Virtual Research Presentation Conference

High Efficiency Superconducting Frequency Multiplier

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Program: Topic Area RTD

Assigned Presentation # RPC-150

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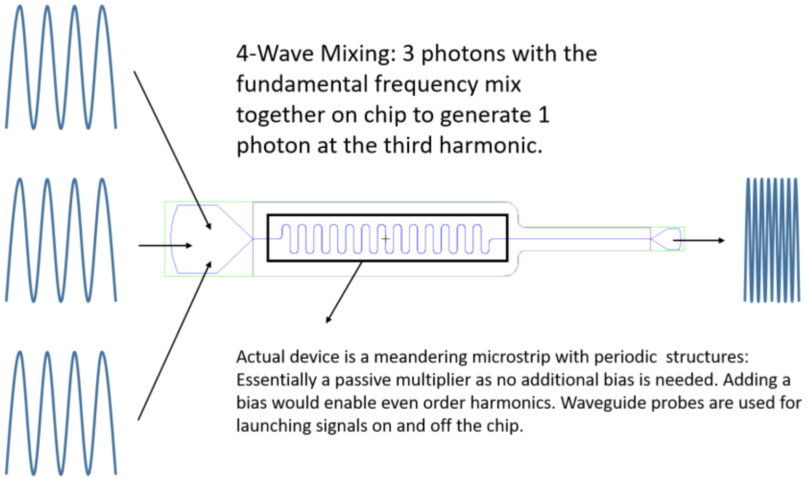
Abstract

Heterodyne spectroscopy is a crucial tool for studying individual constituents of cool dust in our galaxy, giving insight into the early universe. Most scientific results obtained thus far have used single-pixel heterodyne receivers including the best-known HIFI instrument on Herschel Space Observatory. In order to achieve a better understanding of star forming processes, a mapping of THz spectral lines across the galaxy is desirable. Multi-pixel receivers are difficult to develop because of their complexity and a considerable part of that lies with the technology deficiencies for local oscillators (LO). Although many advances have been made using semiconductor, solid-state sources, efficiency is still the bottleneck in achieving LOs for large arrays. This work is an alternative LO technology for heterodyne arrays in a superconducting multiplier utilizing the non-linear kinetic inductance. The improved non-linearity of the kinetic inductance in a superconductor compared to the Schottky diode will lower the per-pixel power requirement to about one mW of input power compared to the 0.5-5 Watts of input power for existing technologies. In FY20, we have demonstrated a first stage Ka-Band 3x multiplier with high efficiency output at 104 GHz.



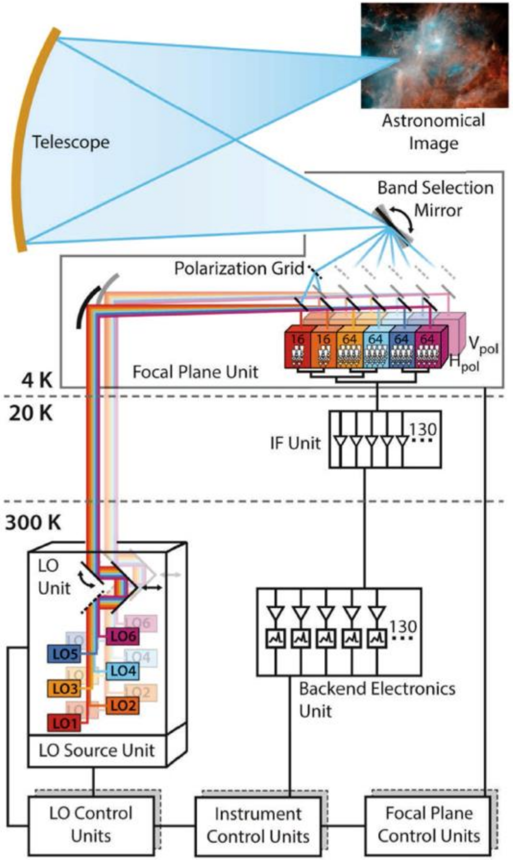
Problem Description

a) There exists a scientific need for large arrays of Heterodyne Receivers for mapping of ISM cooling lines. For example the Heterodyne Receiver for the Origins Space Telescope (HERO) concept includes 128 pixel receivers in multiple bands (64 pixels with dual polarization).

b) Local oscillators for these 6 bands will require hundreds of Watts of power and require ~8 meter long optical path, potentially through sun shields.

c) For such an instrument using cryogenic detectors (necessary for baseline sensitivity to do science), having the LO at room temperature creates as many issues as it solves.

d) The superconducting multiplier outlined here has the potential to reduce the per-pixel cost of a future space instrument to levels consistent with direct detector instruments.



