

COMPASS

a FormFactor users' group conference

1/f Noise Challenges and Solutions

E4727B
Advanced Low-Frequency Noise Analyzer

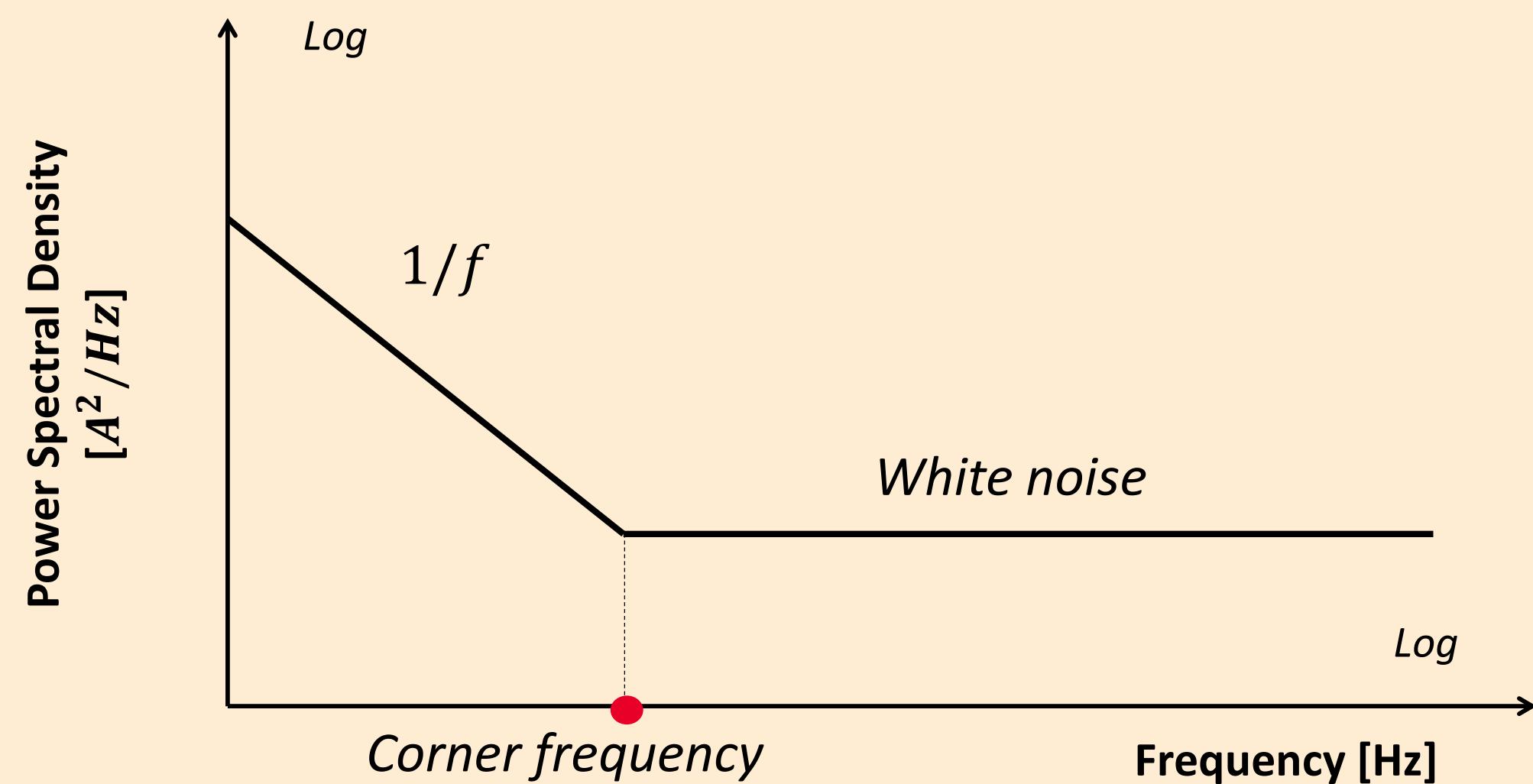
November 17th and 18th, 2020

Low-Frequency Noise

1/f Noise and Random Telegraph Noise

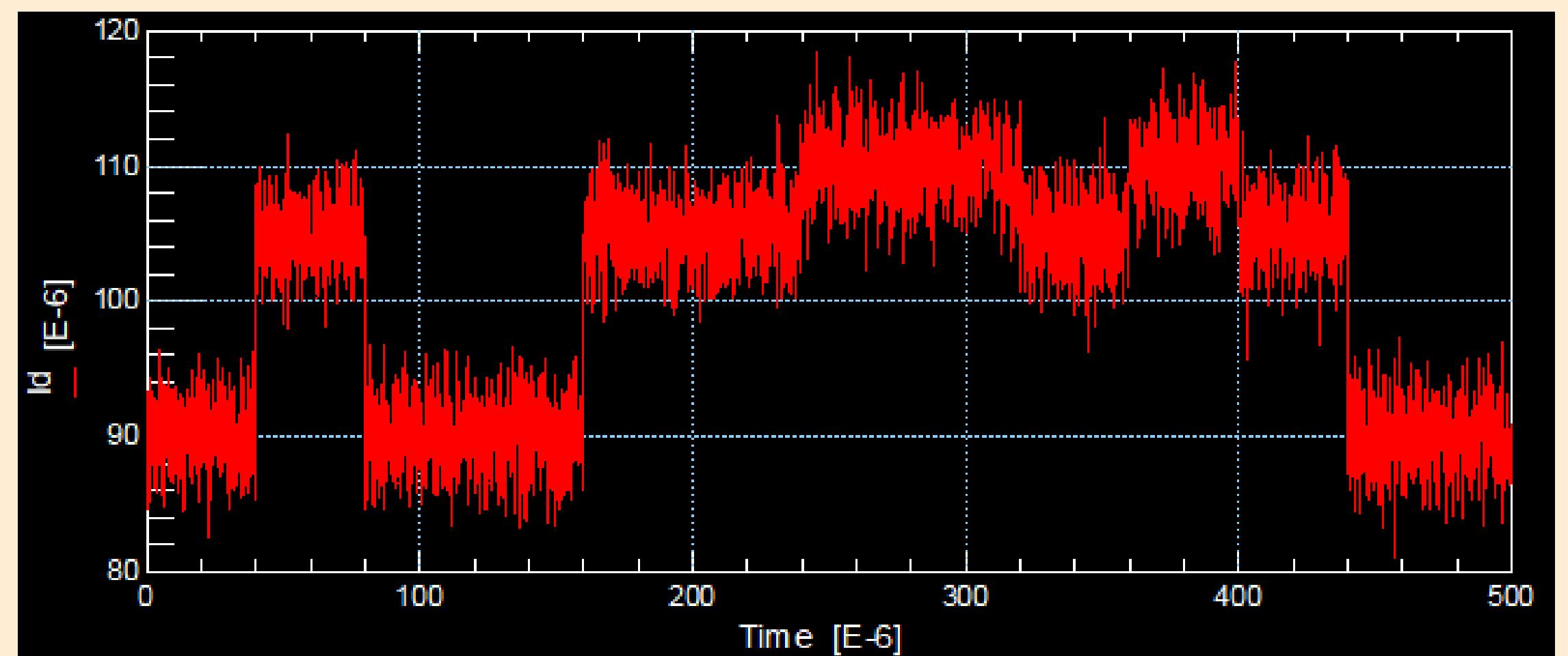
Power Spectral Density (PSD)

