Super Low-noise RF Amplifier via a dc SQUID

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Snowmass 2001
July 9, 2001

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Talk Outline

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- The dc SQUID
- The microstrip SQUID
  - Gain
  - Tuning
  - Noise temperature at ^{4}He temperatures
- Recent results at millikelvin temperatures
- Concluding Remarks

- Collaborators

  Michael Mück (Berkeley, Gießen)
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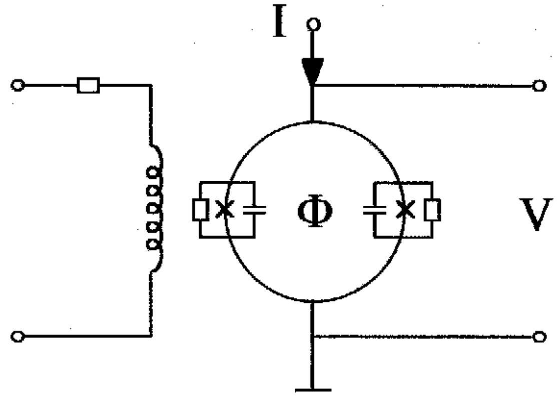
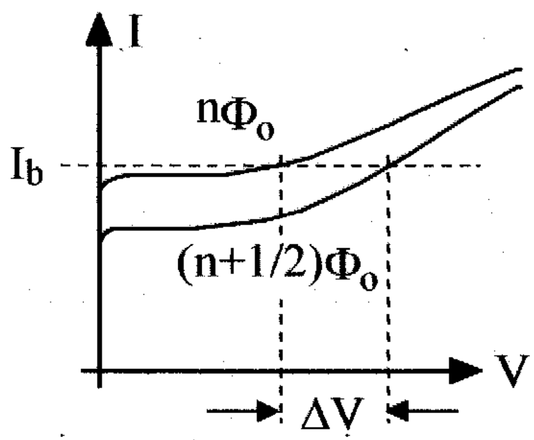
  Darin Kinion (LLNL)
  Jost Gail (Gießen)
  Christoph Heiden (Gießen)

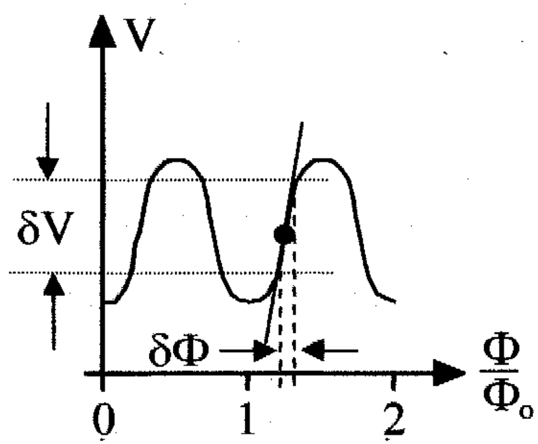
The dc Superconducting Quantum Interference Device

- **DC SQUID**
  - **two resistively shunted Josephson junctions on a superconducting ring**

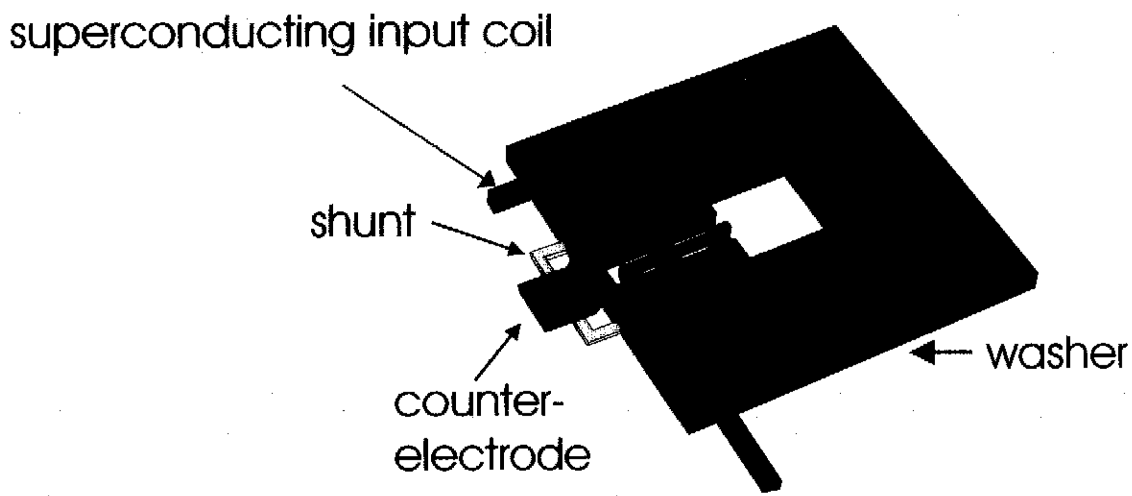


- **Current-voltage (I-V) characteristic modulated by magnetic flux Φ:**
  - **period one flux quantum $\Phi_o = h/2e = 2 \times 10^{-15}$ Tm²**

