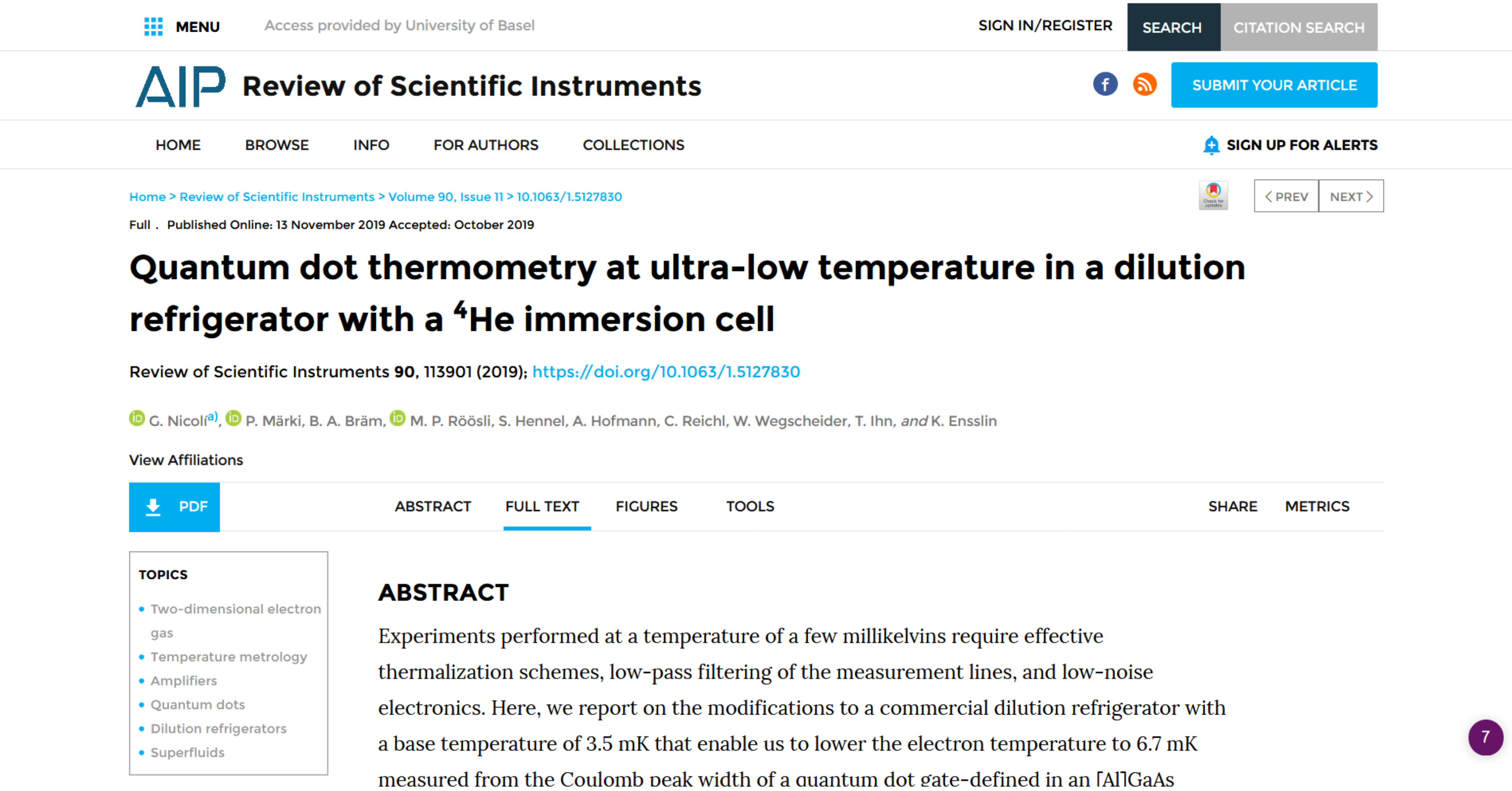

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Quantum dot thermometry at ultra-low temperature in a dilution refrigerator with a ^{4}He immersion cell

