# Contents

1 Introduction
   1.1 Hypothesis ......................................................... 3
   1.2 Objectives ......................................................... 3
      1.2.1 General Objective ............................................ 3
      1.2.2 Specific Objectives ......................................... 4
   1.3 Structure of the Thesis .......................................... 4

2 Bibliographic Review
   2.1 Optical Theory ................................................... 5
      2.1.1 Geometrical Optics .......................................... 6
      2.1.2 Quasioptical Theory ........................................ 8
      2.1.3 Radiation Pattern .......................................... 10
   2.2 Optical Devices ................................................ 12
      2.2.1 Cassegrain Antennas ....................................... 13
      2.2.2 Horn Antennas .............................................. 15
      2.2.3 Focusing Elements: Lenses and Mirrors ................... 16
   2.3 Heterodyne Receivers ........................................... 20
      2.3.1 Noise Temperature .......................................... 21
   2.4 Imaging Systems ................................................ 22
      2.4.1 Gaussian Telescope ......................................... 23
      2.4.2 Pixel distances ............................................ 24
      2.4.3 Pixel distribution ......................................... 25
   2.5 Revision of Existing Focal Plane Arrays ....................... 25
      2.5.1 Submillimeter and Terahertz Regime ....................... 25
      2.5.2 Millimeter Regime ......................................... 27
   2.6 Summary .......................................................... 27

3 Feasibility of a Camera in the SMWT .............................. 28
   3.1 Brief History of the SMWT ...................................... 28
   3.2 Description of the Antenna ..................................... 29
   3.3 Simulations with the current feed antenna ................. 30
      3.3.1 Central Feed .............................................. 30
      3.3.2 Off-axis Feed .............................................. 32
   3.4 Simulations with a new feed antenna .......................... 35
      3.4.1 Using the same aperture .................................. 35
      3.4.2 Using an optimized aperture for a 7-pixel focal plane array 36
List of Tables

2.1 Review of existing submillimeter and terahertz heterodyne arrays. . . . . . . 26
2.2 Review of existing millimeter heterodyne arrays. . . . . . . . . . . . . . . . . 27

3.1 Main parameters of the Cassegrain antenna of the SMWT (Mini). . . . . . . 29
3.2 Main parameters of the corrugated horn antenna of the SMWT (Mini). . . . 30
3.3 Illumination efficiency and percentage of power that passes through the main
hole. Parameters for the outer pixel using the actual characteristics of the feed
horn of the SMWT. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 32
3.4 Illumination efficiency and percentage of power that passes through the main
hole. Parameters for the outer pixel using the actual electrical characteristics
of the feed horn of the SMWT. . . . . . . . . . . . . . . . . . . . . . . . . . . . 35
3.5 Illumination efficiency and percentage of power that passes through the main
hole. Parameters for the outer pixel using an hypothetical beam waist for the
SMWT. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 36

4.1 Main parameters of the 12-m Cassegrain antenna of ALMA. . . . . . . . . . 41
4.2 Illumination efficiency and percentage of power that passes through the hole
of the primary reflector for a 12-m ALMA antenna. Parameters for the outer
design pixel using the actual characteristics of the feed horn+lens+ellipsoidal mirror
of Band-3 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 43
4.3 Parameters for the GBT of ALMA. . . . . . . . . . . . . . . . . . . . . . . 46
4.4 Illumination efficiency and percentage of power that passes through the main
hole of a 12-m ALMA antenna. Parameters for the outer pixel using the GBT
designed for Band-3 . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 47
4.5 Beam distortion in curved mirrors due to reflections and cross polarization in
ALMA’s GBT . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 48
4.6 Parameters for the GBT of LLAMA. . . . . . . . . . . . . . . . . . . . . . 55
4.7 Illumination efficiency and percentage of power that passes through the main
hole of a 12-m LLAMA antenna. Parameters for the outer pixel using the
GBT designed for W band. . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 56
4.8 Beam distortion in curved mirrors due to reflections and cross polarization in
LLAMA’s GBT . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . . 56
4.9 Comparative analysis of hexagonal cameras with 7, 19, 37 and 61 pixels. . . . 57

