling to a cylinder DR ............................ 31
2.16 Slot coupling to a cylinder DR ......................................... 31
2.17 Coplanar waveguide coupling to a cylinder DR ...................... 32
2.18 Sketches of the LP and CP HMSIW-fed DRA ........................ 32
2.19 A balanced coupling method to excite the $\text{TE}_{01\delta}$ mode in a cylindrical DR ............................... 33
3.1 Cross-shaped CP DRA configuration .................................... 38
3.2 Calculated DR length and height for a resonance at 4.5 GHz ........ 39
3.3 Simulated DR height and corresponding effective permittivity for a resonance at 4.5 GHz with different thickness .......................... 40
List of Figures

3.4 Simulated E field distribution in a plane placed on the top of two DRs . . 40
3.5 Realized prototype of cross-shaped DRA ................................. 42
3.6 Simulated and measured reflection coefficient ............................ 42
3.7 Simulated and measured axial ratio for the cross-shaped CP DRA .... 43
3.8 Simulated and measured radiation patterns at left, centre, and right of the CP band ................................................................. 44
3.9 Simulated and measured RHCP gain ......................................... 45
3.10 Sketch of the improved antenna design .................................... 46
3.11 Simulated reflection coefficient of the improved design ............... 47
3.12 Simulated axial ratio of the improved design ............................ 48
3.13 Simulated radiation pattern of the improved design .................. 48
3.14 Simulated useable CP angle of the initial and improved design at the centre of the AR bandwidth ................................. 49

4.1 E-field distribution in one arm of the cross-shaped DR ............... 53
4.2 Realized prototype of the dual-port cross-shaped DRA ................ 54
4.3 Top, bottom, ground plane, and side view of the cross-shaped DRA using one-side feeding .................................................... 55
4.4 Simulated S parameters of the cross-shaped DR using one-side feeding . 56
4.5 Side view of the proposed multifunction cross-shaped DRA .......... 56
4.6 Simulated E-field distribution of TE_{111} and Quasi-TM_{111} mode at 4.7 GHz in one rectangular arm of the cross-shaped DR using one-side feeding lines 57
4.7 Simulated E-field distribution of TE_{111} and Quasi-TM_{111} mode at 4.7 GHz in one parallelogrammatic arm of the cross-shaped DR using one-side feeding lines 58
4.8 Simulated S parameters of the cross-shaped DR composed by two parallelogrammatic arms using one-side feeding ......................... 58
4.9 Simulated E-field distribution of TE_{111} and Quasi-TM_{111} mode at 4.7 GHz in one rectangular arm of the cross-shaped DR using two-side feeding . 59
4.10 Simulated S parameters of the cross-shaped DR using two side feeding . 59
4.11 Top, side and bottom view of the feeding network for the proposed antenna .......................................................... 60
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.12</td>
<td>Simulated S parameters of different values of centre probe diameter</td>
<td>61</td>
</tr>
<tr>
<td>4.13</td>
<td>Simulated S parameters of different values of centre probe height</td>
<td>61</td>
</tr>
<tr>
<td>4.14</td>
<td>Simulated E-field distribution of Quasi-TM$_{111}$ mode in one rectangular arm of the cross-shaped DR using two-side feeding</td>
<td>62</td>
</tr>
<tr>
<td>4.15</td>
<td>Simulated and measured antenna reflection and coupling coefficient for Port 1 (TE$<em>{111}$ mode) and Port 2 (Quasi-TM$</em>{111}$ mode)</td>
<td>63</td>
</tr>
<tr>
<td>4.16</td>
