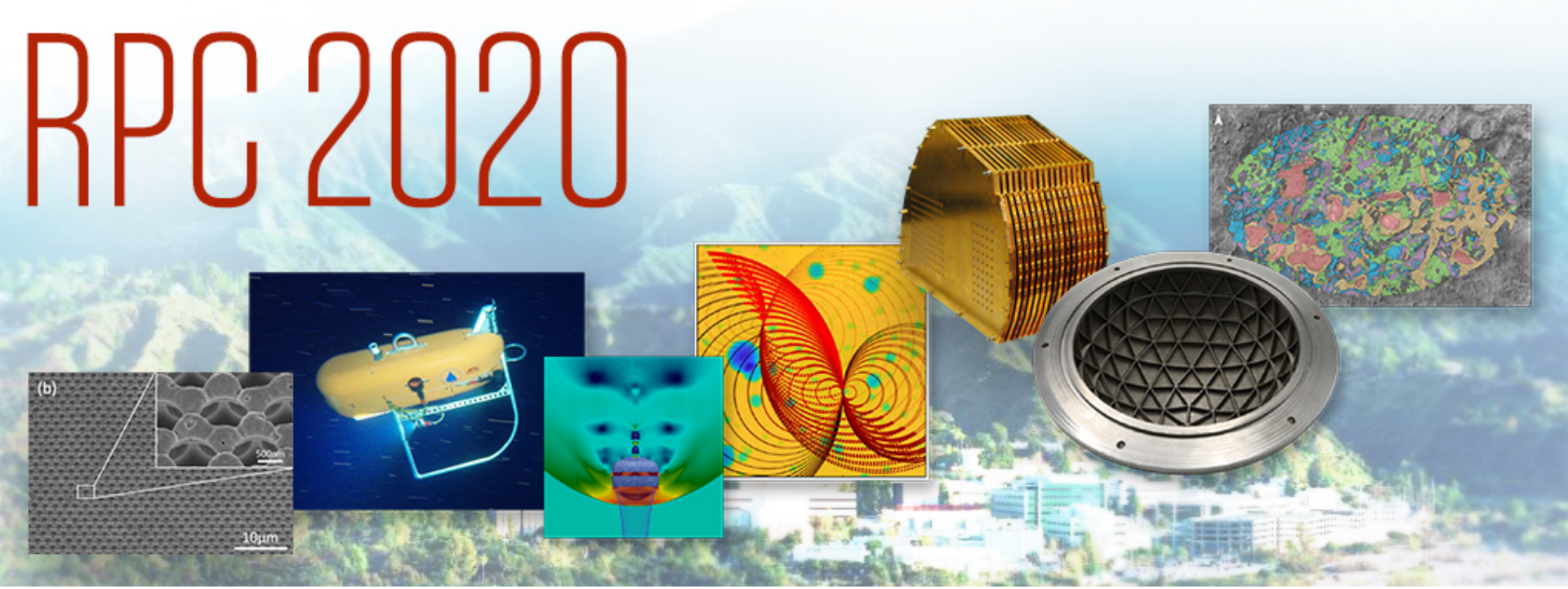
# RPC 2020




# Virtual Research Presentation Conference

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

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**Program: Strategic Initiative**

Assigned Presentation # RPC-146

Jet Propulsion Laboratory
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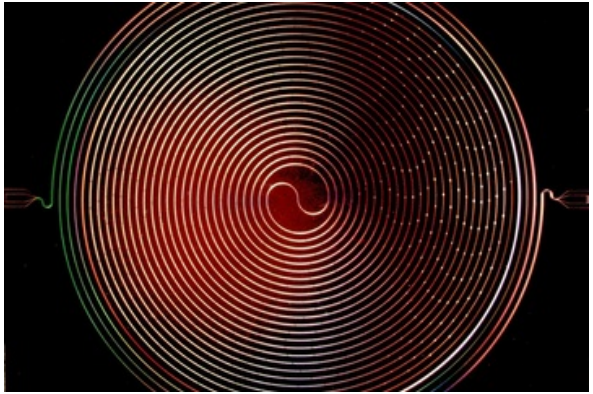
# Tutorial Introduction

- Amplifiers based on transistors are ubiquitous elements of measurement systems
- In astronomy, amplifiers are used as front ends in many receivers including mm/submm radiometers and interferometers and as IF amplifiers in spectrometers with SIS or HEB mixers.
- Cryogenically cooled transistor amplifiers can have very wide bandwidth and high dynamic range, but while their sensitivity is quite good, they still add noise that is several times the limit set by quantum mechanics
- Superconducting parametric amplifiers reach the quantum sensitivity limit at microwave frequencies, but have been narrow band, low dynamic range and are generally difficult to use, making them unsuitable for astronomical instruments.
- Recently JPL has demonstrated a new superconducting parametric amplifier configuration that offers both wide dynamic range and quantum limited at microwave frequencies. This is the first superconducting microwave amplifier demonstrating these properties simultaneously.