- Minute fluctuation of DC current observed in an electronic device at the low frequencies
- Its power spectral density usually exhibits 1/f behavior – known as 1/f noise



Random Telegraph Noise (RTN)

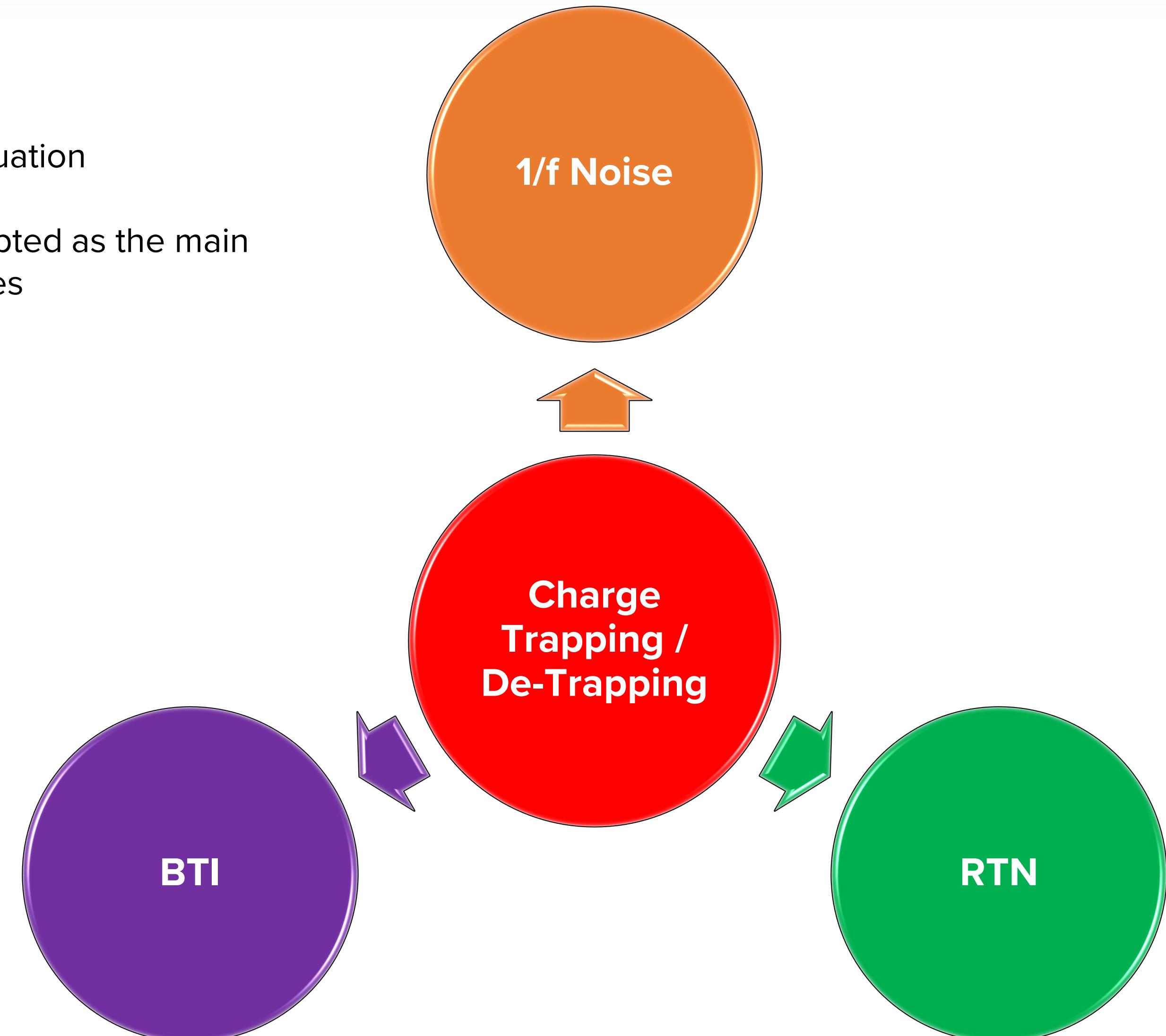
- Noise represented in the time domain exhibiting two or more stable levels



