Tu1B-3

Investigation of drain noise in InP pHEMTs using on-wafer characterization

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Rising Demand for Low Noise Amplification

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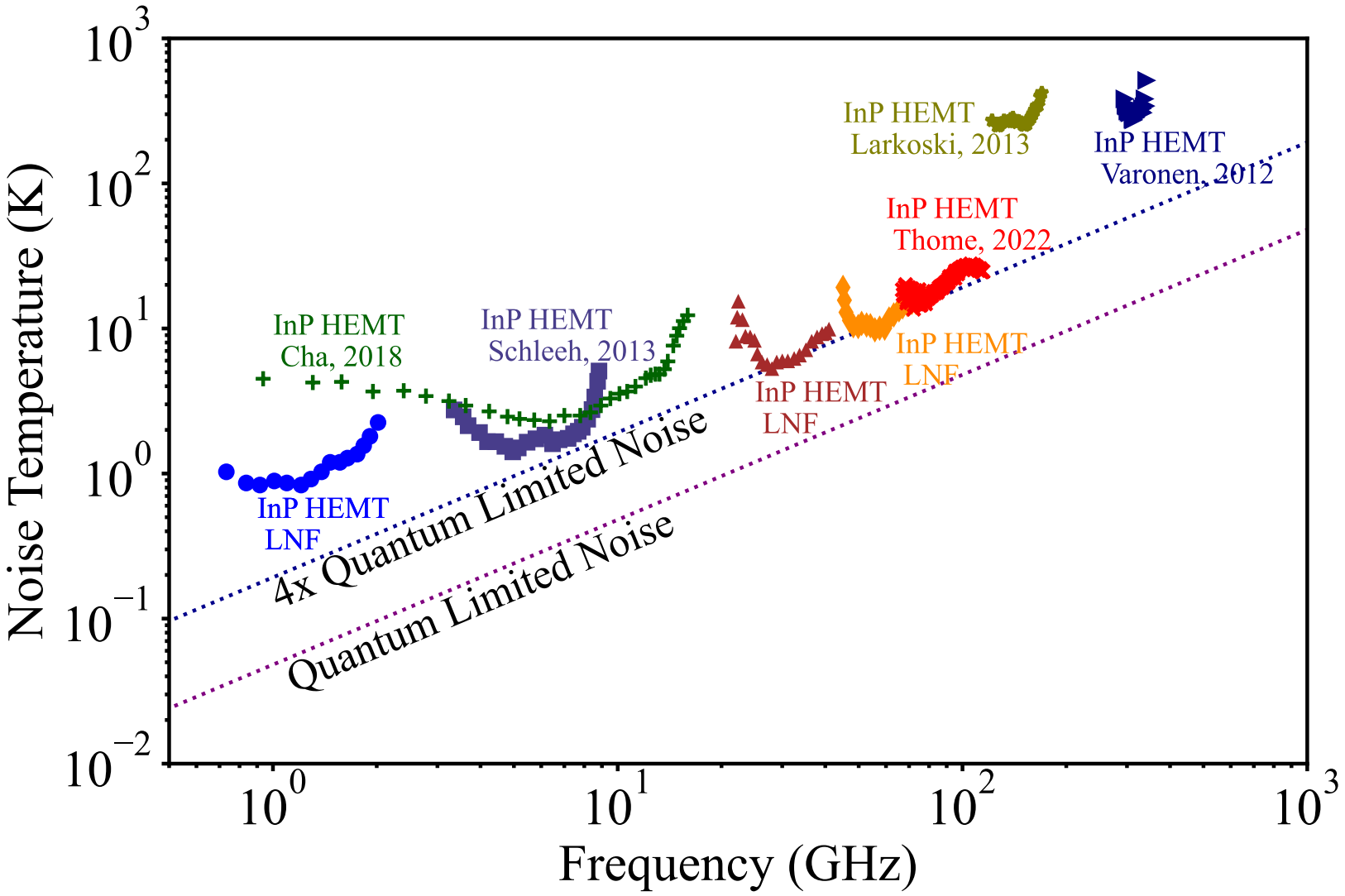
Demand for low noise amplification is driven by :

- Telecommunications (5G, 6G, GPS etc.) [1]
- Military and aerospace(radar, sonar etc.) [2]
- Radio Astronomy (CMB polarization, Galaxy formation etc.) [3]

