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Noise Parameter Solutions for Cryogenic LNA Design

Feb 2025

Agenda

- Presenter
- Cryogenic applications
- LNA design
- Traditional noise measurements
- Cryogenic noise measurements
- Results

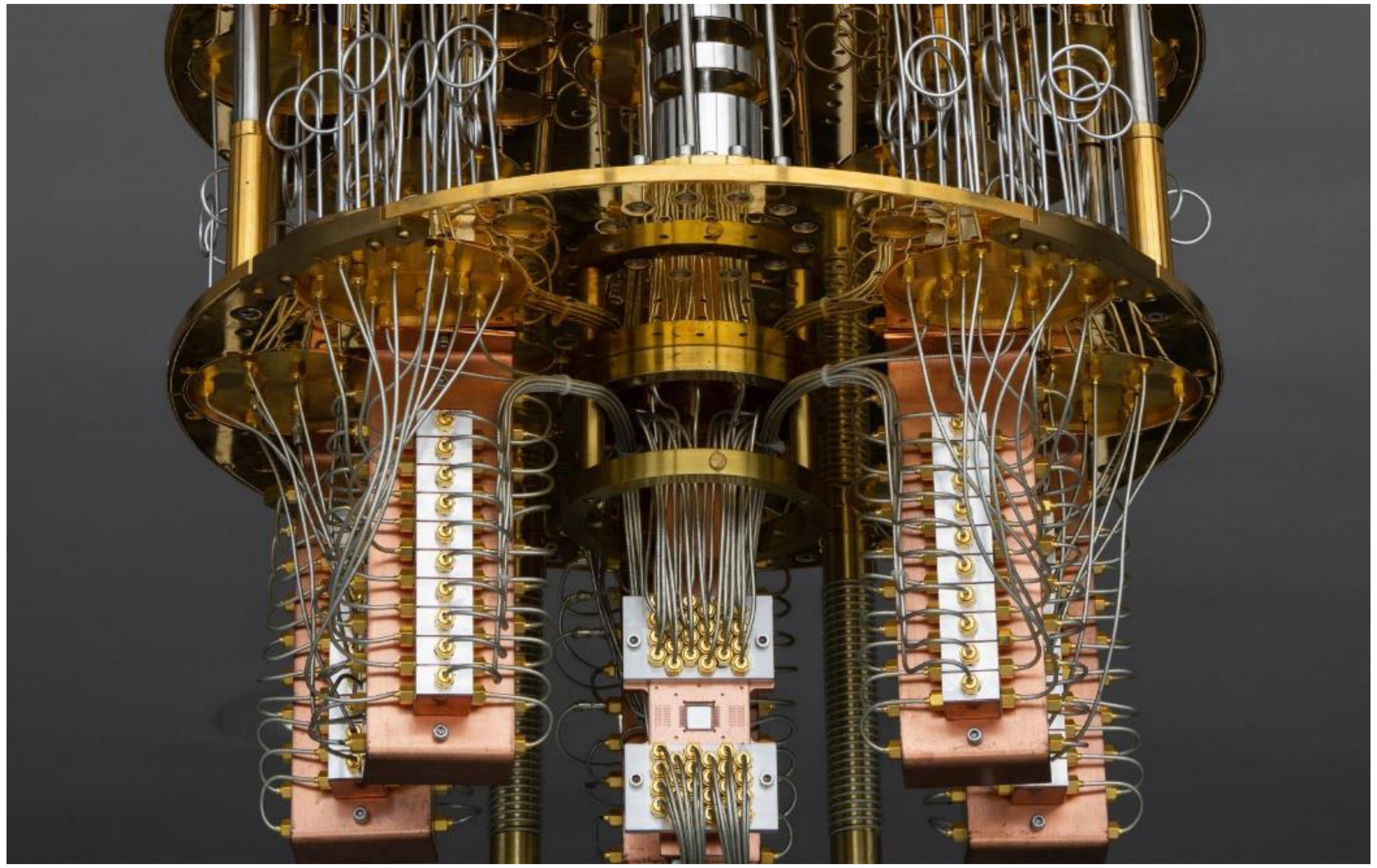
Presenter

Giampiero Esposito (Maury)

Business Development and Produce Line Manager at Maury Microwave Corporation is responsible for product line successes including market intelligence, sales enablement, planning, development, and lifecycle management of products.

He joined the company in October 2012, as an application engineer responsible for product support and has since held various technical, management positions within the company.

Cryogenic applications



Radio Astronomy

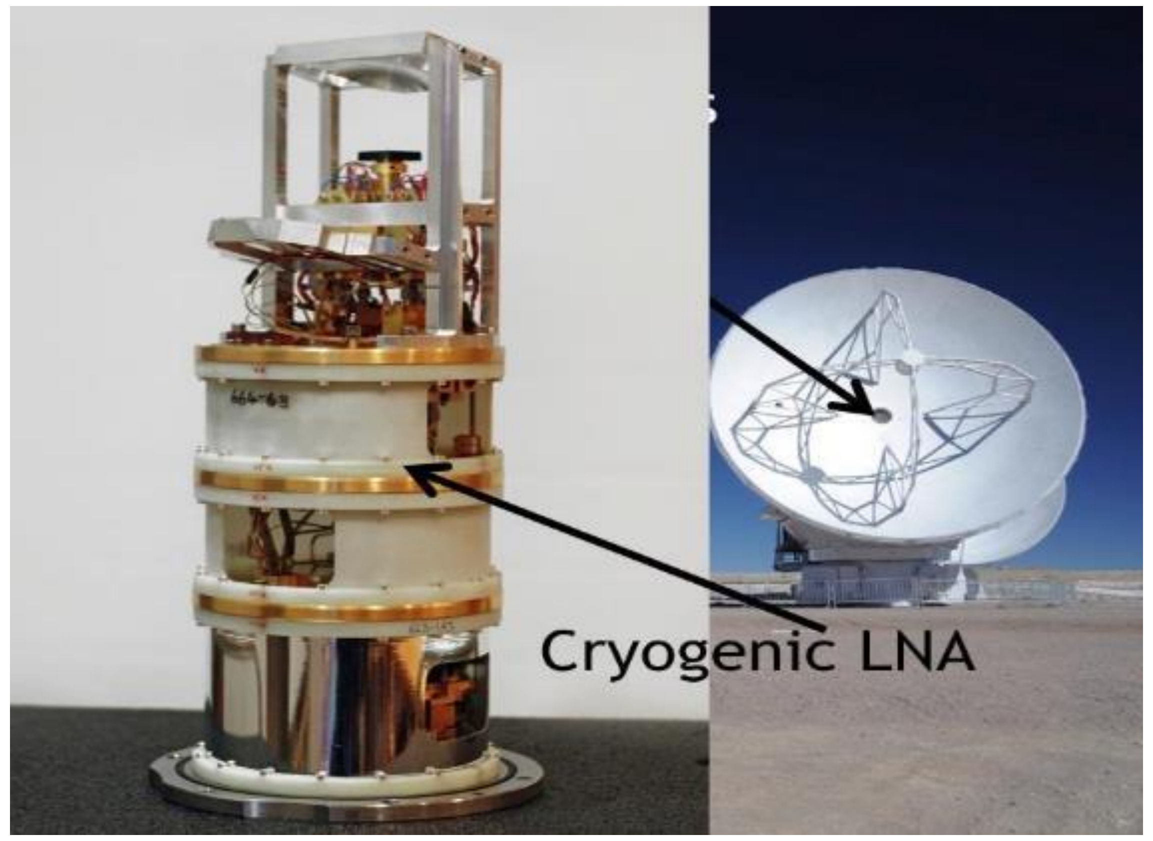
cryogenic cooling reduces noise temperature and increases sensitivity of receiver

Quantum Computing

cryogenic cooling minimizes disturbances in quantum states by reducing thermal energy