Physical Origins

Charge Trapping and De-Trapping

- Fluctuations of the number of carriers and mobility fluctuation
- The trapping/de-trapping of carriers is now widely accepted as the main reason for low-frequency noise in semiconductor devices
- Effective indicator of material quality



A-LFNA Application Examples

SUPPORT ALL SEMICONDUCTOR DEVICES

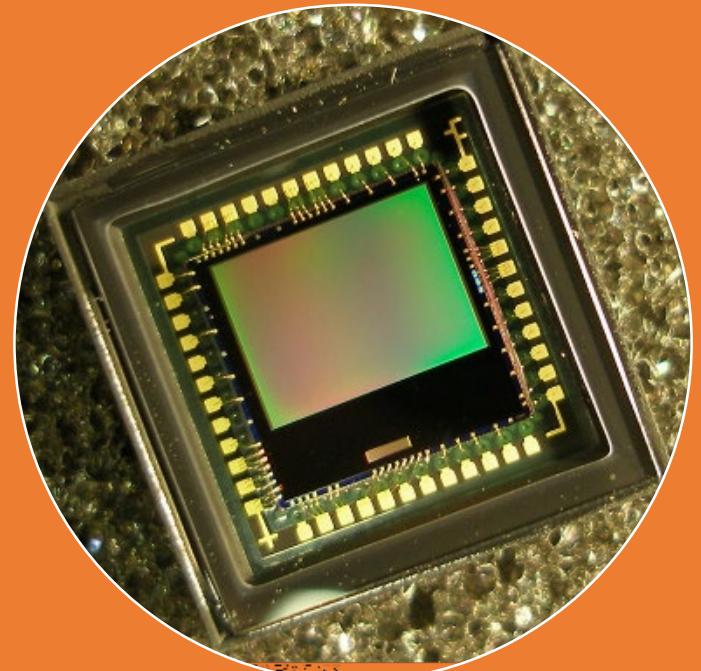
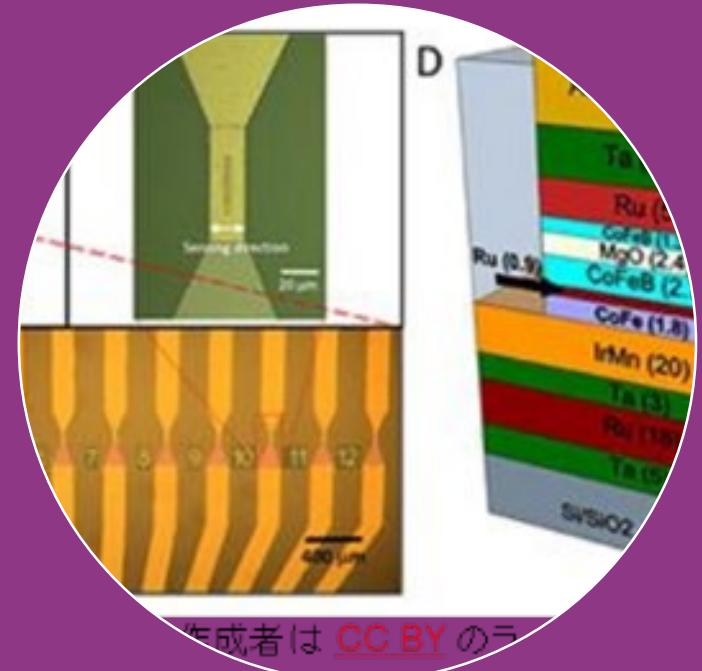