<td>Simulated and measured axial ratio of Port 1</td>
<td>64</td>
</tr>
<tr>
<td>4.17</td>
<td>Simulated and measured circularly polarized radiation patterns of Port 1 at 4.52, 4.70 and 4.84 GHz</td>
<td>65</td>
</tr>
<tr>
<td>4.18</td>
<td>Simulated and measured linearly polarized radiation patterns of Port 2 at 4.52, 4.70 and 4.84 GHz</td>
<td>66</td>
</tr>
<tr>
<td>4.19</td>
<td>Simulated and measured linearly polarized radiation patterns of Port 2 at 5.5 and 6 GHz</td>
<td>67</td>
</tr>
<tr>
<td>4.20</td>
<td>Simulated and measured gain of Port 1 and 2</td>
<td>68</td>
</tr>
<tr>
<td>4.21</td>
<td>Simulated 3D radiation patterns at 4.93 and 5.54 GHz</td>
<td>68</td>
</tr>
<tr>
<td>4.22</td>
<td>Simulated and measured mean effective gain</td>
<td>70</td>
</tr>
<tr>
<td>4.23</td>
<td>Simulated and measured ratio of mean effective gain of Port 1 and 2</td>
<td>70</td>
</tr>
<tr>
<td>4.24</td>
<td>Simulated and measured envelope correlation coefficients</td>
<td>73</td>
</tr>
<tr>
<td>5.1</td>
<td>(a). Field distribution of TE$_{01\delta}$ mode in a cylindrical DR. (b). A balanced coupling method by placing two arc-shaped microstrip feeding lines in each side of a DR</td>
<td>78</td>
</tr>
<tr>
<td>5.2</td>
<td>Simulated reflection coefficient for two DRAs, showing the increase of bandwidth resulting from the addition of a 1 mm air gap</td>
<td>79</td>
</tr>
<tr>
<td>5.3</td>
<td>Side and top view of the proposed antenna.</td>
<td>80</td>
</tr>
<tr>
<td>5.4</td>
<td>Simulated reflection coefficient of different the lower cylinder height and radius values</td>
<td>81</td>
</tr>
<tr>
<td>5.5</td>
<td>Top view of electric field distribution inside the DR with 1 mm air gap</td>
<td>81</td>
</tr>
<tr>
<td>5.6</td>
<td>Side view (YZ plane) of magnetic field distribution inside the DR with 1 mm air gap</td>
<td>82</td>
</tr>
<tr>
<td>5.7</td>
<td>Simulated 3D radiation patterns of the TE$<em>{01\delta}$ mode at 3.9 GHz and the HEM$</em>{21\delta}$ mode at 5.1 GHz</td>
<td>82</td>
</tr>
<tr>
<td>5.8</td>
<td>Simulated impedance bandwidth for different values of $\alpha$</td>
<td>83</td>
</tr>
</tbody>
</table>
List of Figures

5.9 Simulated radiation patterns at the upper limit of the bandwidth, for different values of $\alpha$ ....................................................... 84
5.10 Realized prototype of horizontally polarized DRA .......................... 85
5.11 Simulated and measured antenna reflection coefficient ................... 85
5.12 Bottom view of the substrate showing the ground plane ................. 86
5.13 Simulated and measured gain patterns at 3.9 GHz .......................... 87
5.14 Simulated and measured maximum gain of the conical pattern .......... 87

6.1 Prototype of the proposed dual polarized omnidirectional DRA with schematic field distributions for the two orthogonal modes excited .... 91
6.2 Geometry of the proposed dual-polarized DRA .............................. 93
6.3 Prototype of DR ................................................................. 94
6.4 Simulated reflection coefficient and impedance of Port 1 .................. 95
6.5 Simulated reflection coefficient of Port 1 with different length of $L_1$ .. 96
6.6 Simulated reflection coefficient of Port 1 .................................. 96
6.7 Physical layout of the substrate .............................................. 96
6.8 Top (a) and bottom (b) view of the first prototype antenna without back cavity ................................................................. 97
6.9 Simulated radiation patterns of Port 2 of the first prototype antenna without back cavity ......................................................... 97