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View Affiliations

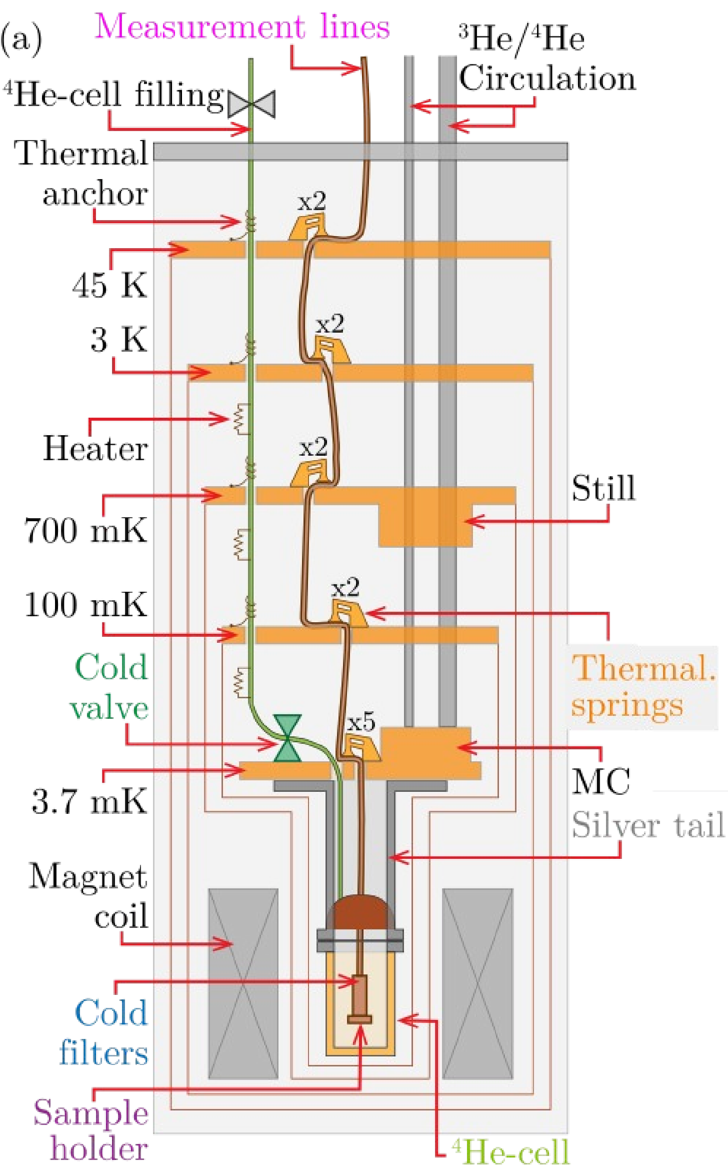
TOPICS

- Two-dimensional electron gas
- Temperature metrology
- Amplifiers
- Quantum dots
- Dilution refrigerators
- Superfluids

ABSTRACT

Experiments performed at a temperature of a few millikelvins require effective thermalization schemes, low-pass filtering of the measurement lines, and low-noise electronics. Here, we report on the modifications to a commercial dilution refrigerator with a base temperature of 3.5 mK that enable us to lower the electron temperature to 6.7 mK measured from the Coulomb peak width of a quantum dot gate-defined in an [Al]GaAs