1. S. Chrisben Gladson et al. (2021), 2. Armin W. Doerry, Sandia Report (2016) 3. Russel, Ph.D thesis, Caltech (2013)

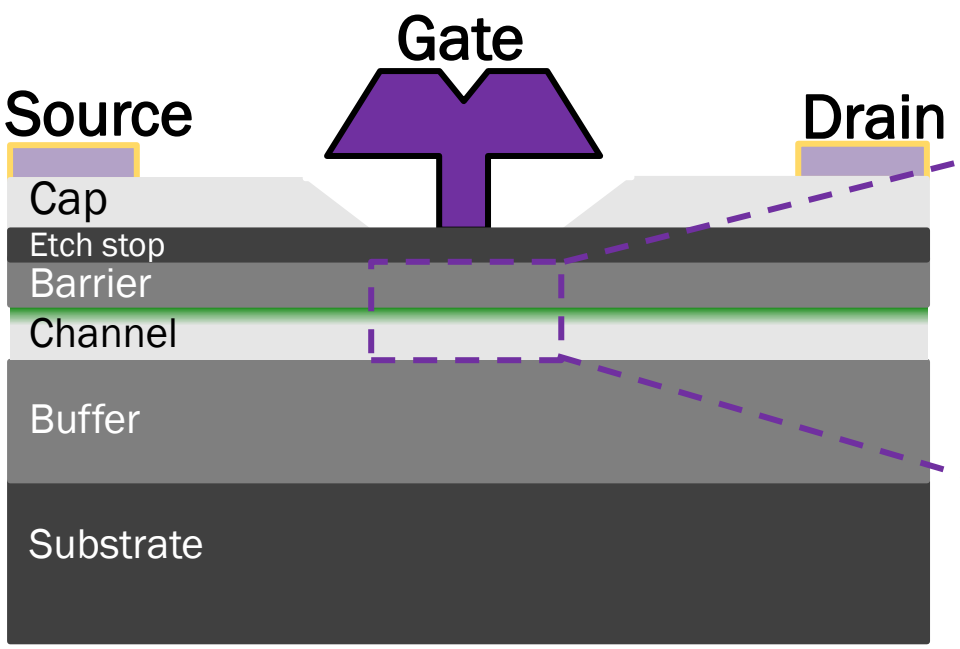
Fundamental Limits of Noise in HEMTs

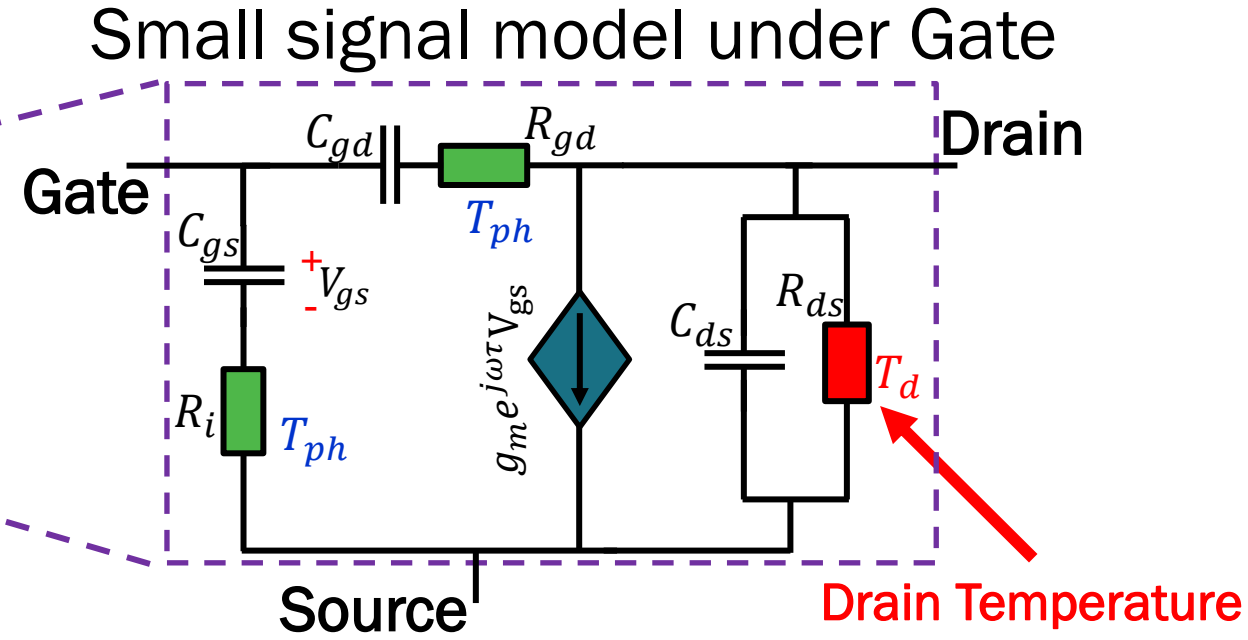


Noise performance of the state-of-the-art LNAs is limited to 4xQuantum Limit.

Why can't we achieve Quantum Limited noise in HEMTs ?

