The University of Manchester

CryoMe

Automated Cryogenic Equipment
Characterisation Software

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The Advanced Radio Instrumentation Group (ARIG)

- State of the art ultra low noise amplifier (LNA) design for radio astronomy applications.
- Low noise amplifiers allow for higher sensitivity radio receivers/telescopes.
- Beginning to broaden into full receiver/radio telescope topologies.
- Our designs pioneer world leading semiconductor fabrication techniques, and are used by multiple observatories/telescopes across the world (e.g. SKA, ALMA).

- My niche in the group is expanding beyond LNAs into more full receiver integration, as well as measurement automation.

In this talk:

- 1. What is CryoMe?
- 2. A brief introduction to the system and y-factor calculations
- 3. What features are included and what problems does CryoMe solve?
- 4. What is output by CryoMe?
- 5. Going forward, how can CryoMe aid receiver production and research?

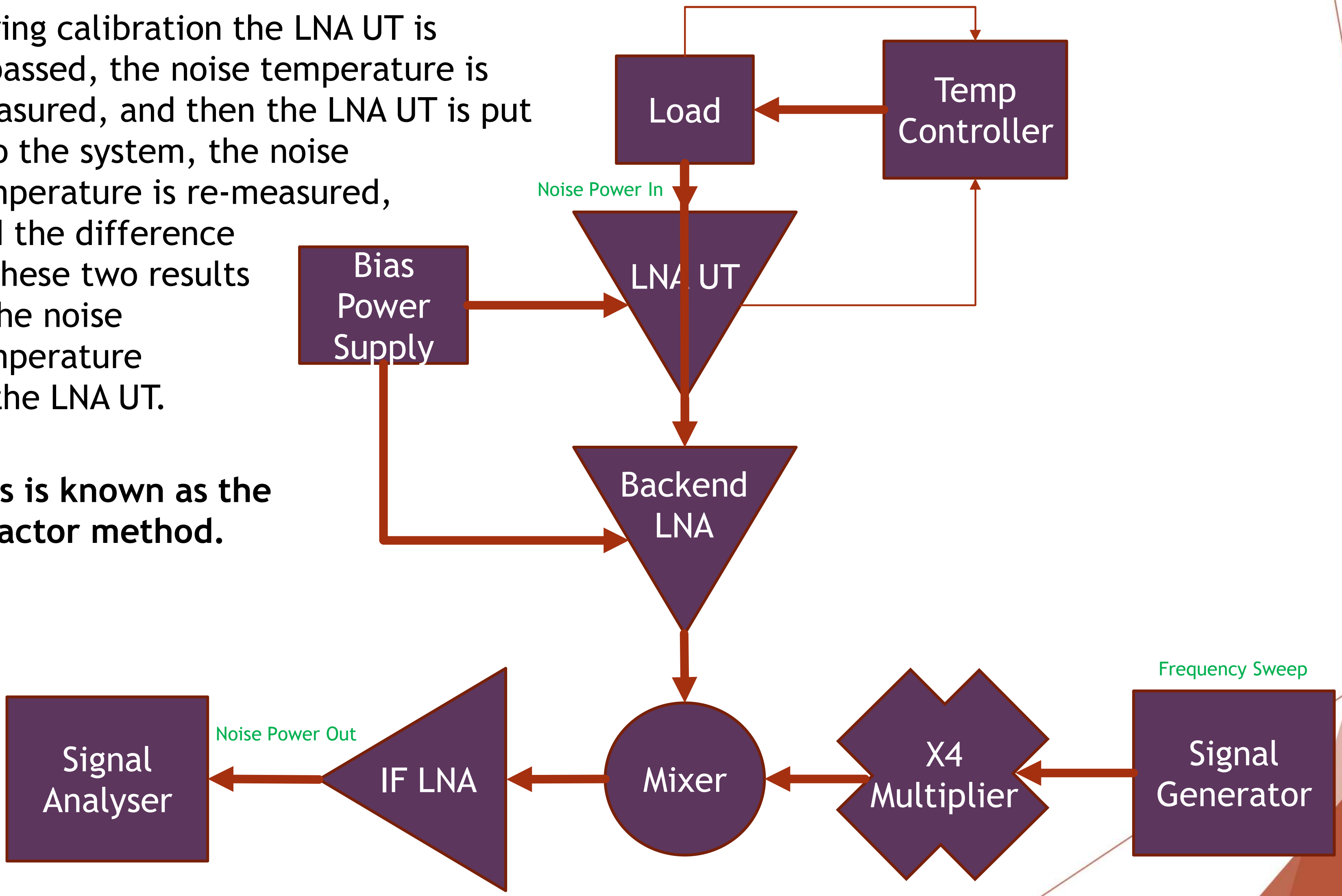
What is CryoMe?

- Scalable and well-documented python based lab automation software.
- Currently being used in the automation of y-factor LNA characterisation for noise and gain of many LNAs.
- Provides a quick and remote way to trigger measurements in the lab with automatic analysis.
- The various other benefits of this software will be covered throughout this talk.