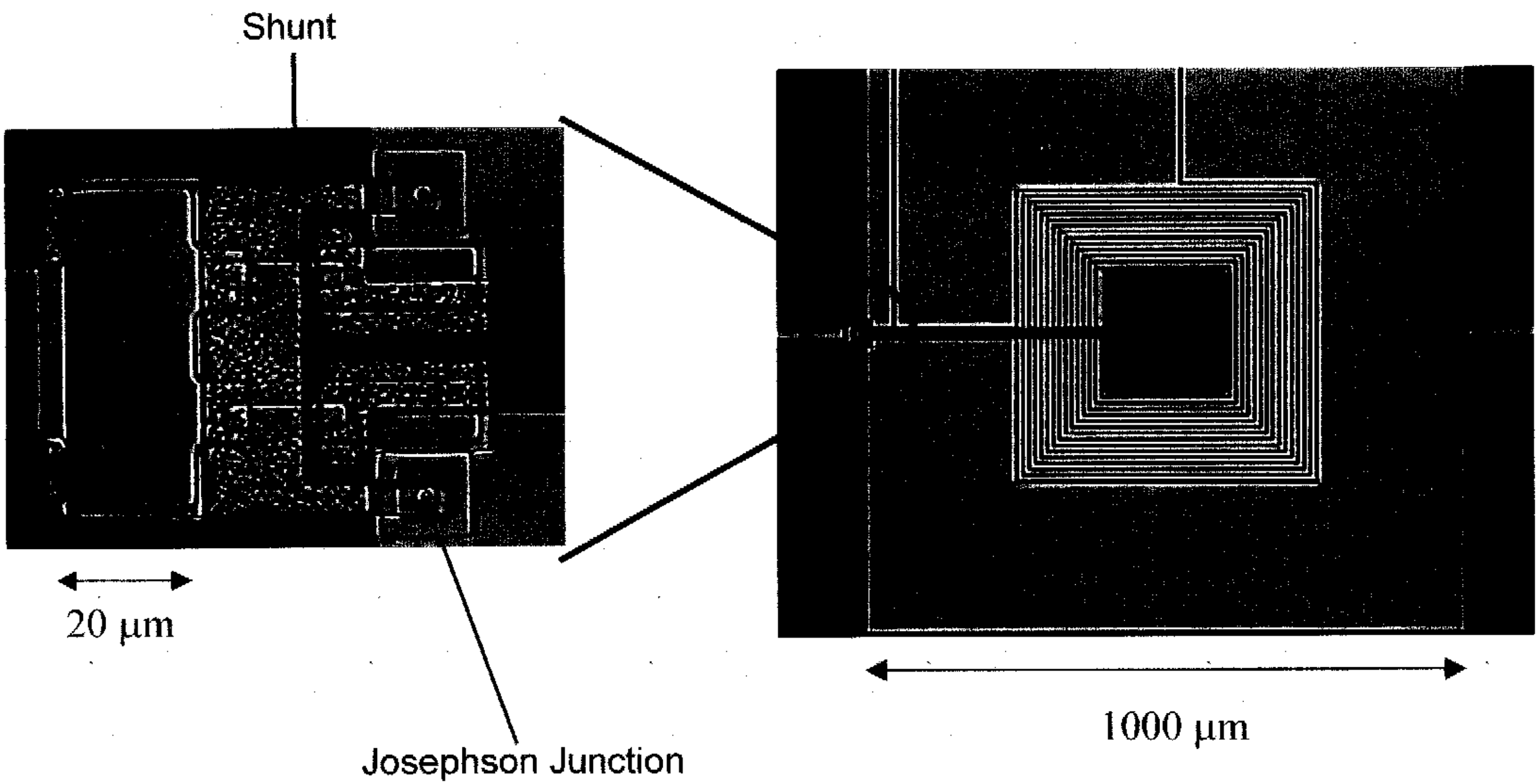




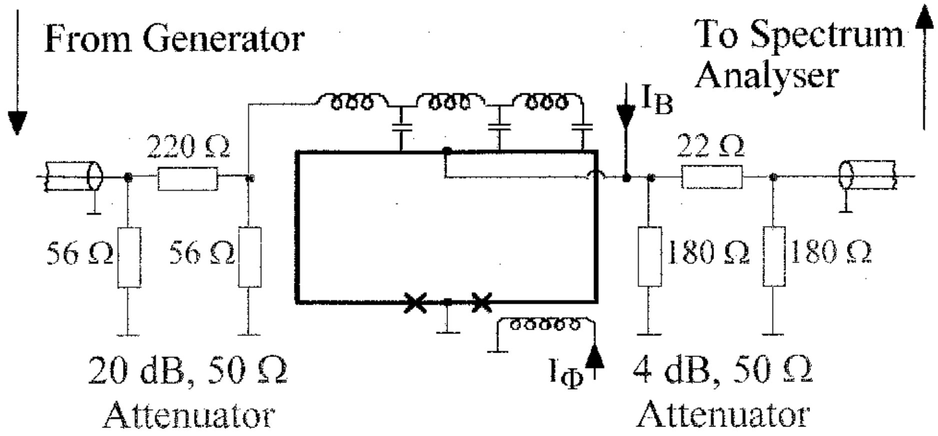
Square Washer dc SQUID

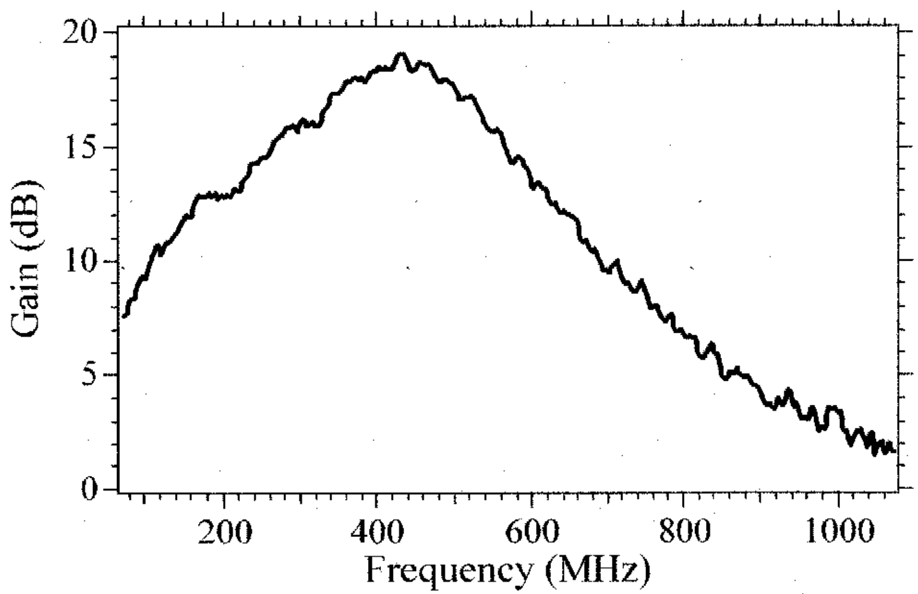


What the devices look like



Gain Measurements





- **Gain of 11-turn microstrip SQUID with the washer grounded**

Microstrip λ/2 Resonance Frequency f_o

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- **To a reasonable approximation, for a coil of *n* turns and length ℓ :**

