Superconducting Kinetic Inductance Parametric Amplifiers

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Traveling-wave, superconducting parametric amplifiers based on nonlinear transmission lines are well suited for use as readout amplifiers for low temperature detector technologies involving frequency domain multiplexing at GHz frequencies. These paramps can have very wide instantaneous bandwidth and large enough dynamic range to handle thousands of signals at typical levels for superconducting detectors. The measured noise is very close to the quantum limit and is a factor of several lower than the best transistor amplifiers. Another device utilizing nonlinear kinetic inductance, the Kinetic Inductance Parametric UP-converter (KPUP), is based on a current-sensitive resonator. Arrays of KPUPs are an interesting approach to reading out TES bolometers or other superconducting detectors.

Motivation for wideband paramps

- (Cryogenic) Transistor microwave amplifiers: HEMT, SiGe BPT are
  - Broad band, high dynamic range,
  - But: Added noise several hν / second / Hz (Quantum limit = ½ hν)
- For many applications we would like:
  - Near quantum limited noise performance
  - Wide instantaneous bandwidth
  - High dynamic range
  - Low power dissipation
- Some applications:
  - Direct detector array readout in the microwave domain
  - MKID readout amplifier
  - RF or IF amplifiers for heterodyne receiver arrays
  - Pre-amplifiers for radiometers or other recievers
  - Millimeter-wave interferometry

Superconducting film surface inductance:

- Parametric amplifiers are based around a nonlinear circuit response – in this case we use the nonlinear kinetic inductance
- The absence of dissipation in the superconducting circuit implies minimal added noise (consistent with quantum mechanics)
- $L_s = L_0 (1 + I^2/I_*^2 + \ldots)$ (Quadratic in current to leading order)
- E.g. Ginsberg Landau theory:
  - Order parameter suppressed by superfluid velocity

$$|\psi|^2 = \psi_\infty^2 [1 - (\frac{\xi m^* v_s}{\hbar})^2]$$

$$\frac{n_s^*}{n_{s,0}^*} = 1 - \frac{1}{2}\frac{\mu_0 \lambda_{eff}^2 J_s^2}{\mu_0 H_c^2}$$

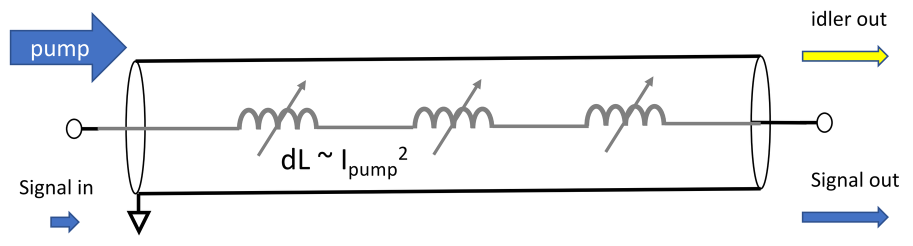
→ Kinetic energy of super current (numerator)

→ Condensation energy (denominator)

$$\frac{\delta L_s}{L_s} = \frac{\delta \lambda_{eff}}{\lambda_{eff}} = \frac{1}{2}\frac{\delta n_s^*}{n_{s,0}^*}$$

Traveling-wave amplifier design:

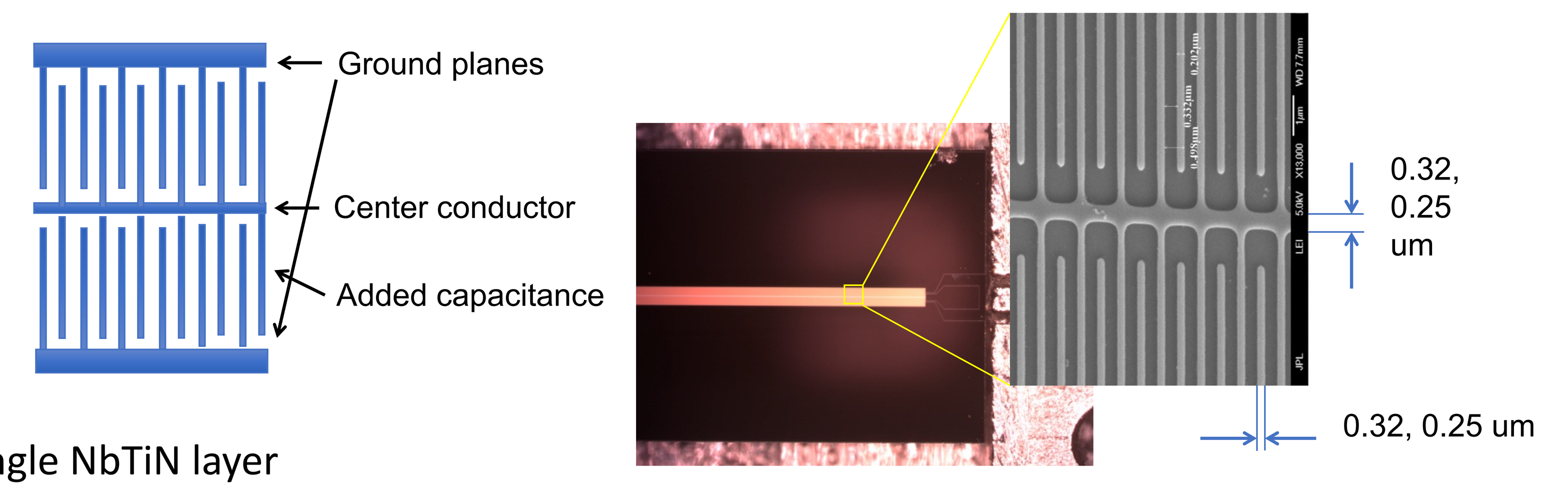
- Nonlinear element is distributed along a transmission line structure
- Pump and signal tones are injected at one end of the device



- The dispersion of the structure can be tailored, for instance by adding a periodic structure, to promote phase matching between pump, signal and idler waves

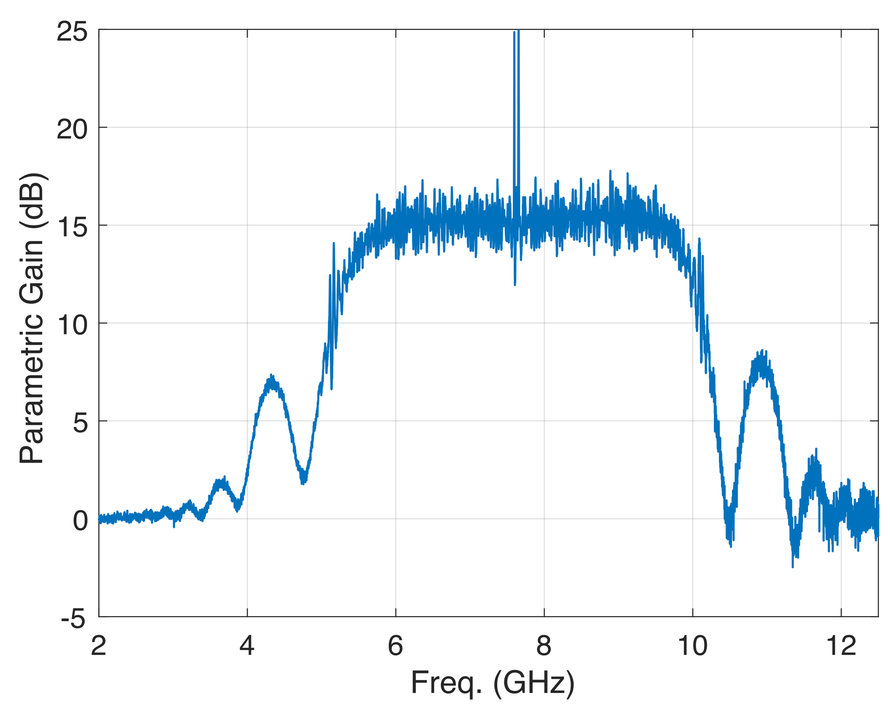
A capacitively loaded CPW paramp:

- Capacitive fingers increase capacitance, reducing impedance to 50 ohms
- 2.5 cm length, v = 0.005 c, electrical length = 5 meters



