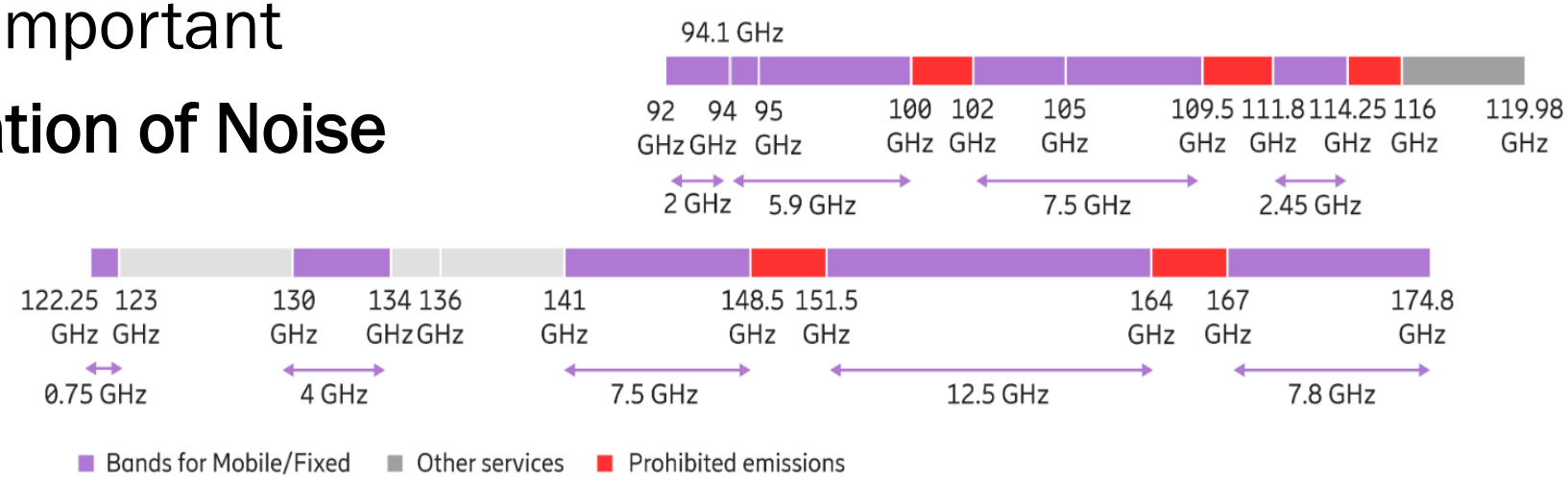
KEYSIGHT

Sub-THz Noise Figure Measurements

Nizar Messaoudi
Keysight Technologies

Motivation

- Future communication and sensing systems will heavily rely on the spectrum in the Sub-THz frequencies
- Path loss at these frequencies is high so receiver sensitivity is important
- **Accurate Characterization of Noise Figure is critical**



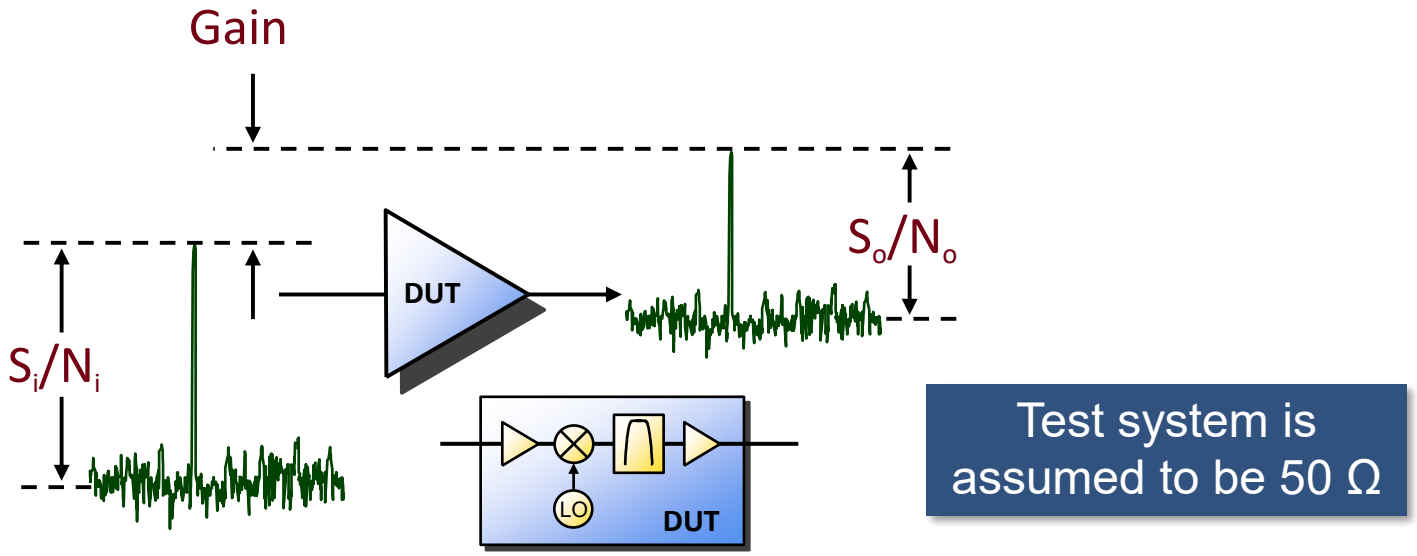
W & D-band Spectrum Resources
[https://www.ericsson.com/en/6g/spectrum/sub-thz]