6.10 The realized feeding network .................................................. 98
6.11 The comparison between the calculated resonance frequency of TE$_{01\delta}$ and TM$_{01\delta}$ mode in a cylindrical DR with dielectric permittivity of 10 .................................. 99
6.12 Simulated reflection coefficient of Port 2 for different values of inner radius of the annular cylindrical DR .................................. 99
6.13 Simulated and measured magnitude of the antenna reflection coefficient for both ports (a) and inter-port coupling coefficient (b) ....... 100
6.14 Simulated and measured radiation pattern of Port 1 (HP) at 3.93 GHz .. 101
6.15 Simulated and measured radiation pattern of Port 2 (VP) at 3.93 GHz .. 102
6.16 Simulated and measured maximum gain of the conical pattern of Port 1 and 2 ................................................................. 102
6.17 Simulated and measured envelope correlation coefficients and mean effective gain .............................................................. 103
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Calculated complex surface impedance of silver using the modified relaxation-effect model</td>
<td>109</td>
</tr>
<tr>
<td>7.2</td>
<td>Calculated complex permittivity of silver using the Drude model</td>
<td>110</td>
</tr>
<tr>
<td>7.3</td>
<td>3D sketch of the proposed scalable DRA model</td>
<td>111</td>
</tr>
<tr>
<td>7.4</td>
<td>3D HFSS model of the proposed scalable DRA model</td>
<td>112</td>
</tr>
<tr>
<td>7.5</td>
<td>Field distribution in the cylindrical DR mounted on a PEC block</td>
<td>113</td>
</tr>
<tr>
<td>7.6</td>
<td>Scaling behaviour of a cylindrical DRA from microwave to visible frequencies</td>
<td>114</td>
</tr>
<tr>
<td>7.7</td>
<td>Mesh plot of DRAs simulated in HFSS</td>
<td>115</td>
</tr>
<tr>
<td>7.8</td>
<td>Number of generated tetrahedra for the resonant DRA models at different frequencies</td>
<td>116</td>
</tr>
<tr>
<td>7.9</td>
<td>The cross section view of the E field amplitude and mesh</td>
<td>116</td>
</tr>
<tr>
<td>7.10</td>
<td>Magnitude and phase of the Y-component direction magnetic field at the probe location</td>
<td>117</td>
</tr>
<tr>
<td>7.11</td>
<td>Field distributions in the cylindrical DR and silver excited by a wavelength of 500 THz incident plane wave</td>
<td>118</td>
</tr>
<tr>
<td>8.1</td>
<td>3D HFSS model of the TiO$_2$-Silver DR array model</td>
<td>125</td>
</tr>
<tr>
<td>8.2</td>
<td>Phase and magnitude variation of DR diameter with different distance between DR centre at 474 THz</td>
<td>126</td>
</tr>
<tr>
<td>8.3</td>
<td>Phase and magnitude variation of DR diameter with different DR height at 474 THz</td>
<td>126</td>
</tr>
<tr>
<td>8.4</td>
<td>Partial view of 6-element DRA reflectarray</td>
<td>127</td>
</tr>
<tr>
<td>8.5</td>
<td>Numerically resolved phase and magnitude response of DRs with height of 50 nm at 474 THz</td>
<td>128</td>
</tr>
<tr>
<td>8.6</td>
<td>Numerically resolved phase and magnitude response of DRs with and without silicon layer at 474 THz</td>
<td>129</td>
</tr>
<tr>
<td>8.7</td>
<td>Incident (a) and scattered (b) electric fields of 6-element subarray DRA reflectarray for the TE polarized wave</td>
<td>129</td>
</tr>
<tr>
<td>8.8</td>
<td>Incident (a) and scattered (b) electric fields of 6-element subarray DRA reflectarray for the TM polarized wave</td>
<td>130</td>
</tr>
<tr>
<td>8.9</td>
<td>Scattered electric fields of 4 element DRA reflectarray for the TE (a) and TM (b) polarized normal incident wave</td>
<td>131</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
<td>------</td>
</tr>
<tr>
<td>8.10</td>