Drain Noise in HEMTs



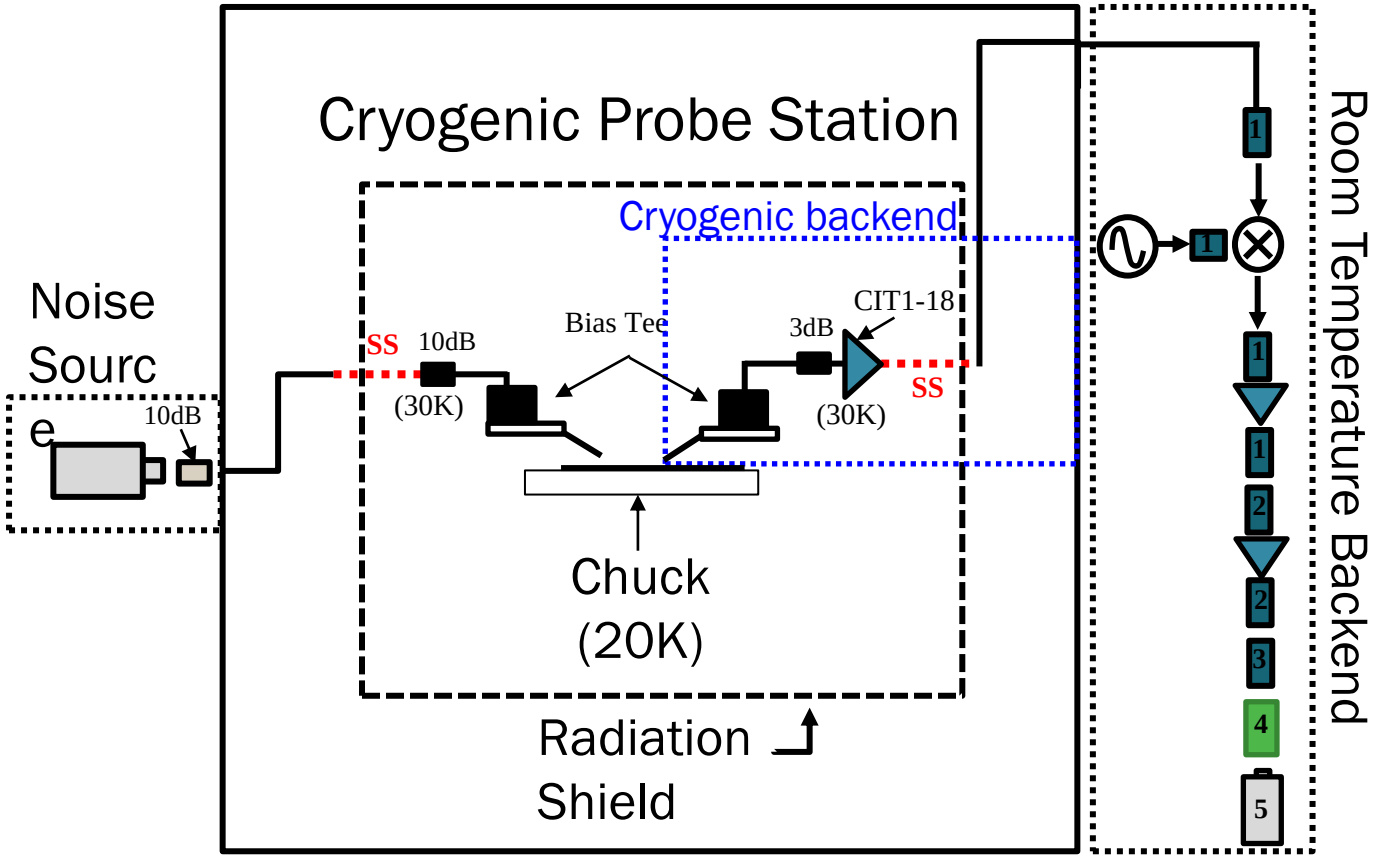


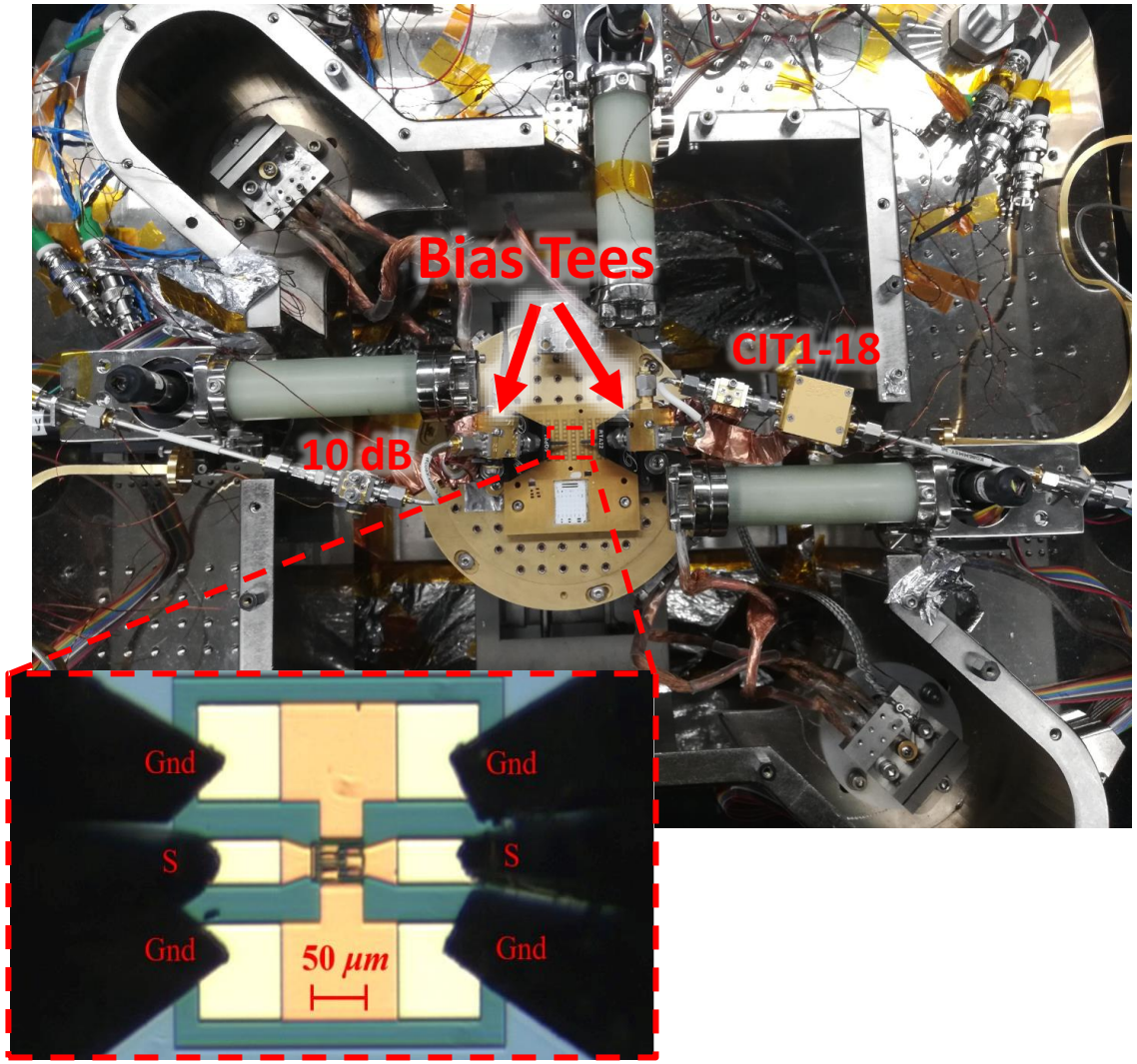
Noise sources such as thermal and shot noise have been well understood and mitigated by cryogenic operation and reduced leakage currents.

