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Sandia National Laboratories

Cryogenic Preamplification using a Heterojunction-Bipolar-Transistor Inline with a Silicon Single-Electron-Transistor

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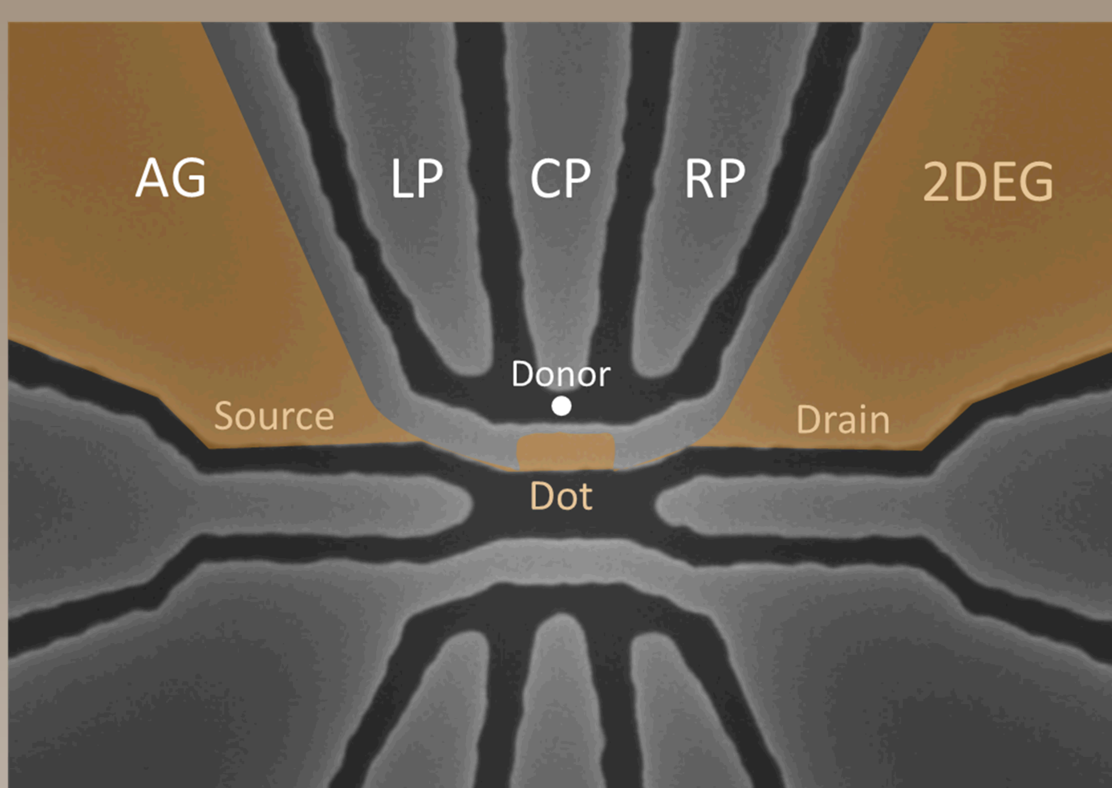
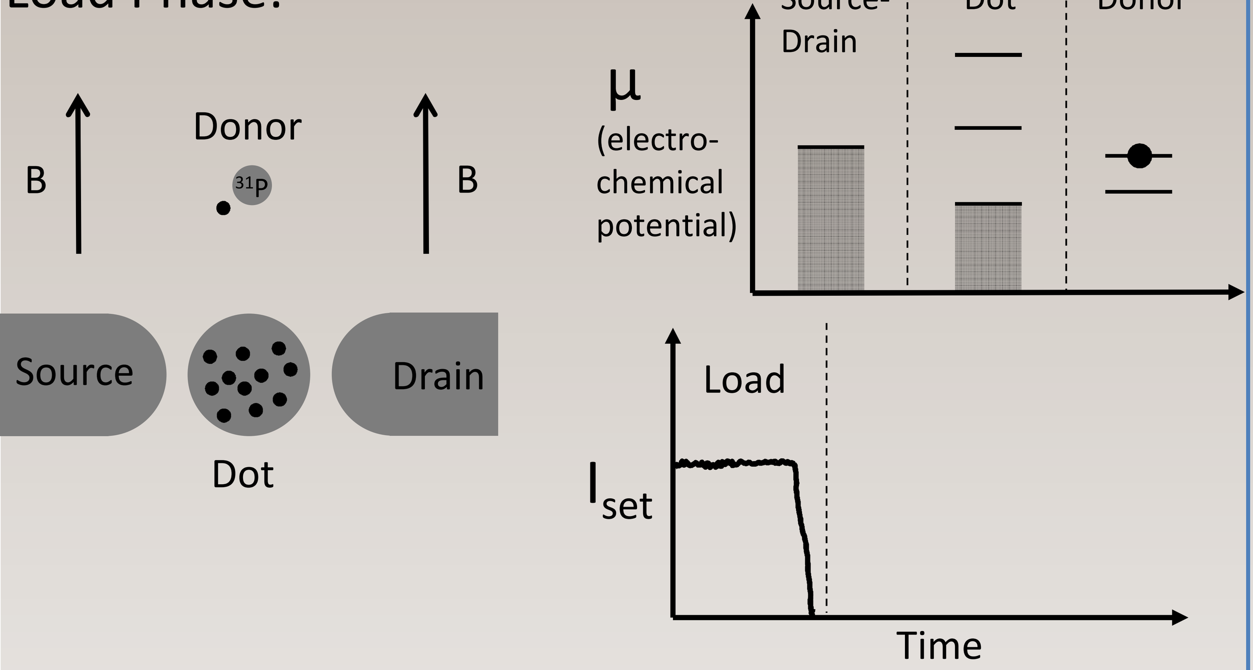
Silicon SET Nanostructure