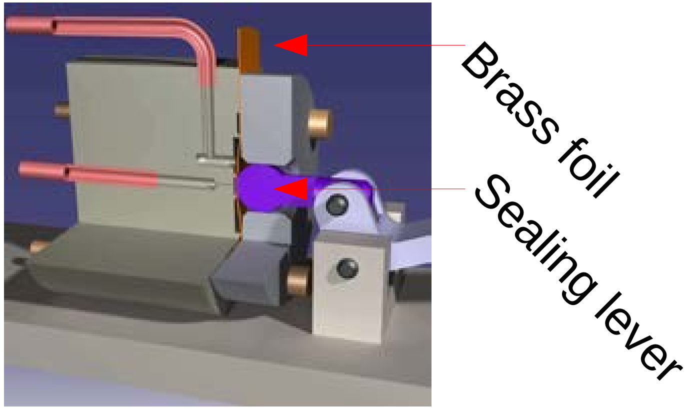
Mohammad Samani – December 6, 2019

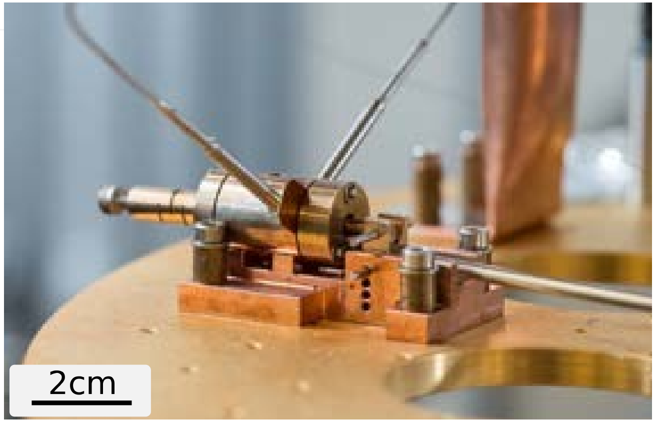


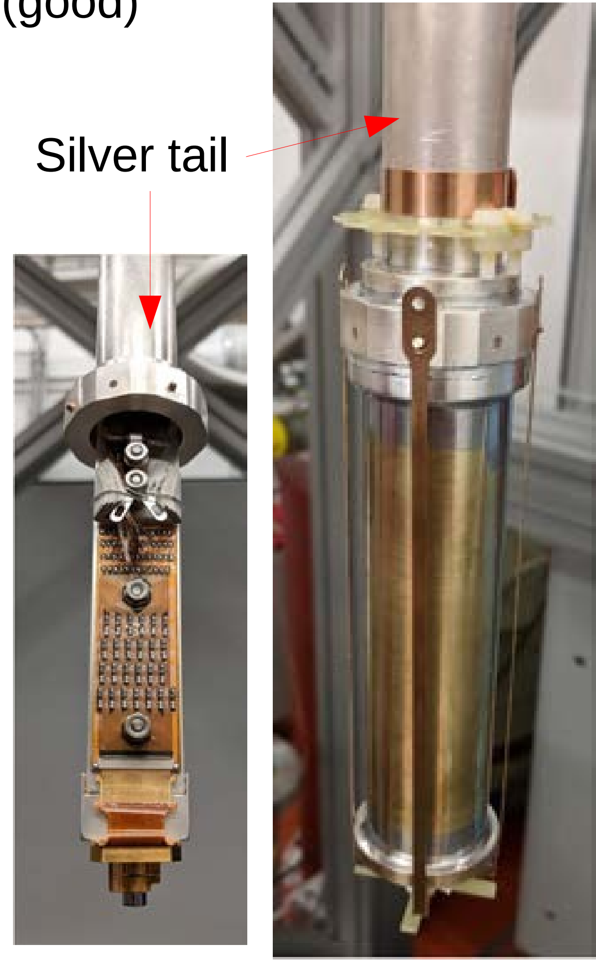
A. The Immersion Cell

At 2.2K ^{4}He phase-transitions to super-fluid

- No temperature gradient (good)
- No viscosity (bad)