The channel noise represented by drain noise and the equivalent drain temperature remains a topic of debate.

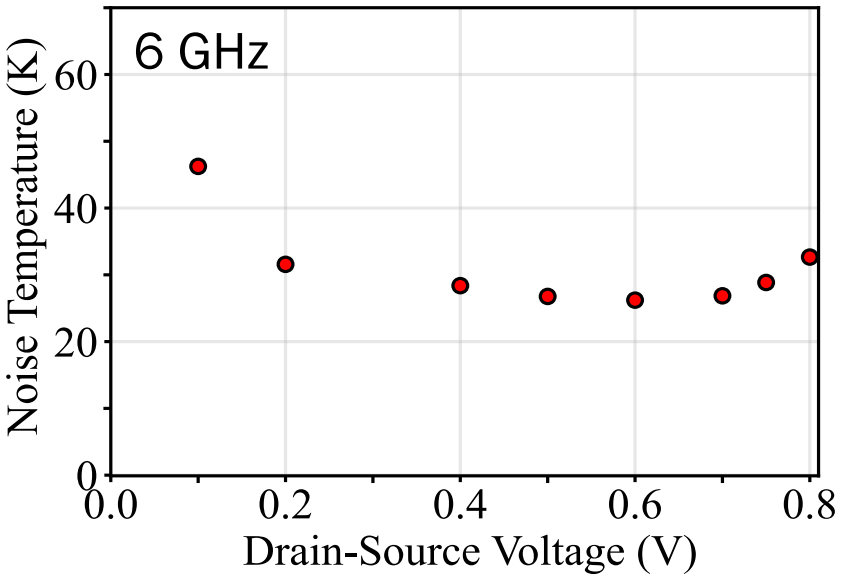
On-Wafer Cryogenic Characterization

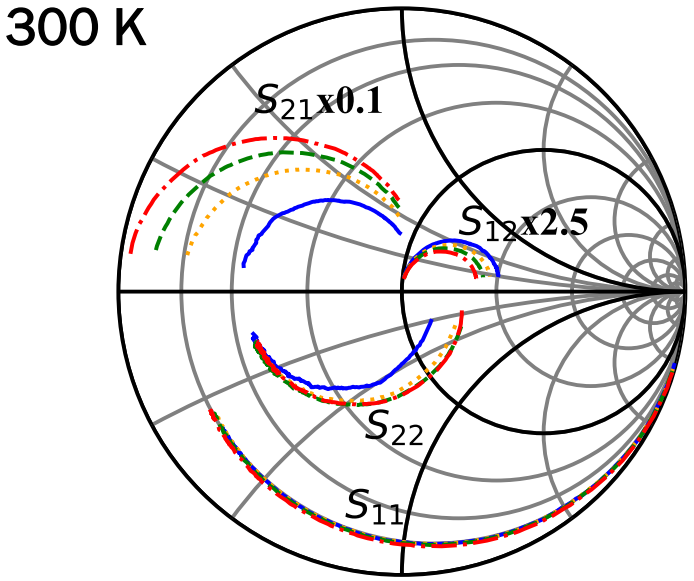
Configuration for microwave noise measurements