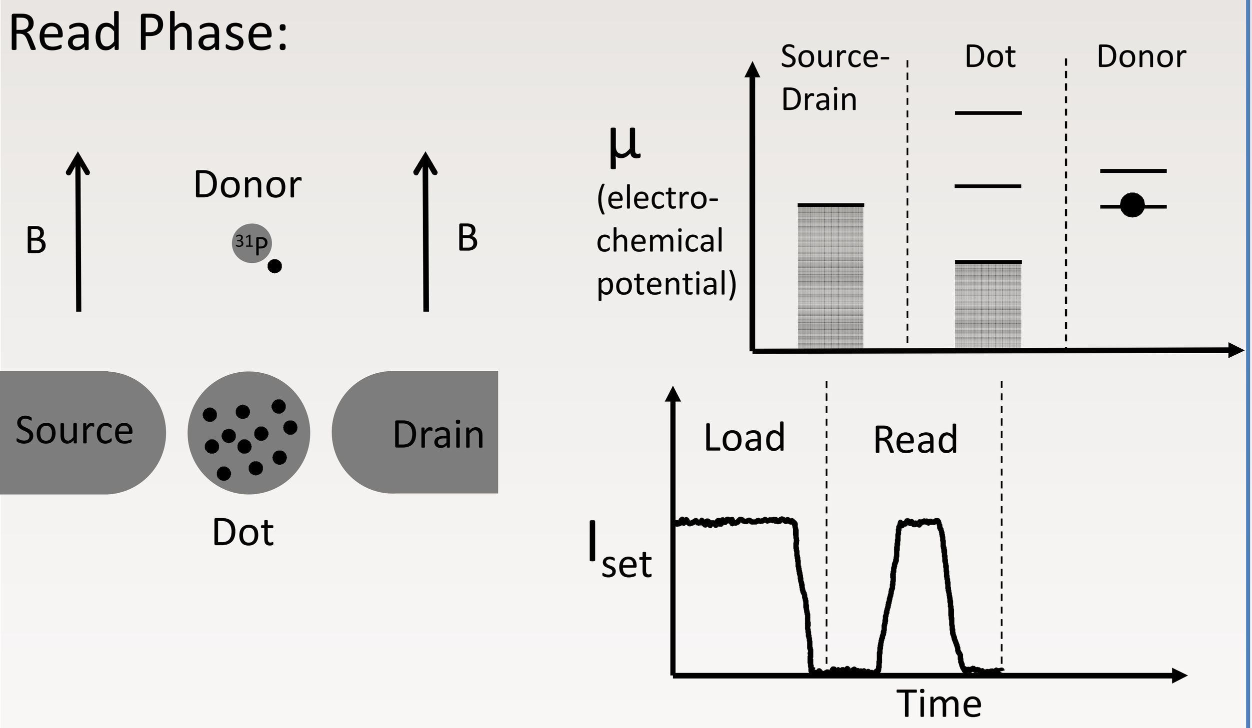
- Fabricated at Sandia National Laboratories.
- Electrostatically defined quantum dot.
- Bulk ^{28}Si for longer coherence.