Image Sensors

- CMOS Imagers



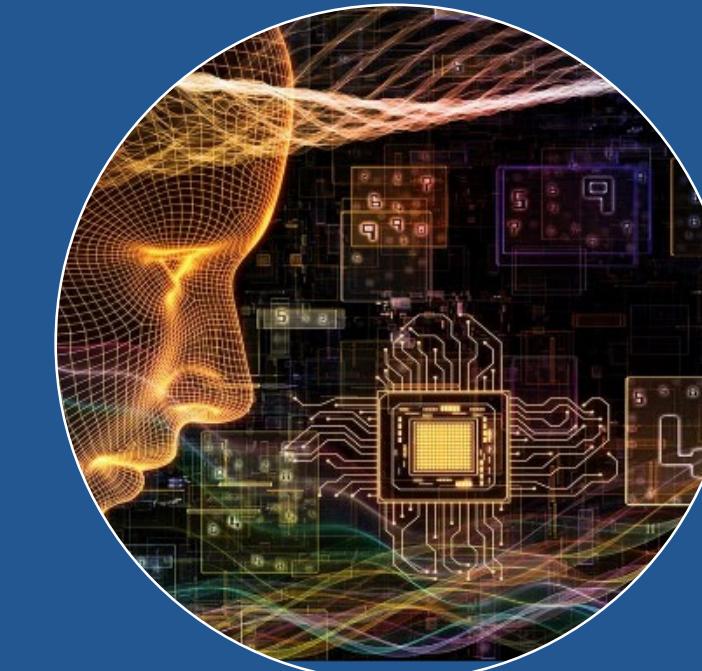
MTJ (Magnetic Tunnel Junction) Devices

- MR sensors (TMR)
- STT-MRAM



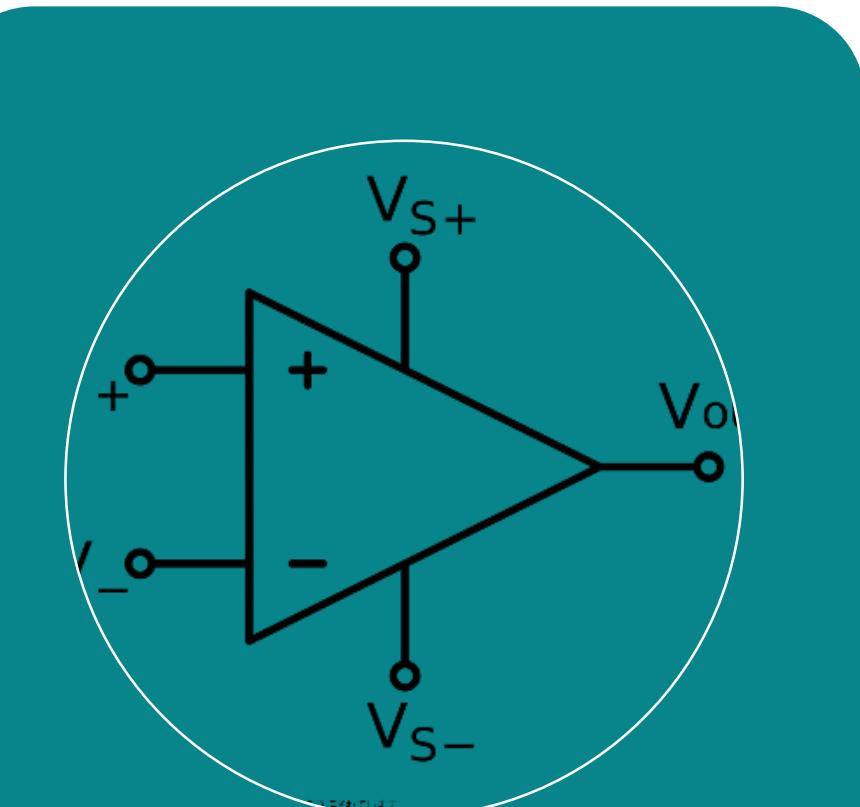
Organic Semi. / Printing Electronics