An NbTiN kinetic inductance parametric amplifier based on a spiraled thin film transmission line.

# Problem Description

a) NASA (as well as ESA and JAXA) have been studying concepts for a next generation CMB polarimetry mission.
   - While these studies have baselined bolometers, coherent radiometers can offer advantages for the low frequency channels

b) Inspired by the results of the Event Horizon Telescope, there is interest in a space Very Long Baseline Interferometry (VLBI) experiment to greatly expand the baseline and set of possible targets

c) SOA for Radiometry: Bolometers are best for higher frequencies
   - At the lowest synchrotron monitoring channels, amplifier-based polarimeter modules offer internal polarization switching, low 1/f, relative cosmic ray insensitivity, background-limited noise and higher temperature operation

   SOA for coherent receivers: HEMT amplifers
   - Sensitivity is ~4 times the quantum limit, which parametric amplifiers reach that limit
   - HEMTs dissipate several mW per amplifier, which paramp dissipation is ~10 microwatts

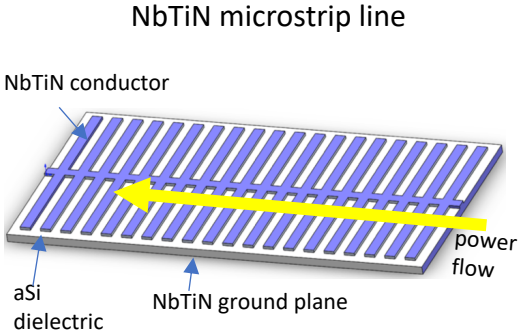
   SOA for VLBI: SIS receivers
   - Also reach around ~4 times Q.L.

d) Relevance to NASA and JPL: Missions targeting CMB, VLBI, comets (spectroscopy)

# Methodology

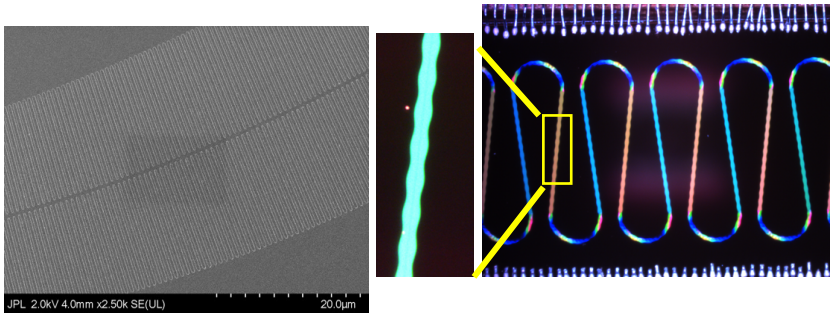
a) Formulation / theory:

- Parametric amplifiers (paramps) are based on a nonlinear response of a circuit
- Our superconducting parametric amplifier uses the nonlinearity of the kinetic inductance of a superconducting film
- Previous examples of superconducting paramps were based on resonant circuits –> inherently narrow band
- Wide band operation is possible by using a nonlinear transmission line. This is a 'traveling-wave' paramp.
- Analogous to nonlinear optical media eg. fiber optic parametric amplifier (OPA)
- The kinetic inductance results in a 'Kerr' nonlinearity




b) Innovation, advancement

- Changed TRL geometry from CPW-like to microstrip for operation through mm-wave band
- Miniaturized devices for high frequency operation
- Developing low-reflection components for introduction of pump and bias current

