THz frequency multiplier chains based on planar Schottky diodes

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Outline:

- Motivation
- Design of the THz frequency multiplier chain
- Performance
- Output power leveling scheme
- Optical interface requirements
- Summary
Motivation
Development of components for space-based heterodyne sensor technology
for
High resolution spectroscopy with HIFI (Herschel)

Need: Sufficient LO power at THz frequencies
Goal: Compact solid state frequency chain

Power: 150mW 40mW 7mW >40μW

Synthesizer Power +multiplier amplifier 1st 2nd 3rd multiplier stages output

1127-1242 GHz
THz frequency multiplier chains based on planar Schottky diodes

Design of a (x2x2x3) 1200GHz local oscillator chain
- Designs are based on an iterative process to optimize multiplier performance
- Two different diode fabrication technologies at JPL
  - substrate less or framed designs for f<1THz
  - monolithic membrane diode (MoMeD) design for f>1THz
- Machining tolerances +/- 2μm
- Operating conditions: input power (more than 150mW) and temperature (120K)
- Design of in-line and simple to assemble waveguide multiplier blocks
  - E-plane split block machined from brass and gold-plated.
    - Last stage block has a diagonal feed horn integrated.

For example:
- Band 5a: 1127 – 1178 GHz (RF input 93.91 - 98.17 GHz)
- Band 5b: 1192 – 1242 GHz (RF input 99.33 - 103.50 GHz)
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Design of the first stage doubler in the $2\times2\times4$ local oscillator chain

- Broadband balanced design 184 – 212 GHz
- Three diodes in each branch, used for impedance matching and power handling
- Nominal anode size 3.0 x 12.0 $\mu$m$^2$, variations +/- 20% and frame, 1E17 or 2E17 $1/cm^3$ doping
- Substrate removed to reduce losses
- Reduced waveguide height in input and output waveguides to accommodate impedance matching
- No mechanical tuning element
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Design of the second stage doubler in the x2x2x4 local oscillator chain

- Broadband balanced design 369 – 424 GHz
- Two diodes in each branch, used for impedance matching and power handling
- Nominal anode size 1.5 x 4.3 μm², variations +/- 20%, frame, and stub, 1E17 or 2E17 1/cm³ doping
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Design of the third stage tripler in the x2x2x3 local oscillator chain

- Reduced losses in GaAs substrate due to 3 μm thin membrane.
- Beam leads for mechanical support and ground contact.
- Beam leads as RF probes in the input and output waveguides.
- Several device variations (anode, bias).
- Nominal anode size 0.4 x 0.9μm², variations +/- 20%, 5E17 1/cm³ doping.
- Broadband balanced design 1127 - 1242 GHz.
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Design of the third stage tripler in the x2x2x3 local oscillator chain cont.
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Design of the (x2x2x3) 1200GHz local oscillator chain

**Terminator for 400 GHz doubler**

**Terminator for 200 GHz doubler**

**Band 5 Base plate**

**Short for power amplifier**

**1200 GHz tripler**

**WR-5 dummy isolator**

**WR-10 Isolator**

**400 GHz doubler**

**200 GHz doubler**

**45 degree twist waveguide**

**Power amplifier**

**WR-10 Isolator**
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Performance of the first doubler in the x2x2x3 local oscillator chain

Output Frequency [GHz] vs. Output Power [mW], Efficiency [%], Input Power [mW]

Output Power • Efficiency ▲ Input Power
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Performance of the second doubler in the $x2x2x3$ local oscillator chain

![Graph showing output power, efficiency, and input power versus output frequency.](image)

Output Frequency (GHz)

- Output Power
- Efficiency
- Input Power
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Performance of the third stage in the x2x2x3 local oscillator chain

Band 5a: 1127-1178GHz
Band 5b: 1192-1242GHz

Output Power [μW], (100x for 400GHz)

Frequency [GHz]

- 295K
- 113.6K
- 400GHz doubler at 295K
- Efficiency of last stage at 295K

Efficiency of the 1200GHz tripler [%]

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120K test bench for measurements
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Output power leveling

- No mechanical tuner
- Frequency multiplier in the x2x2x3 LO chain:
  - 200GHz doubler
  - 400GHz doubler
  - 1200GHz tripler (bias-less)
- Power amplifier
  - Drain voltages
  - Gate voltages
- Electronic attenuator (under development by Neal Erickson, UMass)
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THz chain power tuning with the first stage x2

Bias voltage of the 200GHz multiplier [V]

Output Power at 1138.6GHz [uW]

Bias current [uA]

Output Power — 200GHz bias current — 400GHz bias current

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THz chain power tuning with the second stage x2

Output Power at 1138.6GHz (µW)

Bias voltage of the 400GHz multiplier [-V]

Output Power

400GHz Bias Current

Reverse current

Bias Current [mA]
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Concerns when tuning the output power with the multiplier bias

- Reliability of diode device
- Limited bias voltage range
- Limited bias current range
- Have to be carefully to avoid voltage swing close to breakdown (only the average voltage is monitored)

Solution:
Primary tuning with the power amplifier while finer adjustments can be made with multiplier bias
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THz chain power tuning with the power amplifier bias

- Gate bias is 0V
- Input power is 3.5dBm
- Bias voltages on the 200 and 400 GHz doublers are constant
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Power amplifier (PA) output power vs. PA drain voltage

S/N 102 output power vs. drain voltage at 120K with +0dBm input
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Power amplifier (PA) output power vs. PA drain voltage

S/N 102 output power vs. drain voltage at 120K with +0dBm input
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Axis definition and tolerances specification

[Diagram showing axis definitions and tolerances with labels for Y, Z, X, Yaw, X, Y, Z +/- 100μm, X +/- 50μm, Y +/- 50μm, pitch, horizontal alignment screws, and vertical alignment screws.]
Alignment Flexure

Material: base plate, horizontal screws, and saddle aluminum
vertical screws stainless steel

Adjustment: x,y plane maximal 70μm, z axes is defined by length of THz chain

4x vertical alignment screws

2x horizontal alignment screws
Mounted and aligned x2x2x3 frequency multiplier chain
Beam pattern measurement

(performated at the MPIfR (Max-Planck-Institut fuer Radioastronomie) in Bonn/Germany
by Christoph Kasemann and Thomas Klein.)

Side loops at \(-20\text{dB}\)

50\mu W at 1124GHz

AB Millimetre network analyzer
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Summary

- Design and realization of a x2x2x3 multiplier frequency chain for Band 5 of HIFI/Herschel
- Design is easy to assemble, robust, flight suitable
- Measured RF results:
  - Bandwidth 1120 – 1255GHz, Output power > 60uW at 120K
  - Bandwidth 1140 – 1250GHz, Output power > 35uW at 295K
- Beam pattern, side loobs < 20dB
- Mechanical Design meets subsystem requirements

Future work

- further assessment of power handling
- qualify hardware for flight
- Confirm save operating conditions
- Investigating high frequency chains
  1400-1900GHz for band 6, x16, x18, and/or x24
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