National Aeronautics and Space Administration

High Efficiency Superconducting Frequency Multiplier

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Program: Spontaneous Concepts

Project Objective:

Local Oscillator sources become incredibly inefficient in the regime that has come to be known as the THz gap. This region of the electromagnetic spectrum (300 GHz to 3 THz) is largely untapped due to this technology gap, particularly when it comes to observing our solar system, galaxy, and cosmos. The two standard generators of coherent radiation, the Quantum Cascade Laser (QCL) and the Schottky Diode Multiplier (SDM) have major drawbacks preventing significant advancement in state-of-the-art heterodyne receivers. The QCL can produce reasonable power output at higher frequency, but becomes more inefficient at lower frequency (<3 THz). The operating temperature of the QCL is around 50 K and so any inefficiency will result in dumping heat onto a cold stage (of the order of watts), requiring significant power requirements for potential space missions. Additionally, QCL sources have not yet demonstrated practical output power below 3 THz. SDM sources operate at room temperature but become very inefficient at higher frequencies (> 1 THz) leading to 5-10 W of input power for a few uW of output power. For high-resolution spectroscopy in the far infrared, the scientific goals will require multi-pixel receivers on the order of 100 pixels (or even higher). The objective of this task was the first step in realizing a high efficiency frequency multiplier using the non-linear kinetic inductance in a superconducting microstrip. In order to achieve a practical coherent radiation source, a large gap superconductor is needed to achieve multiplication into the THz frequencies. Our goal was to make a 3x multiplier from 100 GHz. **The main goal was to create a first stage multiplier from 100 GHz to 300 GHz.**

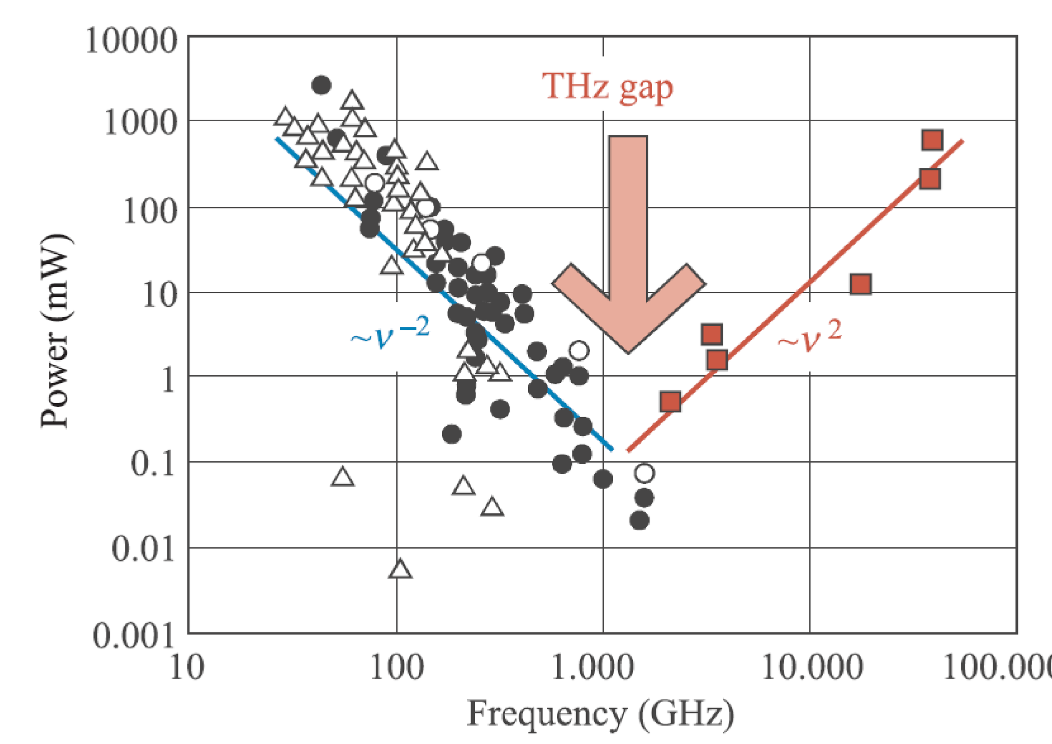

Figure 1. Plot showing the output powers of THz sources. The difficult region around 1 THz is a well-defined technology gap.