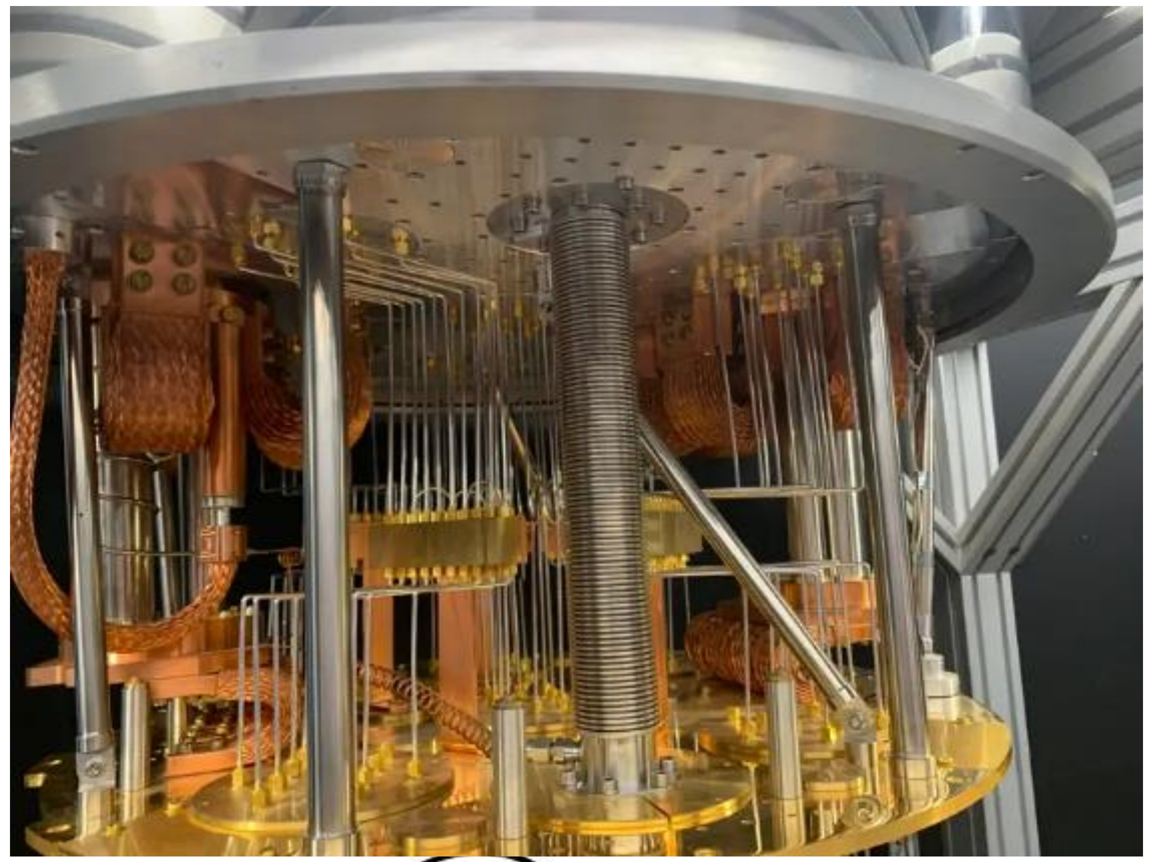
Cryogenic low noise amplifiers

Cryogenic low noise amplifiers (LNAs) are critical components in radio telescopes and in quantum computers



LNAs are used in radio astronomy to:

- Amplify weak signals received from space with minimal introduction of additional noise
- To increase the sensitivity of the radio telescope receiver
- And process and analyze better data to uncover the mysteries of the universe

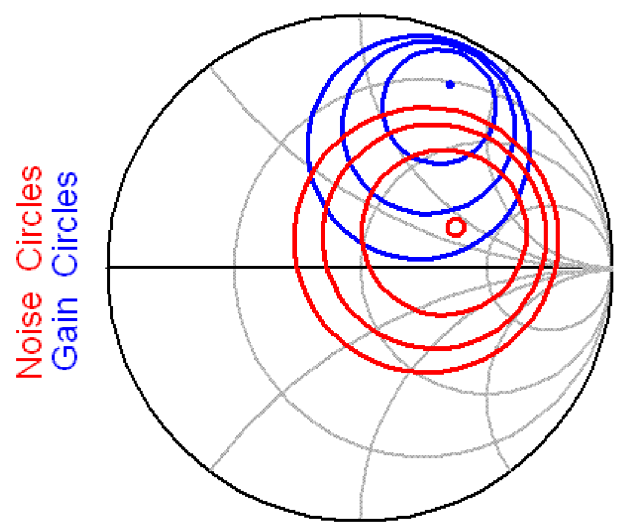


LNAs are used in quantum computing to:

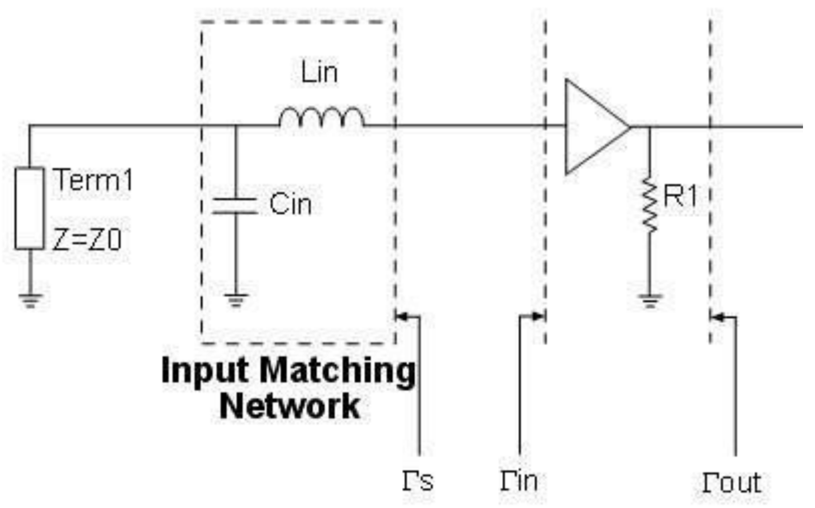
- Amplify weak signals received from qubit with minimal introduction of additional noise
- To increase the sensitivity of the qubit state measurement and preserve the delicate qubit state
- And empower the world's most powerful computers

LNA design (simplified)

Perform noise parameters (NP) measurements on unmatched transistor or existing LNA



Evaluate noise and gain circles and determine the best impedance match that meets design requirement



Build matching network that optimizes LNA performance

Traditional Noise Parameters measurements

- **VNA** used for S-parameters measurements
- **VNA/NFA** for noise power measurements
- **Noise source** used for Y factor technique
- **Source tuner** used for generating multiple source impedance to extract noise parameters

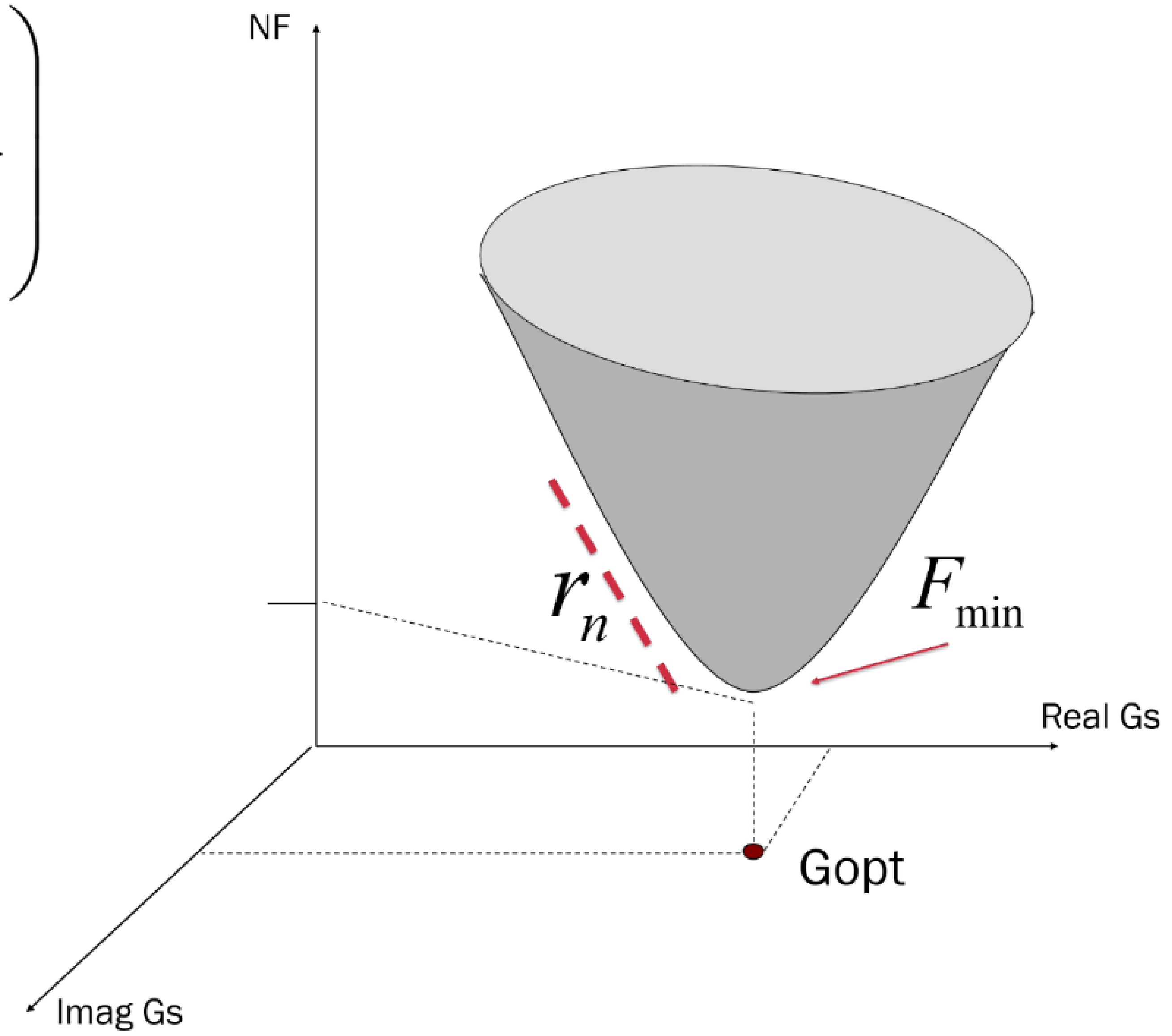
$$F = F_{\min} + 4r_n \left(\frac{|\Gamma_s - \Gamma_{opt}|^2}{|1+\Gamma_{opt}|^2 \left(1 - |\Gamma_s|\right)^2} \right)$$