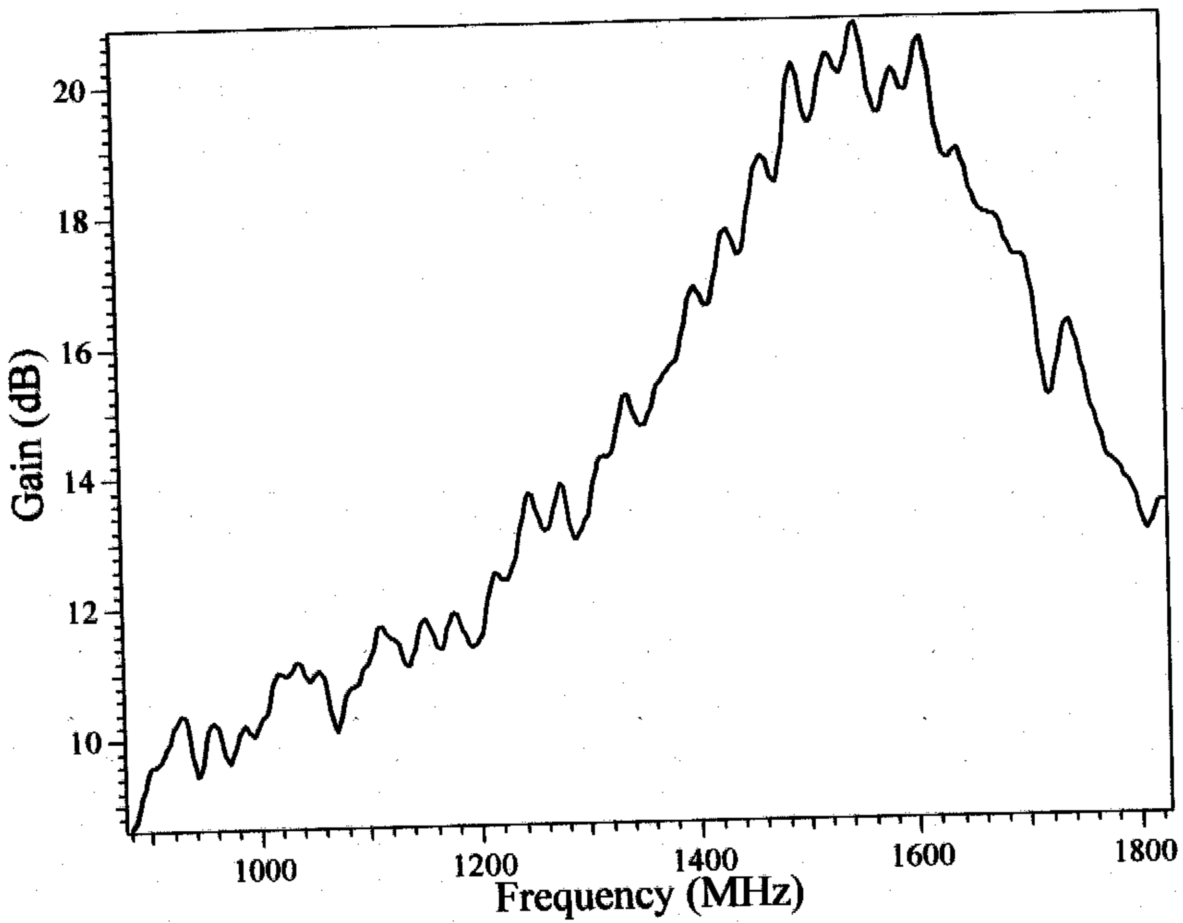
$$f_o \approx \frac{\bar{c}}{2\ell}$$

$$\text{where } \bar{c} \approx \frac{1}{\sqrt{C_o L_i / \ell}}$$

C_o = capacitance per unit length

$L_i = n^2 L$, where L = SQUID Inductance (Ketchen - Jaycox)

