Traveling-wave parametric amplifiers for microwave and millimeter-wave radiometers

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Program: Strategic RT&D

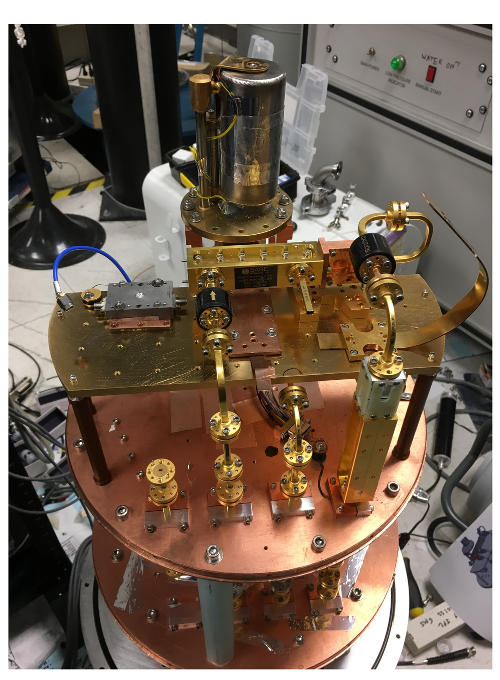
Project Objective:

Superconducting amplifiers have recently been developed for frequencies in the range of ~1 to 10 GHz that reach sensitivity that is consistent with the limit imposed by quantum mechanical fluctuations.

This project seeks to explore astronomical applications of this technology, especially its use in a radiometer system for CMB polarization measurements. Toward this objective, we seek to extend the operating frequency range of the amplifiers to 20– 70 GHz, to characterize the noise and stability of amplifiers in that frequency range, and to develop the necessary components and packaging for integrating these devices into radiometer modules.

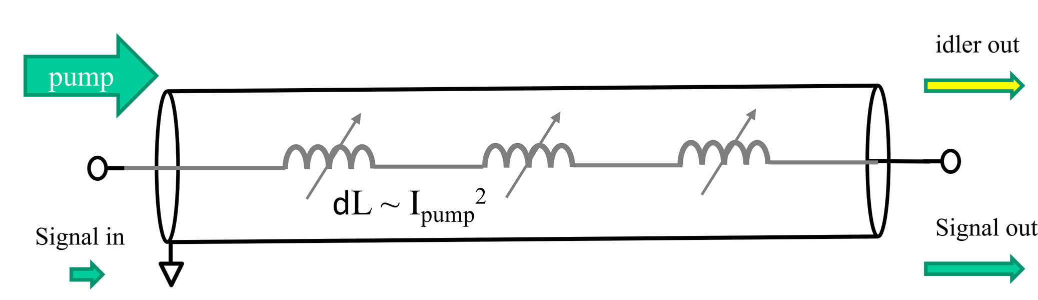
FY18/19 Results :

- Testbed
  - Completed construction of a testbed capable of measurements from 1 – 118 GHz
  - Compact system based on a GM cooler
  - Internal He4 sorption cooler for operation down to 1K
  - Variable temperature load for Y-factor measurements



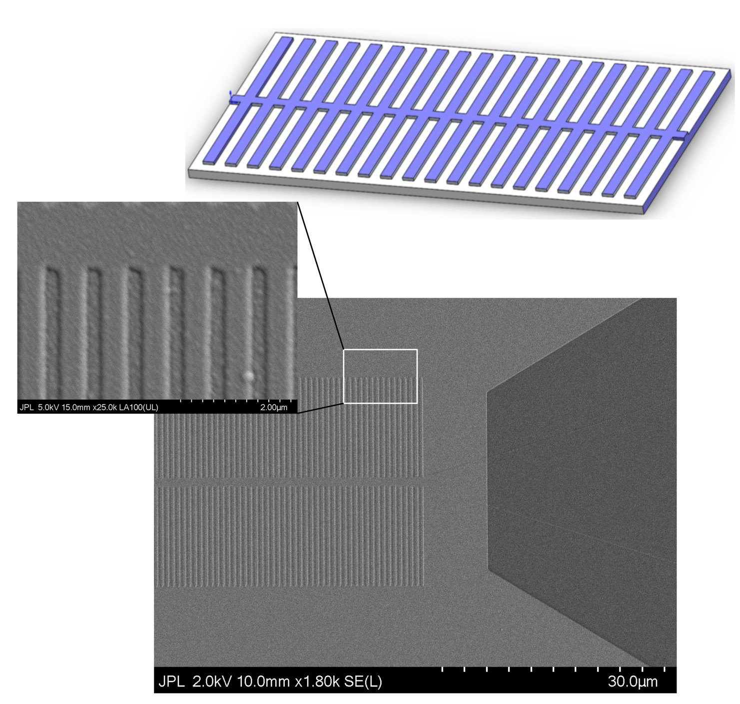
FY18/19 Results:

- Superconducting Kinetic Inductance traveling-wave (KIT) parametric amplifiers
  - The devices under development belong to a class of amplifiers known as "parametric amplifiers" (called paramps), which are based on a non-linearity of circuit. In this case the nonlinearity is associated with the kinetic inductance of a superconductor, which is the inductive effect of the momentum of the supercurrent (Cooper pairs) that does not scatter like the current in a normal metal. The inductance of a thin superconducting wire depends on the current according to $L_s = L_0 (1 + I^2/I_*^2 + \ldots)$, which is the nonlinearity we exploit.
  - While parametric amplifiers in the past have been based on narrow-band resonant circuits, we have successfully demonstrated a traveling-wave paramp, which is based on an inherently wide-band transmission line (depicted below), rather than a resonator. This type of amplifier can be thought of as the superconducting analogue of the fiber optical parametric amplifier (OPA)



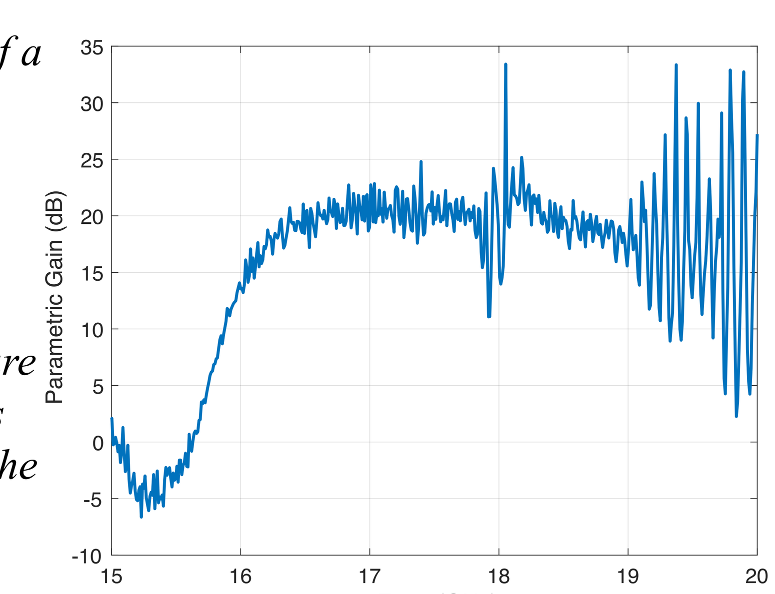
Transmission line with a distributed nonlinearity. A pump tone is injected in one end with a weak signal. Amplification results from the non-dissipative transfer of power from pump to signal.

  - Devices we had developed previous to last year were based on single-layer transmission lines with an ungrounded coplanar wave guide (CPW) geometry. In the past year, we have developed paramps based on microstrip lines, which consist of ground plane, dielectric and conductor layers (shown below). The superconducting layers are made of NbTiN and the dielectric is deposited amorphous silicon.



Section of the microstrip paramp. The NbTiN microstrip has a sub-micron linewidth to increase the kinetic inductance. A series of microstrip stubs are arranged along the microstrip line to lower the impedance to 50 ohms

Measured gain of a paramp near 20 GHz. Excessive ripples near 18 GHz and at the higher frequency end of the span are due to reflections associated with the device housing



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

- CMB
  - It is advantageous to JPL and NASA to develop coherent receivers for future flight missions. The cost of implementing a mixed-technology focal plane can be outweighed by cost savings at the lower frequencies associated with higher operational temperature, including in windows and filters, and the lower noise performance and better control over systematics provide important scientific advantages. To achieve the required resolution for foreground removal it may become necessary also to have a two telescope system with larger aperture for the lower frequencies. Thus each focal plane would use a single technology.
- Heterodyne receivers
  - Parametric amplifiers operating at millimeter/sub-millimeter wavelengths could be used as a front end for a heterodyne spectrometer instrument
  - Would allow for the use of a noisier, but wider band, mixer in place of the SIS mixer. E.g., cover the 500-560 GHz band, which is of interest for a possible comet mission, with a single LO setting.
  - A GHz frequency paramp would also be of interest as an IF amplifier for a SIS or HEB heterodyne instrument, would would lower the system noise and could also open a pathway to large arrays, as the paramp's power dissipation is orders of magnitude lower than for a HEMT.
- Space VLBI
  - Another application of current interest would be for a space-borne 230 GHz (or higher frequency band) VLBI receiver, which would allow the number of targets accessible to projects like Event Horizon Telescope to be significantly expanded.
  - A paramp could be used either as a front end amplifier or as an IF amplifier following an SIS mixer for this application.

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