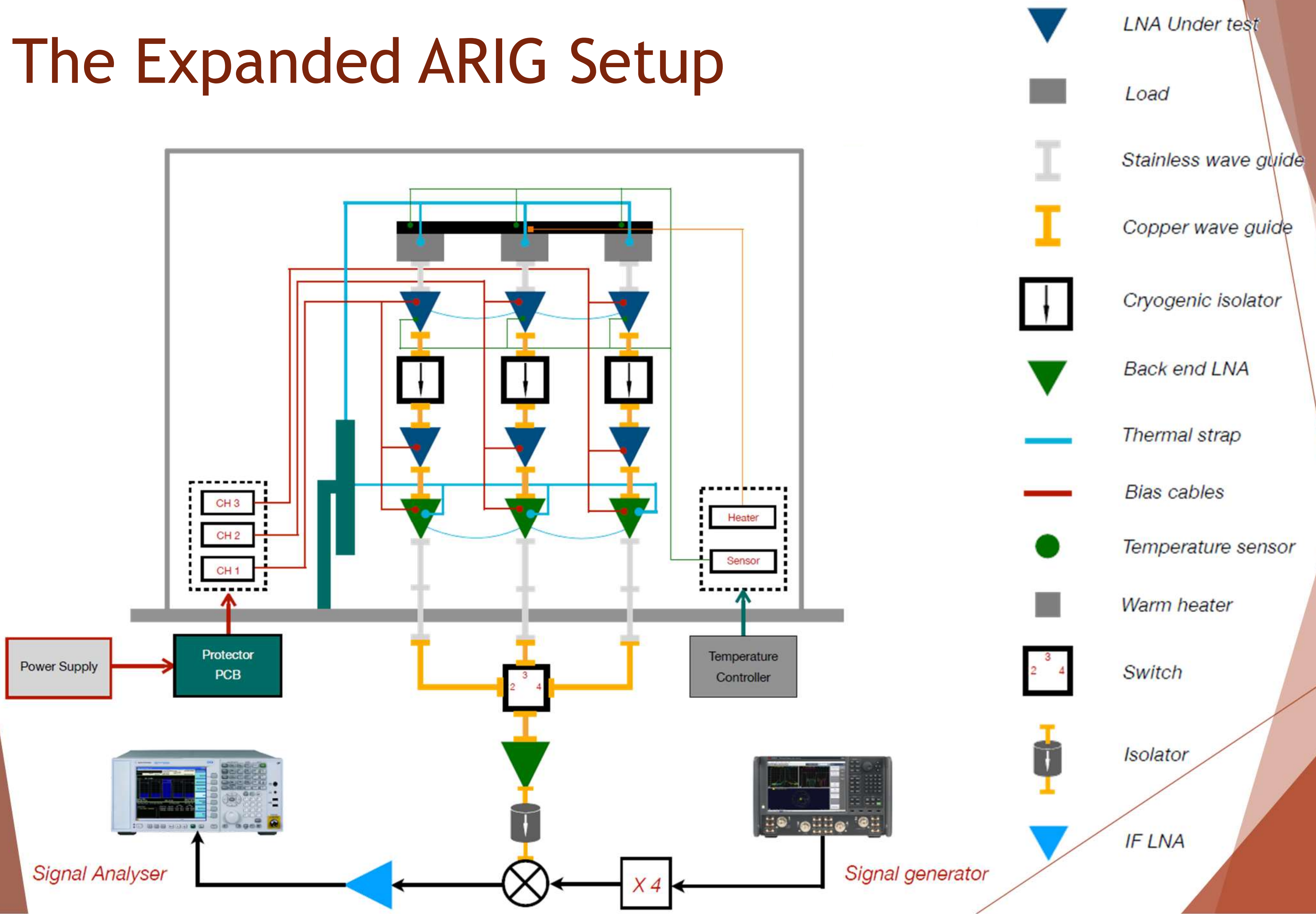
The Basic Noise Temperature Measurement Setup

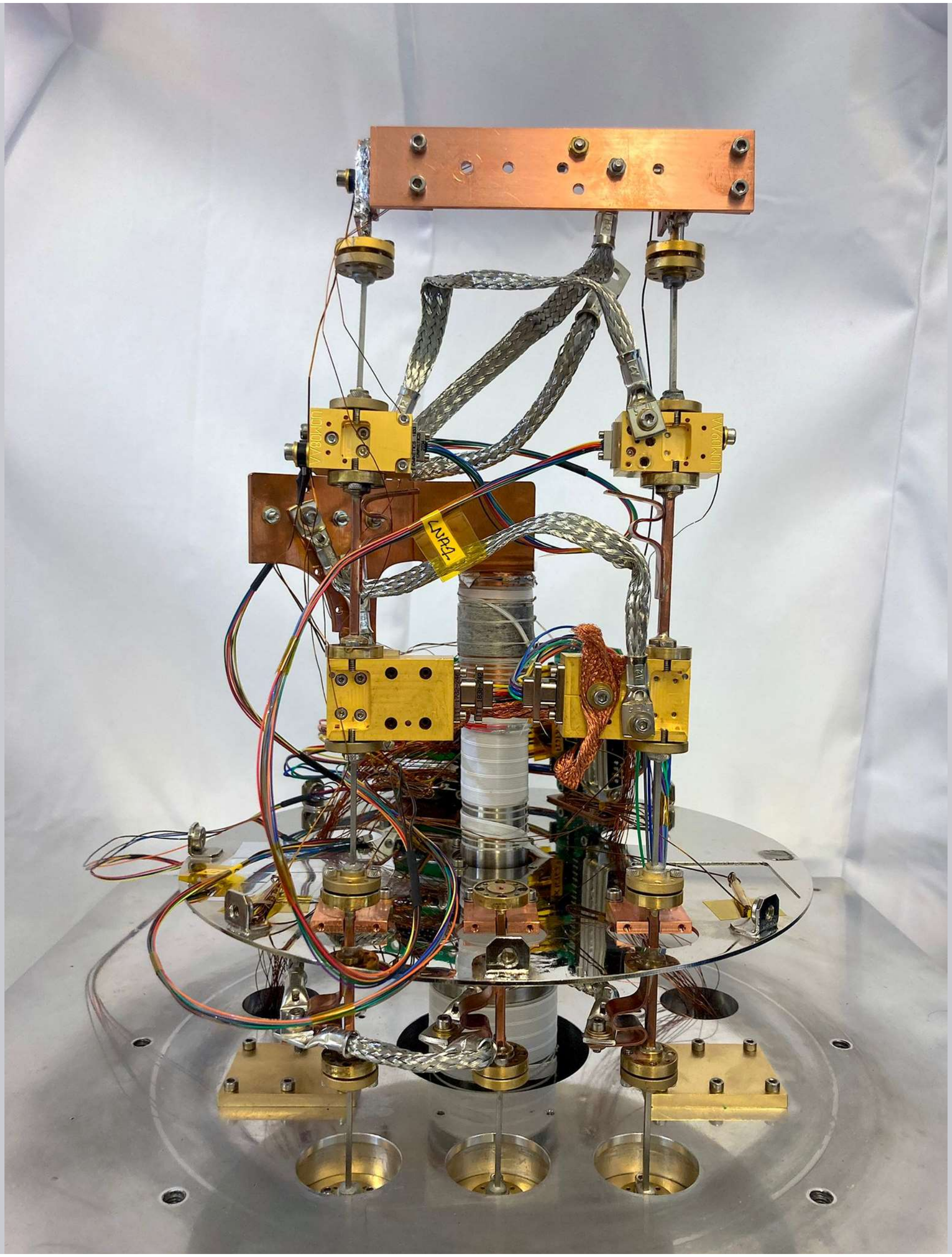
During calibration the LNA UT is bypassed, the noise temperature is measured, and then the LNA UT is put into the system, the noise temperature is re-measured, and the difference in these two results is the noise temperature of the LNA UT.