Noise Figure Definition

Noise Figure is Defined in Terms of SNR Degradation

$$F = \frac{(S_i/N_i)}{(S_o/N_o)} = \frac{(N_o)}{(G \times N_i)} = \frac{N_a + kT_oBG}{kT_oBG} \quad \text{(noise factor)}$$

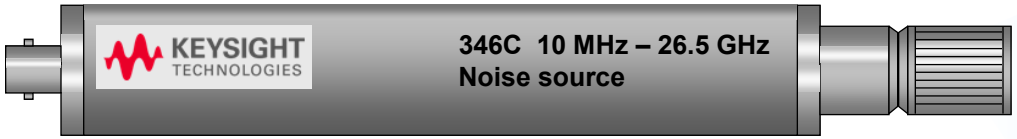
$$NF = 10 \times \log (F) \quad \text{(noise figure)}$$

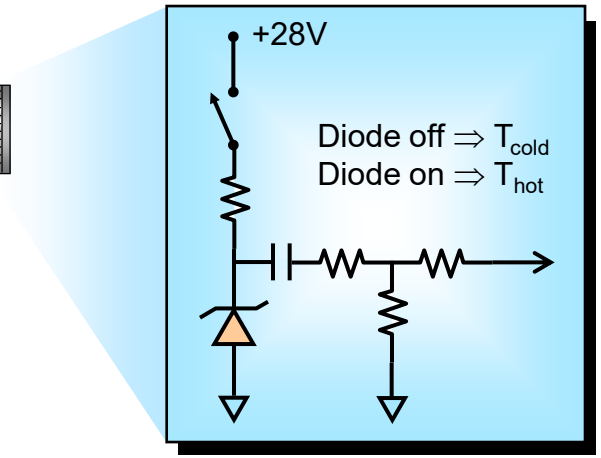


Test system is assumed to be 50 Ω

Noise Figure Measurement Techniques

- **Y-factor (hot/cold source)**
  - Used by NFA and spectrum-analyzer-based solutions
  - Uses noise source with specified “excess noise ratio” (ENR)
  - Measures noise figure and gain of DUT