Single-Shot Donor Spin Readout

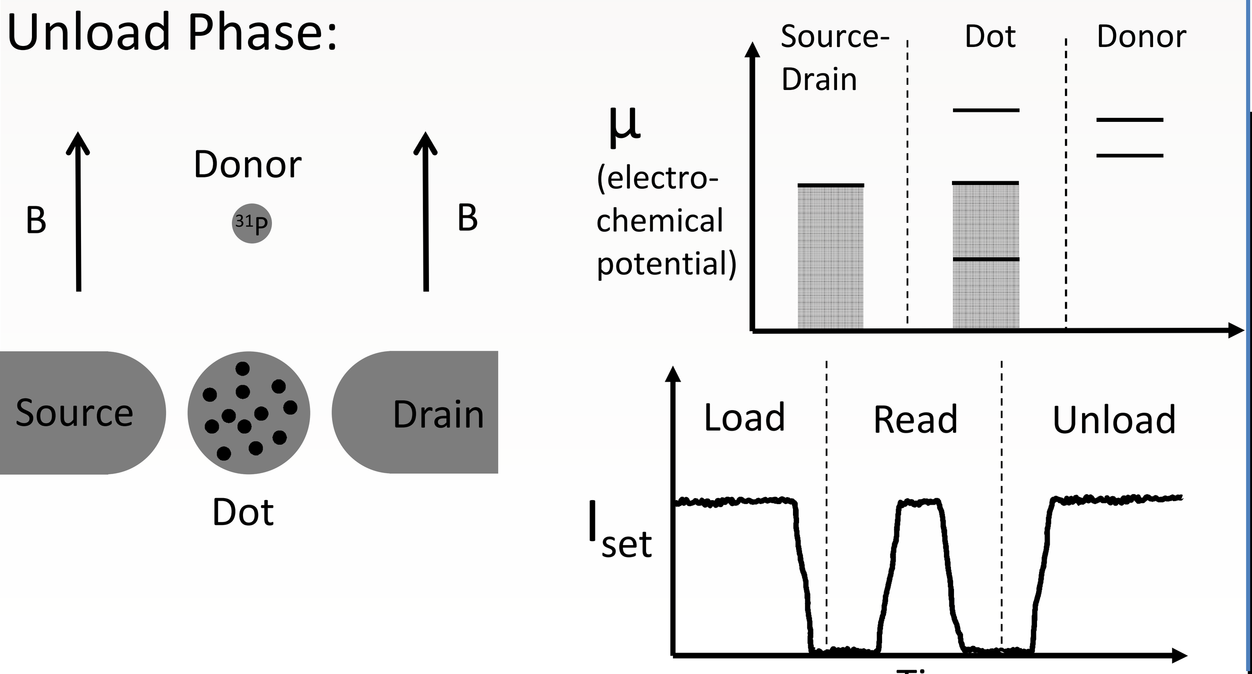
Load Phase:



Read Phase:



Unload Phase:

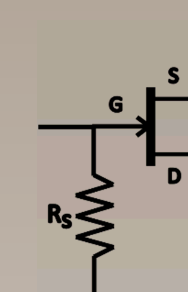


Motivation

- **Goal:** Increase SNR and time resolution for higher fidelity donor spin readout.
- **Approach:** Explore possible benefits of cryogenic, non-linear pre-amplification.
- **Challenges:** Noise, parasitic capacitance, staging, power dissipation, floating drain.