FY19 Results:

Utilizing high quality NbTiN thin films on Silicon-on-insulator substrates, microstrip devices were fabricated. The structure shown in Fig. 2 consists of a 40 nm NbTiN microstrip layer covered by an amorphous Si dielectric layer. A NbTiN ground plane (sky plane) is used to reduce the geometric inductance of the microstrip. The length of the inductor was varied from device to device to test the accuracy of simulations. After fabrication of the device layers, the chips were defined by a front side etch of the device layer and released by a subsequent removal of the handle wafer. In the first devices, the chip thickness was about 25 um. In parallel, a waveguide block was developed with a wr-10 input (75-110 GHz) and WR-3 output (220-330 GHz). In the center of the block (shown in figure 2) is a channel for housing the chip.

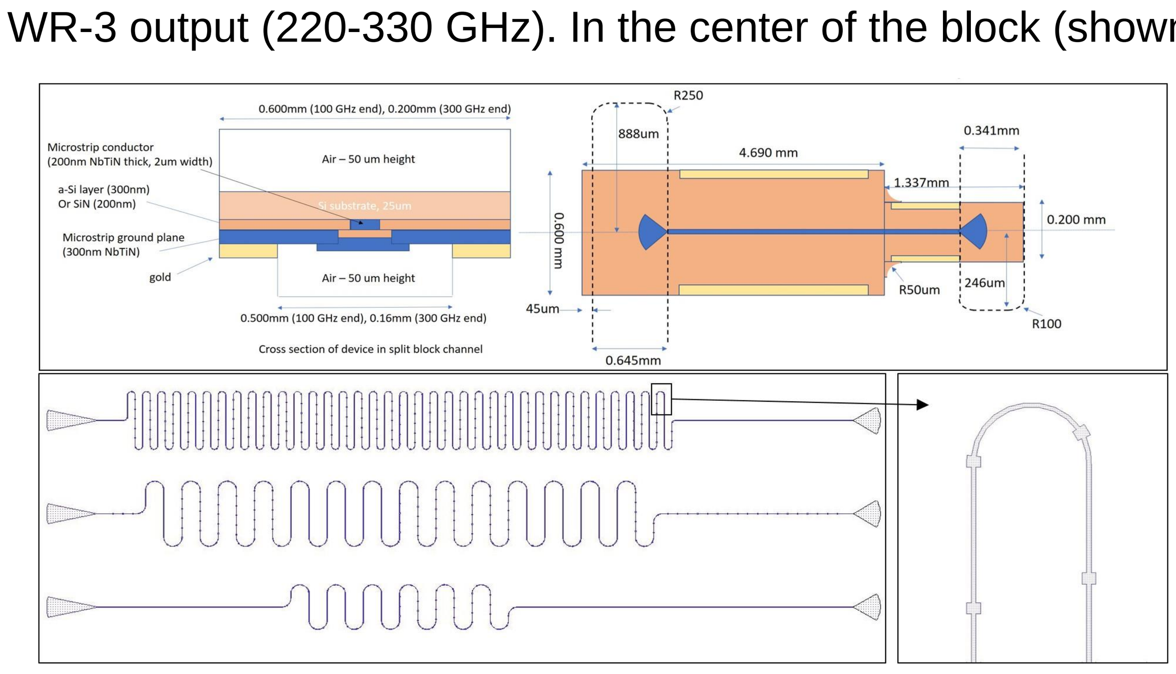

Figure 2. (Top) Cross sectional and birds-eye view of the superconducting multiplier devices. The ground plane is omitted from the birds-eye view to show the shape of the device. The straight microstrip shown between the waveguide probes will be replaced with the meanders (shown on the bottom).