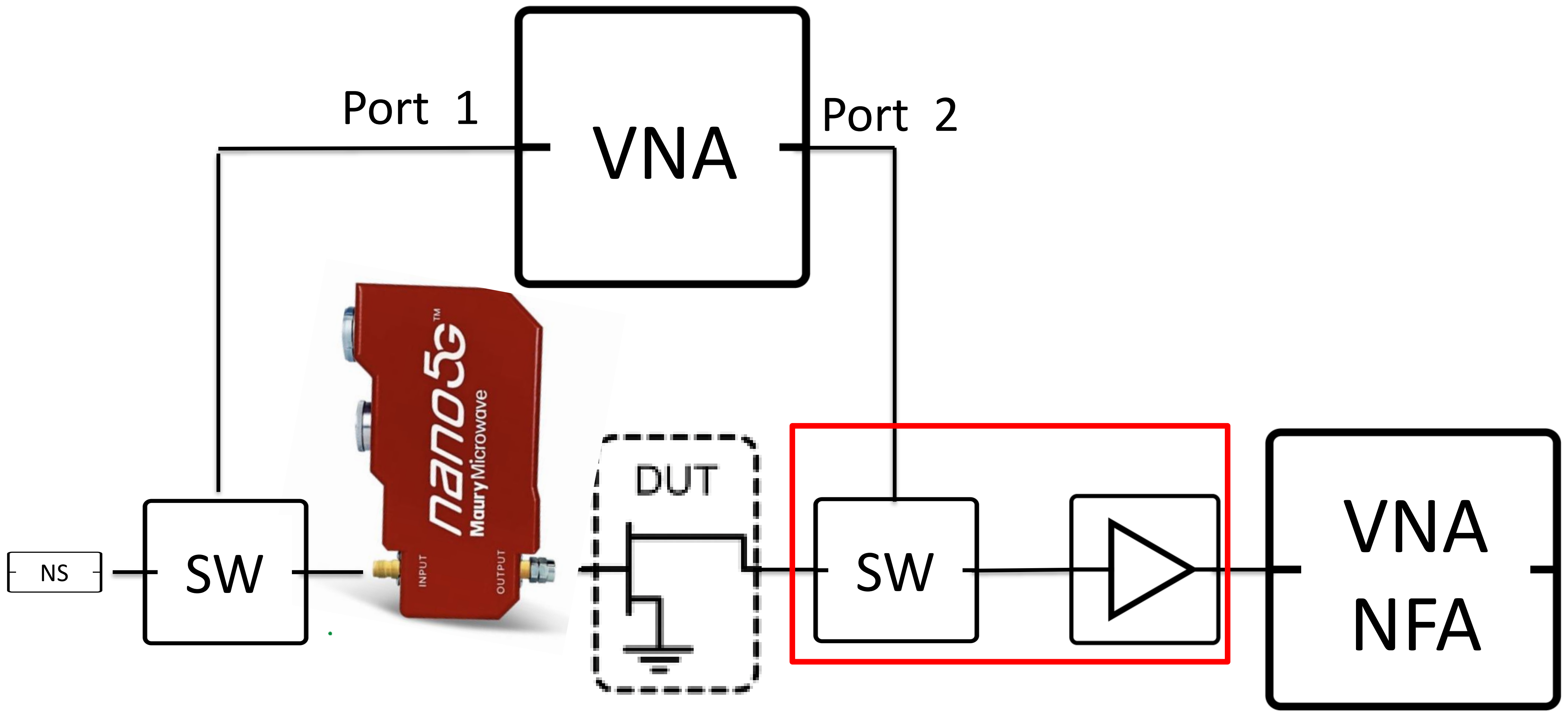
Four Scalar Values:

$F_{\min}$

$\Gamma_{opt} \rightarrow |\Gamma_{opt}|, \angle\Gamma_{opt}$

r_n





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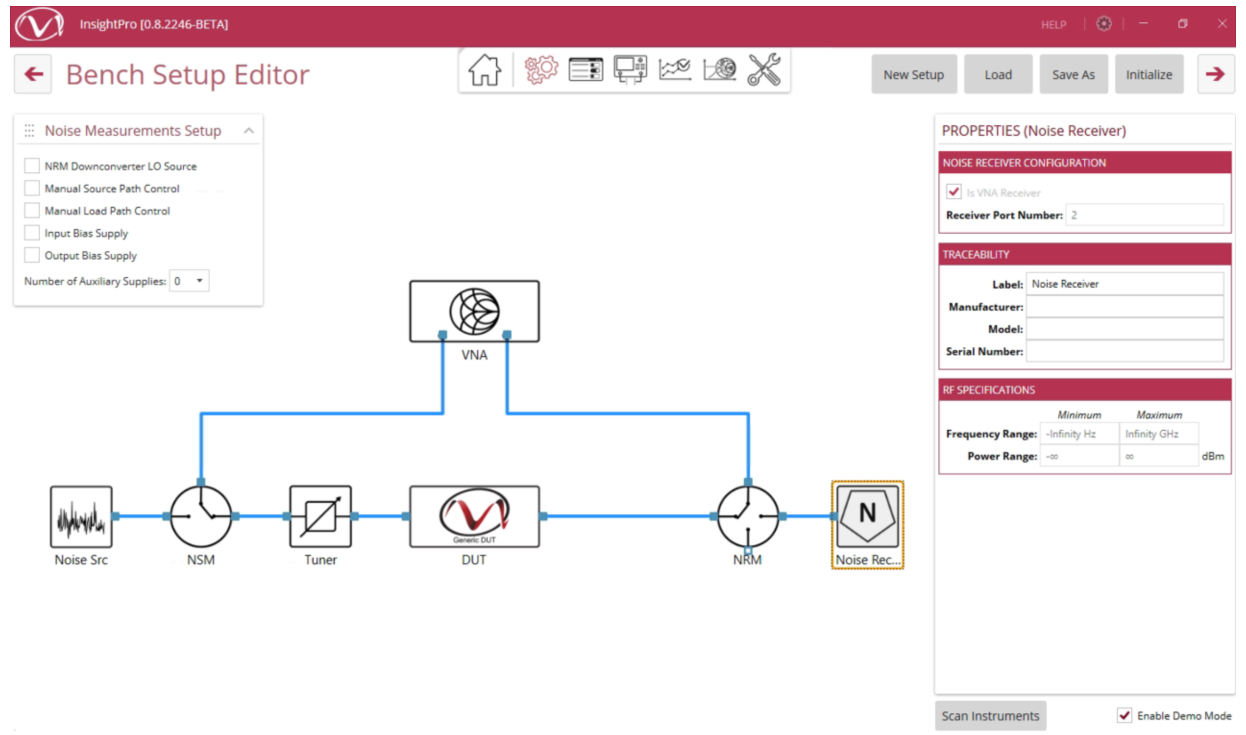
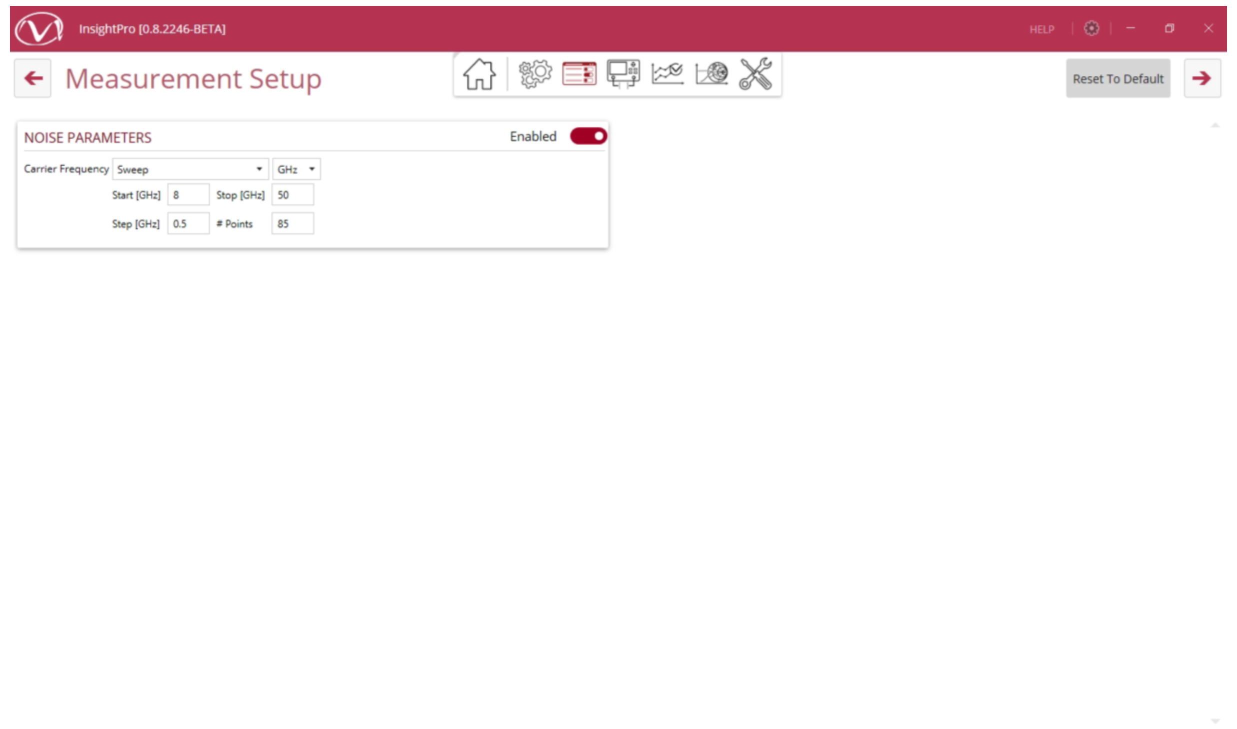
New measurement flow simplifies setup