This is known as the Y Factor method.



The Expanded ARIG Setup





Calculation of Noise Temperature

1. For each frequency calculate the Y Factor from two measured noise power levels at 'hot' (50 K), and 'cold' (20 K) temperatures.

$$Y\ Factor = \frac{10^{\frac{P_{MeasHot}}{10}}}{10^{\frac{P_{MeasCold}}{10}}}$$

2. Calculate the raw noise temperature
3. Apply the correction for the temperature drop between the load and the amplifier UT input
4. Apply the calibration to remove the noise temperature of the rest of the system from the result.

Calculation of Gain

From the 'hot' and 'cold' power measurements, alongside the calibration, the gain can be calculated using those four values.

$$Gain = 10\log_{10}\left(\frac{10^{\frac{P_{MeasH}}{10}} - 10^{\frac{P_{MeasCol}}{10}}}{10^{\frac{P_{CalHo}}{10}} - 10^{\frac{P_{CalCo}}{10}}}\right)[dB]$$

Noise Figure Measurement Accuracy: The Y-Factor Method, Keysight, Oct 15 2020

Pre-CryoMe Measurement Method

1. Manually set up, calibrate, and record conditions of the signal generator, signal analyser, temperature controller, switch, and bias power supply in the correct order. Cool Cryostat (~2 hours).

2. For Each Chain
   a) For All Bias Positions:
      i. Run measurement loop at cold and hot (20K, and 50K) load temperatures.
      ii. Manually set to next bias position and record settings.
   b) Manually Turn off power supply and change switch to next position, re-bias and record conditions for the new chain UT.

3. Turn off cold head and compressor and wait for cryostat to warm up (~12 hrs).

Potential Disadvantages

- Manual setup and measurement triggering
- Subtle measurement variables easily not accounted for consistently
- No standard format for results or calibrations
- Inefficient and limited results processing
- Unstandardised instrumentation code
- Disorganisation

CryoMe Features

- Two sweeping algorithms
- Clear and standardised output structure
- Settings logging
- Output console logging
- Results analysis over full & sub-bandwidths
- 1080p customisable plotting
- PEP compliant code base
- Adaptive PSU drain current searching
- Replotting/reprocessing functionality.

CryoMe Benefits

- Time saving
  - Ability to automate 100 measurements a day when previously up to 20 possible.
- Remote use
- Potential Optimisation Route
- Better results formatting and organisation
- Easy to use/read/extend code base

Bias Control Algorithm

Target of drain current = 7mA, step gate voltage as below until as close to target drain current as possible with resolution.

Broad Gate Voltage Steps

Current exceeds target between these two gate voltages

Dashed lines are not measured as over crossover

Gate V: -0.25V -0.15V -0.05V 0.05V 0.15V 0.25V

Drain I: 0mA **2mA** **9mA**

Mid Gate Voltage Steps

Gate V: -0.15V -0.05V

9 mA closer to target of 7 mA so start at -0.05 and go backwards until target crossover.

Gate V: -0.09V -0.07V

Drain I: 6.7mA 7.1mA

Narrow Gate Voltage Steps

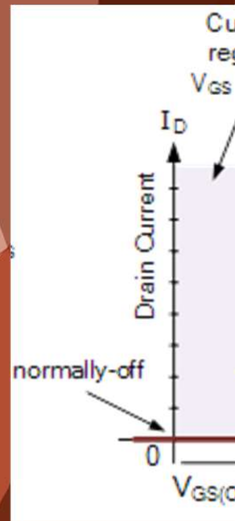
Gate V: -0.09V -0.07V

7.1mA closer to target of 7mA so start at -0.07V and go backwards.

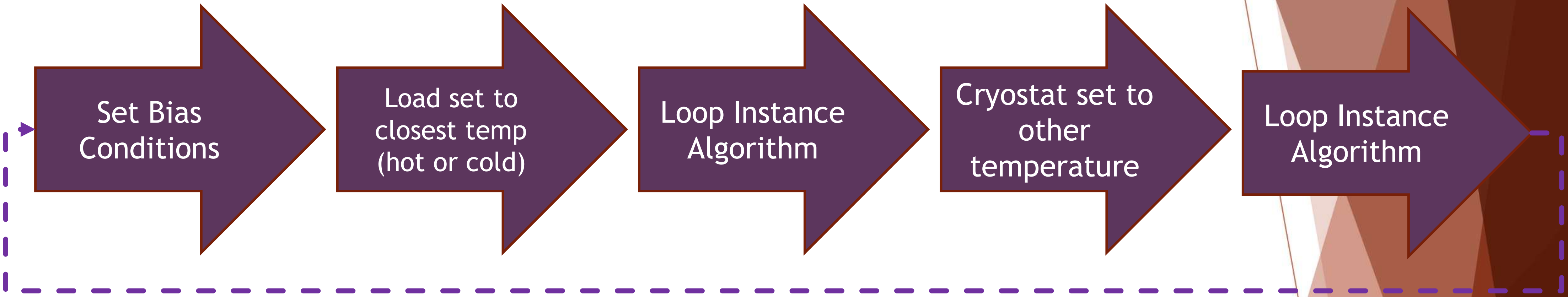
Closest of the narrowest level given as gate voltage for target drain current.