- OLED
- Wearable sensors



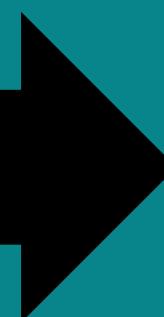
Quantum Technologies

- Quantumchips



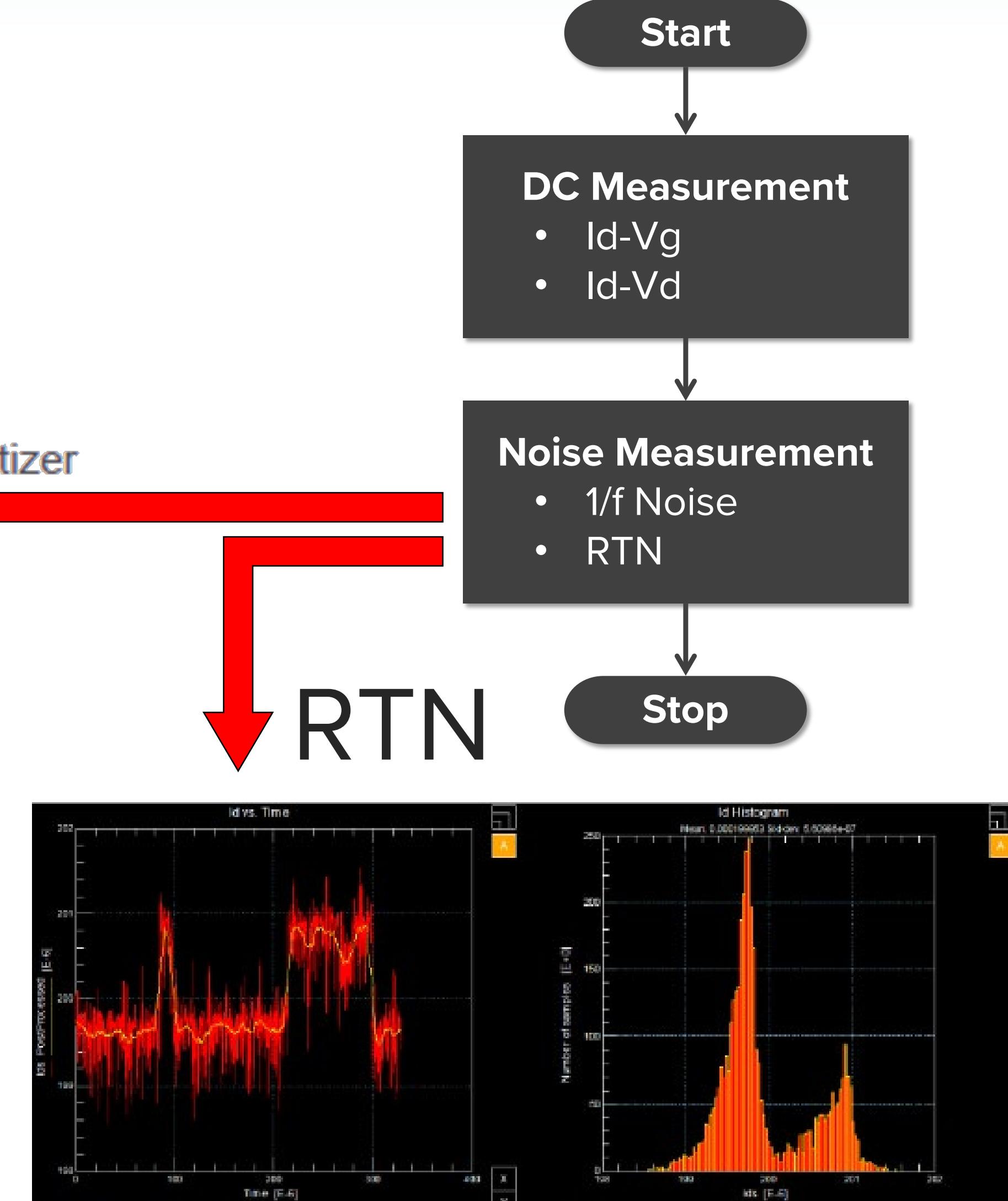
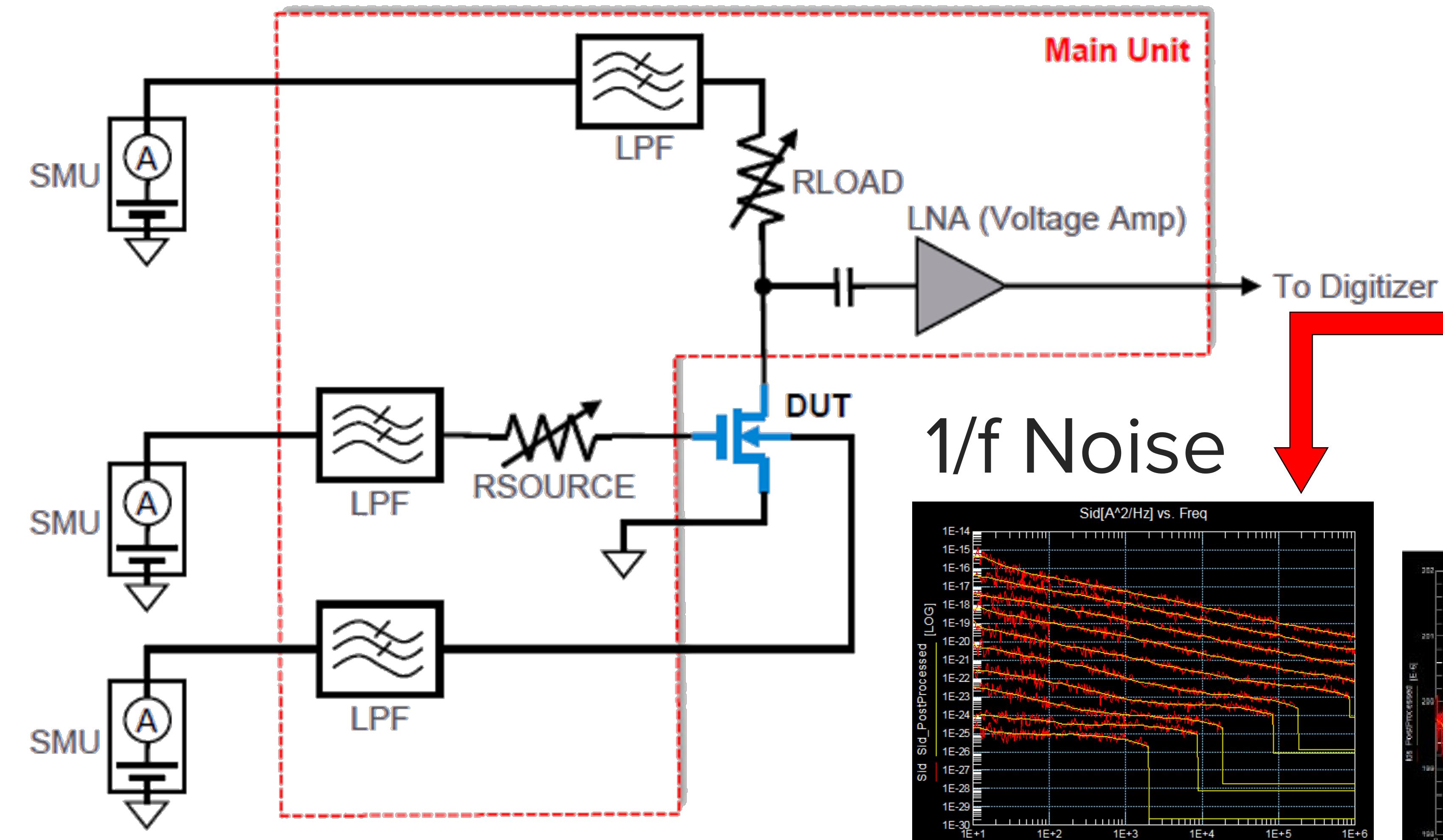
Analog Circuit Devices