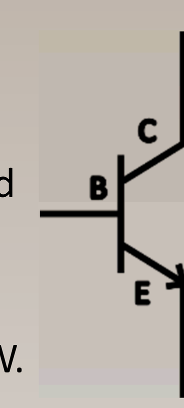
One option: HEMT (High Electron Mobility Transistor)

- Field Effect Transistor (FET).
- Shunting resistor Rs for voltage input.
- DC power dissipation of 10 μW to 1 mW.



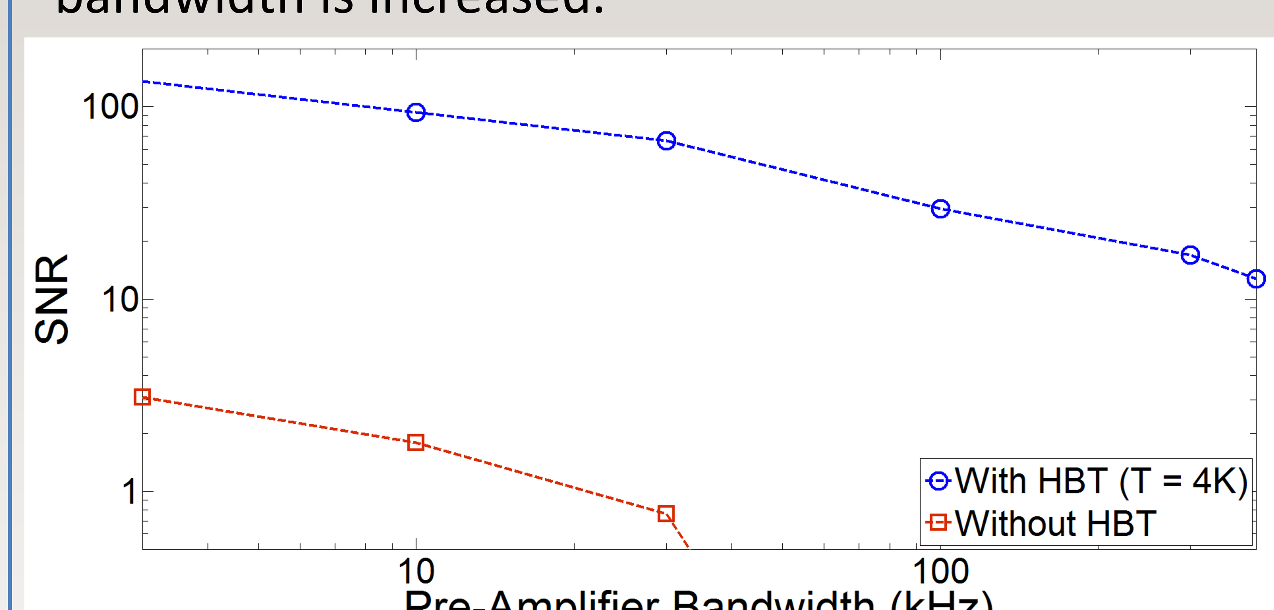
An alternative: HBT (Heterojunction Bipolar Transistor)