Voltage dependent characterization of HEMTs

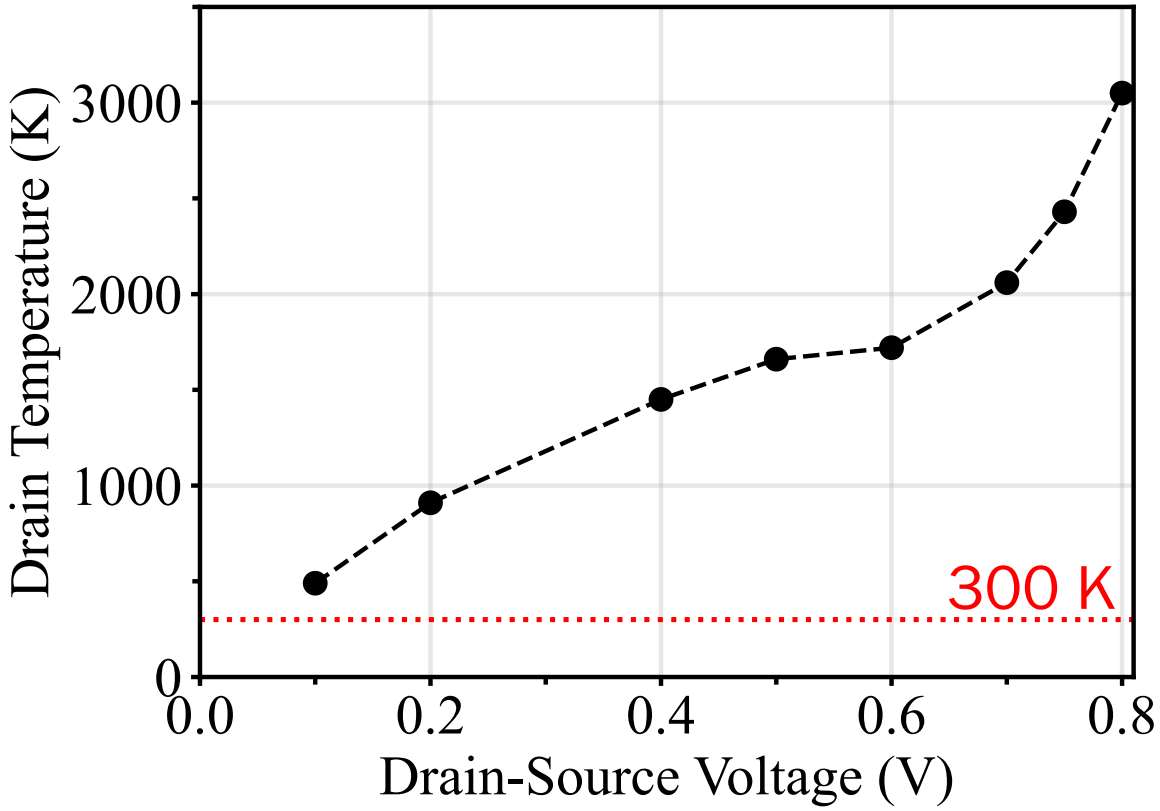


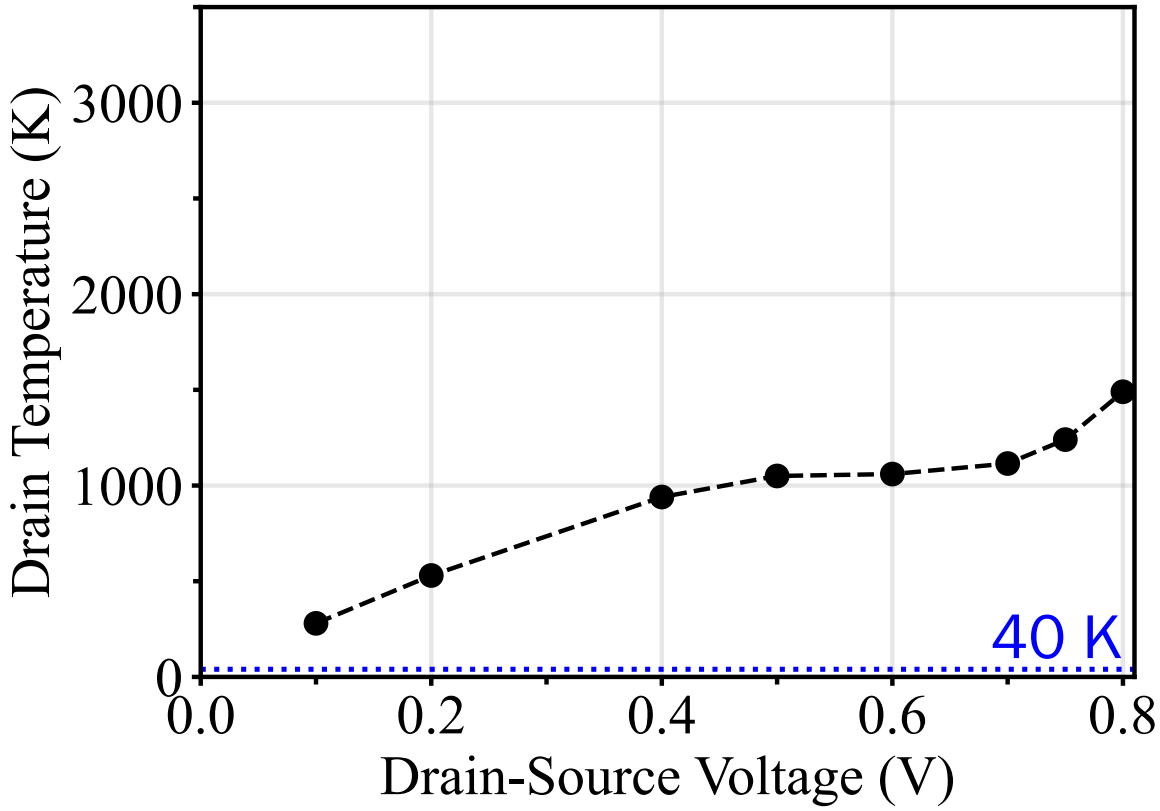


We measure noise temperature, at a generator impedance of 50 Ohm, (T_{50}) and S-parameters.

We use the above data to develop small signal model (SSM) and a noise model, from which we extract drain noise.