5 intuitive steps and the most powerful viewer:

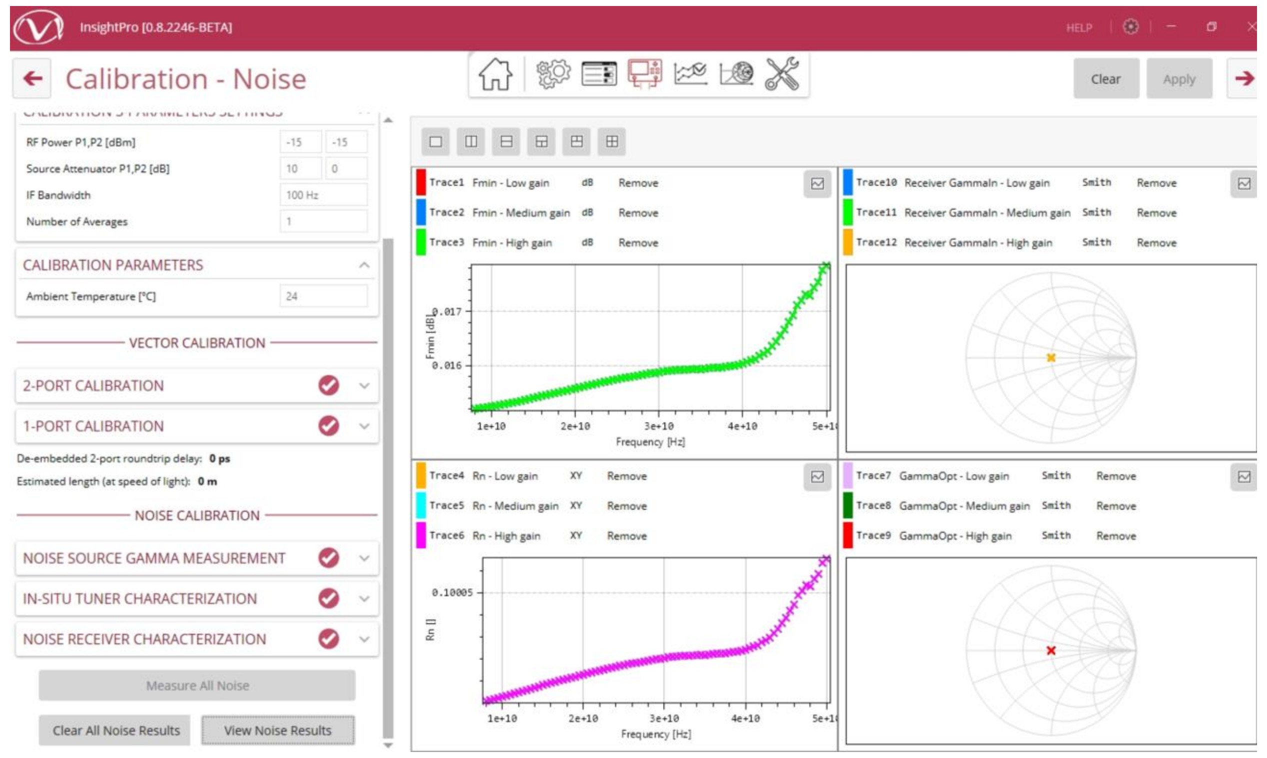
Step 1: Bench Setup



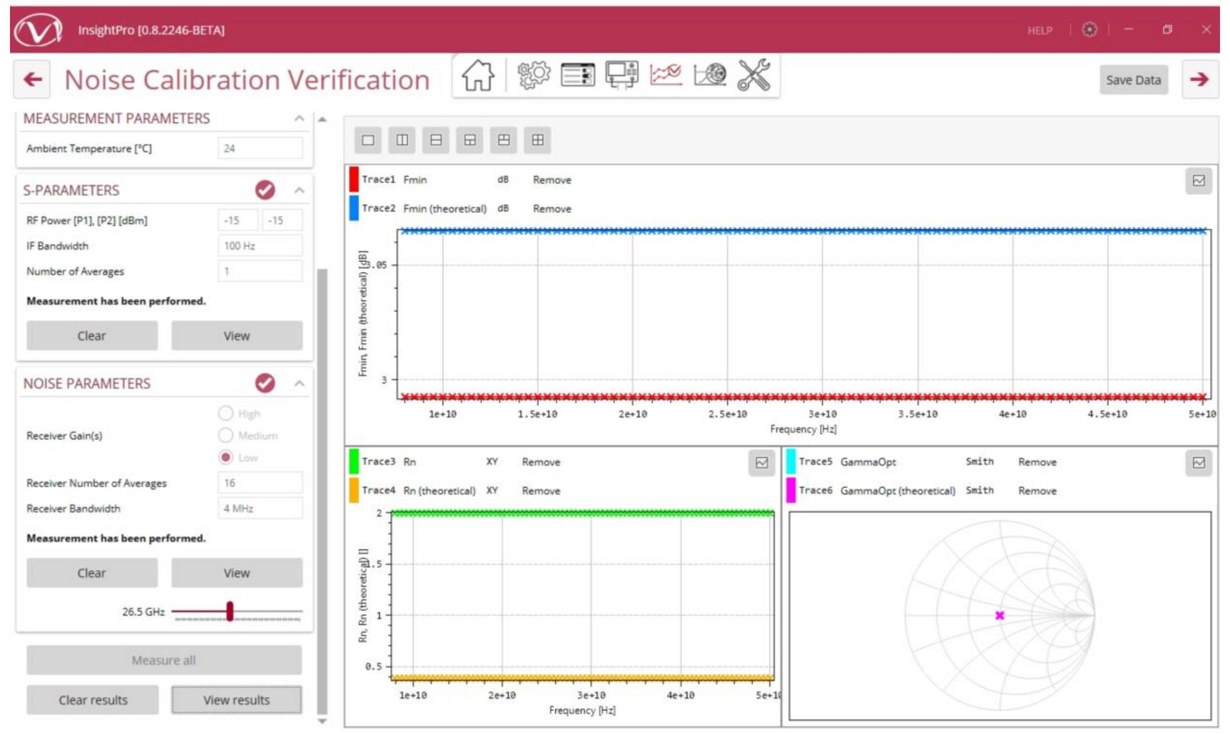
Step 2: Select Freq



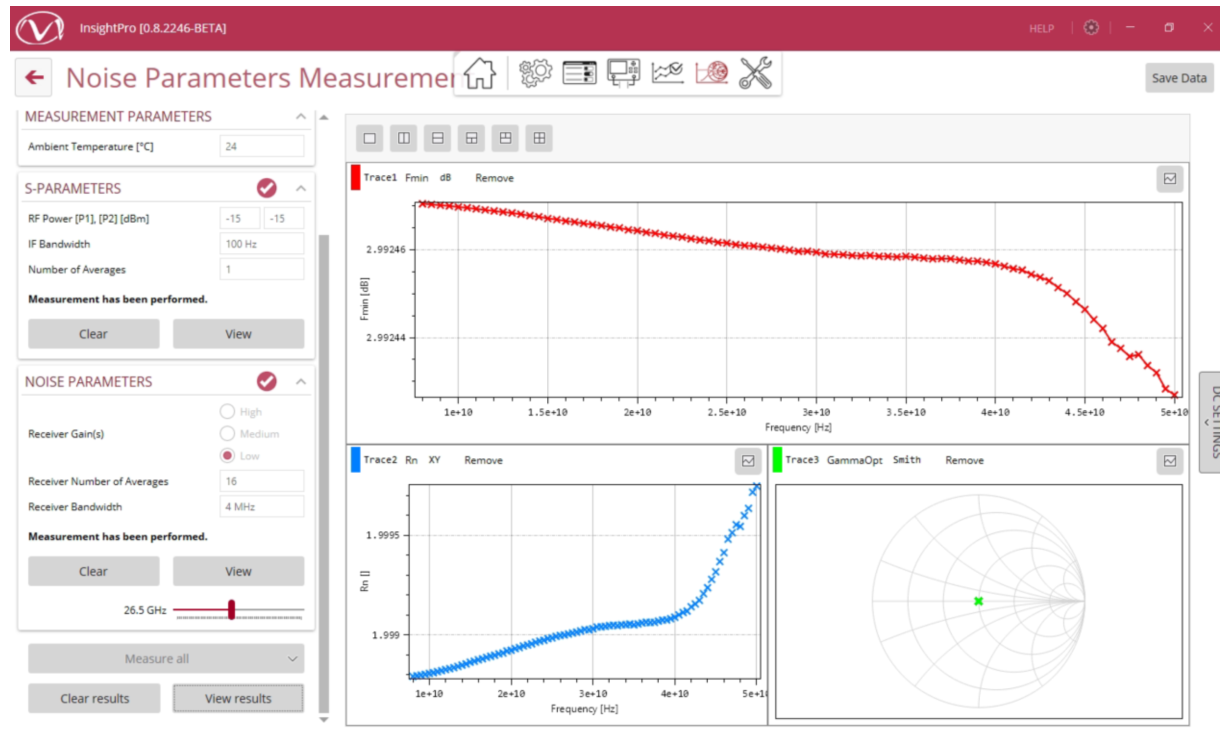
Step 3: System calibration



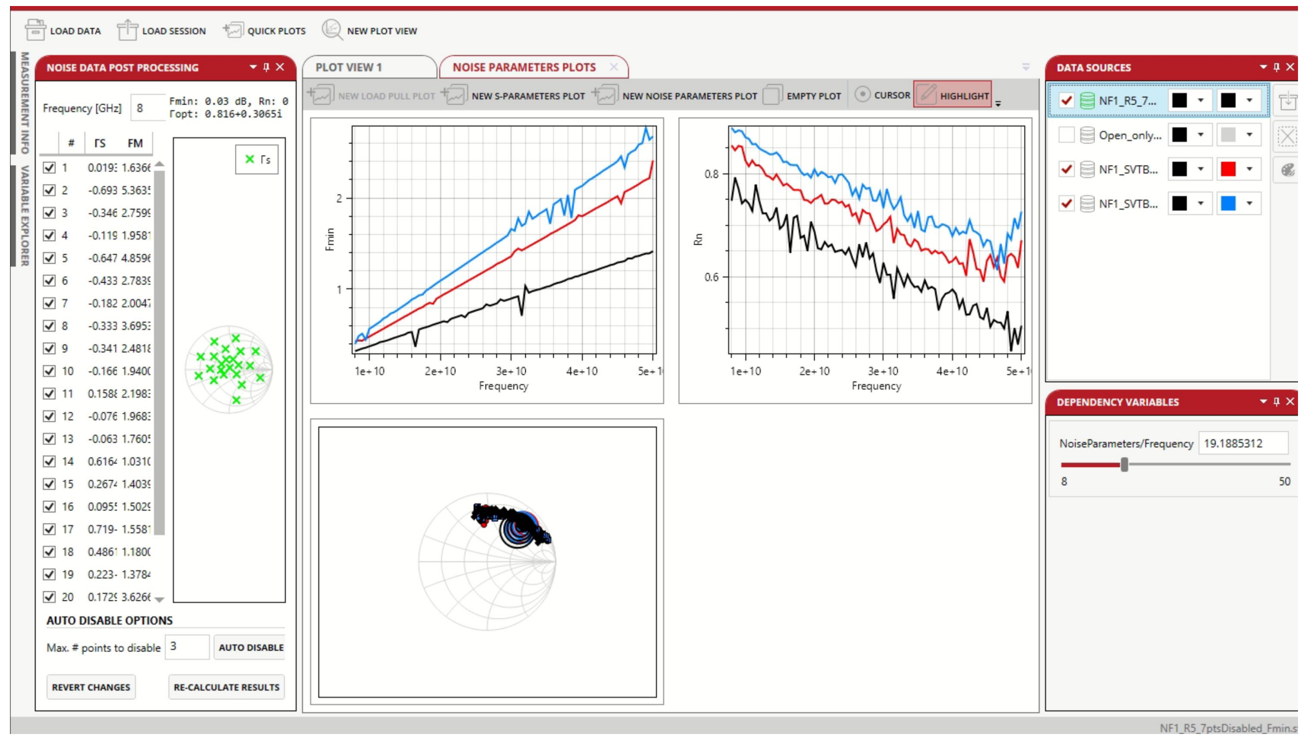
Step 4: Calibration check



Step 5: DUT measurements



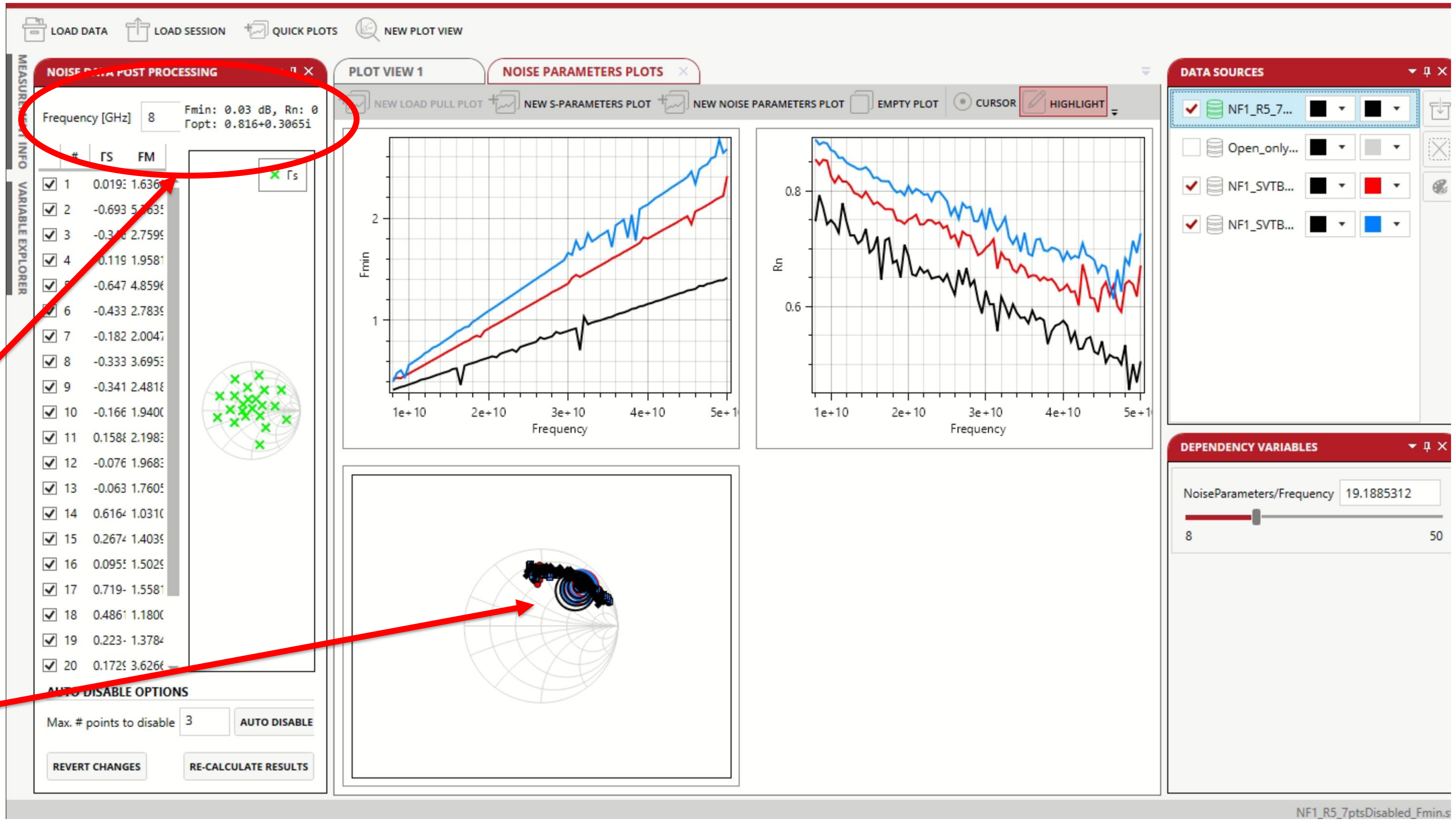