A.1 Main parameters and formulas to define a conic section. . . . . . . . . . . . . 68
B.1 Examples of ABCD matrix. . . . . . . . . . . . . . . . . . . . . . . . . . . . 69
## List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Electromagnetic spectrum and the atmospheric windows.</td>
<td>3</td>
</tr>
<tr>
<td>2.1</td>
<td>Electromagnetic propagation theories.</td>
<td>5</td>
</tr>
<tr>
<td>2.2</td>
<td>Reflection and refraction.</td>
<td>6</td>
</tr>
<tr>
<td>2.3</td>
<td>Image formation using geometrical optics.</td>
<td>7</td>
</tr>
<tr>
<td>2.4</td>
<td>Scheme of ray transfer.</td>
<td>8</td>
</tr>
<tr>
<td>2.5</td>
<td>Optics versus quasi-optics focusing.</td>
<td>9</td>
</tr>
<tr>
<td>2.6</td>
<td>Gaussian beam parameters.</td>
<td>10</td>
</tr>
<tr>
<td>2.7</td>
<td>Near and far-field regions of radiation.</td>
<td>11</td>
</tr>
<tr>
<td>2.8</td>
<td>A 2-D radiation pattern of an antenna.</td>
<td>12</td>
</tr>
<tr>
<td>2.9</td>
<td>Cassegrain antenna and its main parameters.</td>
<td>13</td>
</tr>
<tr>
<td>2.10</td>
<td>Dual-mode horn.</td>
<td>15</td>
</tr>
<tr>
<td>2.11</td>
<td>Parameters of a conical corrugated horn antenna.</td>
<td>16</td>
</tr>
<tr>
<td>2.12</td>
<td>Lens geometry.</td>
<td>17</td>
</tr>
<tr>
<td>2.13</td>
<td>Paraboloid and ellipsoid geometry.</td>
<td>19</td>
</tr>
<tr>
<td>2.14</td>
<td>Heterodyne receiver: DSB, SSB, 2SB.</td>
<td>21</td>
</tr>
<tr>
<td>2.15</td>
<td>Gaussian Beam Telescope configuration.</td>
<td>23</td>
</tr>
<tr>
<td>2.16</td>
<td>Hexagonal distribution of seven pixels for a focal plane array.</td>
<td>24</td>
</tr>
<tr>
<td>3.1</td>
<td>Scheme of the proposed 7 pixel circular array.</td>
<td>29</td>
</tr>
<tr>
<td>3.2</td>
<td>SMWT in Zemax</td>
<td>31</td>
</tr>
<tr>
<td>3.3</td>
<td>SMWT. Huygens PSF for the central pixel (d=0 mm).</td>
<td>31</td>
</tr>
<tr>
<td>3.4</td>
<td>SMWT. Huygens PSF for an outer pixel (d=42.42 mm).</td>
<td>33</td>
</tr>
<tr>
<td>3.5</td>
<td>Percentage of power due to truncation and illumination efficiency (spillover and taper).</td>
<td>33</td>
</tr>
<tr>
<td>3.6</td>
<td>Seven beams at the hole of the main reflector.</td>
<td>34</td>
</tr>
<tr>
<td>3.7</td>
<td>Illumination efficiency as a function of displacement off-axis for the SMWT (using actual horn antenna).</td>
<td>34</td>
</tr>
<tr>
<td>3.8</td>
<td>SMWT. Huygens PSF for an outer pixel (d=31.54 mm).</td>
<td>35</td>
</tr>
<tr>
<td>3.9</td>
<td>SMWT. Huygens PSF for an outer pixel (d=21.63 mm).</td>
<td>36</td>
</tr>
<tr>
<td>3.10</td>
<td>Beam propagation plot on axis for the SMWT at 115 GHz.</td>
<td>37</td>
</tr>
<tr>
<td>4.1</td>
<td>Scheme of ALMA 12-m antenna and its cryostat.</td>
<td>43</td>
</tr>
<tr>
<td>4.2</td>
<td>Upper view of the actual cryostat of ALMA. 10 bands are placed in the available space.</td>
<td>44</td>
</tr>
<tr>
<td>4.3</td>
<td>Model of the optical system proposed for ALMA heterodyne receiver.</td>
<td>46</td>
</tr>
</tbody>
</table>
4.4 Huygens PSF obtained in Zemax for the central and 29.28-mm offset pixel of ALMA model.

4.5 Beam propagation plot on axis for ALMA’s GBT at 100 GHz.

4.6 3-D model of the intermediate optical system designed for ALMA Band-3.

4.7 Mechanical model of the cartridge inside the cryostat.

4.8 Coupling Efficiency as a function of the displacement, tilt and offset.

4.9 Scheme of a Cassegrain Telescope with three possibilities of focal planes.

4.10 Scheme of LLAMA 12-m antenna and its cryostat.

4.11 Scheme of GBT designed for LLAMA 12-m antenna.

4.12 Huygens PSF and Wave-front function obtained in Zemax for the central and 13.01-mm offset pixel of LLAMA model.

4.13 Beam propagation plot on axis for LLAMA’s GBT at 100 GHz.

4.14 3-D model of the intermediate optical system designed for LLAMA Band-3.

A.1 Conic sections.

C.1 Displacement of pixels in a hexagonal distribution.

C.2 Area compared to a hexagonal distribution over a single pixel.

D.1 Original blueprint of the horn antenna of the SMWT.

F.1 Power through the main reflector hole of the SMWT (d=42.42 mm).

F.2 Power through the main reflector hole of the SMWT (d=31.54 mm).

F.3 Power through the main reflector hole of the SMWT (d=21.63 mm).

F.4 Beam Radius and Edge Taper at the secondary reflector of the SMWT as a function of the beam waist \(w_0\).

F.5 Distribution of E for an outer pixel displaced 42.42 mm off axis and the secondary reflector border of the SMWT. Results for the current horn antenna.

F.6 Distribution of E for an outer pixel displaced 31.54 mm off axis and the secondary reflector border of the SMWT. Results for the current horn antenna with a thinner wall.

F.7 Distribution of E for an outer pixel displaced 21.63 mm off axis and the secondary reflector border of the SMWT. Results for a horn antenna with a beam waist of 6.8 mm.

F.8 Illumination efficiency as a function of the beam waist size and the displacement off the center for the SMWT.

H.1 Power through the main reflector hole of the 12-m ALMA antenna (d=58.56 mm).

H.2 Power at the secondary reflector of the 12-m ALMA antenna (d=58.56 mm).

H.3 Beam Radius and Edge Taper at the secondary reflector of the 12-m ALMA antenna as a function of the beam waist \(w_0\).

H.4 Distribution of E for a central and an outer pixel displaced 58.56 mm off axis and the secondary reflector border of the 12-m ALMA antenna. Results for 100 GHz and an edge taper of 10.9 dB.