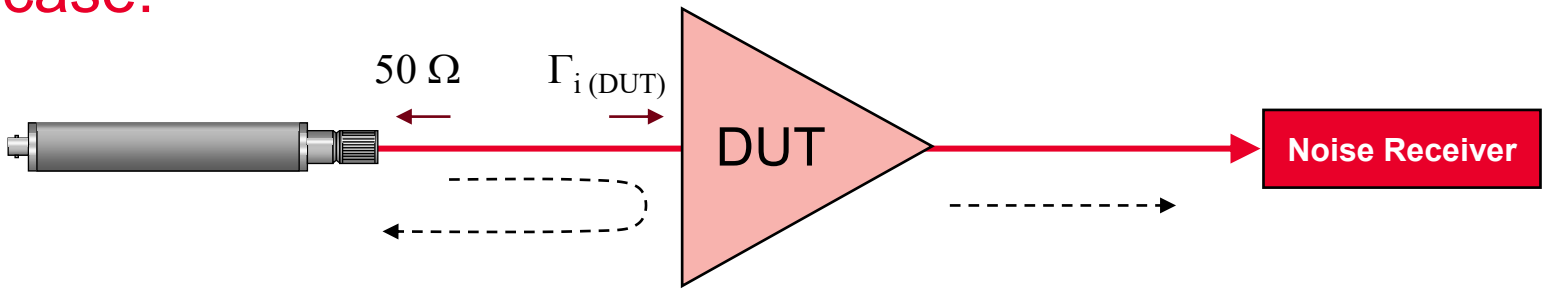


$$\text{Excess noise ratio (ENR)} = \frac{T_{hot} - T_{cold}}{290K}$$

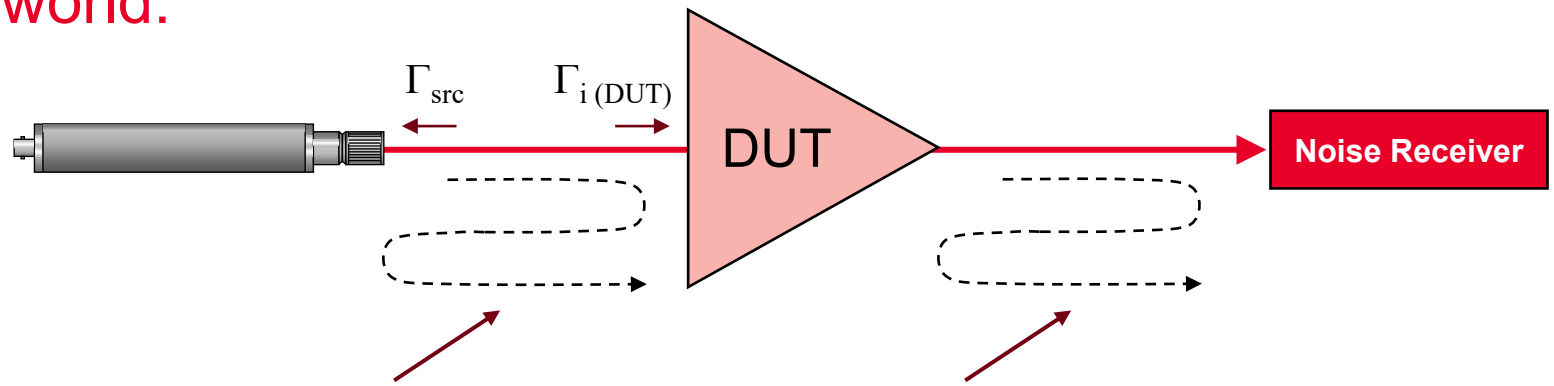
- **Cold source (direct noise)**
  - Used by vector network analyzers (e.g. PNA-X)
  - Uses cold (room temperature) termination plus separate gain measurement
  - Allows single-connection S-parameters and noise figure (and more)
  - More advanced error correction yields higher measurement accuracy

Noise Figure Mismatch errors with Y-Factor

Ideal case:

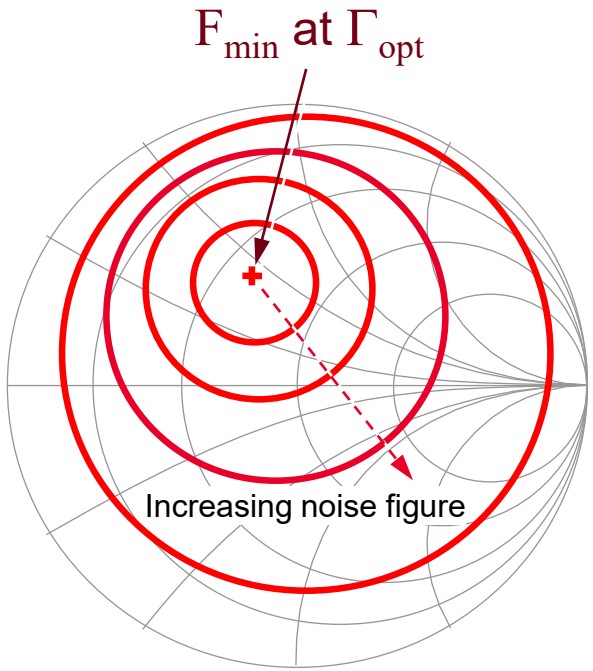


Real world:

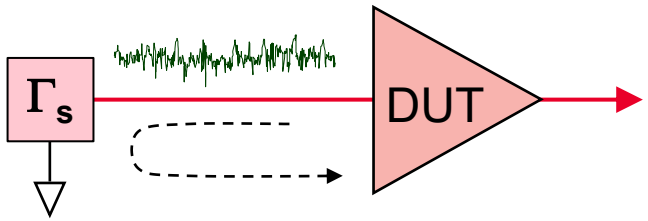


Re-reflection causes ripple versus frequency

Noise Parameter Errors



- NPs characterize amount of DUT-generated noise and sensitivity to source impedance
- NPs typically plotted as noise-figure circles on a Smith chart, giving NF versus impedance (one frequency at a time)
- Re-reflection of internally-generated noise occurs when $\Gamma_s \neq 50\ \Omega$, causing additional measurement ripple
- This source of error is independent from noise-source mismatch error



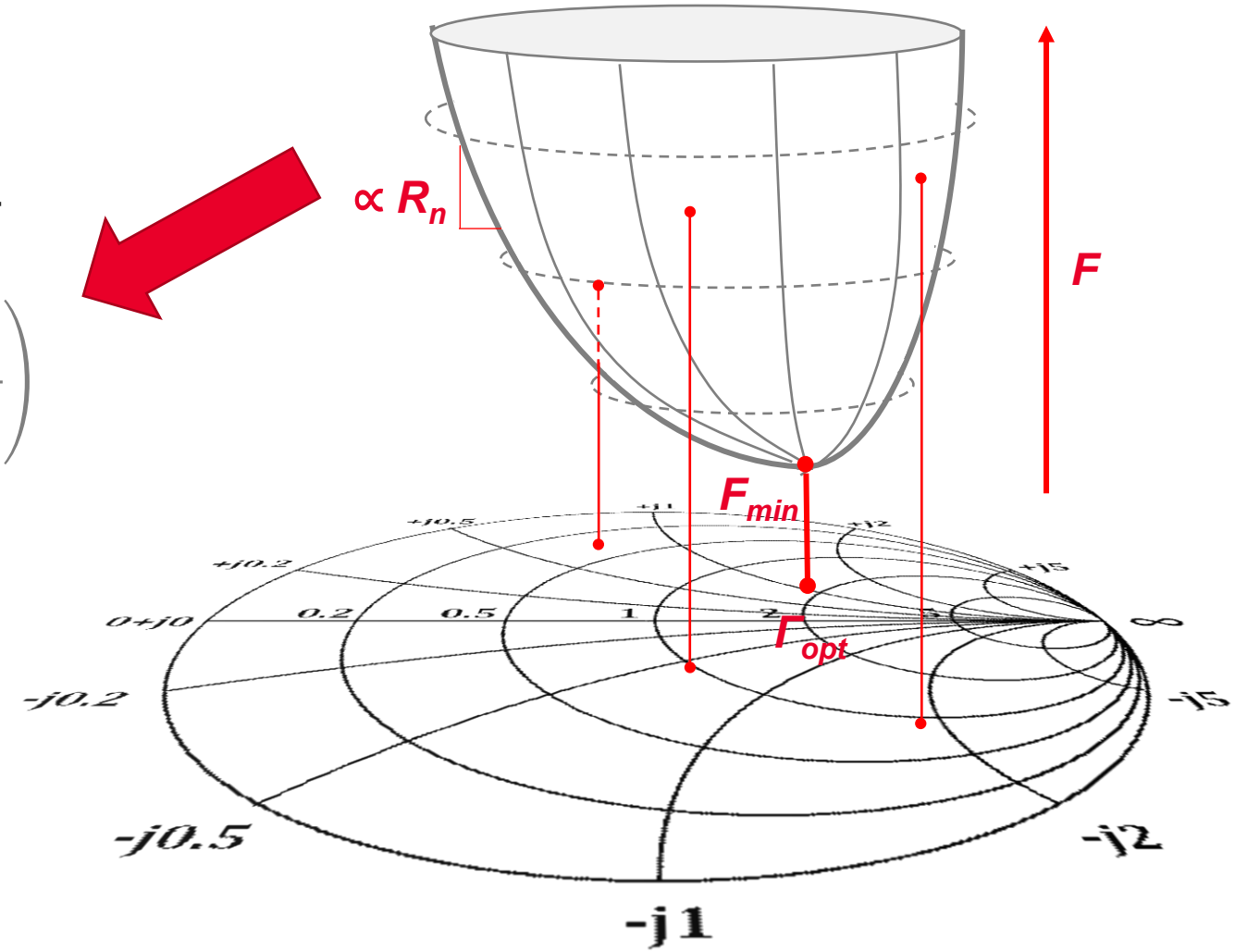
Four Noise Parameters

- By extracting noise parameters, we can correct for systematic errors and find NF