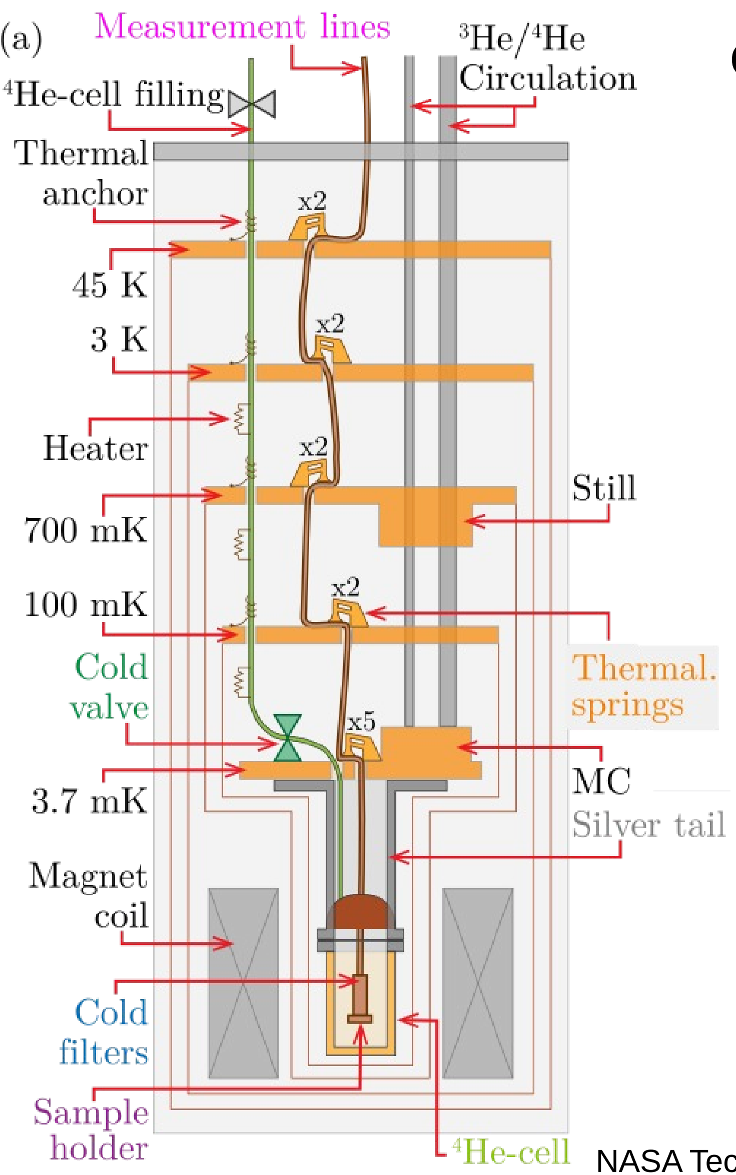


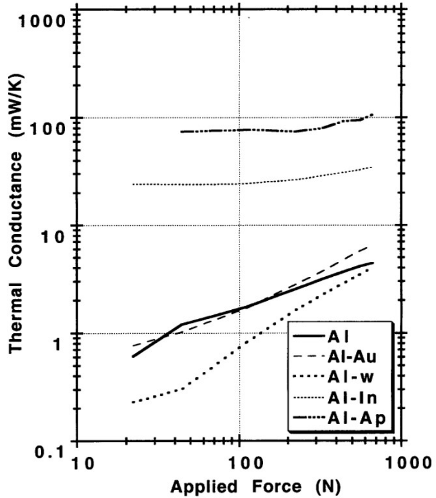




C. Measurement Lines

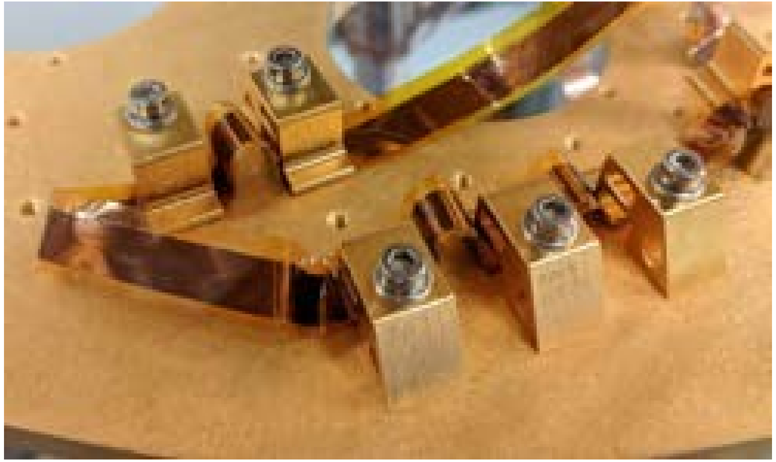
Replace coaxial wires with flat-band wires