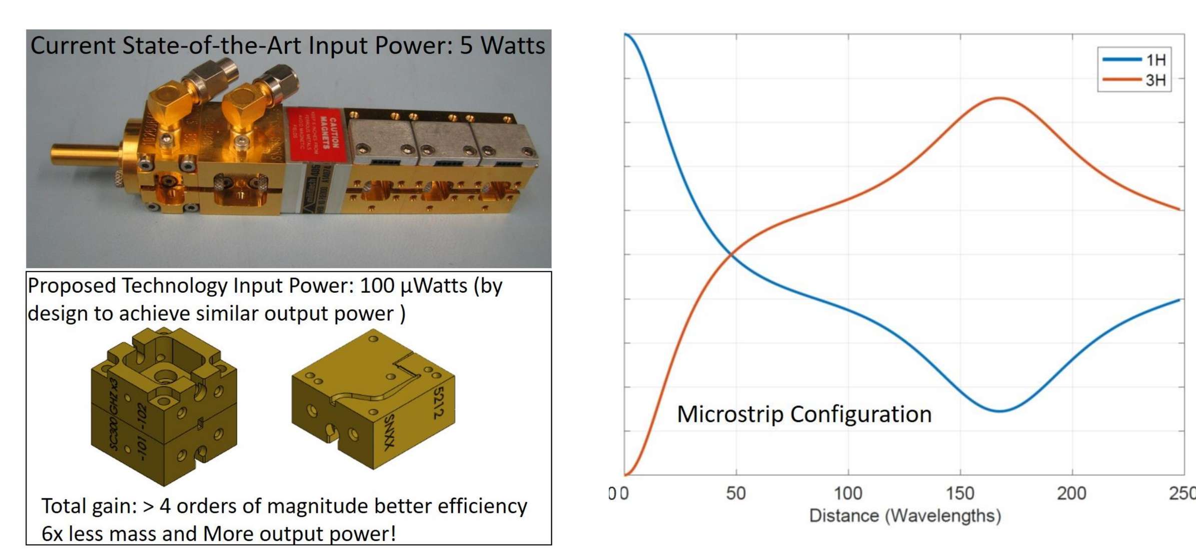

Figure 3. (Left) Schematic diagram of a waveguide block for housing a 100 GHz trippler. (Right) The simulated efficiency of the tripler as a function of length (in wavelengths of the fundamental frequency).

In the first devices, the chip thickness was about 25 um. It will necessarily get thinner at higher frequencies. In parallel, a waveguide block was developed with a wr-10 input (75-110 GHz) and WR-3 output (220-330 GHz). In the center of the block (shown in figure 3) is a channel for housing the chip.

Benefits to NASA and JPL (or significance of results):

The non-linear kinetic inductance effect has been shown to produce state-of-the-art parametric amplifiers that will prove useful for future astrophysics missions. This work has taken the first step to repurpose the physical phenomenon using a large gap superconductor to achieve frequency multiplication up to 2 THz. This is scientifically significant because C+ plays a large role in the cooling process of the interstellar medium lifecycle. Mapping this molecular identifier in our sky will give invaluable insight into the star formation process. Mapping with such high spectral resolution is currently a very time consuming task. The scientific data yield is too low to consider for the fairly expensive instruments. The innovation of a local oscillator with high efficiency would imply large pixel-count heterodyne receivers (100+ pixels) can one day be practical. Reducing wall plug power requirements of local oscillators by 3 orders of magnitude will eliminate a large obstacle in the path to engineer such an instrument. Integrating this element directly with the detector (either on the same chip, or in the same waveguide block) will have a similar impact on the size and mass of a potential space instrument.