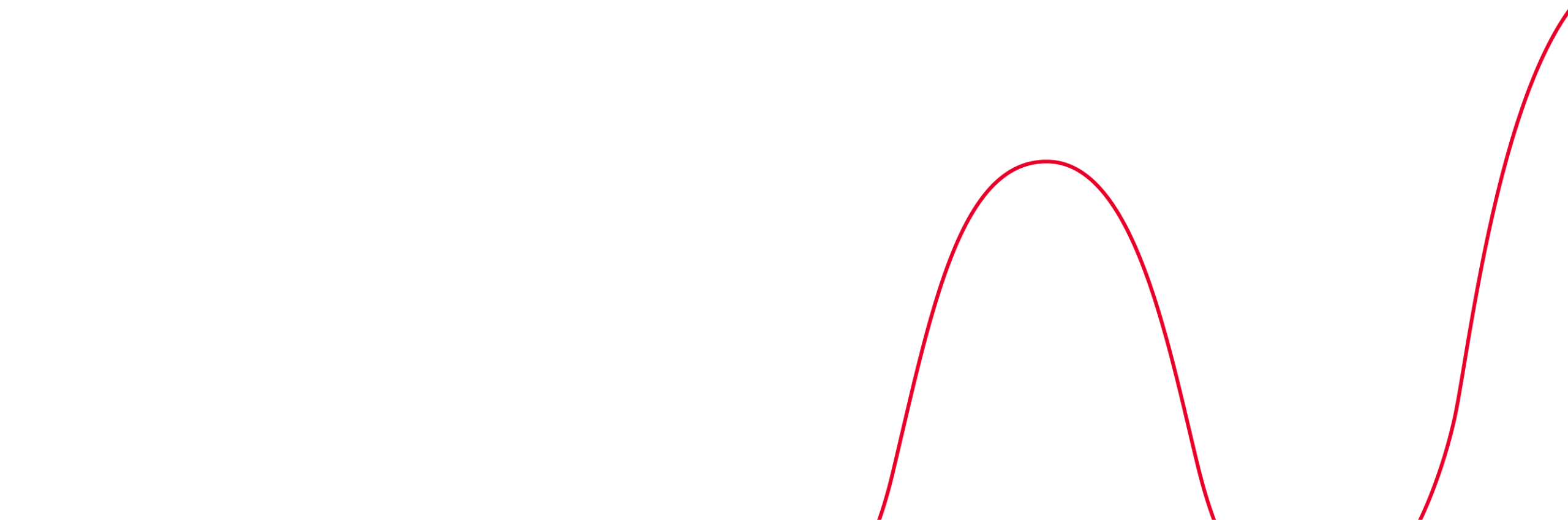
$$F(\Gamma_s) = F_{min} + \frac{4R_n}{Z_0}\left(\frac{|\Gamma_{opt} - \Gamma_s|^2}{|1+\Gamma_{opt}|^2(1-|\Gamma_s|^2)}\right)$$