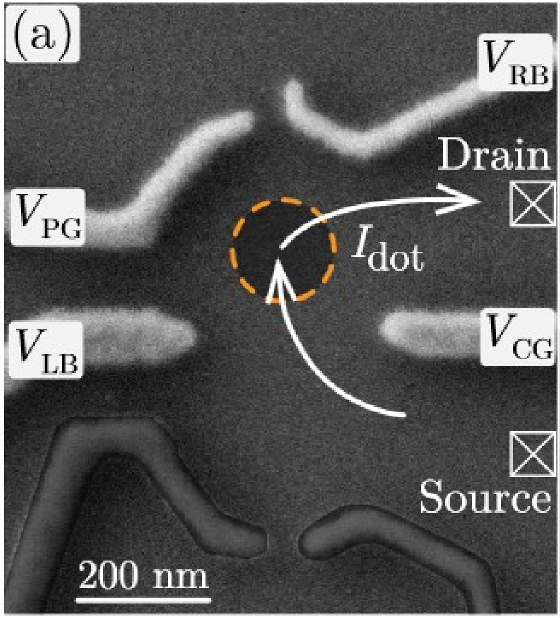


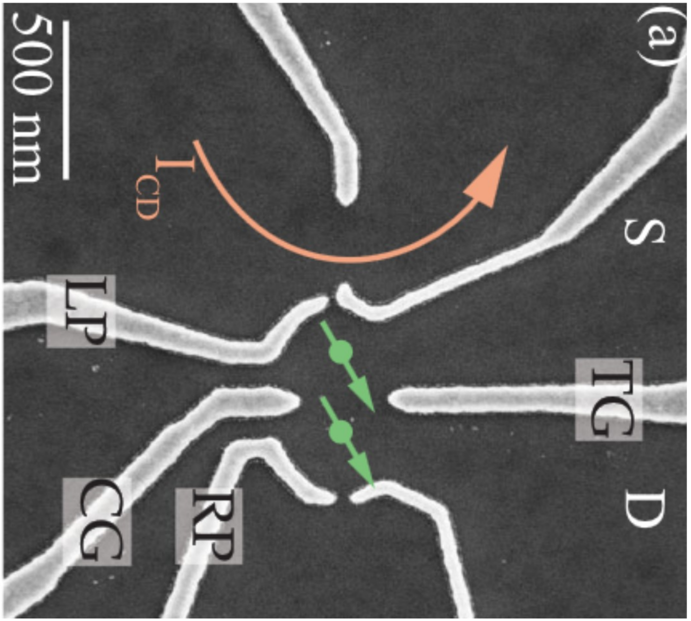
NASA Technical Memorandum 110429

Applies 500N



III. Quantum Dot Thermometry





GaAs/AlGaAs heterostructure 2DEG depleted to the last dot

Quantum dot thermometry:

i. conduction through the dot in a single level

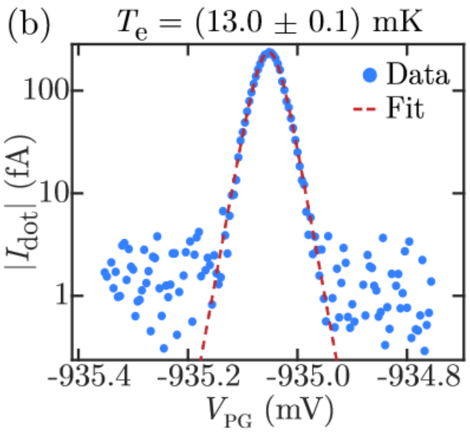
ii. tunnel coupling broadening

$$\Gamma \ll k_B T$$

iii. small source-drain bias

$$eV_{sd} < 4k_B T$$

=> Small dot, low occupation number



$$I_{dot} = \frac{I_0}{\cosh\left[\alpha e(V_{PG} - V_0)/2k_B T\right]}$$

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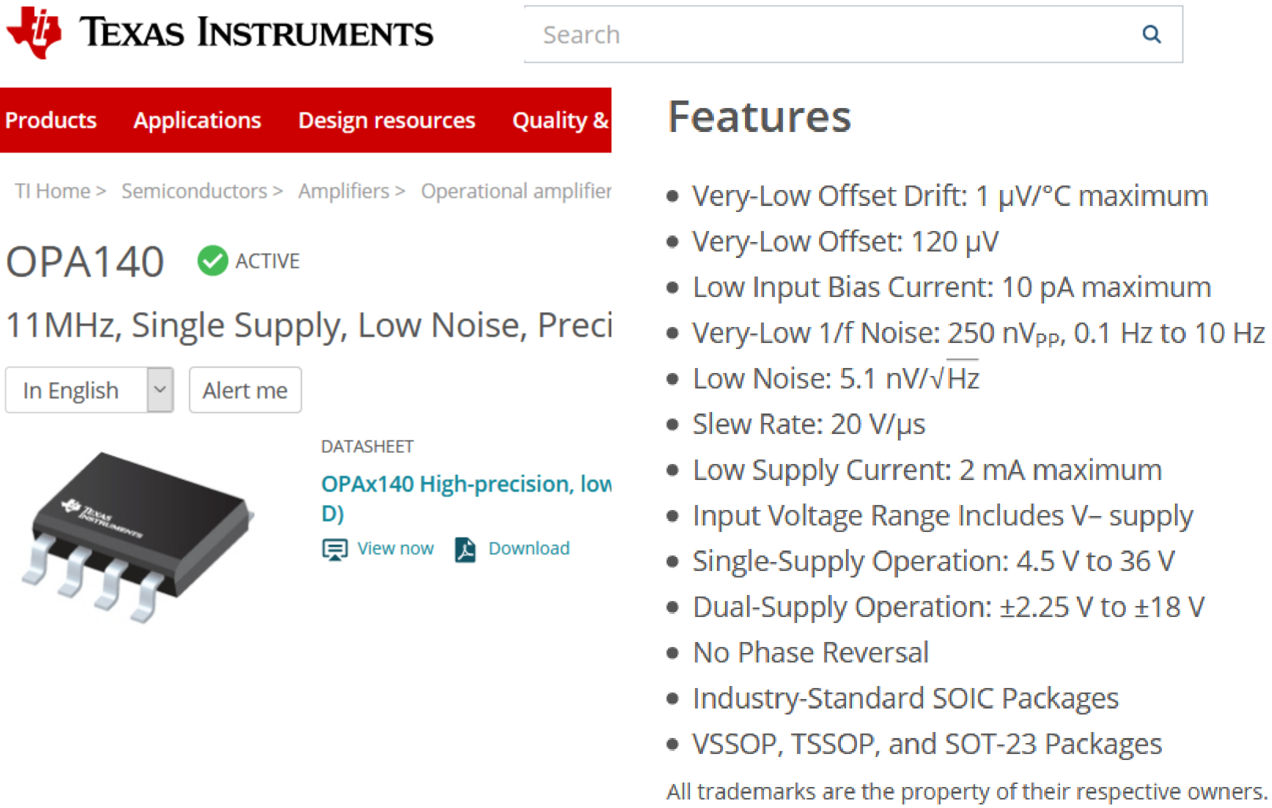
S1. Standard DC Measurement. T_e=13.0mK

ETH In-house IV Converter
8nV/√Hz @ 33Hz input noise

BasPI IV Converter
2nV/√Hz @ 10Hz input noise



TI Home > Semiconductors > Amplifiers > Operational amplifier

OPA140 ACTIVE

11MHz, Single Supply, Low Noise, Preci

DATASHEET

OPAx140 High-precision, low
D)

Features

- Very-Low Offset Drift: 1 µV/°C maximum
- Very-Low Offset: 120 µV
- Low Input Bias Current: 10 pA maximum
- Very-Low 1/f Noise: 250 nV$_{PP}$, 0.1 Hz to 10 Hz
- Low Noise: 5.1 nV/√Hz
- Slew Rate: 20 V/µs
- Low Supply Current: 2 mA maximum
- Input Voltage Range Includes V– supply
- Single-Supply Operation: 4.5 V to 36 V
- Dual-Supply Operation: ±2.25 V to ±18 V
- No Phase Reversal
- Industry-Standard SOIC Packages
- VSSOP, TSSOP, and SOT-23 Packages