In this example 3 measurements in broad range, 3 in mid, and 2 in narrow

Return



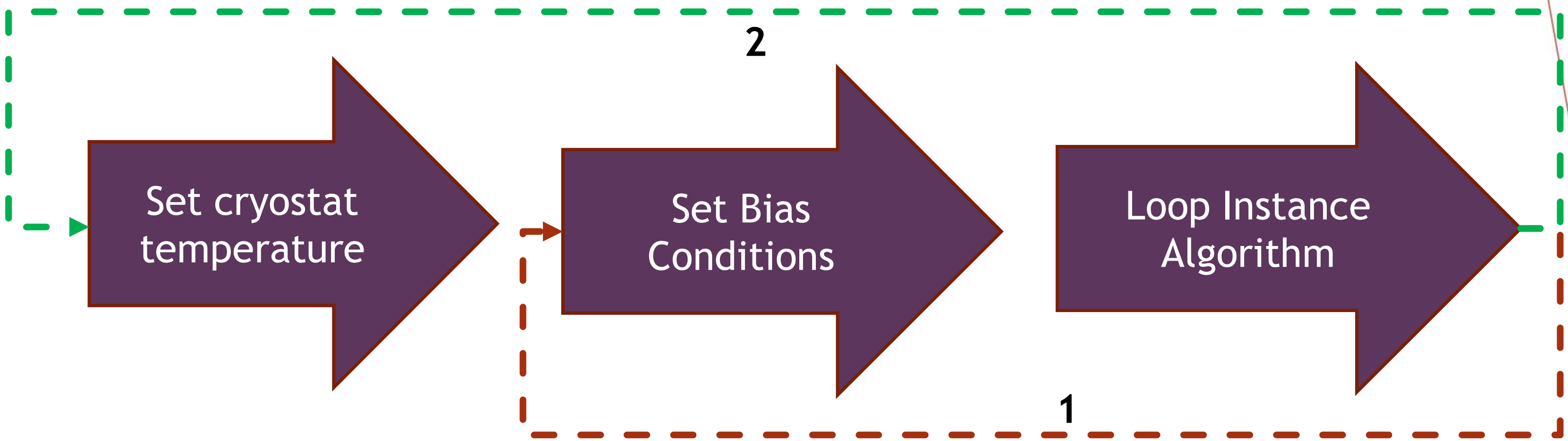
Sweeping Algorithms – Alternating Temperatures



- Alternating Temperatures ('AT'):
  - Series measurements.
  - Cryostat set to nearest of either the hot or cold temperature from where it is at the start of measurement.
  - Loop instance is performed, results are taken.
  - Cryostat temperature is changed to the other temperature.
  - Loop instance is performed, results are taken.
  - Results are compiled and analysed as a pair, then the next bias is performed.

Return

Sweeping Algorithms – All Cold To All Hot

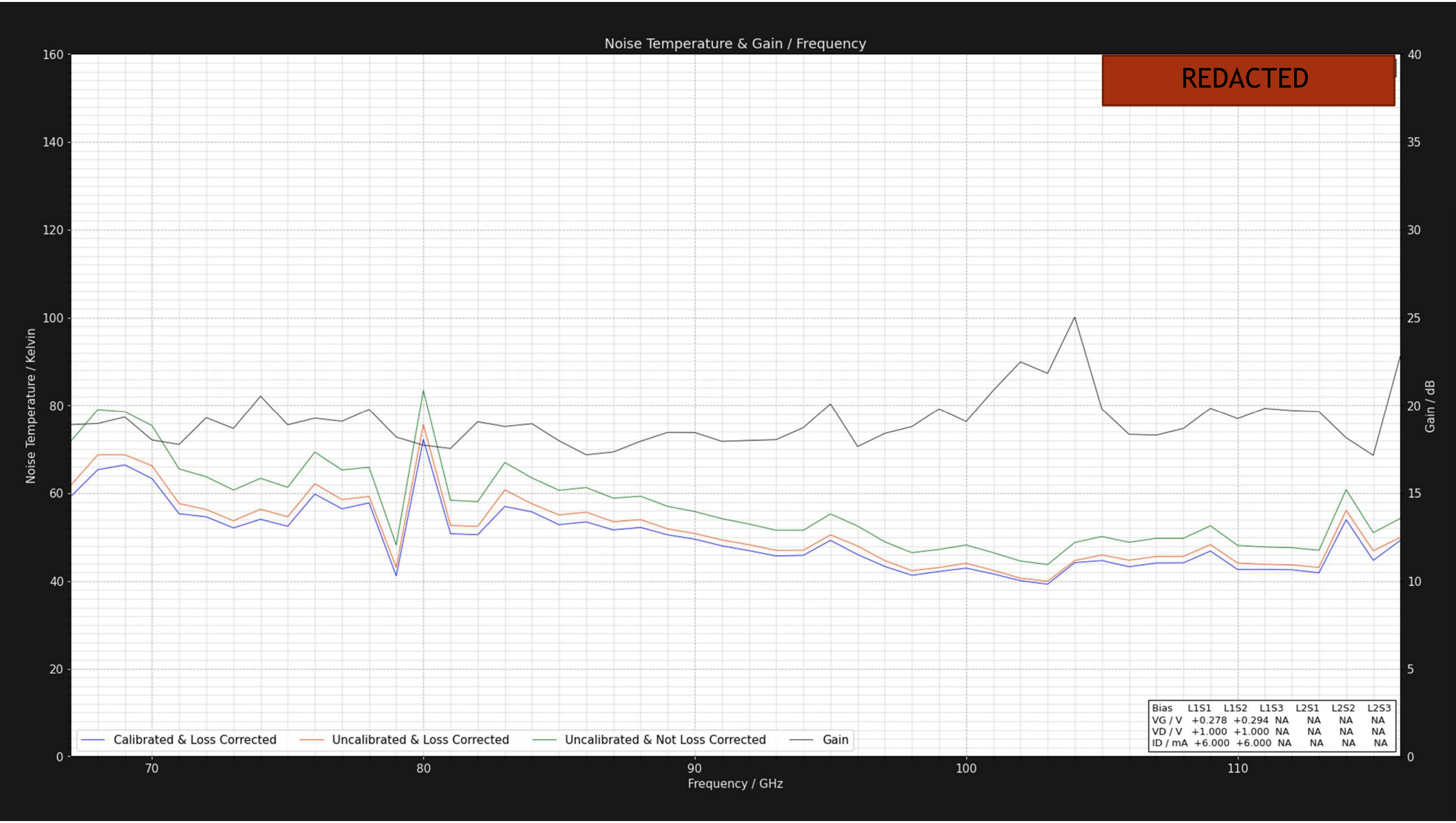


- All Cold To All Hot ('ACTAH'):
  - Semi-parallel measurements.
  - Gets the cryostat to the cold load temperature specified (usually 20K).
  - Perform all the cold temperature measurement loops for each bias and store them.
  - Raise the cryostat to hot temperature (usually 50K).
  - Perform all the hot temperature measurement loops for each bias and store them.
  - Compile loop instance results into pairs and analyse them, output all the results at once .