Gain of 6-turn Microstrip SQUID



Gain vs. Coil Length

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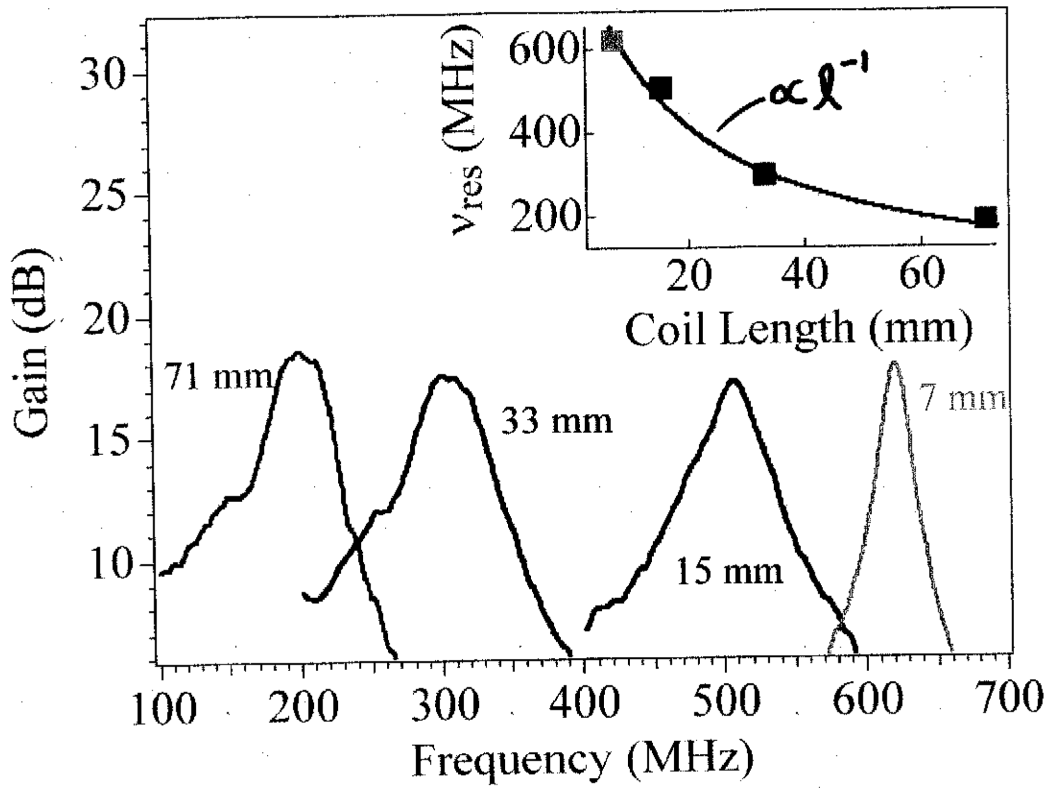
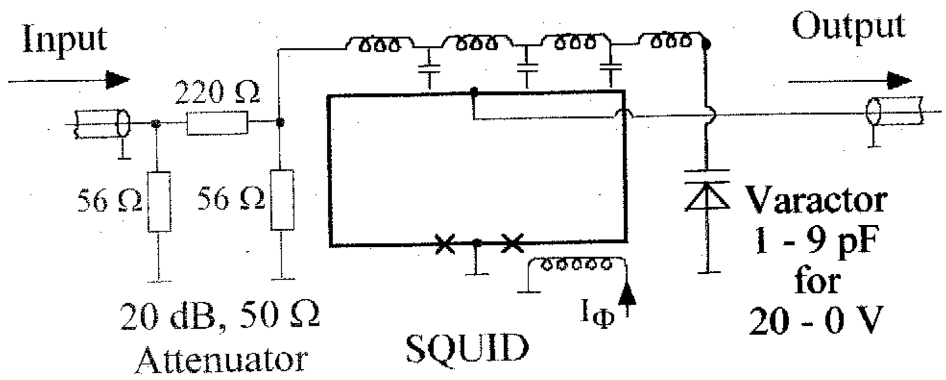
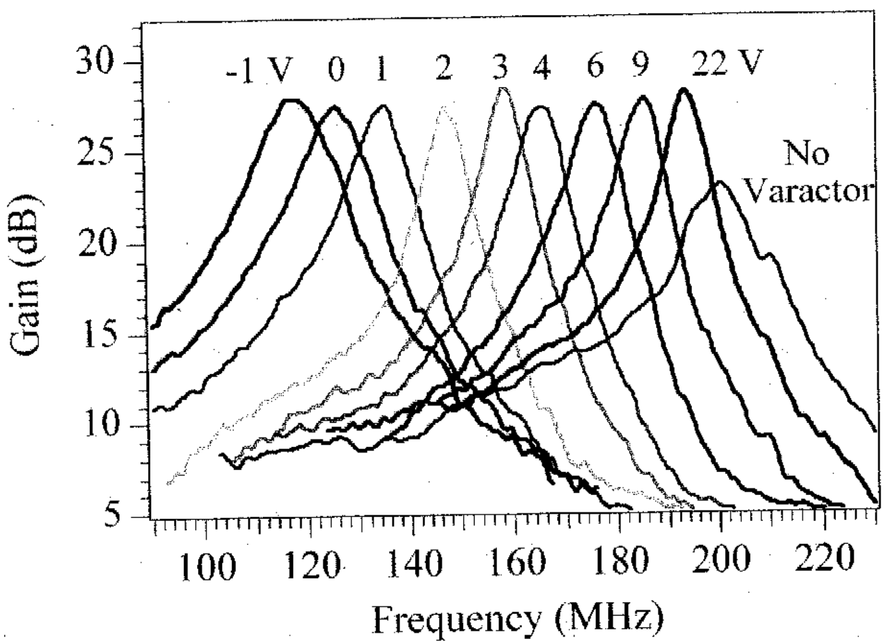