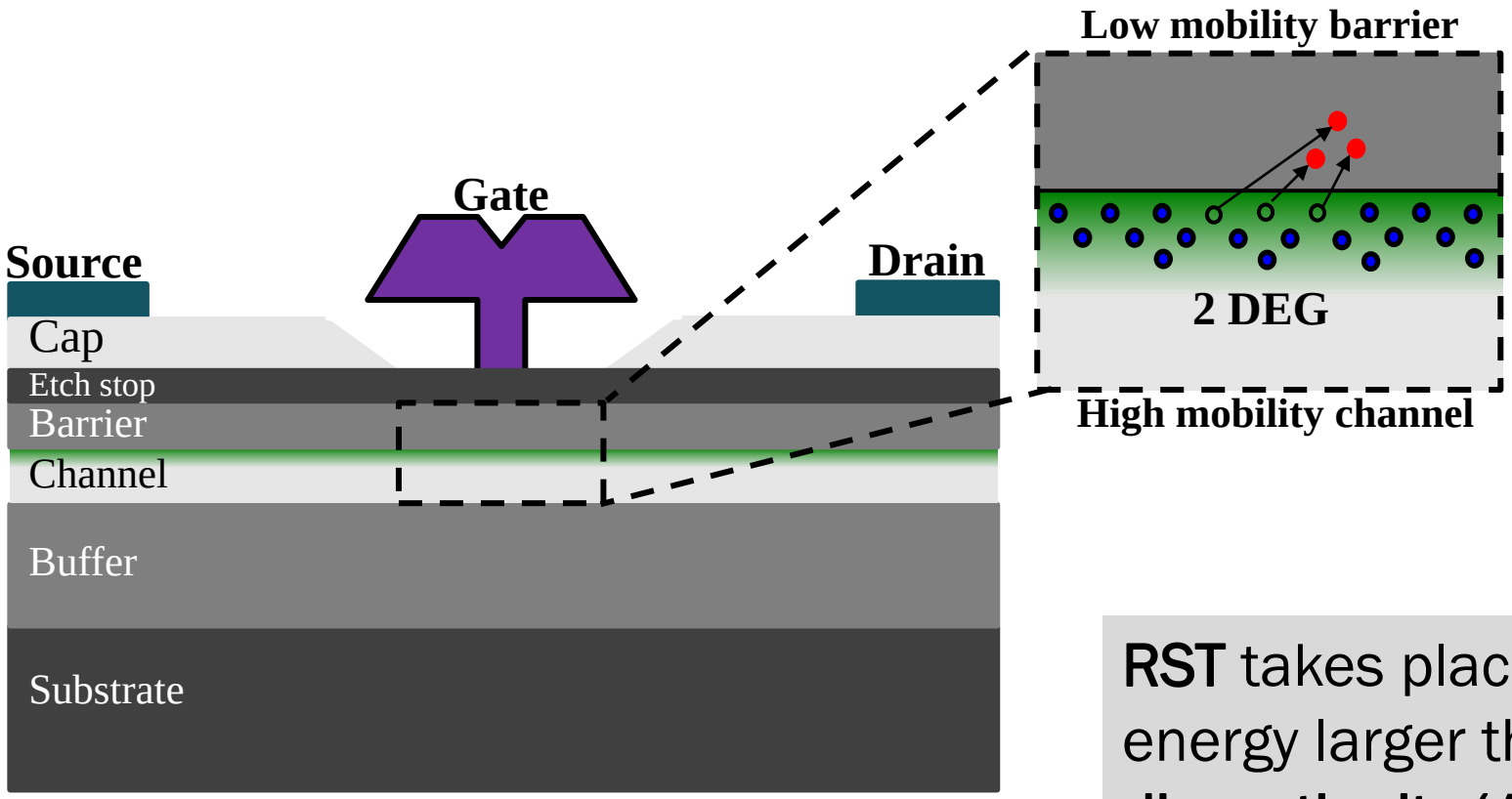
Extracted Drain Temperature





The drain temperature is 1 to 2 orders of magnitude larger than the physical temperature and rises exponentially at high drain-source voltages.