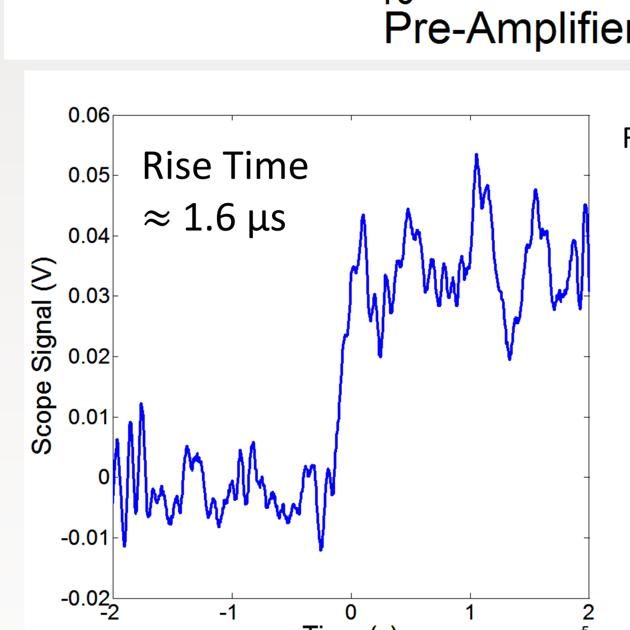
- Bipolar Junction Transistor (BJT)
- Current input into the base.
- We chose a commercial HBT model based on measured performance at low temperature.
- No shunting resistor -> no (Rs*C) time constant.
- We measured a DC power dissipation of 50 nW to 5 μW.



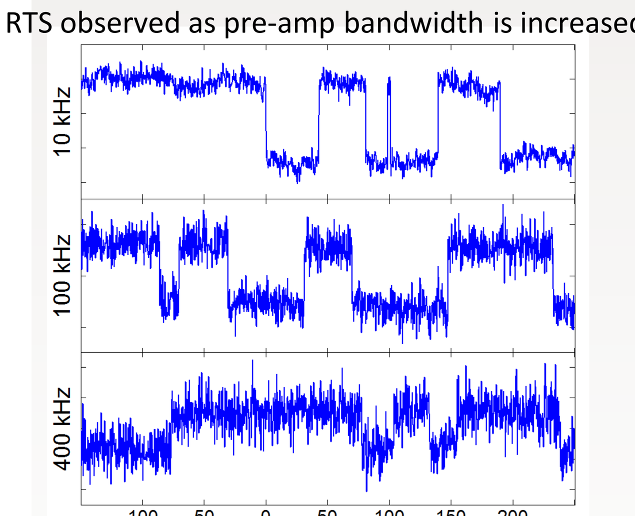
Single-Shot Time-Domain Results

Source is pulsed in Coulomb blockade region and single-shot oscilloscope data is recorded as pre-amp bandwidth is increased.