- OpAMP
- LDO
- Comparators



Measuring 1/f Noise and RTN

MEASUREMENT BLOCK DIAGRAM AND FLOW-CHART



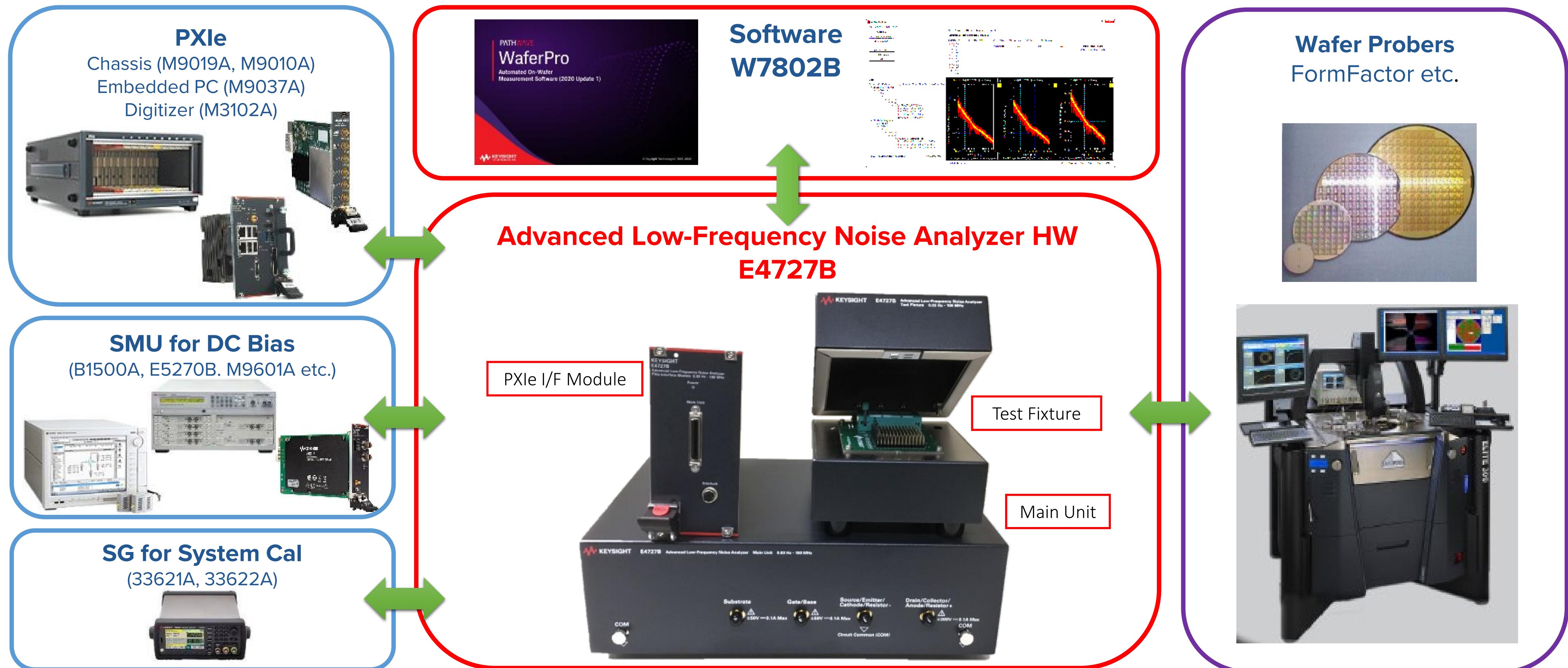
E4727B Advanced Low-Frequency Noise Analyzer

CORE HARDWARE



E4727B Advanced Low-Frequency Noise Analyzer

System CONFIGURATION



E4727B Advanced Low-Frequency Noise Analyzer

INSTRUMENT AND PROBE STATION BY CONTROL SOFTWARE E4727P3

Semiconductor Parameter Analyzers

- Keysight 4155B/C
- Keysight 4156B/C
- Keysight B1500A
- Keysight B1530A WGFMU
- Keysight E5260A
- Keysight E5270B



Full- and Semi-Automatic Probe Stations

Formfactor

- Summit 12000
- S300
- Elite300
- PA200/PA300
- CM300
- CM300xi-ULN

MPI

- TS2000-SE
- TS3000-SE

E4727B Advanced Low-Frequency Noise Analyzer

BEST LF NOISE MEASUREMENT SYSTEM



Items	E4727A	E4727B
Maximum Analog Bandwidth	0.03Hz – 40MHz	0.03Hz – 100MHz
Vamp Noise Floor	$-183\text{dBV}^2/\text{Hz}$ $=0.67\text{nV}/\sqrt{\text{Hz}}$	$-185\text{dBV}^2/\text{Hz}$ $=0.56\text{nV}/\sqrt{\text{Hz}}$
Vamp Corner Frequency	200Hz	100Hz
Minimum Sid	$2 \times 10^{-27}\text{A}^2/\text{Hz}$	$1 \times 10^{-28}\text{A}^2/\text{Hz}$
Minimum Id	70pA	30pA
Maximum Voltage	$\pm 200\text{V}$	$\pm 200\text{V}$
Maximum Current	$\pm 0.1\text{A}$	$> \pm 0.1\text{A}$ e.g. >1A
Noise Measurement Time (Preliminary Data)	92 sec	32 sec
System Software	E4727P3	