<td>Scattered electric fields of 9 element DRA reflectarray for the TE (a) and TM (b) polarized normal incident wave</td>
<td>131</td>
</tr>
<tr>
<td>8.11</td>
<td>Schematic of the fabrication sequence for the optical DRA reflectarray</td>
<td>132</td>
</tr>
<tr>
<td>8.12(a)</td>
<td>Photo of fabricated DRA reflectarrays; (b) Zoomed in picture of 4 areas with the same reflectarray layout. (c) Zoomed in picture of one area</td>
<td>132</td>
</tr>
<tr>
<td>8.13</td>
<td>Scanning electron micrograph revealing an area on the fabricated 4, 6 and 9-element reflectarrays</td>
<td>133</td>
</tr>
<tr>
<td>8.14</td>
<td>Designed and realized DR diameters of 4, 6 and 9-element reflectarrays</td>
<td>134</td>
</tr>
<tr>
<td>8.15</td>
<td>Experiment setup</td>
<td>135</td>
</tr>
<tr>
<td>8.16</td>
<td>Beam reflection patterns obtained from a CCD camera</td>
<td>135</td>
</tr>
<tr>
<td>8.17</td>
<td>3D representation of the beam shapes for the 6-element reflectarray measured by the Thorlabs LC100 CCD linear camera</td>
<td>136</td>
</tr>
<tr>
<td>8.18</td>
<td>Normalized radiation pattern of 6 element reflectarray</td>
<td>136</td>
</tr>
<tr>
<td>8.19</td>
<td>Normalized beam reflection pattern of 6 element reflectarray</td>
<td>137</td>
</tr>
<tr>
<td>8.20</td>
<td>Numerically resolved phase and magnitude response of DRs by using different silver permittivity at 474 THz</td>
<td>138</td>
</tr>
<tr>
<td>8.21</td>
<td>Scanning electron micrograph revealing an area on the fabricated 6 and 9 element reflectarrays</td>
<td>139</td>
</tr>
<tr>
<td>8.22</td>
<td>Designed and realized DR diameters of 6 and 9 element reflectarray</td>
<td>140</td>
</tr>
<tr>
<td>8.23</td>
<td>CCD imaging of beam reflection patterns excited by TE polarized incident wave</td>
<td>140</td>
</tr>
<tr>
<td>8.24</td>
<td>The beam reflection patterns obtained from array theory calculation (a), the linear camera (b) and CCD camera (c)</td>
<td>141</td>
</tr>
<tr>
<td>8.25</td>
<td>Measured radiation pattern of 6 element reflectarray in the second sample</td>
<td>141</td>
</tr>
<tr>
<td>8.26</td>
<td>Numerically resolved phase and magnitude response of of silver and uniform DRA array with different dielectric loss tangent at 474 THz</td>
<td>142</td>
</tr>
<tr>
<td>8.27</td>
<td>Scanning electron micrograph revealing an area on the fabricated uniform DRA array</td>
<td>143</td>
</tr>
<tr>
<td>8.28</td>
<td>Reflection power from uniform array measurement</td>
<td>143</td>
</tr>
<tr>
<td>8.29</td>
<td>Grating reflector with the same TiO$_2$ volume as DRA reflectarray</td>
<td>144</td>
</tr>
<tr>
<td>8.30</td>
<td>Scattered electric fields of grating reflector for the TE (a) and TM (b) normally polarized incident waves</td>
<td>145</td>
</tr>
</tbody>
</table>
List of Tables

3.1 Antenna parameters of the CP DRA .............................................. 41
3.2 Antenna parameters of the improved CP DRA ................................. 46
4.1 Antenna parameters of the Multifunction and diversity DRA .............. 60
5.1 Antenna parameters for the final design, in the geometry of Fig. 5.3 ...... 83
5.2 Comparison between horizontally-polarized omnidirectional antennas . 88
6.1 Antenna parameters of the dual polarized DRA ............................... 92
8.1 DR diameters of 6-element subarray. The calculated angle of deflection is 17.5° ................................................................. 127
8.2 DR diameters of 4-element subarray. The calculated angle of deflection is 27.0° ................................................................. 130
8.3 DR diameters of 9-element subarray. The calculated angle of deflection is 11.6° ................................................................. 130