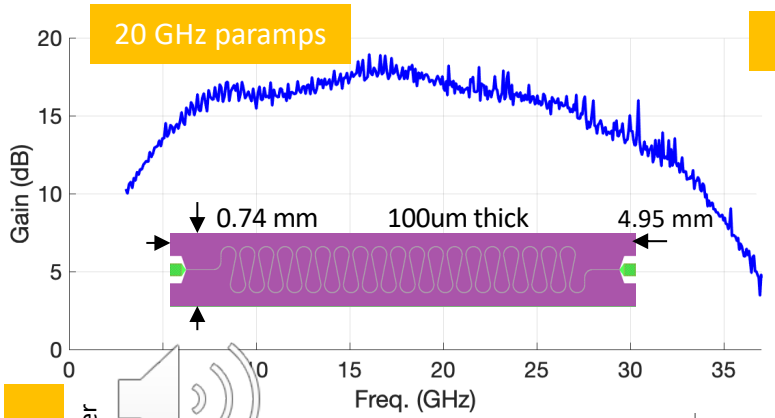


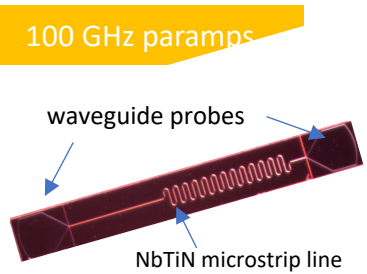
# Results

a) Accomplishments
- Demonstrated parametric gain in a miniaturized paramp in a wide band around 20 GHz
- Fabricated superconducting diplexers for pump tone injection
- Designed/simulated a wideband edge mode cryogenic isolator
- Initial testing of 100 GHz paramps – observed first indications of gain

b) Significance
- First wide band paramp around 20 GHz
- First indication of wideband gain in W-band

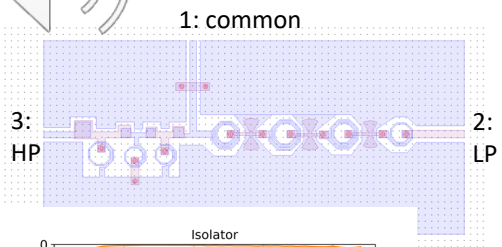
c) Next steps
- Improve gain – better matching
- Integrate into modules

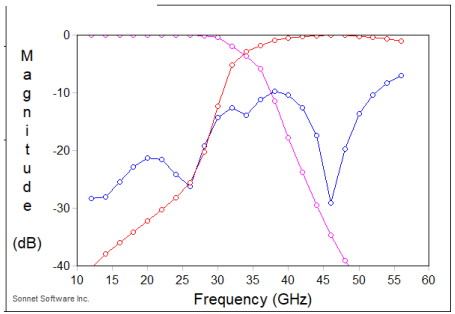


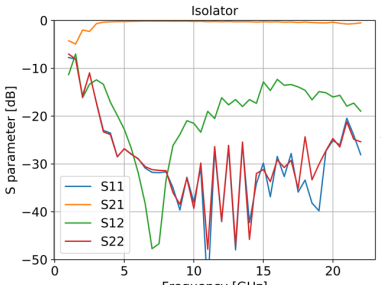

components for module integration

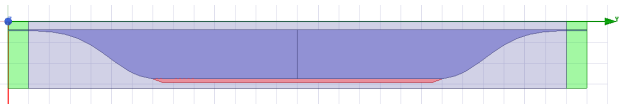
superconducting diplexer




wideband isolator

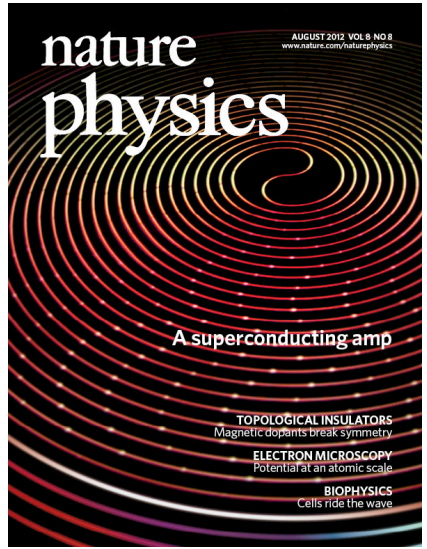


# Publications and References

First publication on traveling-wave superconducting parametric amplifiers – describes the basic theory of the device:

Eom, B. H., Day, P. K., LeDuc, H. G., & Zmuidzinas, J. (2012). A wideband, low-noise superconducting amplifier with high dynamic range. *Nature Physics*, *8*(8), 623-627.




A paper describing the use of a paramp for reading out a cryogenic detector array and reporting quantum limited sensitivity:

Zobrist, Nicholas, et al. "Wide-band parametric amplifier readout and resolution of optical microwave kinetic inductance detectors." *Applied Physics Letters* 115.4 (2019): 042601.