Challenge-1

Challenge-2

Challenge-3

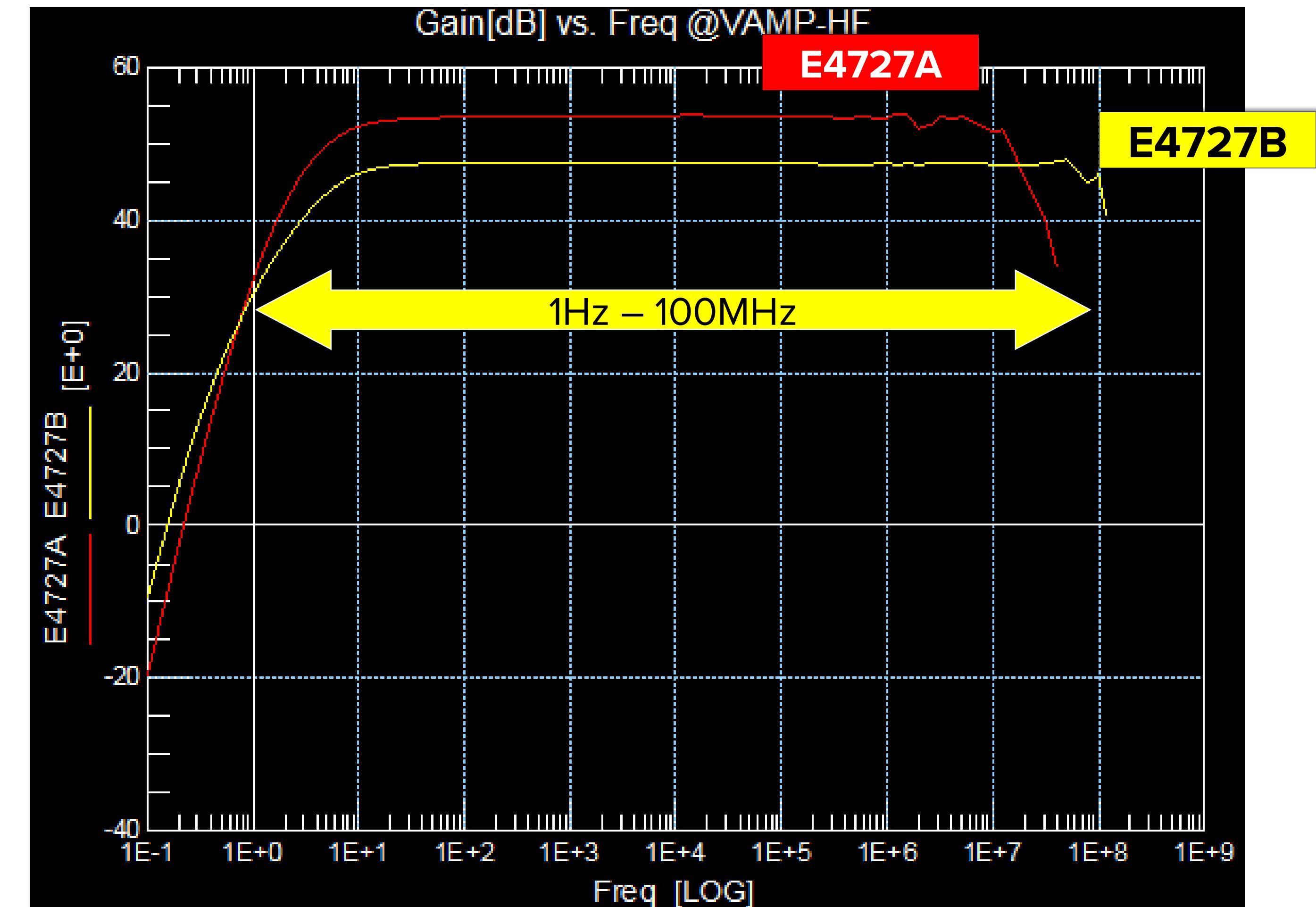
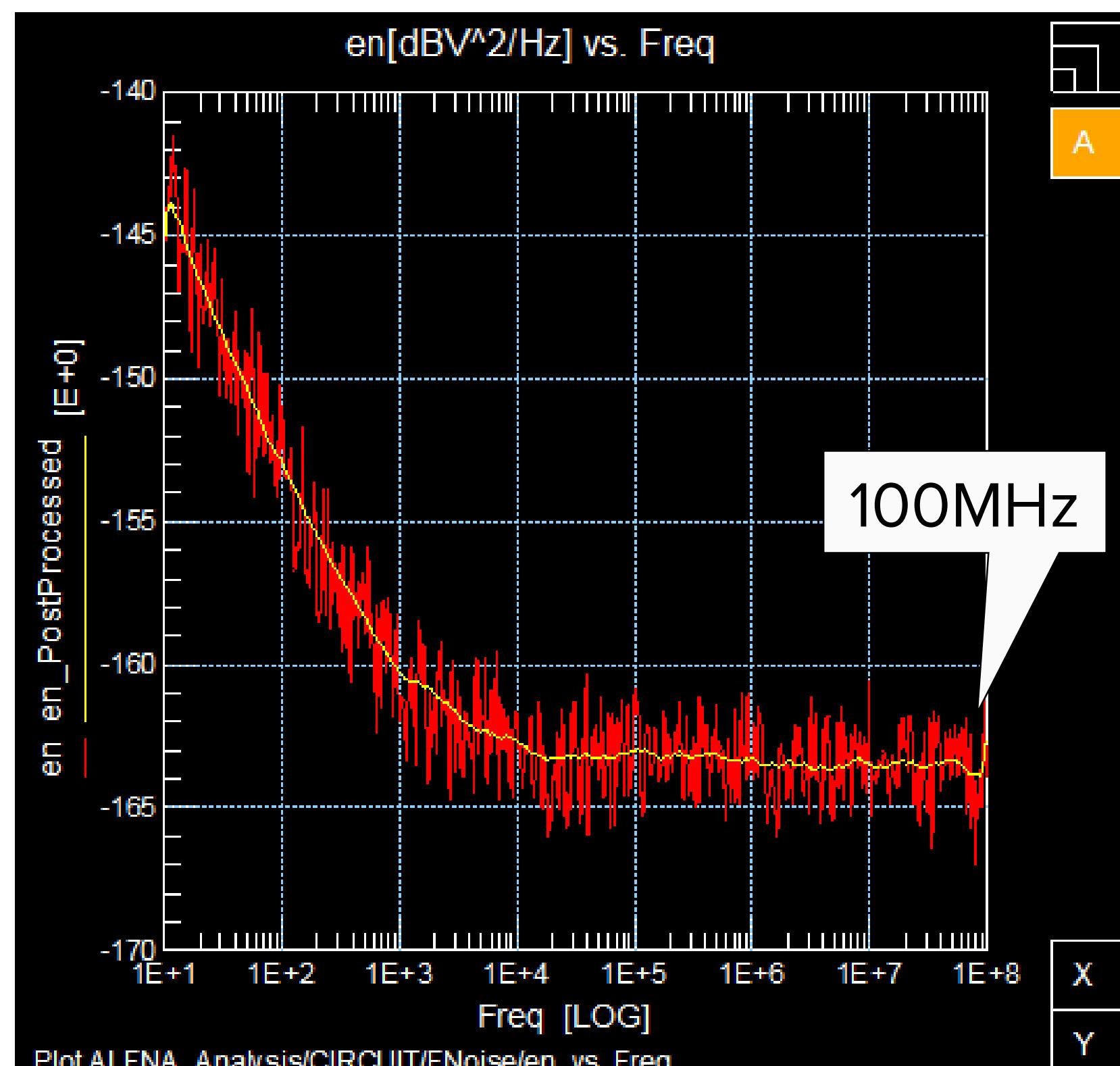
Challenge-4