$$\boldsymbol{F_{min}, R_n\ (|\Gamma_{opt}|, \varphi_{opt})}$$

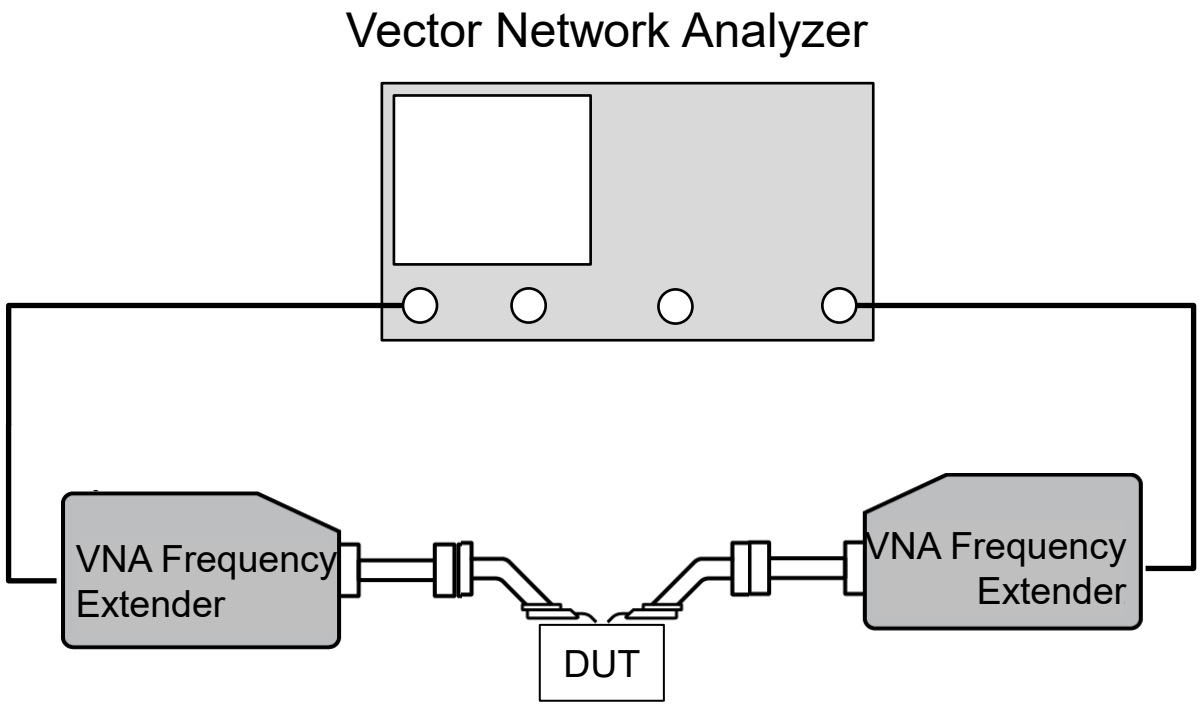
The 4 noise parameters



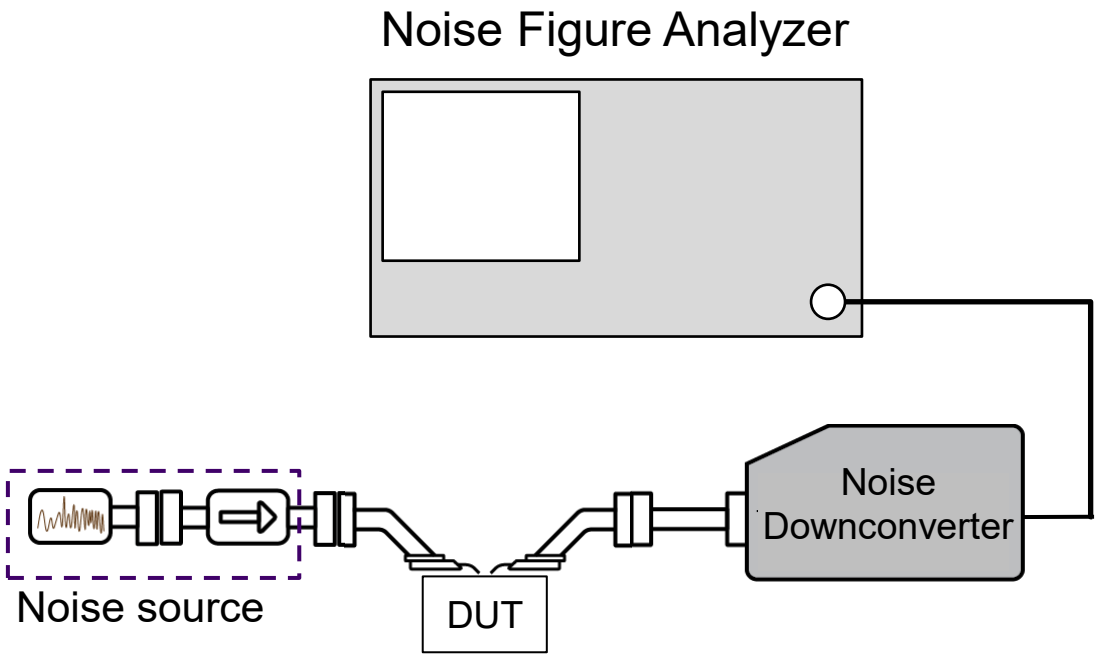