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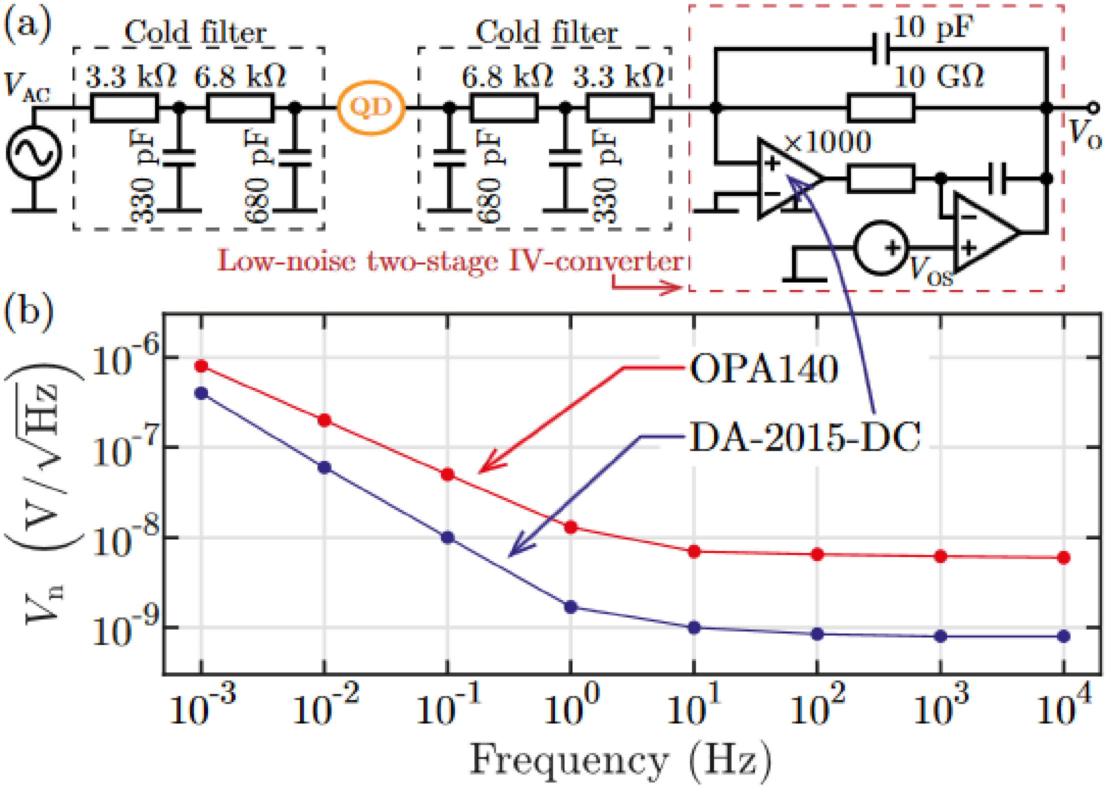
S2. Improve filtering. T_e=11.2mK (Underwhelming step)