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Problem Description

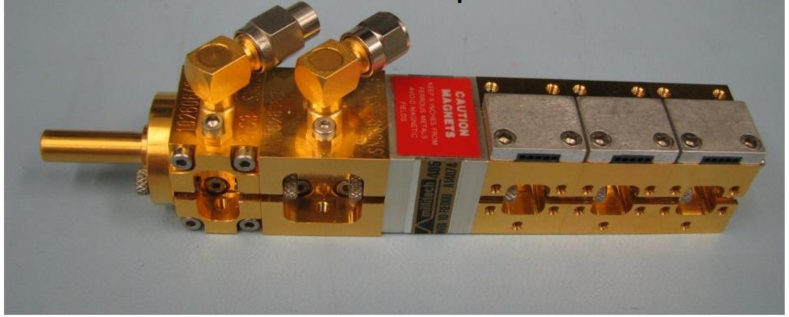
a) Existing technology is based on Schottky Diode multiplier Chains

b) Schottky Diodes operate at room temperature

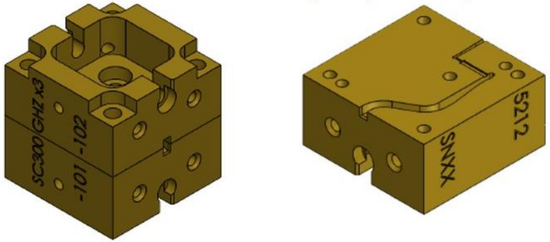
c) High flight heritage Technology: Flown on Herschel HIFI et al.

d) Efficiency scales with ~ 1 / (frequency)^3

Current State-of-the-Art Input Power: 5 Watts



Proposed Technology Input Power: 100 µWatts (by design to achieve similar output power)



Total gain: > 4 orders of magnitude better efficiency
6x less mass and More output power!

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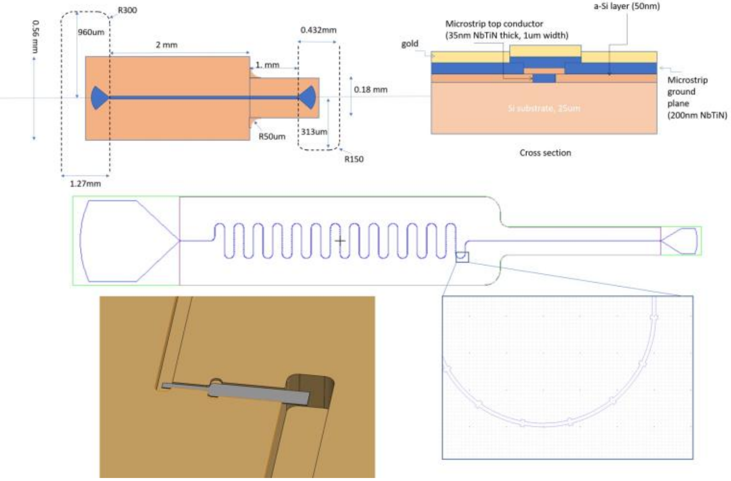
Methodology

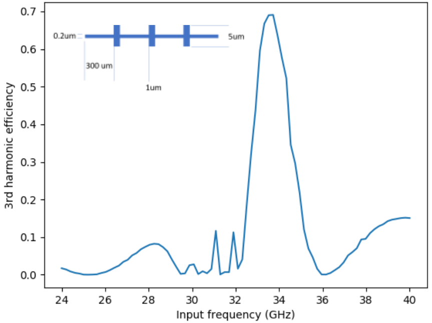
a) This work is the beginnings of a concept that can actually be integrated with the cryogenic detector, emulating a front-end-on-chip architecture similar to FIR direct detection instruments.