Real-space transfer (RST) and drain noise

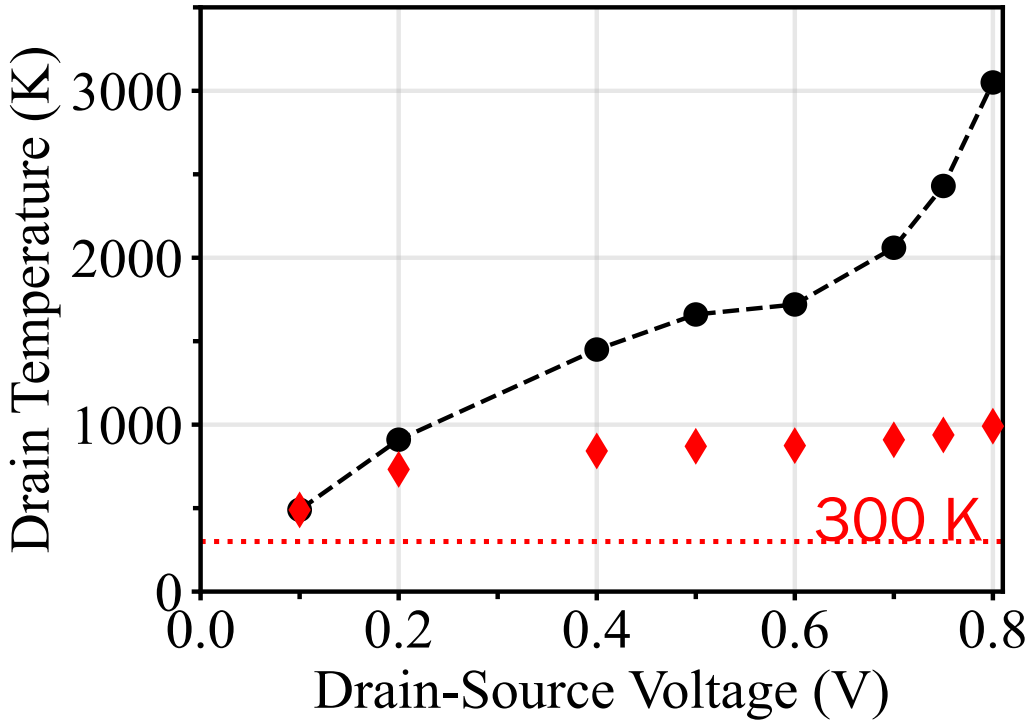


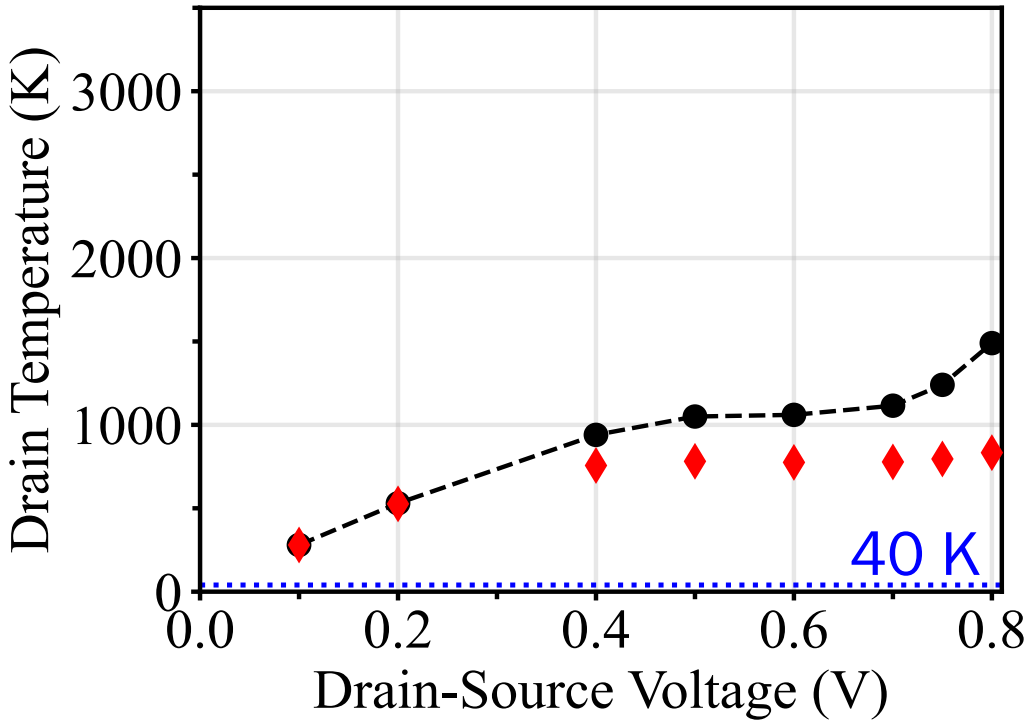
Real space transfer (RST) takes place when electrons emit thermionically from the channel to the barrier.

RST takes place when electrons have thermal energy larger than the **conduction band discontinuity (ΔE_C)** at barrier/channel heterojunction.

H. Hartnagel, *et.al*, John Wiley & Sons, 2001.

Drain Temperature and Electron Temperatures





Drain noise can be decomposed into a thermal component and RST component.

Gate and threshold voltage.

Conduction band discontinuity

$$T_d \propto T_{el} + constant * e^{-\frac{\Delta E_c - q(V_{gs} - V_{th})}{k_B T_{el}}}$$

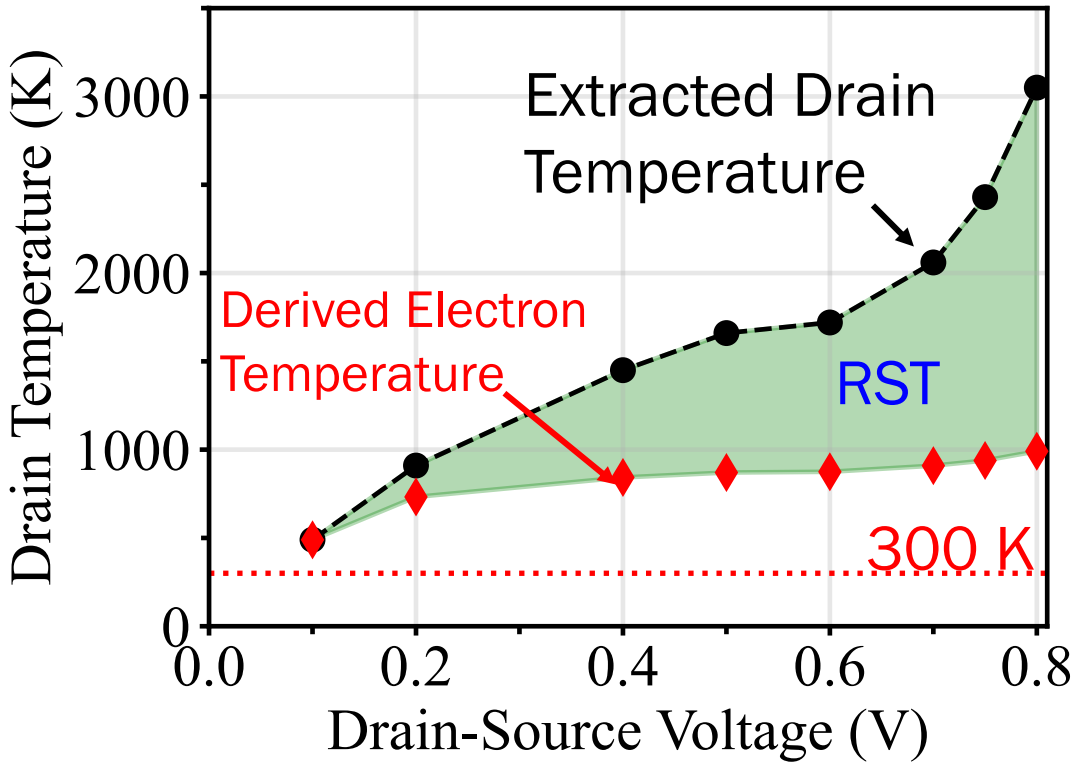
Hot electron temperature.