Return

Outputs: Individual Measurement

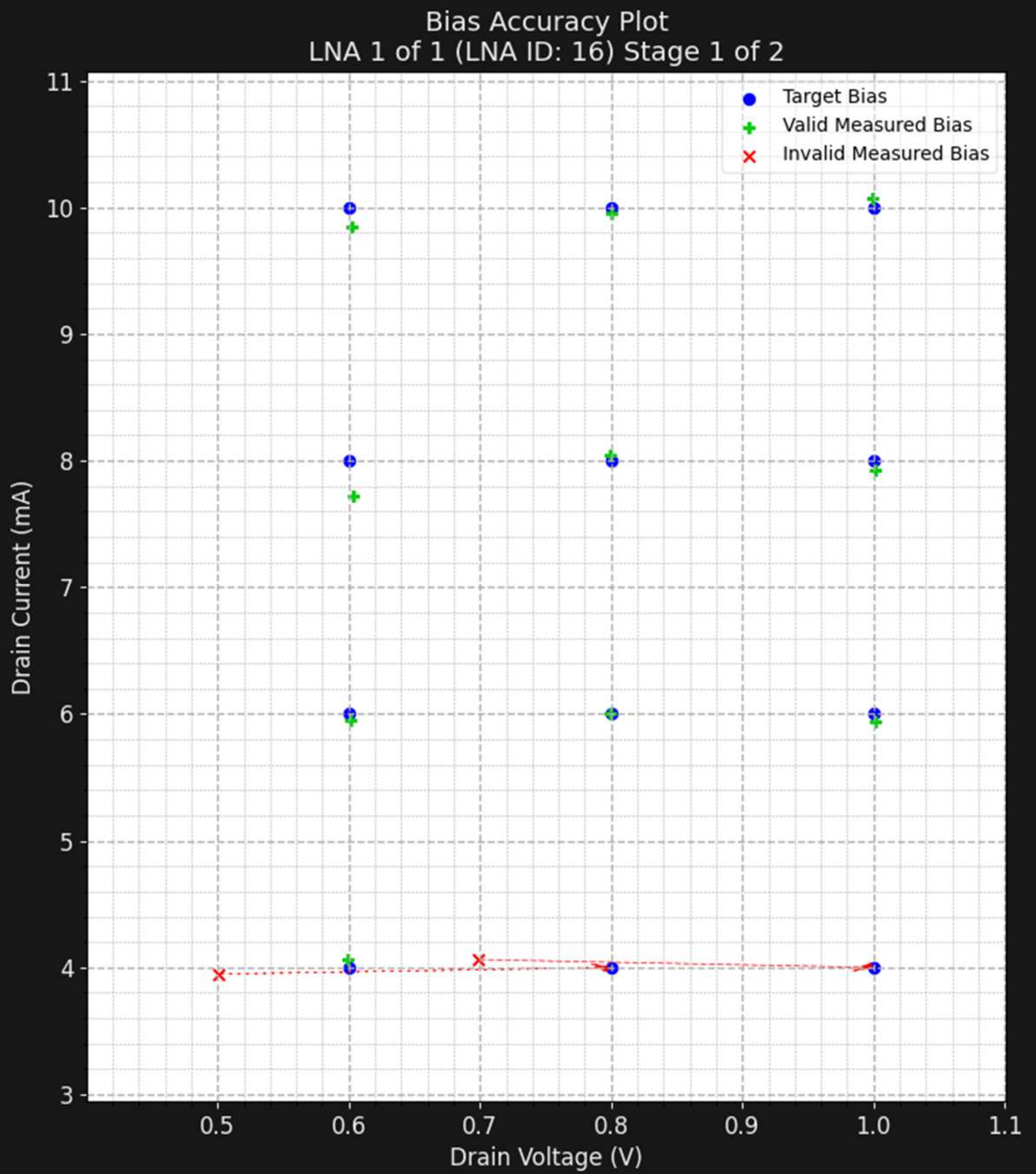
- **Individual Output File:**
  - Heading containing settings log detail.
  - For each frequency: meas/cal hot/cold power, noise temp calc stages, gain, sensor temps pre, mid, and post loop.
- **Settings Log:**
  - **Identifications:** Project Title, LNA ID, Session ID, Bias ID, Chain #, Cal ID, Date, Time, Comment, # LNAs per chain, LNA UT, # Stages / LNA, Stage UT
  - **Spec An Settings:** Center & Marker Freqs, Res/Vid/Power BW, Freq Span, Attenuation
  - **LNA UT & Backend LNA:** Set & Measured Biases, Protection PCB Drain Resistances
- **Results Log:**
  - **Identifications:** Project Title, LNA ID, Session ID, Bias ID, Chain #, Cal ID, Date, Time, Comment
  - **Bandwidths:** Full and sub bandwidths
  - **For each bandwidth:**
    - **Gain/Noise Temperature: Average, Std Dev, Min, Max, Range**
- **Noise/Gain Plot**