Standalone Viewer

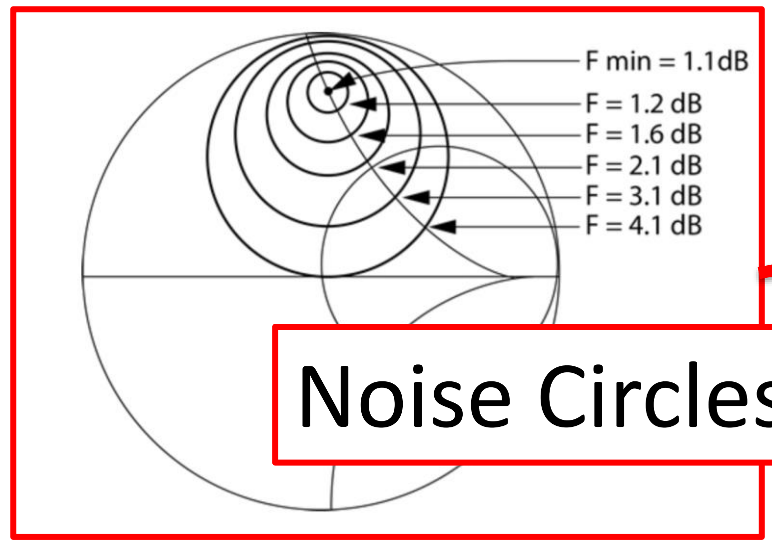


InsightPro uses the 20+ years of experience in ATS to create an optimized, intuitive measurement flow.
In particular:

- Intuitive measurement flow
- Automated verification steps
- Optimized for modern HW
- Fewer steps and faster to results
- Easy integration and customization
- New viewer (multiple data comparison)