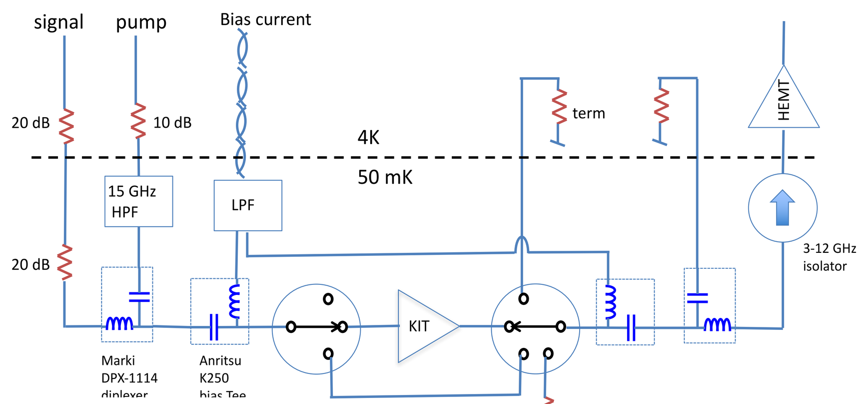
- Single NbTiN layer

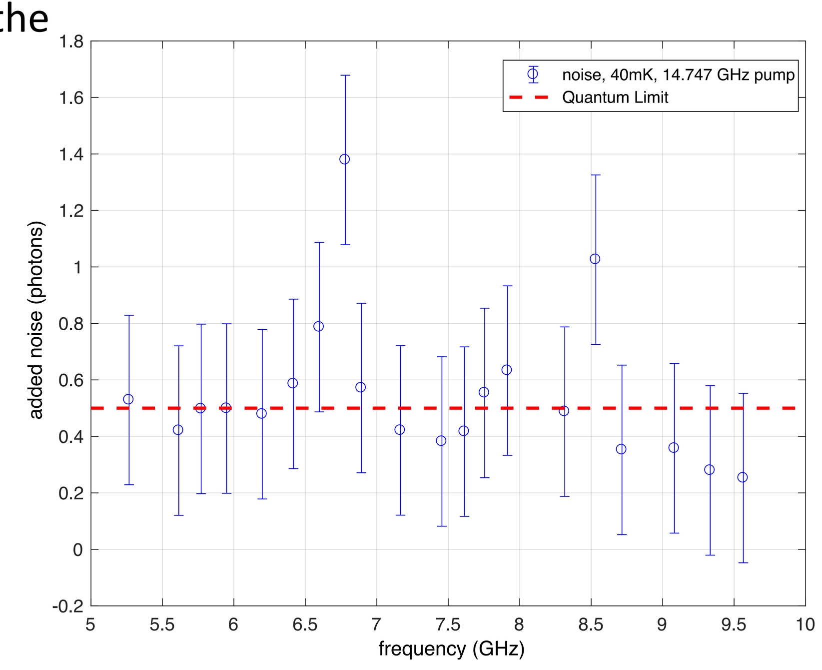
- Gain measured in 3-wave mixing mode (DC bias applied)
- Pump @ 15 GHz
- Pump power ~ 1 - 5 micro-watt
- Bias current ~ 0.5 mA



Noise measurement:

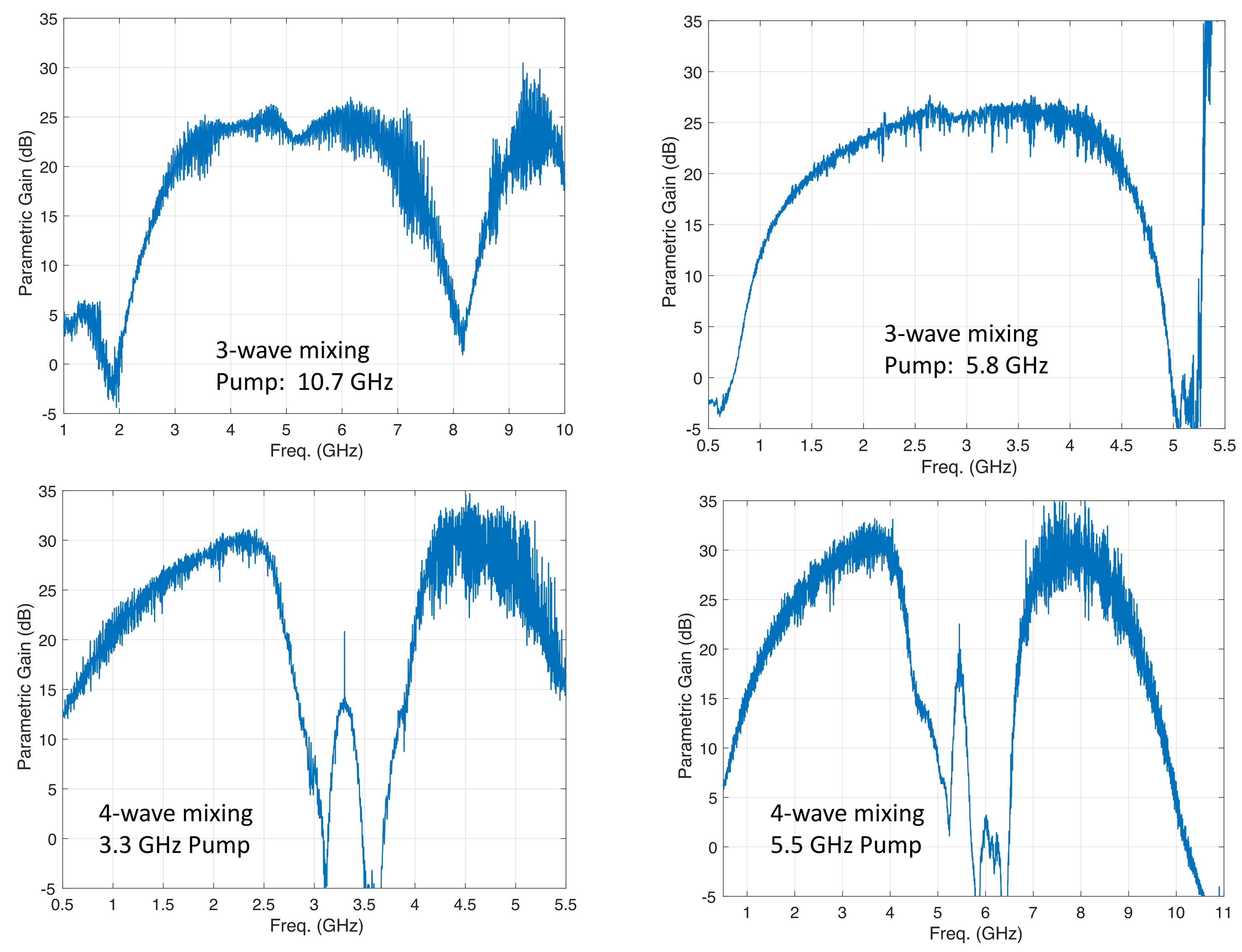
- Y-factor like method
- Noise is consistent with quantum limit across the band
- Setup:





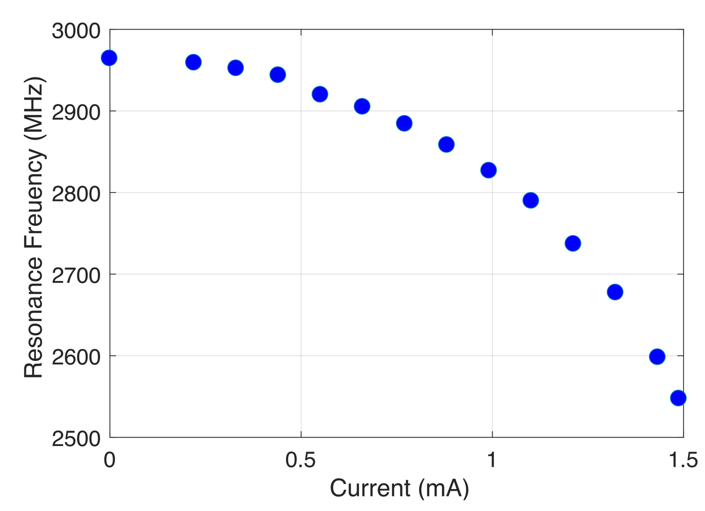
Microstrip paramps:

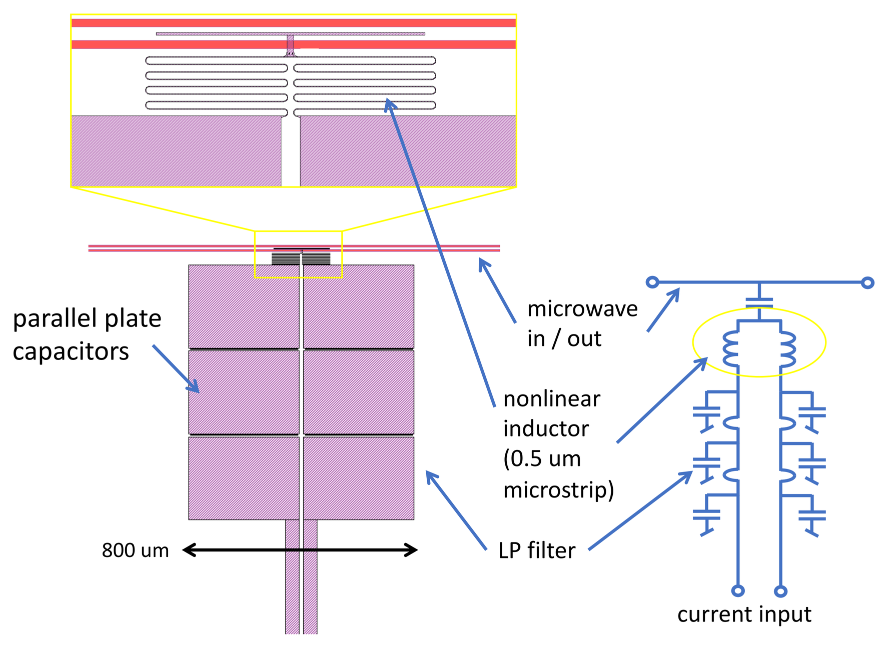
- Multilayer process – NbTiN conductor and ground plane with deposited dielectric
- Microstrip TRL is easier to meander – longer devices can be fabricated
- Example gain curves for 11 cm TRL (22 m electrical length):



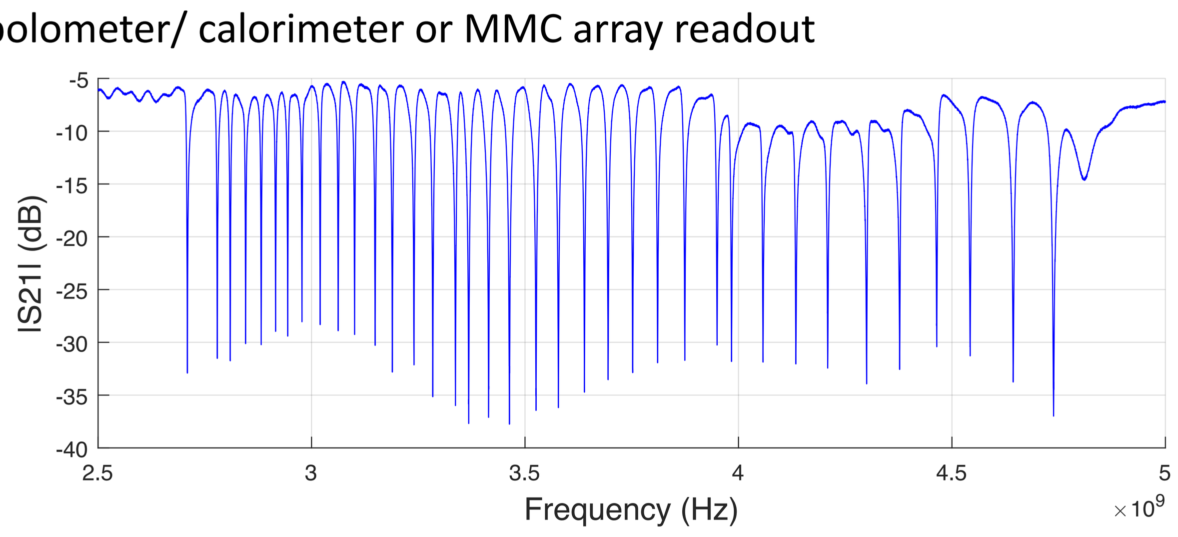
Multiplexed current sensors (KPUP):

- Current sensitive microwave resonator
- Low readout power ~ 10 nW
- Input inductance = 20 nH





- Small footprint
- Applications to TES bolometer/ calorimeter or MMC array readout
- Noise ~ 30 pA / rtHz
- 40 element array:



For more information or to request any of these devices, contact:
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