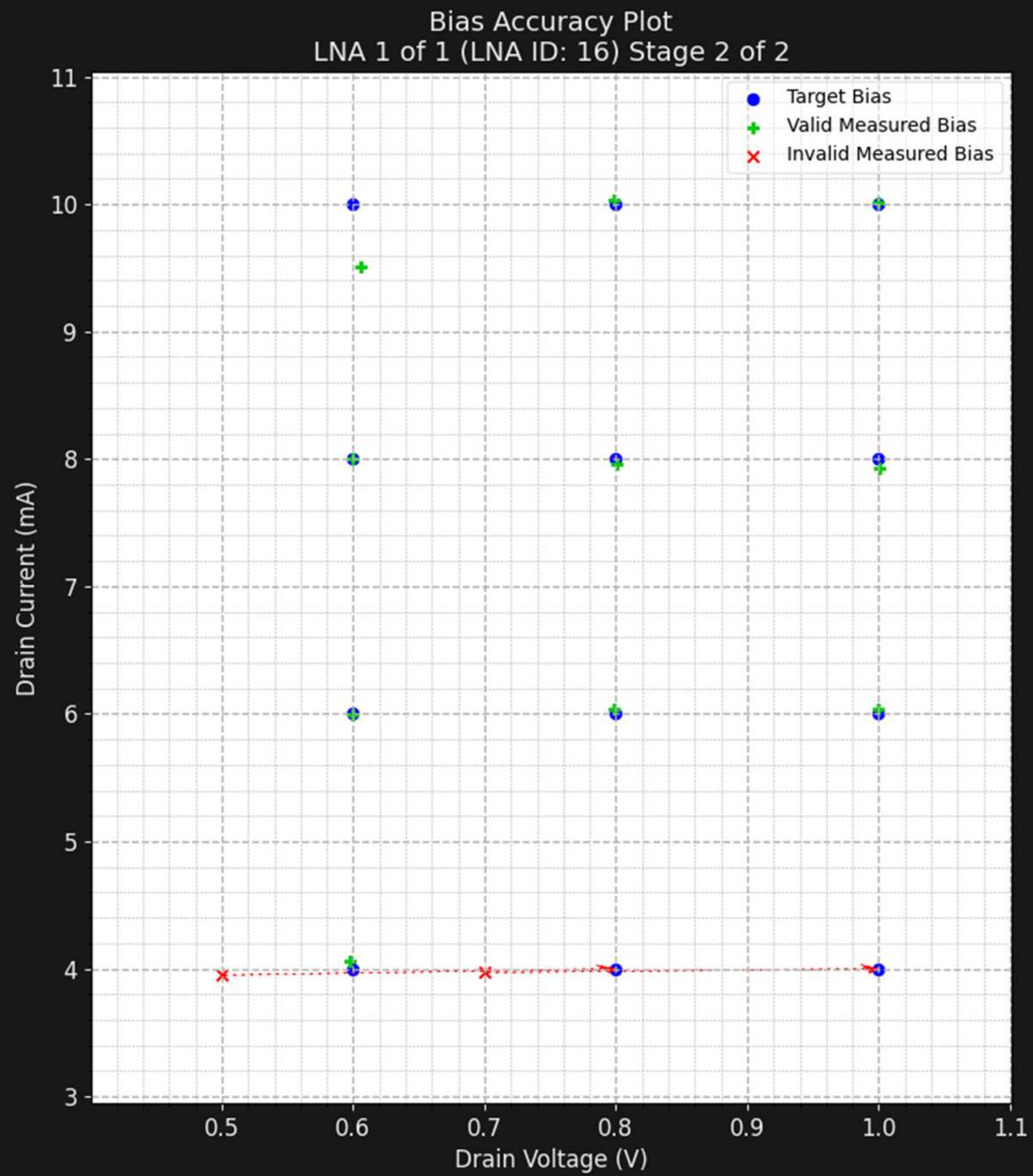


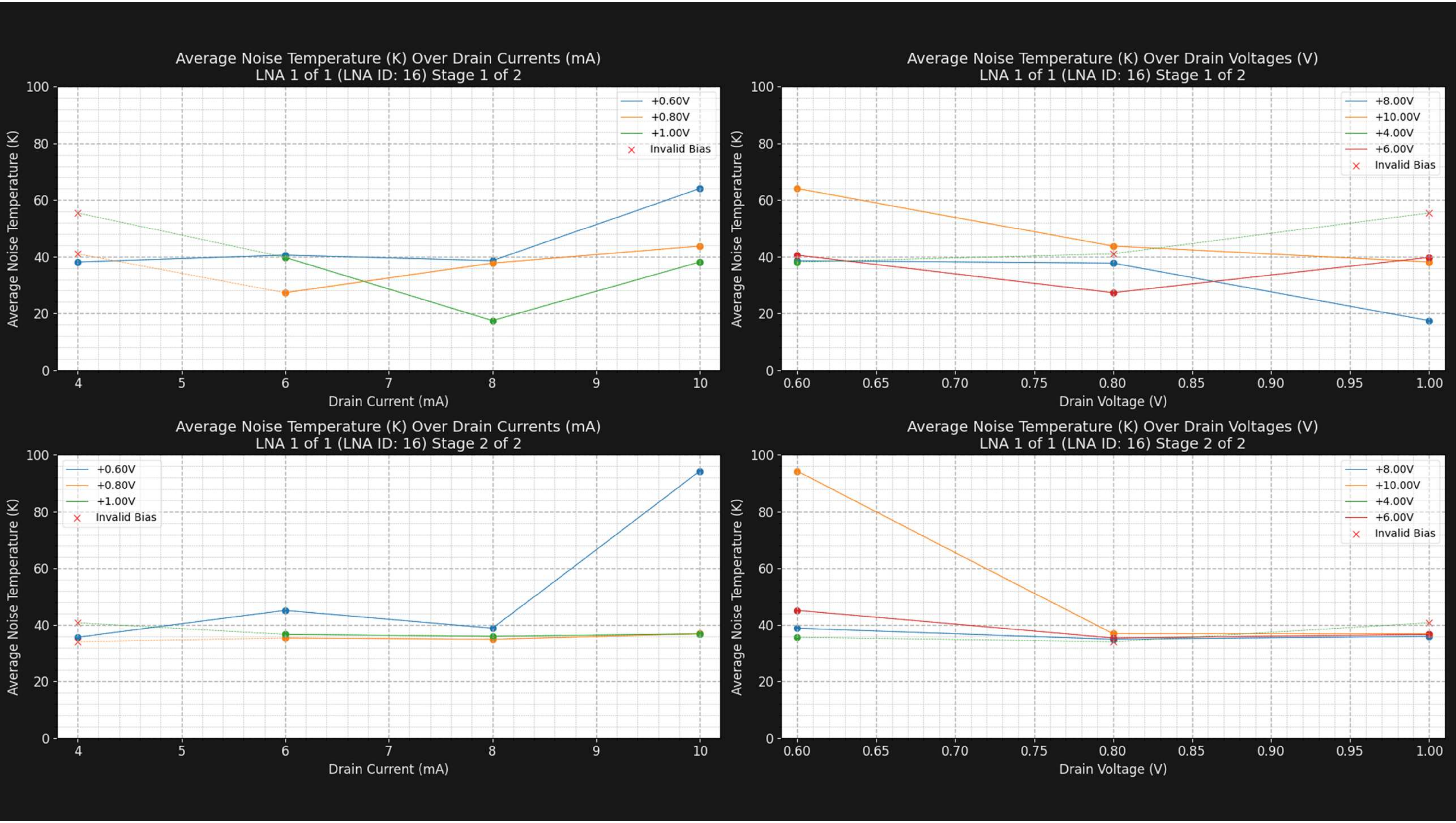
Noise Temperature & Gain / Frequency
REDACTED
Noise Temperature / Kelvin
Gain / dB
Frequency / GHz
0
20
40
60
80
100
120
140
160
0
5
10
15
20
25
30
35
40
70
80
90
100
110
Calibrated & Loss Corrected
Uncalibrated & Loss Corrected
Uncalibrated & Not Loss Corrected
Gain
Bias L1S1 L1S2 L1S3 L2S1 L2S2 L2S3
VG / V +0.278 +0.294 NA NA NA NA
VD / V +1.000 +1.000 NA NA NA NA
ID / mA +6.000 +6.000 NA NA NA NA