Noise parameters:
F_{min}, R_n, $\Re(\Gamma_{OPT})$, $\Im(\Gamma_{OPT})$





Noise Circles

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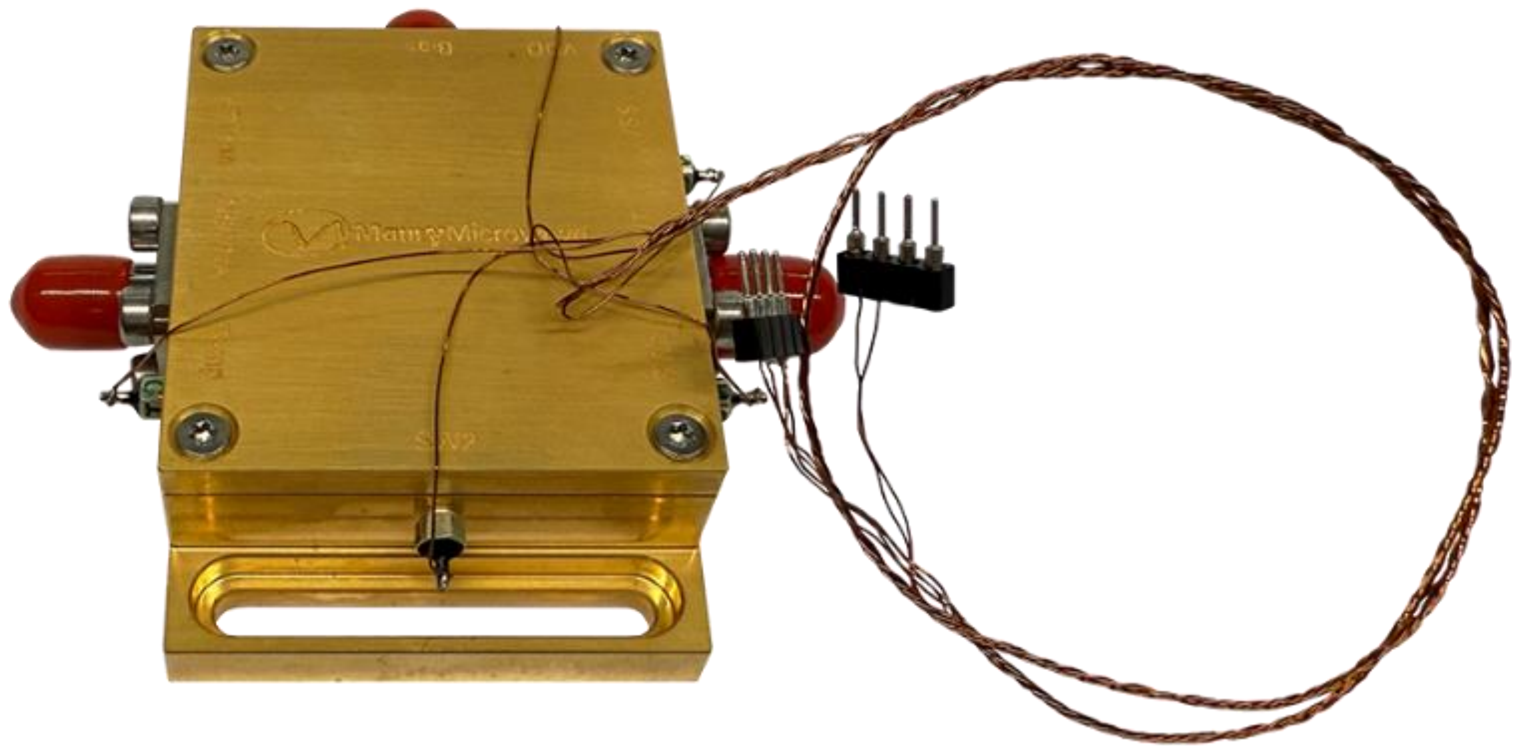
Limitations wrt cryogenic measurements

- Automated impedance tuner cannot fit in cryostat or on cryogenic probe station chuck.
  - Even if it could, it is unlikely that the mechanics will work at 4K and would create heat with each mechanical movement.
- Placing tuner outside the cryostat/chuck reduces tuning range.
  - If tuning range was sufficient, this would result in large measurement uncertainties due to stainless steel cables between tuner and DUT not being thermally equalized.

Cryogenic solid-state tuner (1/2)



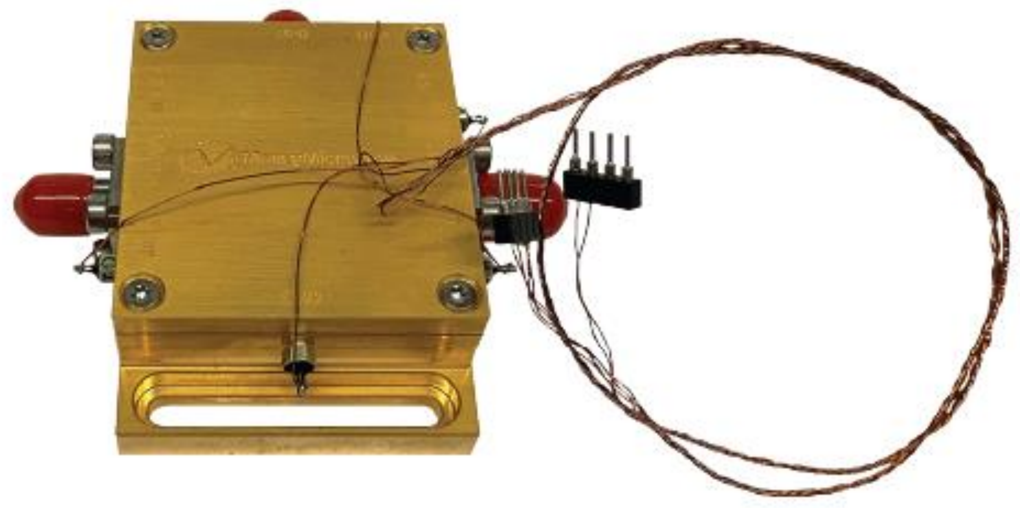
Solid-state automated impedance tuner designed for use down to 4K

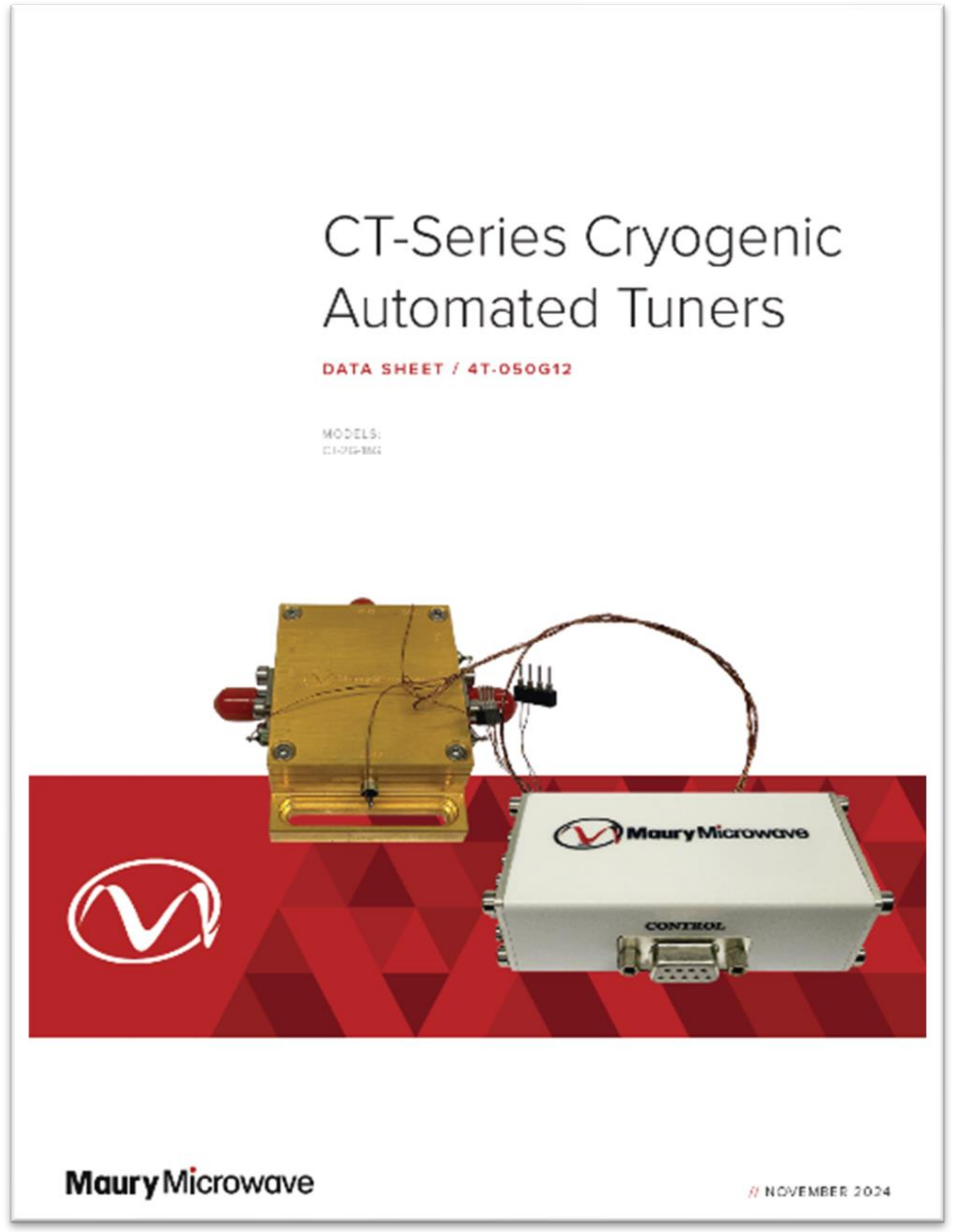
- Solid-state technology with no mechanical movement uses low power and generates low heat (~600uW).
- Small size (57mm x 38mm) and weight (80g) allows for direct installation on cryostat or cryogenic probe station “cold head” for thermal stabilization.
- Integrated cryogenic temperature sensor measures actual tuner temperature to de-embed tuner noise contribution.
- Integrated bias tee for DUT gate bias.