Varactor Tuning of Microstrip SQUID





Noise Temperature Measurements

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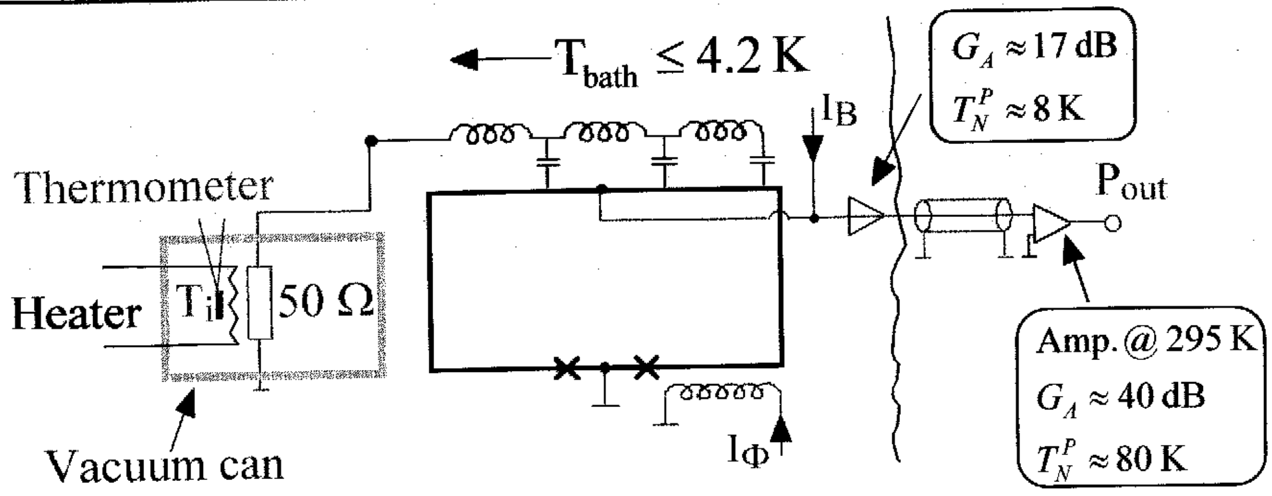
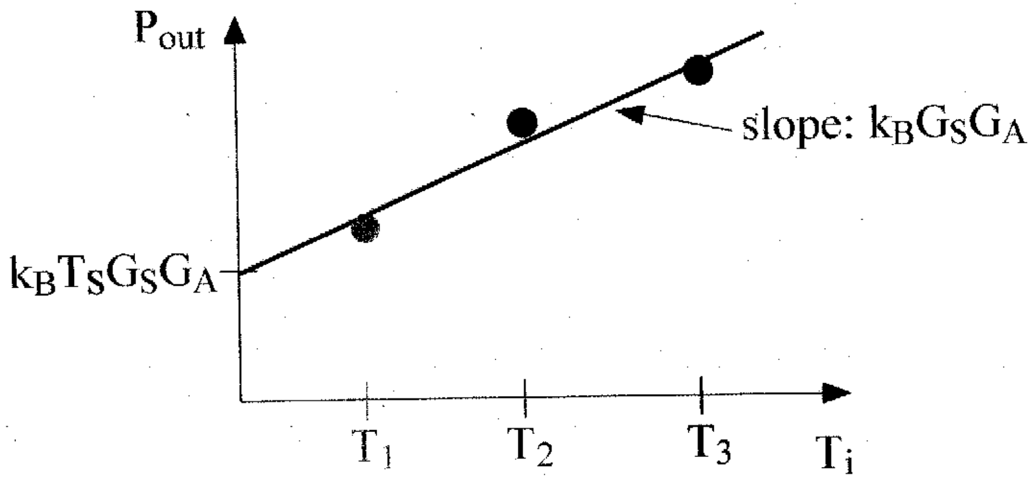


$$P_{out} = k_B(T_i + T_N)G_S G_A + \cancel{k_B T_N^P G_A}$$



Noise Temperature of 31-turn SQUID with Room-temperature Postamplifier

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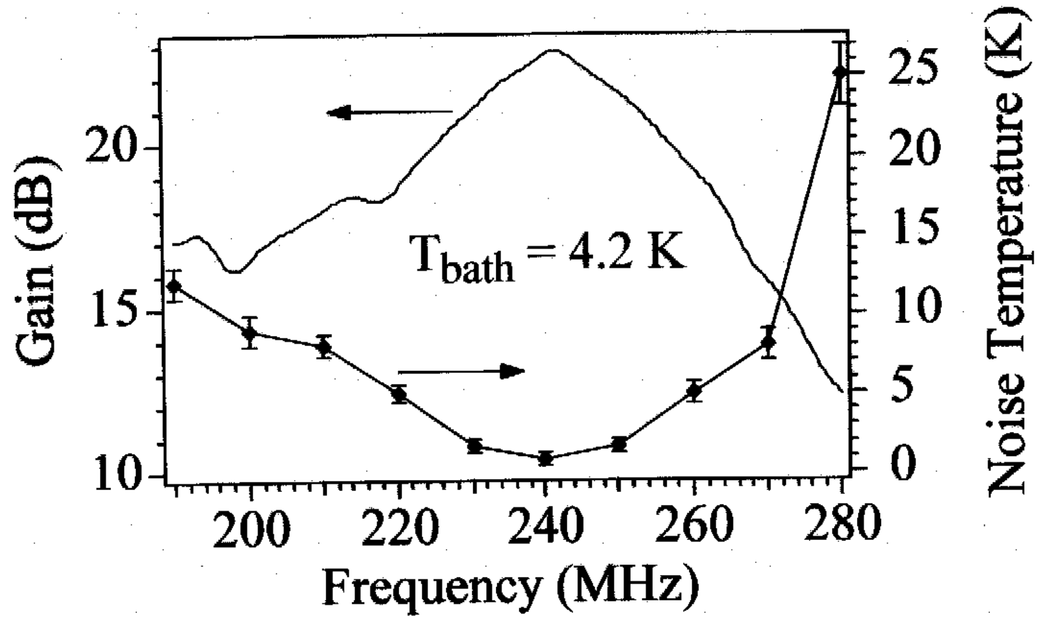