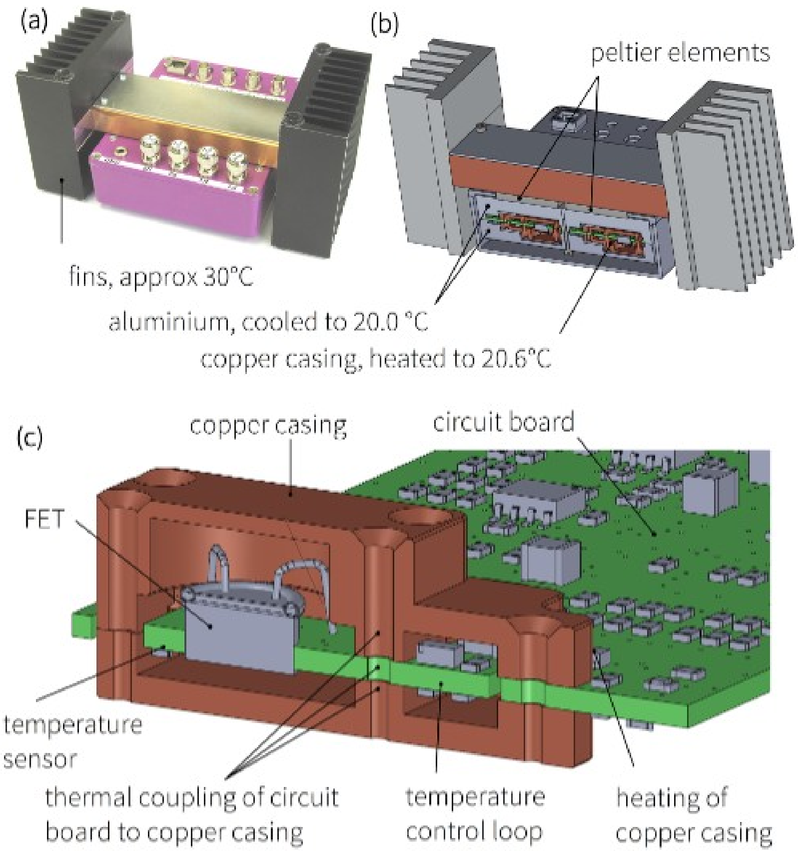
DAC output filter from 4ms to 22ms

It’s important to keep V_0 constant

S3. Replace IV Converter. T_e=9.49mK



Thermal stablization



Johnson noise of 1MΩ is 1nV/√Hz @ 10mK

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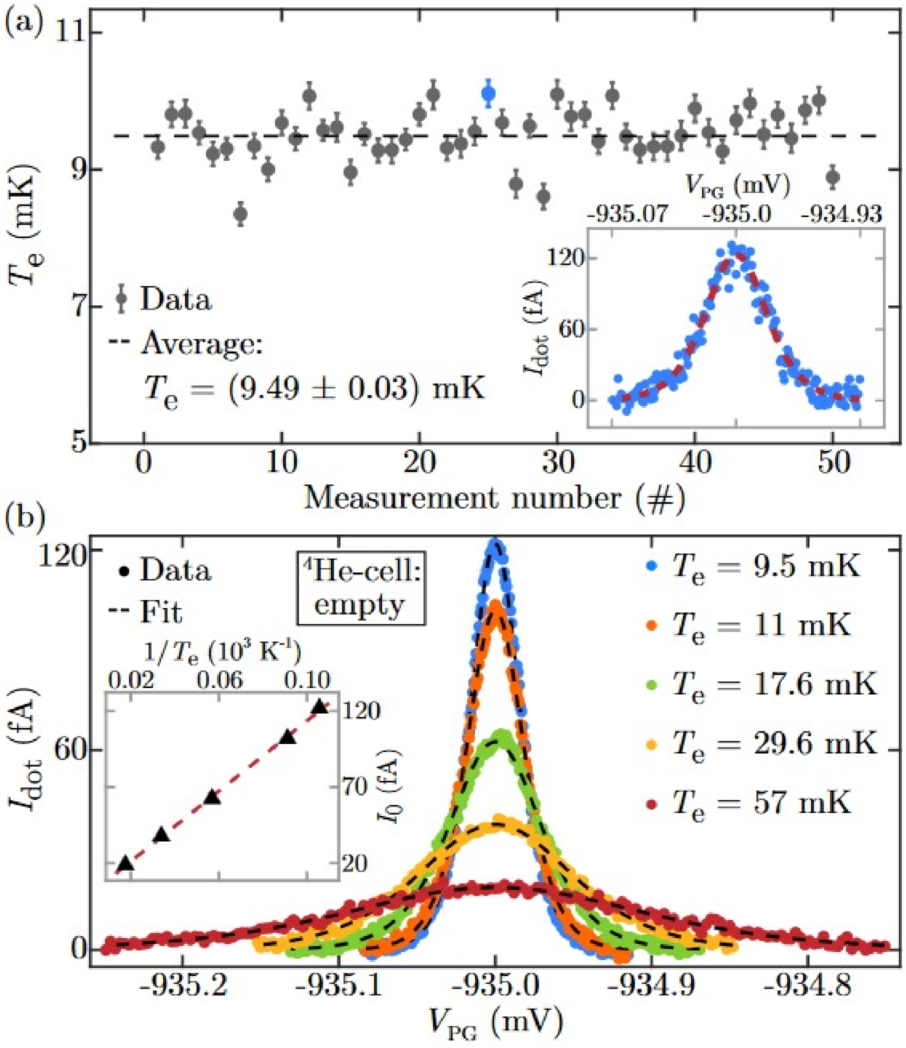
S3. Replace IV Converter. T_e=9.49mK



Fast measurements when 1/f is present

Standard deviation vs. Standard error

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n-1}}$$

$$(\sigma_{\bar{x}}) = \frac{\sigma}{\sqrt{n}}$$

S4. Fill the immersion cell. T_e=8.20mK

S5. Faster measurements. T_e=7.45mK

S6. Pulse-tube off. T_e=6.74mK

Imperfect thermalization at 40mK