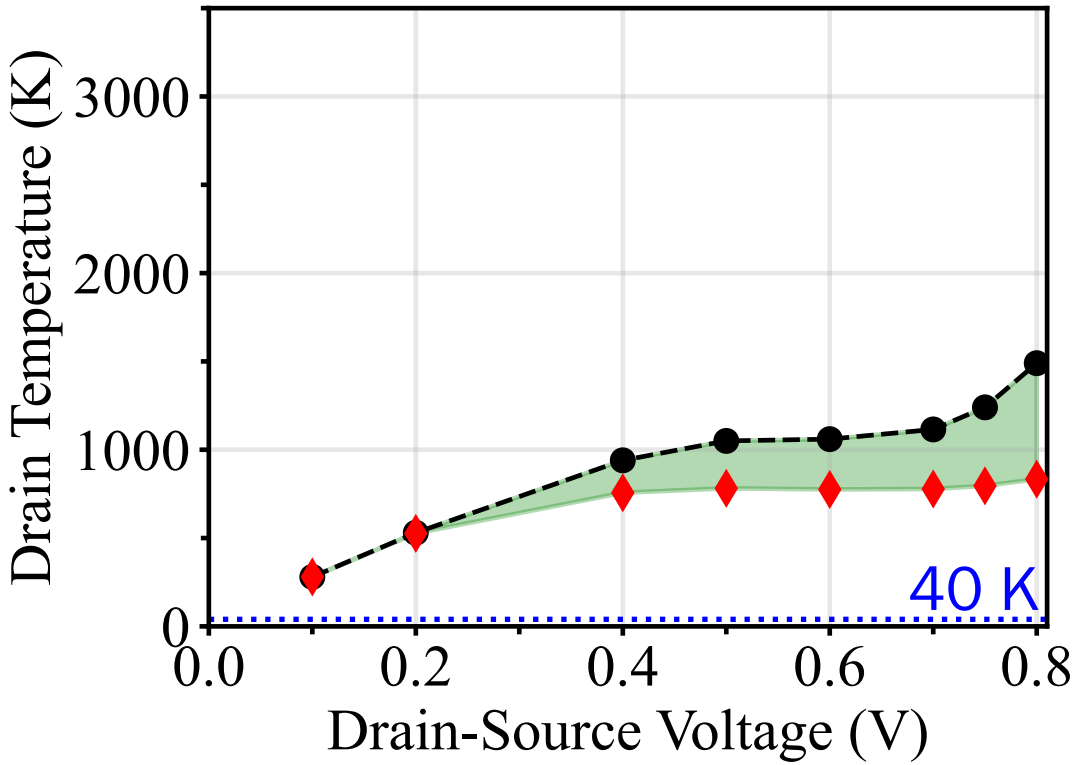
Boltzmann constant.

Bekari Gabritchidze *et.al*, arXiv:2209.02858 *(2022)*

Iretomiwa Esho *et. al*, JAP (2022)

Drain Temperature and RST

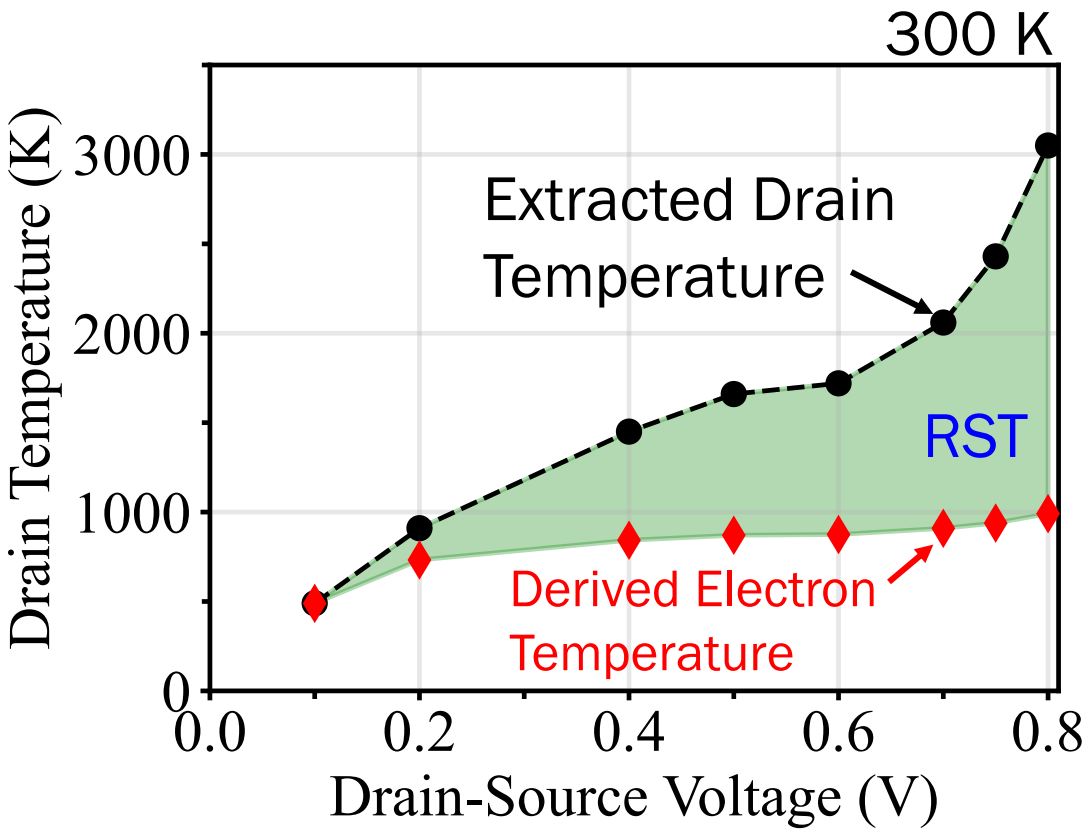




The contribution of RST is represented by the shaded area and is significant at 300 K.

Suppressing RST by improving confinement in quantum well can lead to improved noise performance.

Summary



- We have characterized InP pHEMTs in terms of noise and S-parameters.
- We have extracted drain noise from our data.
- In order to explain the observed trends of drain noise, we proposed a physical model of drain noise that is based on RST and thermal noise.
- We expect that by increasing the ΔE_C we can suppress RST and improve noise performance at 300 K.

Acknowledgements

Caltech