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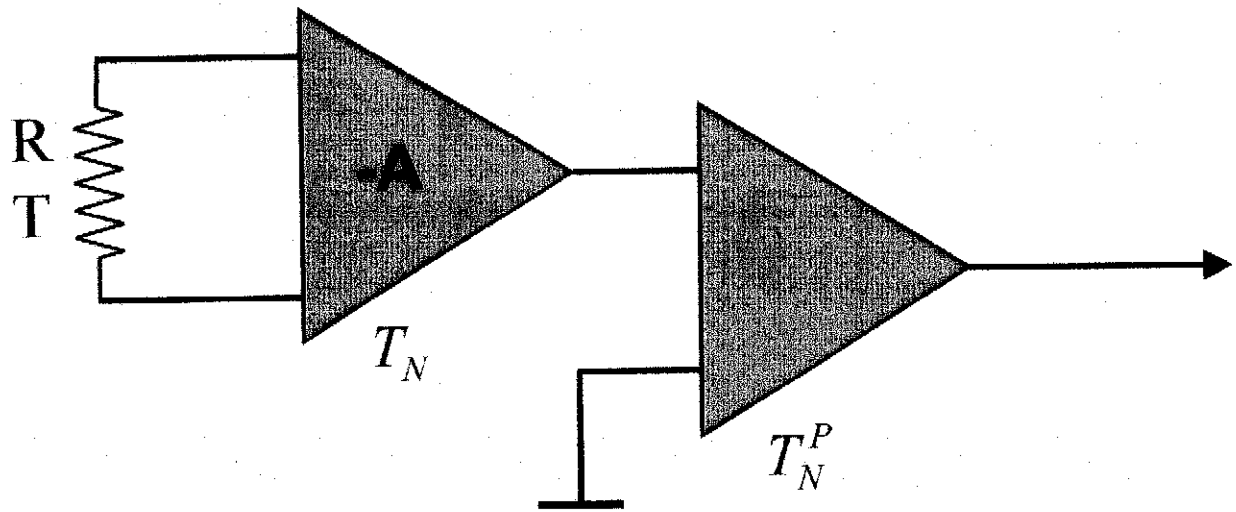
Postamplifier Noise



$$T_N^{sys} = T_N + T_N^P / G \qquad (G = A^2)$$

Thus, require $T_N^P << GT_N$

Noise Temperature of 31-turn SQUID with Cooled HEMT Postamplifier

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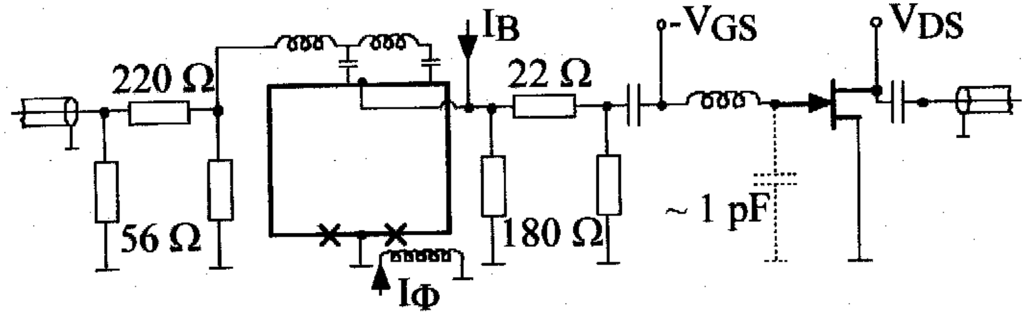

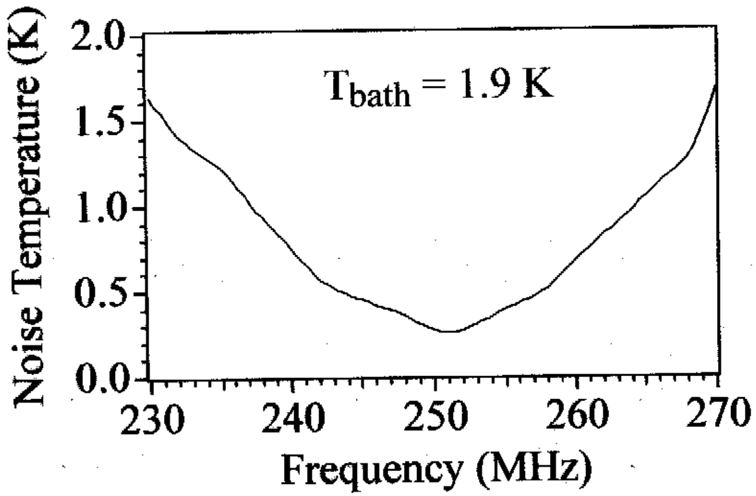

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SQUID Postamplifier

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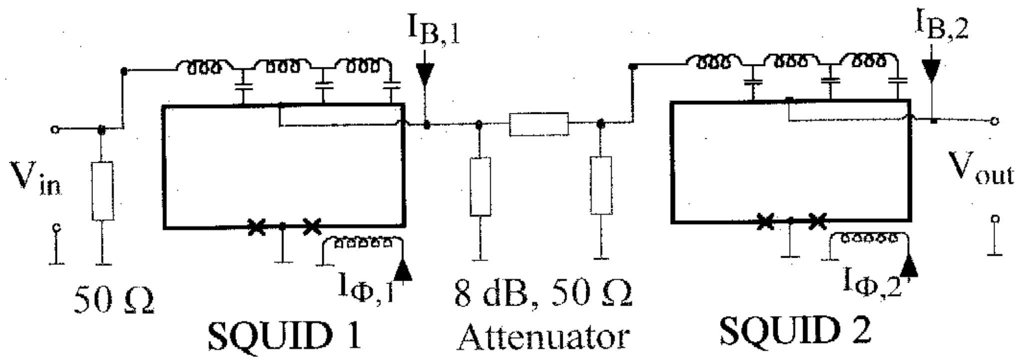