RTS observed as pre-amp bandwidth is increased

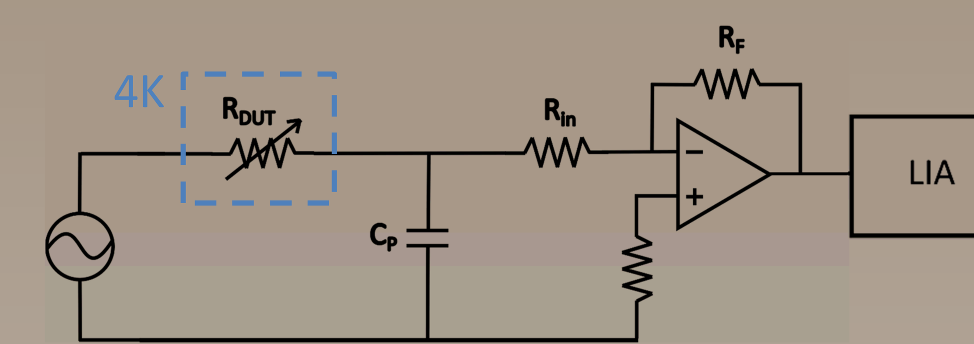


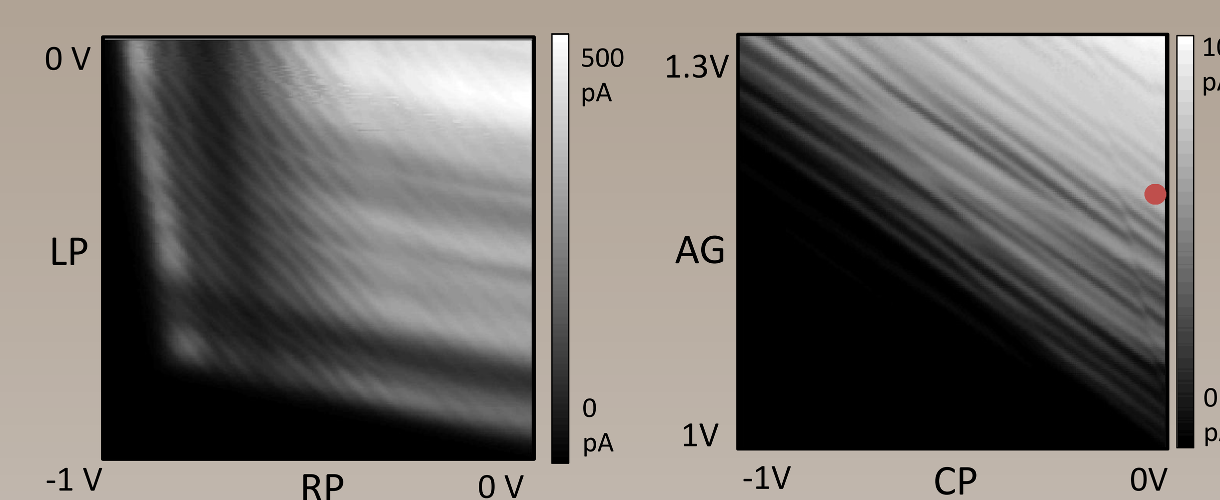
Conclusions

- Calibrated current pulses allow comparison with and without HBT.
- SNR increased by a factor of 10 to 100.
- Measured rise time as low as 1.6 μs.
- DC power dissipation is 50 nW to 5 μW.

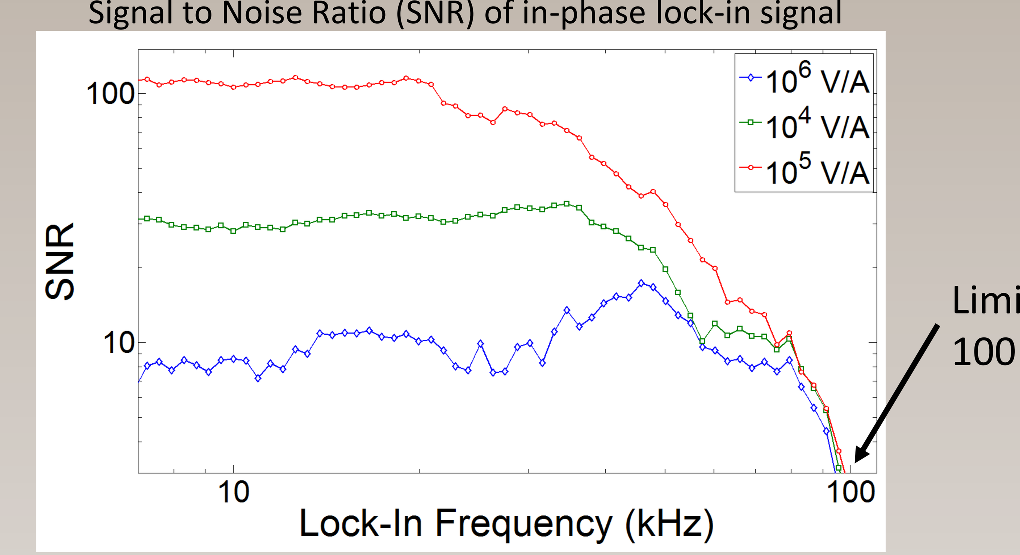
Bandwidth Without HBT

Measurement Circuit:

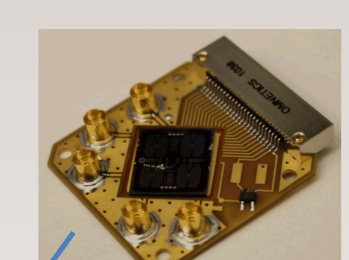




Signal to Noise Ratio (SNR) of in-phase lock-in signal

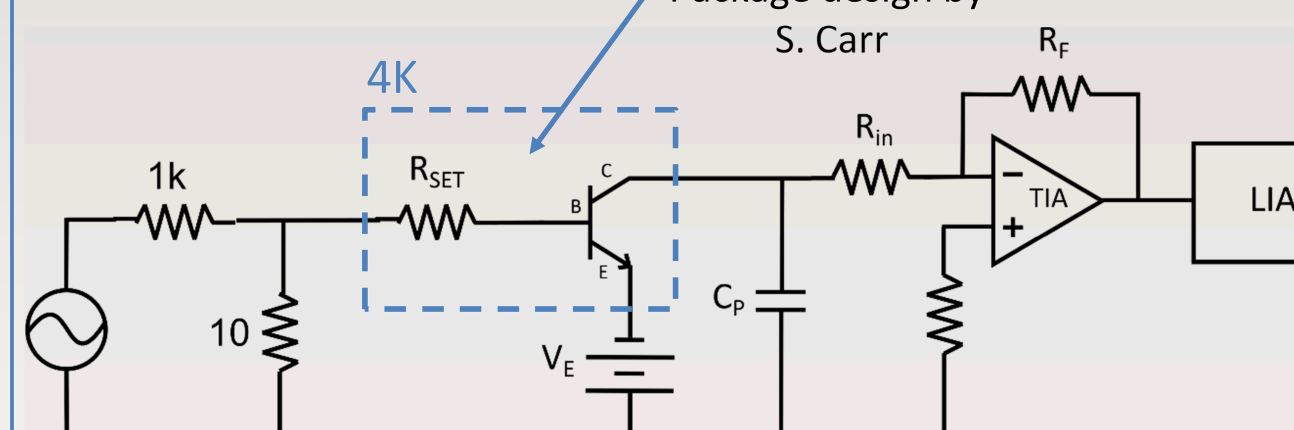


Bandwidth With HBT

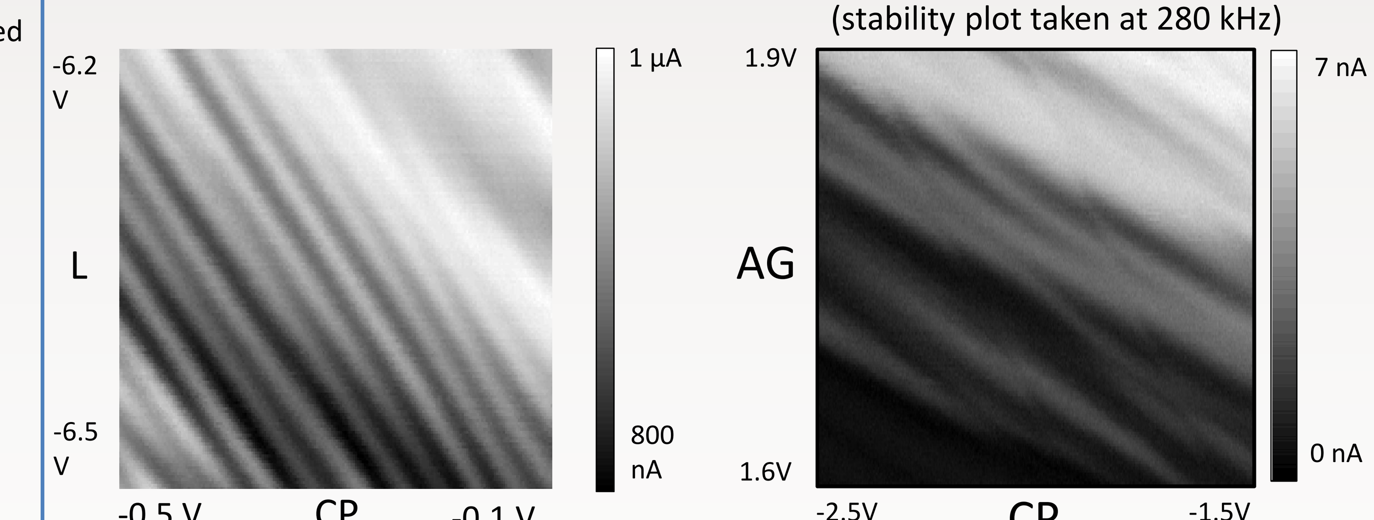


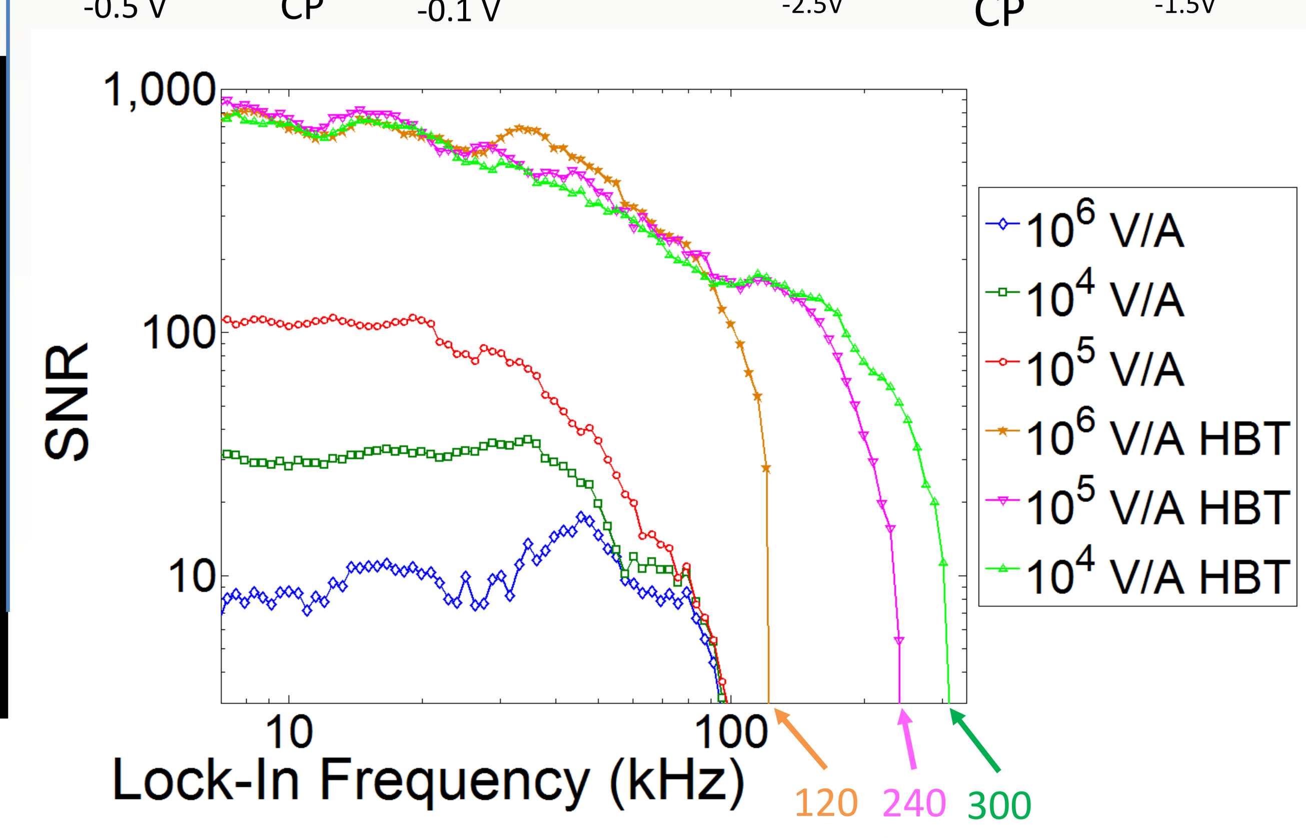
Package design by S. Carr

Measurement Circuit:



(stability plot taken at 280 kHz)





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NNSA National Nuclear Security Administration
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