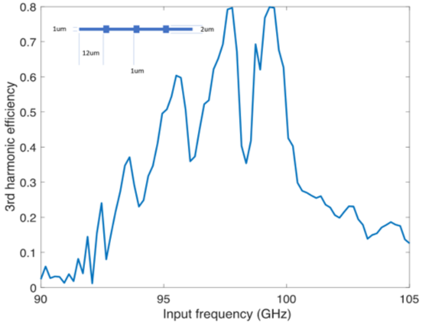
b) The technology utilizes the non-linear kinetic inductance effect, popularized for direct detectors capable of very high sensitivity and scalable to large arrays.

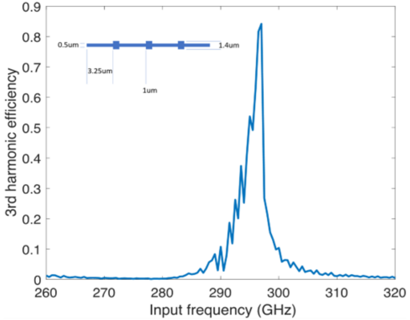
c) Simulated efficiency can be as high as 90% for a tripler, even at close to 1 THz output. Typically, frequency dependence is minimal until near the limit set by the superconducting material (>1 THz for NbTiN).

d) Because signal loss is so small on chip, multiple stages can be integrated on a single chip, reducing size and mass significantly. Additionally, the device is essentially passive, reducing complexity for use on an instrument.





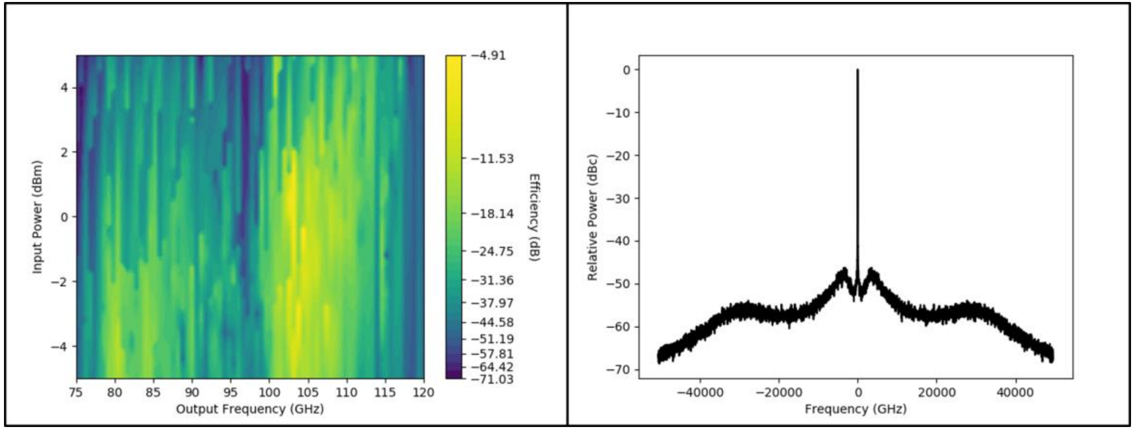




Results

a) A Ka-band multiplier has been tested in FY20 (max output around 104 GHz). The device shows about 40% efficiency, with indications that the simulated 80-90% can be achieved.

b) The device exhibits no measurable addition to phase noise on the fundamental signal, leading to linewidths that are more than sufficient for doing spectroscopy with R~ 10^6.



Future Work

a) The plan is to demonstrate higher frequency multiplication in a graduated way. W-band devices (output around 300 GHz) have already been fabricated in FY20. Testbed infrastructure needs to be updated to measure these devices. A design exists for a third band with >900 GHz output, but devices have yet to be fabricated.

b) Future work would also include increasing the output bandwidth, and integration of stages onto a single chip.

Publications and References

[1] Cunnane, D., Day, P., et al. , High Efficiency Ka-Band Frequency Multiplier Based on the Superconducting Kinetic Inductance Effect, In Preparation