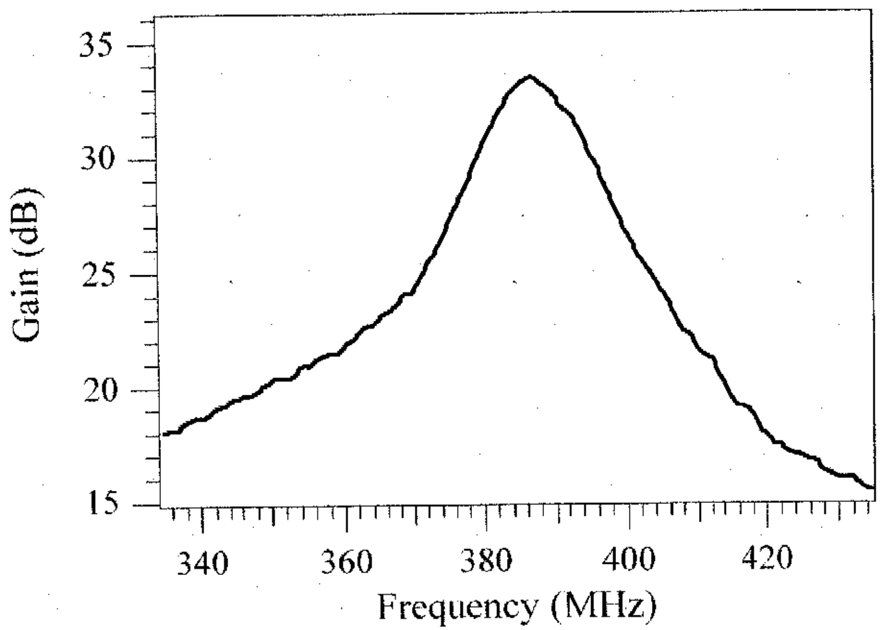

Noise Measurements at mK Temperatures

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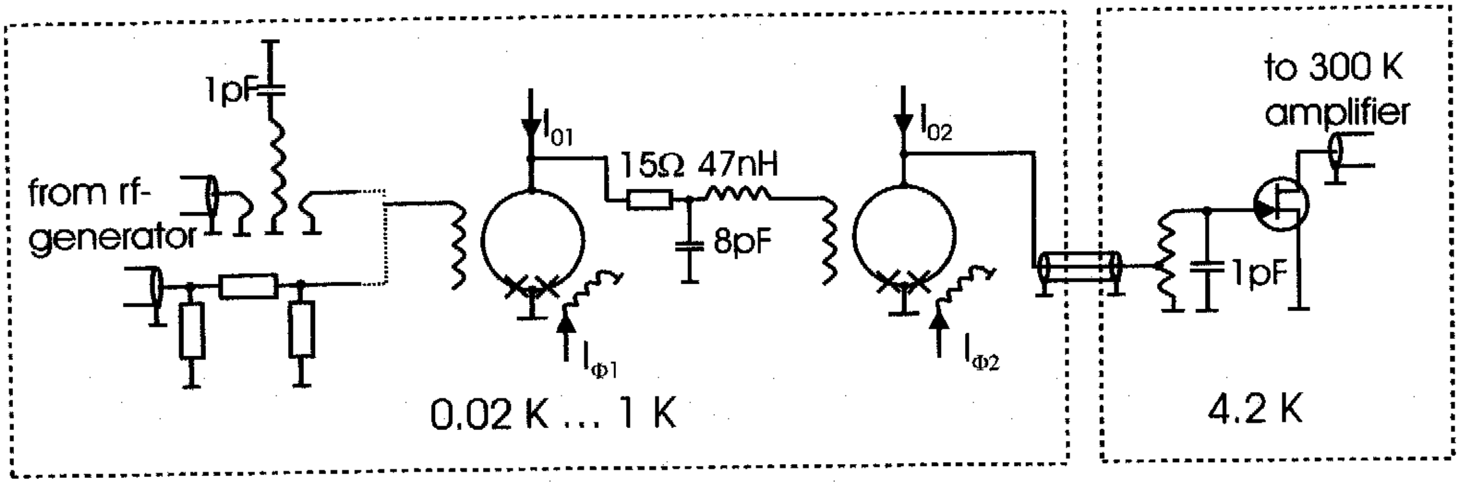

Noise Temperature at 519 MHz vs. Bath Temperature: Resonant Source

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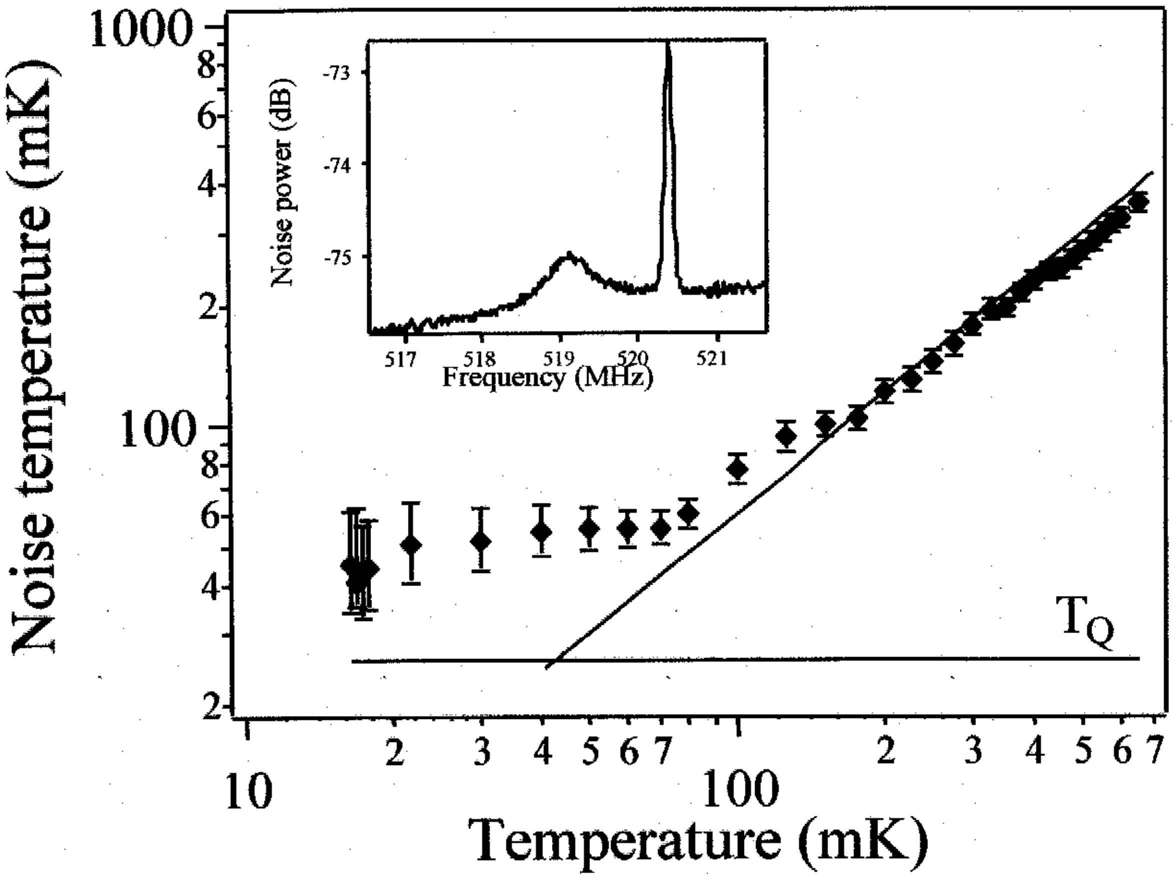