Now push this to sub-THz



Sub- THz Component Testing

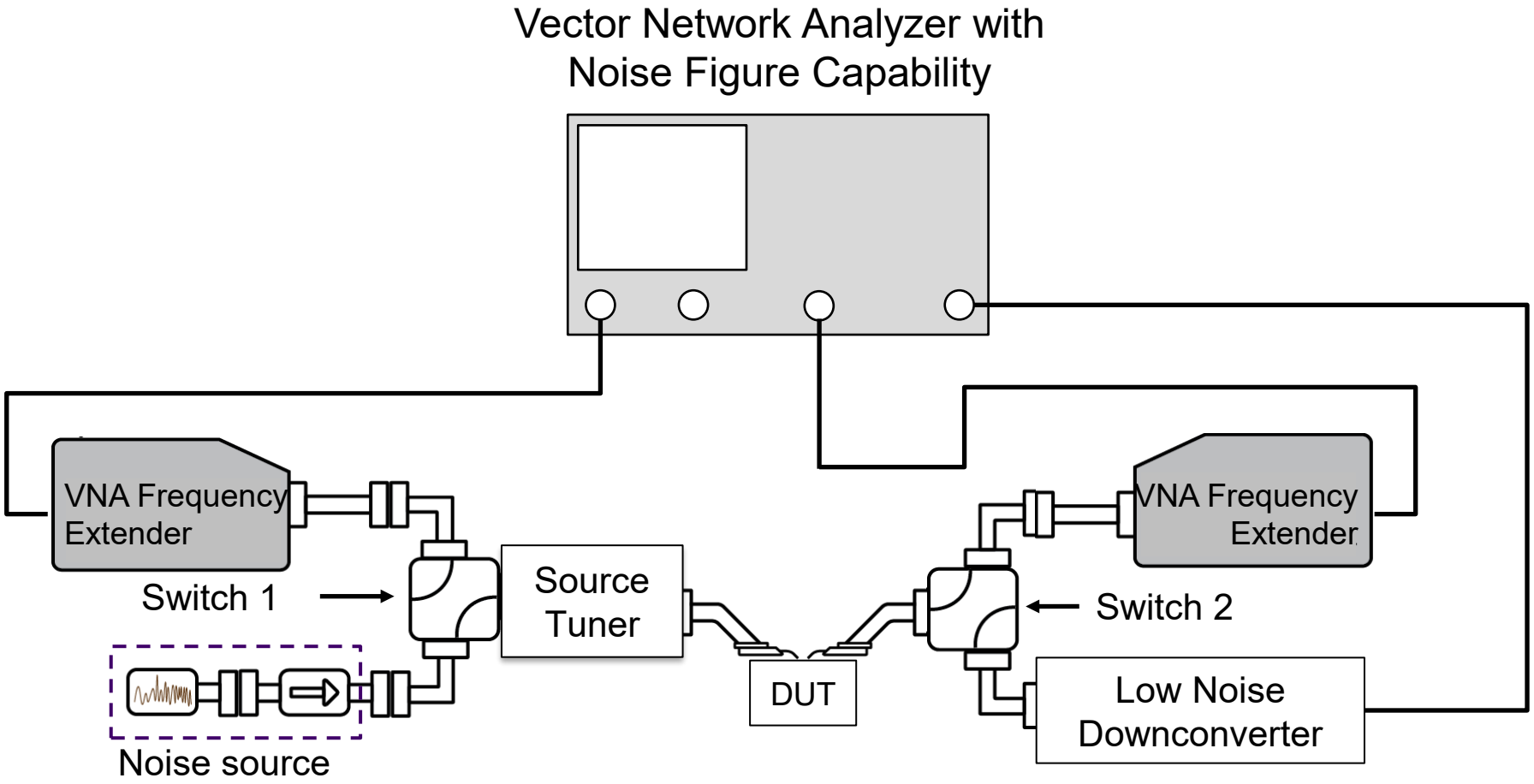


+ Accurate S-Parameters
– Frequency Extenders cannot be used for noise figure measurements