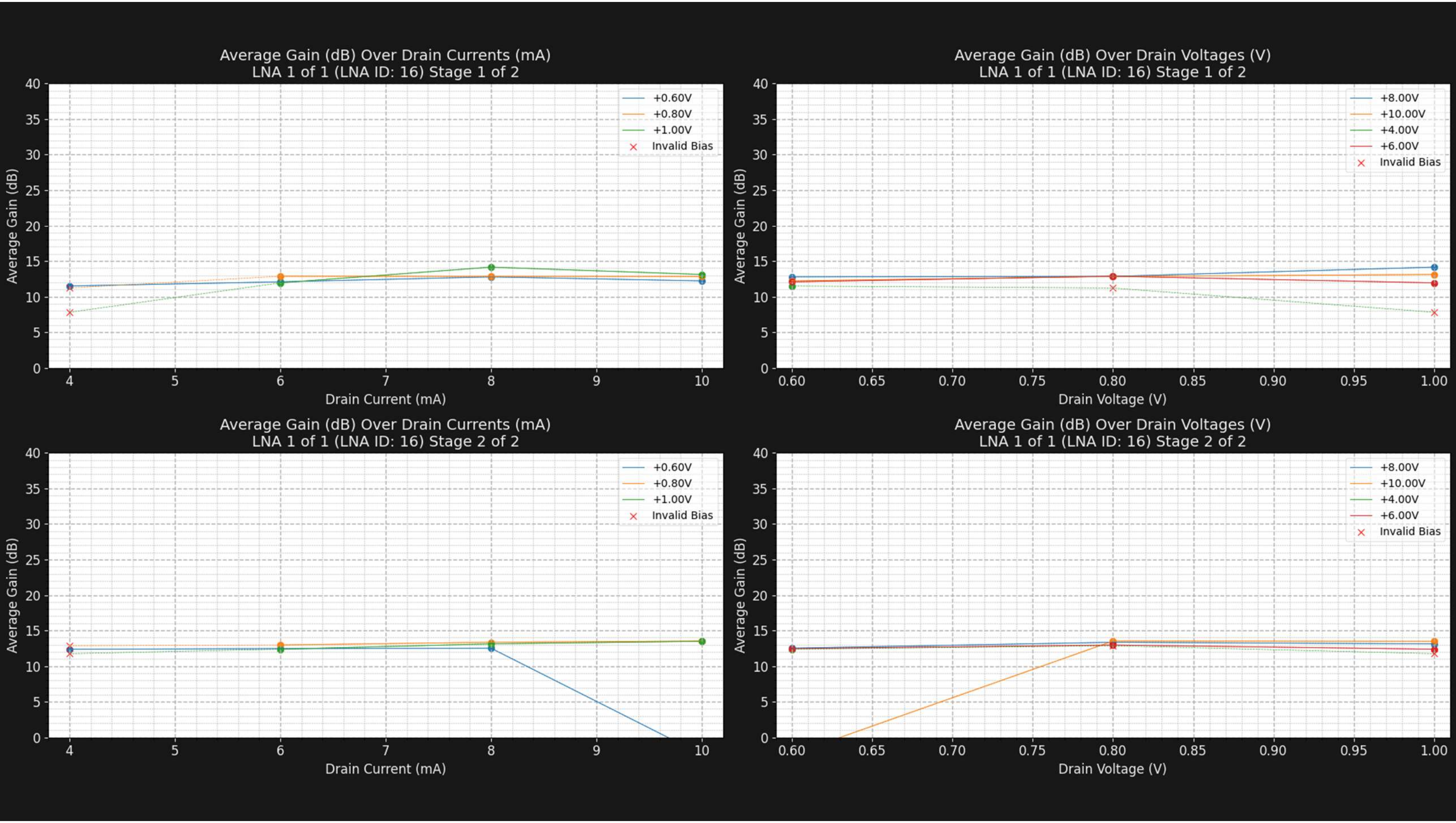
Outputs: Sweep Analysis

- Gain/Noise Bias Heat Maps
- Gain/Noise Over constant drain current/voltage
- Bias accuracy plot