Noise Energy at 140 kHz vs. Bath Temperature

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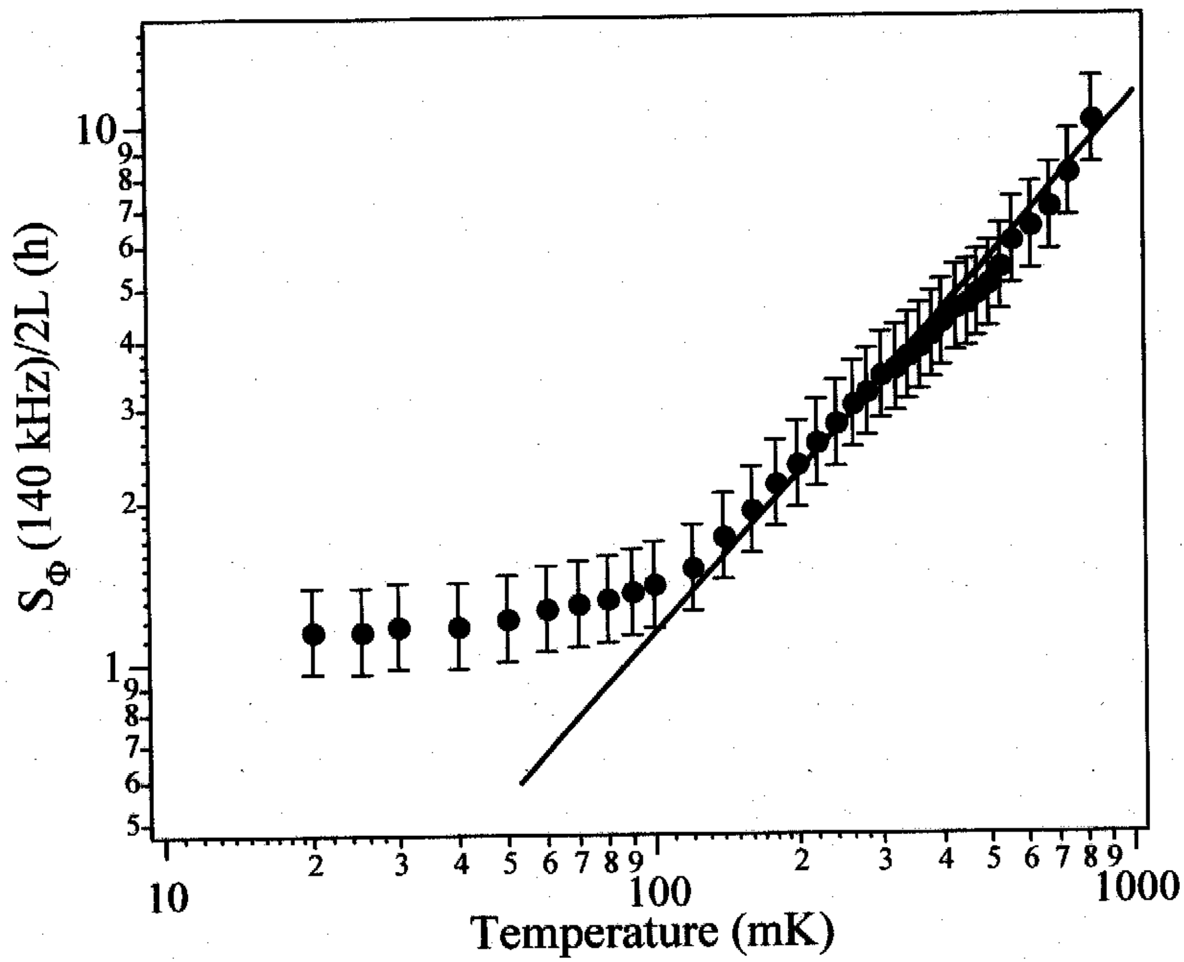

Concluding Remarks

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- Summary
  - Gain > 20 dB for frequencies < 1 GHz
  - Frequency is tunable over factor of 2 with varactor diode
  - At ^4He temperatures, $T_N < 1$ K
  - At 20 mK, T_N is within a factor of two of the quantum limit
    - 40 times lower than state-of-the-art cooled semiconductor amplifiers

- Main issues for axion detector upgrade
  - High-yield, all-Nb SQUID process
  - Packaging
  - Current and flux bias electronics
  - Integration of SQUIDs into the detector

- Research and Development
  - Quantum-limited amplifier (cooling fins)
  - Extension of existing design to higher frequencies (3-5 GHz?)
  - Investigate new designs for much higher frequencies (25 GHz?)

- Other applications
  - Readout of SQUID-based qubits
  - Postamplifier for RFSET - quantum-limited charge detector