1400 – 1900 GHz Local Oscillators for the Herschel Space Observatory

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Herschel Space Observatory
- 3.5 meter passively cooled telescope
- Covers 60 – 670 mm (450 GHz – 5 THz)
- Launch in 2007
- Three science instruments: PACS, SPIRE, and HIFI

Band 6 of the Heterodyne Instrument for the Far-Infrared (HIFI)
- Solid-state local oscillators will pump hot electron bolometer (HEB) mixers
- Covers 1408 – 1908 GHz to observe spectra in the interstellar medium
  - N+ at 1461 GHz
  - H$_2$O at 1661, 1670, and 1717 GHz
  - OH lines from 1834.7 to 1837.8 GHz
  - C+ at 1900.5 GHz
- Broken up into 4 sub-bands

The purpose of these oscillators is to pump HEB mixers from 1.4 to 1.9 THz
1.4 – 1.7 THz Configurations

88-97 GHz
x3

WR-10
215 mW

WR-10
170 mW

176-194 GHz
50 mW

352-388 GHz
10 mW

704-776 GHz
800 mW

1408-1552 GHz
2.1 mW

PA

x2

x2

x2

x2
1.7 – 1.9 THz Configurations

- 98-106 GHz
  - WR-10: 260 mW
  - WR-10: 210 mW, 60 mW
  - 196-211 GHz
  - 588-636 GHz
  - 1764-1908 GHz
    - x3
    - PA
    - x2
    - x3

- 71-79.5 GHz
  - WR-10: 250 mW
  - WR-10: 200 mW
  - 142-159 GHz
  - 284-318 GHz
  - 852-954 GHz
  - 1704-1908 GHz
    - x3
    - PA
    - x2
    - x2
    - x3
    - x2

- 71-79.5 GHz
  - WR-10: 250 mW
  - WR-10: 200 mW
  - 142-159 GHz
  - 284-318 GHz
  - 568-636 GHz
  - 1704-1908 GHz
    - x3
    - PA
    - x2
    - x2
    - x2
    - x3

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Schottky Devices for Band 6

- Based on planar GaAs Schottky diodes
- Multi-diode balanced configurations
- Mostly doublers, plus a few triplers
- Low frequency multipliers (< 1 THz) on “substrateless” process
- High frequency multipliers on membrane process
- See previous publications for more info

- Substrateless devices already fabricated
  - 190 GHz doubler
  - 375 GHz doubler
  - 750 GHz doubler
  - 200 GHz doubler
  - 400 GHz doubler
  - 800 GHz doubler

- New substrateless devices in process
  - 150 GHz doubler
  - 300 GHz doubler
  - 600 GHz doubler
  - 600 GHz tripler

- Membrane devices being tested for Band 6
  - 1.5 THz doubler
  - 1.6 THz doubler
  - 1.8 THz doubler
  - 1.8 THz tripler

- Other devices fabricated
  - 1.46 THz tripler
  - 1.6 THz tripler
  - 900 GHz tripler (UMass)
Device Status

- High frequency devices (above 1 THz)
  - Primary wafer completed, some anodes not optimal
  - Backup wafer completed, but the yield for 1800 triplers is close to zero
- New low-frequency wafer due this summer
  - New 150/300/600 GHz doublers, 600 GHz triplers
  - Low dopings (1·10^{17} \text{ cm}^{-3}) for higher-power driver stages
- May run a new high frequency mask this fall
Several power meter technologies available
- Golay cell
- Keating meter
- Erickson calorimeter
- Bolometer

Each meter brings specific calibration challenges
- Impedance mismatch / standing waves
- Waveguide losses
- Optical losses / coupling
- Atmospheric absorption
- Drift
- Linearity

Factor of 2 discrepancies are common
Agreement to 30% possible with care

The ultimate figure of merit is to pump a mixer
See Tong et al. MTT-S International Microwave Symposium 2003
JPL 1500 GHz Doubler
1500 GHz Results

T = 295 K, Power measured with Erickson Calorimeter

Output Frequency (GHz)

Output Power (mW)
1.9 THz Tripler
1900 Tripler Frequency Sweep

Pin ≈ 3 mW from BWO, T = 295 K

- SN1 (0.4 x 0.4)
- SN4 (0.6 x 0.4)
- SN5 (0.8 x 0.4)