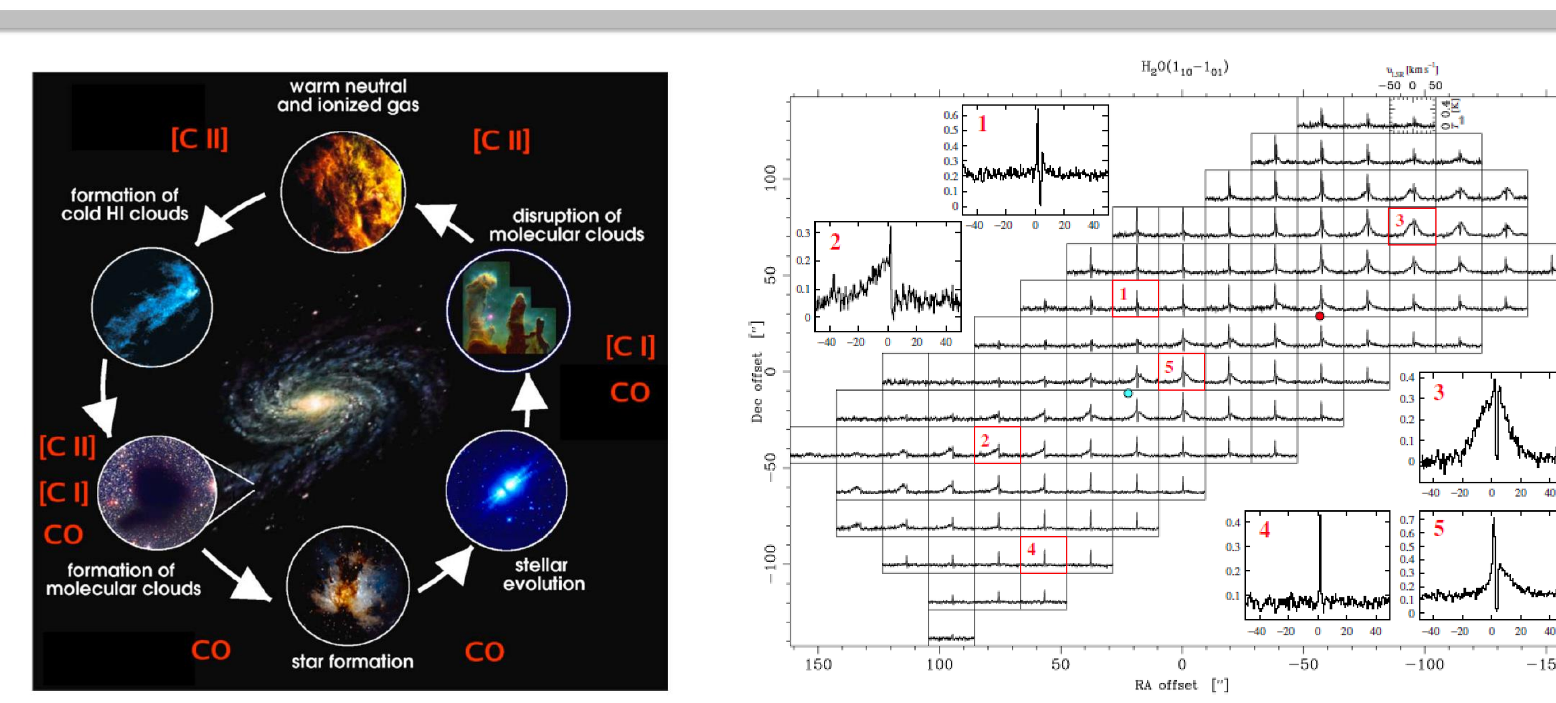

Figure 4. (Left) Diagram showing the lifecycle of the interstellar medium and the role of ionized carbon in the different cooling processes. (Right) A 100+ scan map of water (557 GHz) in a young stellar object taken with Herschel HIFI. Each scan was taken individually and the array was reconstructed later. Science goals now aim to map much larger parts of the sky with large pixel-count heterodyne arrays as high as 1.9 THz.

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