LNA’s for the 1.2 to 55 GHz Range

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1. Semiconductor technology applicable to cryogenic LNA’s
2. Examples of discrete and integrated circuits
3. LNA for 1.2 to 8.4 GHz
4. Prototype LNA for 8 to 55 GHz
5. System noise
Cryogenic LNA Noise is Limited by the Transistors Available from Semiconductor Foundries

- Both HEMT and HBT transistors are used in radio astronomy LNA's.
- Amplifiers can be constructed either from discrete transistors (MICs) or from monolithic integrated circuits. (MMICs)

<table>
<thead>
<tr>
<th>Semiconductor</th>
<th>Application</th>
<th>Key Players</th>
<th>Development Pace</th>
<th>Key Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>InP HEMT</td>
<td>Cooled, &gt; 5 GHz</td>
<td>Northrop, HRL, Teledyne, IAF Chalmers</td>
<td>Slow</td>
<td>Yield,</td>
</tr>
<tr>
<td>GaAs HEMT</td>
<td>Cooled &gt; 5 GHz</td>
<td>WIN, Triquint OMMIC</td>
<td>Slow</td>
<td>Noise</td>
</tr>
<tr>
<td>SiGe HBT</td>
<td>Cooled &lt; 5 GHz</td>
<td>ST, IBM, NXP, Jazz, Infineon</td>
<td>Moderate</td>
<td>Beta</td>
</tr>
<tr>
<td>CMOS FET</td>
<td>Cooled &lt; 20 GHz</td>
<td>Intel, IBM, TSMC</td>
<td>High</td>
<td>Needs Tests</td>
</tr>
</tbody>
</table>
Monolithic Integrated Circuit (MMIC) Amplifiers
Examples of HEMT and SiGe Chips

Assuming an effective dielectric constant of 9, a 0.5mm path length will contribute a 90° phase shift at 40GHz! SiGe and CMOS processes allow for much more compact feedback loops!

Entire active part of 2 stage amplifier
Including feedback loop within 50umx40um

Apr 9, 2015
LNA's for ngVLA
Monolithic Millimeter-Wave Integrated Circuits

Example of a MMIC layout with transmission lines, capacitors, resistors, and active devices on a single substrate. Above chip's dimensions are 2.0 x 0.74 x 0.1 mm.

**Advantages**
- reduced mass and volume
- repeatable performance
- low cost in large quantities
- fine-controlled dimensions through photolithography
- easy to mass produce

**Disadvantages**
- low-Q passive elements
- limited power handling
- long design iteration time
- limited post-fabrication tuning
- requires specialized test and evaluation equipment
- difficult assembly and interconnection
Caltech ST Microelectronics SiGe Reticule, 2010
Size: 2.3 x 4.1 mm = 9.43 mm²

24 Discrete Transistors
0.3 x 0.3 mm

1-2 GHz  Dif LNA  CALS  11-26 LNA

R Tests
Salycide
N+Poly
P+Poly

WBA20
0.1 -12 GHz

ASU Low Power

WBA21
0.1-12 GHz

0.5-3 GHz

16 – 5x 15um=75um
4 – 4x5x12um =240um
2 – 2x10um=20um
2 – 1x10um=10um

Apr 9, 2015
SiGe IC Cross-Section
Many interconnect layers enable complex circuits
Wideband Cryogenic LNA Development at Caltech

- In a 10 year period over 1200 cryogenic LNA’s in the 0.1 to 50 GHz range have been supplied by Caltech to international radio astronomy and quantum physics research groups.
- The LNA’s incorporate InP, GaAs, and SiGe transistors and integrated circuits developed in 4 Ph.D. theses at Caltech.
- Cryogenic LNA’s for 75 to 115 GHz have been developed at Caltech and JPL and have achieve noise temperatures as low as 25K.
- Data and a photograph of on a 1 to 25 GHz LNA is shown below.

<table>
<thead>
<tr>
<th>Country or Institution and Number Sold</th>
<th>Japan</th>
<th>83</th>
<th>US</th>
<th>335</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany</td>
<td>77</td>
<td>Caltech/JPL</td>
<td>72</td>
<td></td>
</tr>
<tr>
<td>Korea</td>
<td>63</td>
<td>Harvard/SAO</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>China</td>
<td>51</td>
<td>Berkeley</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>47</td>
<td>Yale</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>
Caltech LNA for ngVLA 1.2 to 8.4 GHz Band

- Noise <6K from 0.8 to 16 GHz
- Utilizes OMMIC GaAs MMIC available in large quantities
- Amplifier is very stable and repeatable; over 20 in use
- Input power for 1dB gain compression is -36 dBm
Prototype of ngVLA 8 to 55 GHz LNA

- An 8 to 50 GHz MMIC InP HEMT LNA was designed and tested at Caltech in 2012 and shows potential for under 20K noise.
- Amplifier utilizes a Northrop InP MMIC process
## Total System Noise Estimate

<table>
<thead>
<tr>
<th>Noise, K, due to component</th>
<th>Remarks</th>
<th>Tsys 1.4 GHz</th>
<th>Tsys 10 GHz</th>
<th>Tsys 40 GHz</th>
<th>Tsys 80 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sky</td>
<td>Background + atmosphere</td>
<td>4</td>
<td>6</td>
<td>20</td>
<td>55</td>
</tr>
<tr>
<td>Spillover &amp; Blockage</td>
<td>Reduce with offset antenna</td>
<td>10</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Feed loss</td>
<td>Estimate 0.3 dB @80K for 1.4 GHz @20K for 8-116 GHz</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Window loss</td>
<td>Mylar windows</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Feed to LNA</td>
<td>0.30 dB</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>LNA</td>
<td>Robust LNA measured at connector</td>
<td>3</td>
<td>6</td>
<td>15</td>
<td>25</td>
</tr>
<tr>
<td>Total</td>
<td>Estimate, +/- 5K</td>
<td><strong>29</strong></td>
<td><strong>24</strong></td>
<td><strong>50</strong></td>
<td><strong>94</strong></td>
</tr>
</tbody>
</table>
Atmospheric Noise is Appreciable for the ngVLA

- Noise above 40 GHz is weather and altitude dependent; curves below are for zenith at sea level
- The 55-70 GHz range is not covered by receivers.