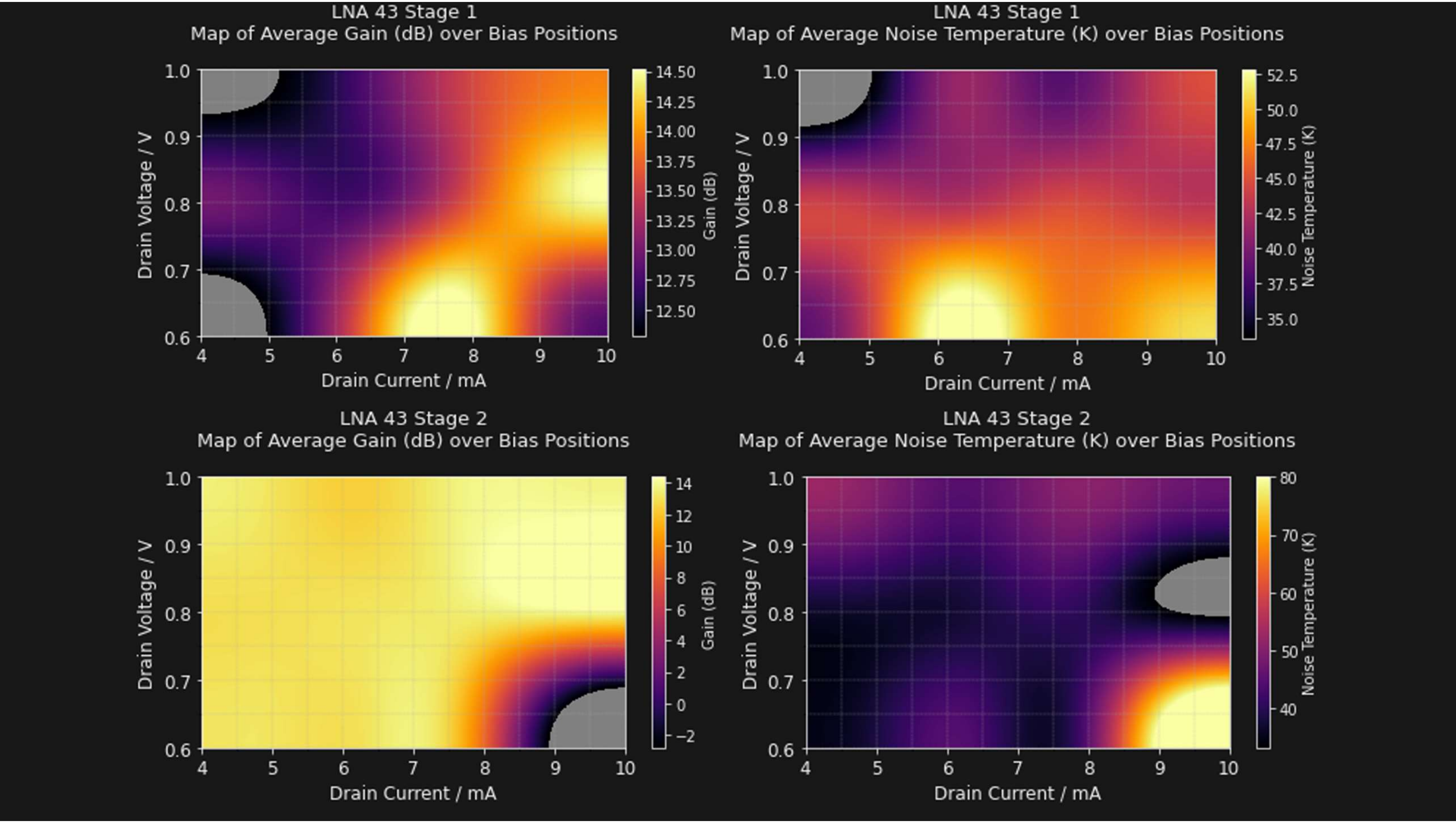

Bias Accuracy Plot
LNA 1 of 1 (LNA ID: 16) Stage 1 of 2
Target Bias
Valid Measured Bias
Invalid Measured Bias
Drain Current (mA)
Drain Voltage (V)
3
4
5
6
7
8
9
10
11
0.5
0.6
0.7
0.8
0.9
1.0
1.1


Bias Accuracy Plot
LNA 1 of 1 (LNA ID: 16) Stage 2 of 2
Target Bias
Valid Measured Bias
Invalid Measured Bias
Drain Current (mA)
Drain Voltage (V)
3
4
5
6
7
8
9
10
11
0.5
0.6
0.7
0.8
0.9
1.0
1.1


Average Noise Temperature (K) Over Drain Currents (mA)
LNA 1 of 1 (LNA ID: 16) Stage 1 of 2
Average Noise Temperature (K)
Drain Current (mA)
+0.60V
+0.80V
+1.00V
Invalid Bias
Average Noise Temperature (K) Over Drain Voltages (V)
LNA 1 of 1 (LNA ID: 16) Stage 1 of 2
Drain Voltage (V)
+8.00V
+10.00V
+4.00V
+6.00V
Invalid Bias
Average Noise Temperature (K) Over Drain Currents (mA)
LNA 1 of 1 (LNA ID: 16) Stage 2 of 2
Average Noise Temperature (K) Over Drain Voltages (V)
LNA 1 of 1 (LNA ID: 16) Stage 2 of 2



Average Gain (dB) Over Drain Currents (mA)
LNA 1 of 1 (LNA ID: 16) Stage 1 of 2
Average Gain (dB)
Drain Current (mA)
+0.60V
+0.80V
+1.00V
Invalid Bias
Average Gain (dB) Over Drain Voltages (V)
LNA 1 of 1 (LNA ID: 16) Stage 1 of 2
Average Gain (dB)
Drain Voltage (V)
+8.00V
+10.00V
+4.00V
+6.00V
Invalid Bias
Average Gain (dB) Over Drain Currents (mA)
LNA 1 of 1 (LNA ID: 16) Stage 2 of 2
Average Gain (dB)
Drain Current (mA)
+0.60V
+0.80V
+1.00V
Invalid Bias
Average Gain (dB) Over Drain Voltages (V)
LNA 1 of 1 (LNA ID: 16) Stage 2 of 2
Average Gain (dB)
Drain Voltage (V)
+8.00V
+10.00V
+4.00V
+6.00V
Invalid Bias


LNA 43 Stage 1
Map of Average Gain (dB) over Bias Positions
Drain Voltage / V
Drain Current / mA
Gain (dB)
LNA 43 Stage 1
Map of Average Noise Temperature (K) over Bias Positions
Drain Voltage / V
Drain Current / mA
Noise Temperature (K)
LNA 43 Stage 2
Map of Average Gain (dB) over Bias Positions
Drain Voltage / V
Drain Current / mA
Gain (dB)
LNA 43 Stage 2
Map of Average Noise Temperature (K) over Bias Positions
Drain Voltage / V
Drain Current / mA
Noise Temperature (K)