Output Frequency (GHz)

Power (nW)
1.9 THz Tripler Power Sweeps

1810 GHz Power Sweeps (295 K)

- SN1 (0.4 x 0.4)
- SN4 (0.6 x 0.4)
- SN5 (0.8 x 0.4)

Output Power (mW)

603.3 GHz Input Power from BWO (mW)
x3x3 Chain Simulations

Band 6 High x3x3 Chain Simulation at 295 K
Includes interaction between 600 and 1800 GHz triplers with 5 mm of waveguide
70 mW input power at 200 GHz, 7.0 fF anodes on 600 tripler and 0.8 fF anodes on 1800 tripler
Erickson / JPL 1900 Doubler

Photo from Neal Erickson
State-of-the-Art at 295 K

Power (mW)

Freq (GHz)

- $X2$
- $x2 \times x2$
- $x2 \times x2 \times x2$
- $x2 \times x2 \times 3$
- $x2 \times x2 \times x2 \times x2$
- $x2 \times x2 \times 3$
- $x2$
- $1/f^2$

1400 – 1900 GHz Local Oscillators for the Herschel Space Observatory
State-of-the-Art at 120 K

Power (mW)

Freq (GHz)

10000
1000
100

0.001
0.01
0.1
1
10
100

- X2
- x2x2
- x2x2x2
- x2x2x3
- x2x2x2
- x2
- x2x3
Summary

- Greater than 10 mW at 1.5 THz demonstrated at 295 K
- Greater than 1 mW demonstrated at points in 1.7 – 1.9 THz range with both a planar tripler and a planar doubler
Ed Tong and Jon Kawamura successfully pumped a Harvard HEB with a JPL / Neal Erickson 1.5 THz solid-state local oscillator chain

- Required LO power (not including optics losses) was about 1 mW
- For HIFI, 27% coupling efficiency and 84% beam efficiency of the horn imply that about 3 mW will be required from the flight LO chain if the flight mixer has similar pump requirements as the Harvard mixer

- HEB was a waveguide mixer, very different from the flight mixer
- Actual required power for the flight band 7 mixers will depend strongly on design decisions made by the mixer development team

References: Tong et al. MTT-S International Microwave Symposium 2003
Pumped HEB Results (2)

References: Tong et al. MTT-S International Microwave Symposium 2003
Pumped HEB Results (3)

References: Tong et al. MTT-S International Microwave Symposium 2003
Band 6 high results

1820 GHz Power Sweeps (137 K)
JPL PN 10216340 SN5 Driven by RPG tripler D2T-B
(Optical coupling not optimized, & bolometer not calibrated)

- 1820 GHz Power (through wire grid) + 6dB
- 1820 GHz Power (no grid)

1820 GHz Power (mW)

101.1 GHz Power (mW)
Simulated 1.9 THz Tripler Power Sweeps

F = 1900 GHz, T = 295 K

1900 GHz Output Power (µW)

633 GHz Input Power (mW)

- 0.6 fF
- 0.8 fF
- 1.0 fF
### Band 6 Low Multiplier Test Status

<table>
<thead>
<tr>
<th>Multiplier</th>
<th>Test Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A.1 – 176-194 GHz doubler</td>
<td>Well tested</td>
</tr>
<tr>
<td>6A.2 – 352-388 GHz doubler</td>
<td>Tested</td>
</tr>
<tr>
<td>6A.3 – 704-776 GHz doubler</td>
<td>No test data, but have a tested backup</td>
</tr>
<tr>
<td>6A.4 – 1408-1552 GHz doubler</td>
<td>Tested</td>
</tr>
<tr>
<td>6B.1 – 194-212 GHz doubler</td>
<td>Well tested</td>
</tr>
<tr>
<td>6B.2 – 388-424 GHz doubler</td>
<td>New design, but have tested backup</td>
</tr>
<tr>
<td>6B.3 – 776-848 GHz doubler</td>
<td>Well tested</td>
</tr>
<tr>
<td>6B.4 – 1552-1696 GHz doubler</td>
<td>No test data, but have a tested backup</td>
</tr>
</tbody>
</table>
1.4 – 1.7 THz Configurations

- Chain 6A: 1408-1552 GHz out

- Chain 6B: 1552-1696 GHz out