Nobody else offers a cryogenic impedance tuner; unique product on market!

Cryogenic solid-state tuner (2/2)

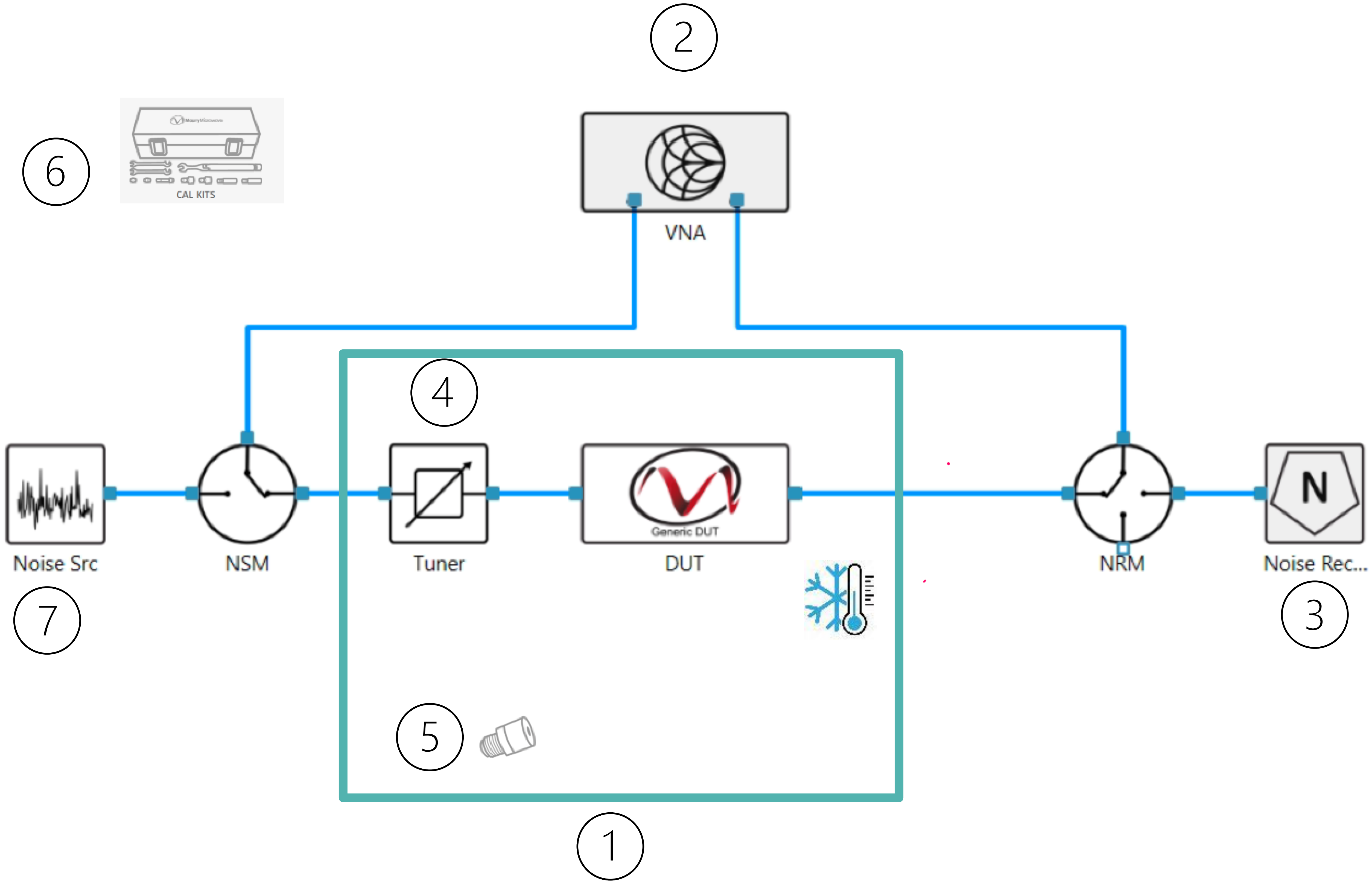
Model	Frequency Range (GHZ)	Impedance States	p1dB (dBm)	Return Loss (dB) typ/min	Insertion Loss (dB) at THRU state	Repeatability (dB)	Integrated Temperatue Sensor	Integrated Bias Tee	Connectors	Weight (g)	Power Consumption (mW)
CT-2G-18G	2-18	4	30	2-4 GHz : 20/15 4-18 GHz: 15/8	2-12 GHz: 3dB typ 12-18 GHz: 9.5dB max	-60	Yes	Max current = 270mA Irms Max voltage = 10V	SMA female	80	0.2





Each tuner is provided with:
> Tuner controller (white box above)
> USB cable (power and communication)
> Operating Manual / User Guide