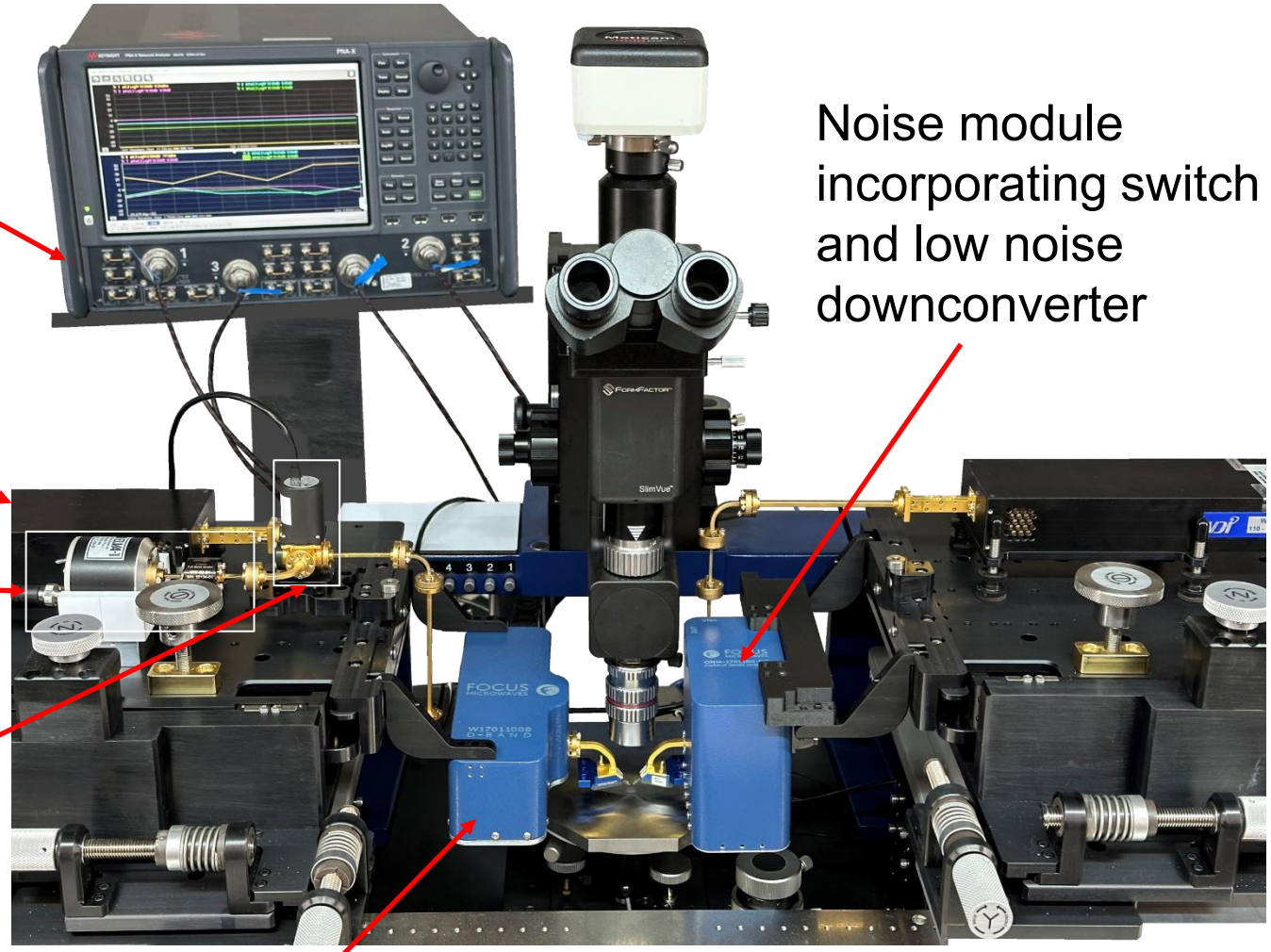


+ Capable of noise figure measurements
- Not capable of accounting for test-system non-idealities

Measurement Block Diagram



Measurement Setup



Why Keysight and Focus Microwaves

Keysight

- VNA-based cold-source and vector-corrected NF architecture as the calibrated reference
- Spurious free DDS sources that can be used for the noise module LO

Focus Microwaves

- Impedance tuners and direct-mount noise modules built for low-loss operation at the probe tip
- Extraction software and algorithms that de-embed system noise and resolve full noise parameters at W-band and D-band

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Thank you