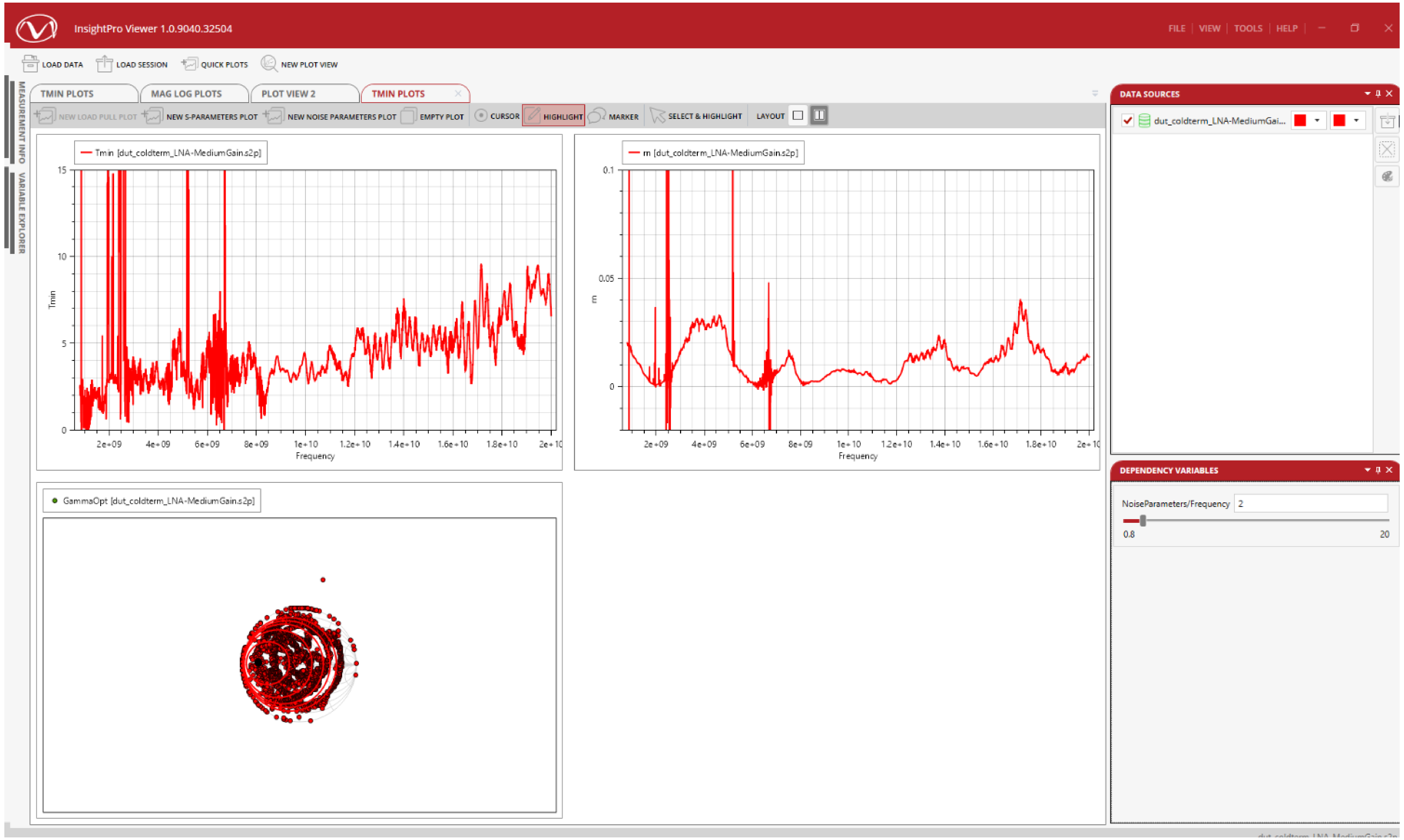
Cryogenic NP measurement system



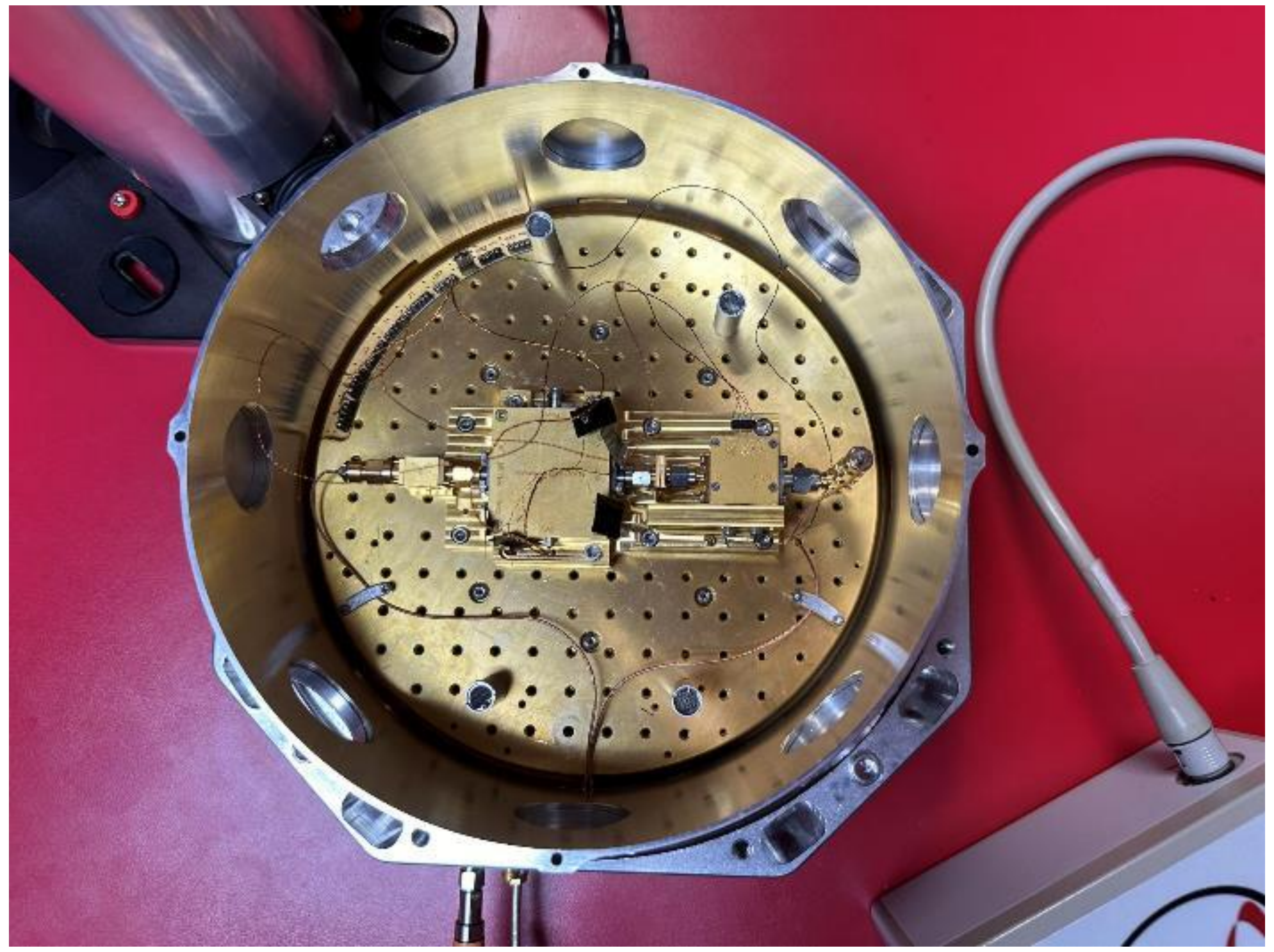
1. Cryostat or cryogenic probe station able to reach the desired temperature
2. Vector network analyzer (VNA) to measure S-parameters
3. Noise figure analyzer (NFA) to measure noise power (can be a standalone NFA or spectrum analyzer with noise personality, or integrated into the VNA)
4. Cryogenic impedance tuner able to set at least four impedance states
5. Cryogenic termination
6. Cryogenic VNA calibration kit
7. Noise source with sufficient ENR for noise power calibration
8. Cryogenic and room-temperature cables and adapters

While we are only offering the CryoTuner for sale at this time, we will provide a cryogenic noise parameter measurement example walkthrough upon request

Cryogenic Noise Parameters



Note: spikes shown above are caused by interference as measurements were not taken in a Faraday cage



Publications

Noise-Parameter Measurements of Very-Low-Noise Amplifiers at Ambient and Cryogenic Temperatures

Radio-telescope receivers are developed to sense very weak astronomical signals. The sensitivity of a radio telescope is inversely proportional to its noise temperature, which is largely dependent on the amount of noise generated in the receiver low-noise amplifier (LNA). In addition, a radio telescope sensitivity is also proportional to its collecting area; however, it is very costly to enhance sensitivity by increasing the collecting area. Given the high costs associated with increasing the collecting area, the development of methods of reducing LNA noise becomes critical to optimizing the operation of radio telescopes. Such LNA-noise reduction techniques must first be verified via laboratory measurements and then subsequently verified using field measurements on the telescope.
https://ieeexplore.ieee.org/document/9400953

Automated Noise-Parameter Measurements of Cryogenic LNAs

This paper addresses the need for measured cryogenic noise parameters. The measurement process is discussed, and an analysis of the measurement uncertainty is performed. To verify proper operation of the measurement system, measurements of a 1-to-2-GHz radio-astronomy low-noise amplifier (LNA) at 20, 75, and 296 K are presented. In these measurements, the typical 1σ measurement uncertainty in noise temperatures and minimum noise temperatures is < 10%.
https://ieeexplore.ieee.org/document/9639993

Cryogenic Noise-Parameter Measurements: Recent Research and a Fully Automated Measurement Application

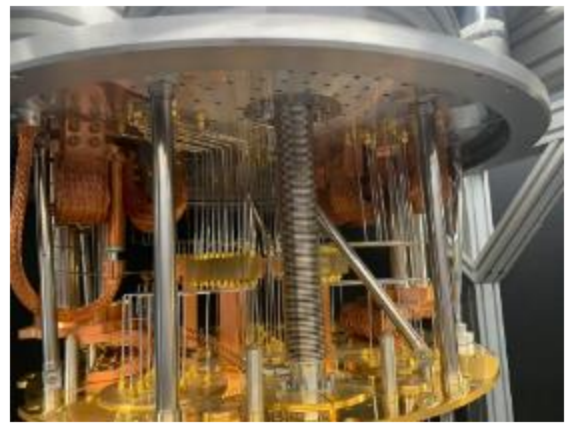
Since the conception of radio astronomy [1], researchers have been striving to develop a "zero-noise" broadband receiver. Although this goal has remained elusive, the pursuit of it has led to numerous low-noise circuit innovations [2], [3]. Perhaps the most notable of these innovations are cryogenic low-noise amplifiers (cryo-LNAs) [3]-[6] as this technology has been able to achieve the lowest noise levels to date. While references to cryogenic amplifiers in the literature date back to the early 1950s [7], they are still a subject of much interest among researchers. Cryo-LNAs were initially conceived of to address challenges in the fields of space exploration [8], [9] and radio astronomy [10]. More recently, researchers in other fields have become interested in "zero-noise" receivers, making this a topic of widespread interest among RF and microwave engineers.
https://ieeexplore.ieee.org/document/9475609

A Cryo-CMOS Low-Noise Amplifier With 2.3-to-8.5-K Noise Temperature at 20 K for Highly Integrated Radio-Astronomy Receivers

This letter presents a 0.9–1.8-GHz cryo-CMOS low-noise amplifier (LNA) built-in standard 65-nm CMOS for highly integrated radio astronomy receivers. The measured cryogenic noise parameters confirm noise matching in the band and demonstrate that the LNA nears its minimum noise temperature at the desired frequency range. The proposed LNA operates at 20 K, consumes 115 mW of power, and provides a 37.2 ± 2.4 dB gain (S21) with a noise temperature (figure) of 2.3 to 8.5 K (0.03 to 0.13 dB) and |S11|<−10 dB.
https://ieeexplore.ieee.org/document/9791109

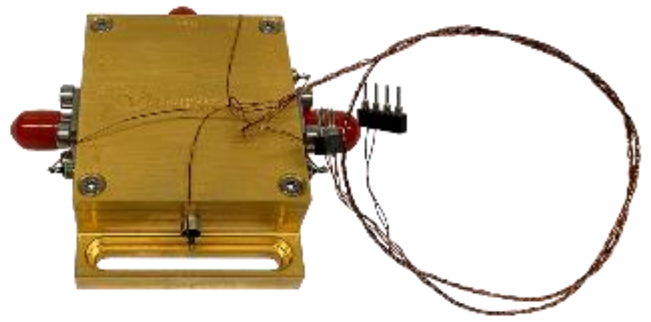
New publications will be released in 2025 as we collaborate with universities on cryogenic noise parameter measurements

Summary



Cryogenic LNAs are critical components in radio telescopes and quantum computers

Maury is an industry-leader in noise parameter measurement solutions for LNA design



And has launched the industry's only cryogenic impedance tuner

And is working with the leading cryostat and cryogenic probe station vendors

To create a fully-proven best-in-class turnkey cryogenic noise parameter solutions *(tuner available now, turnkey solution mid-2025)*

Thank You!

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