Challenge-1: Higher Bandwidth

MAXIMUM BANDWIDTH 100MHz

Challenge

- Can't see device corner at high frequency....

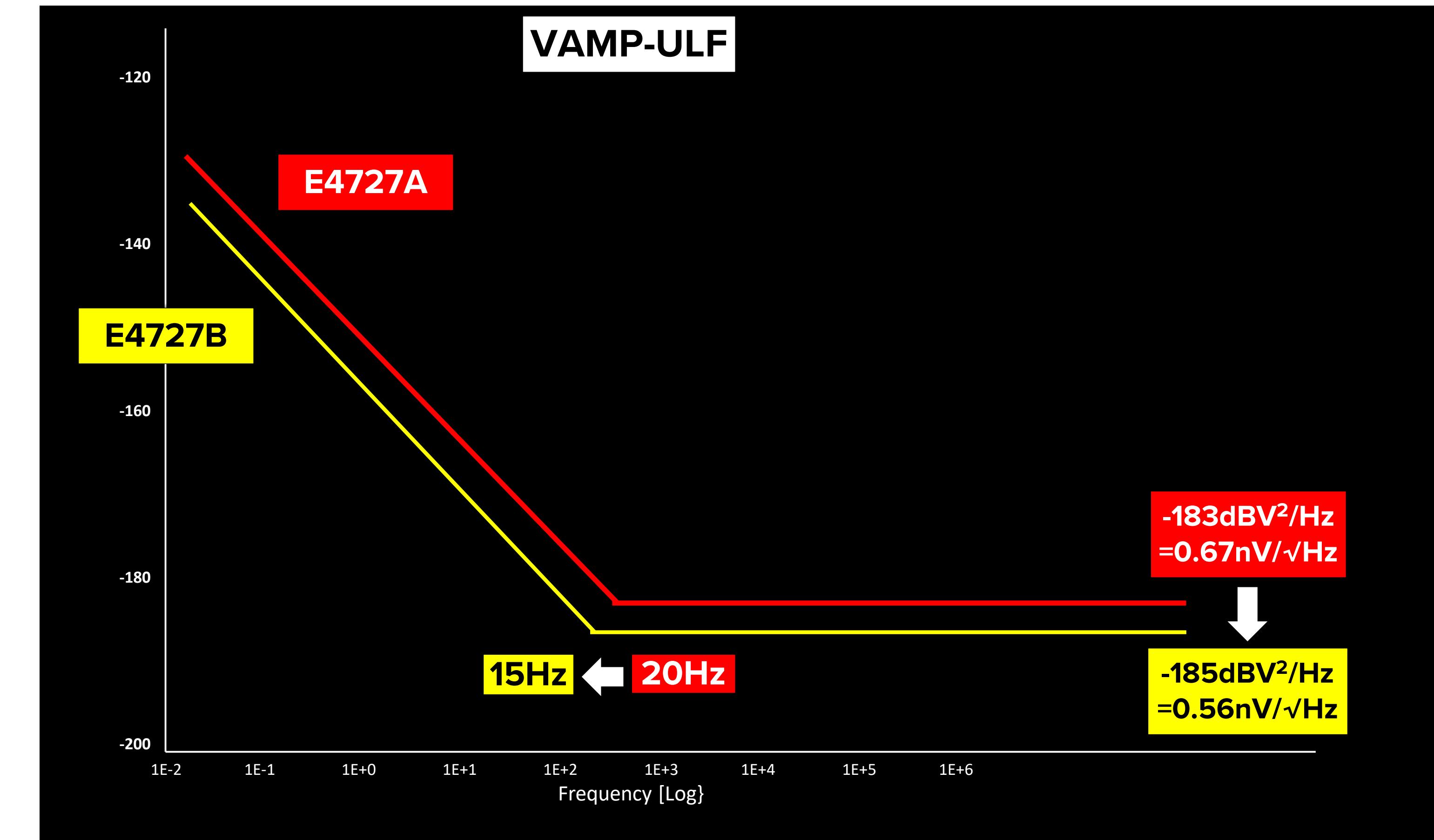
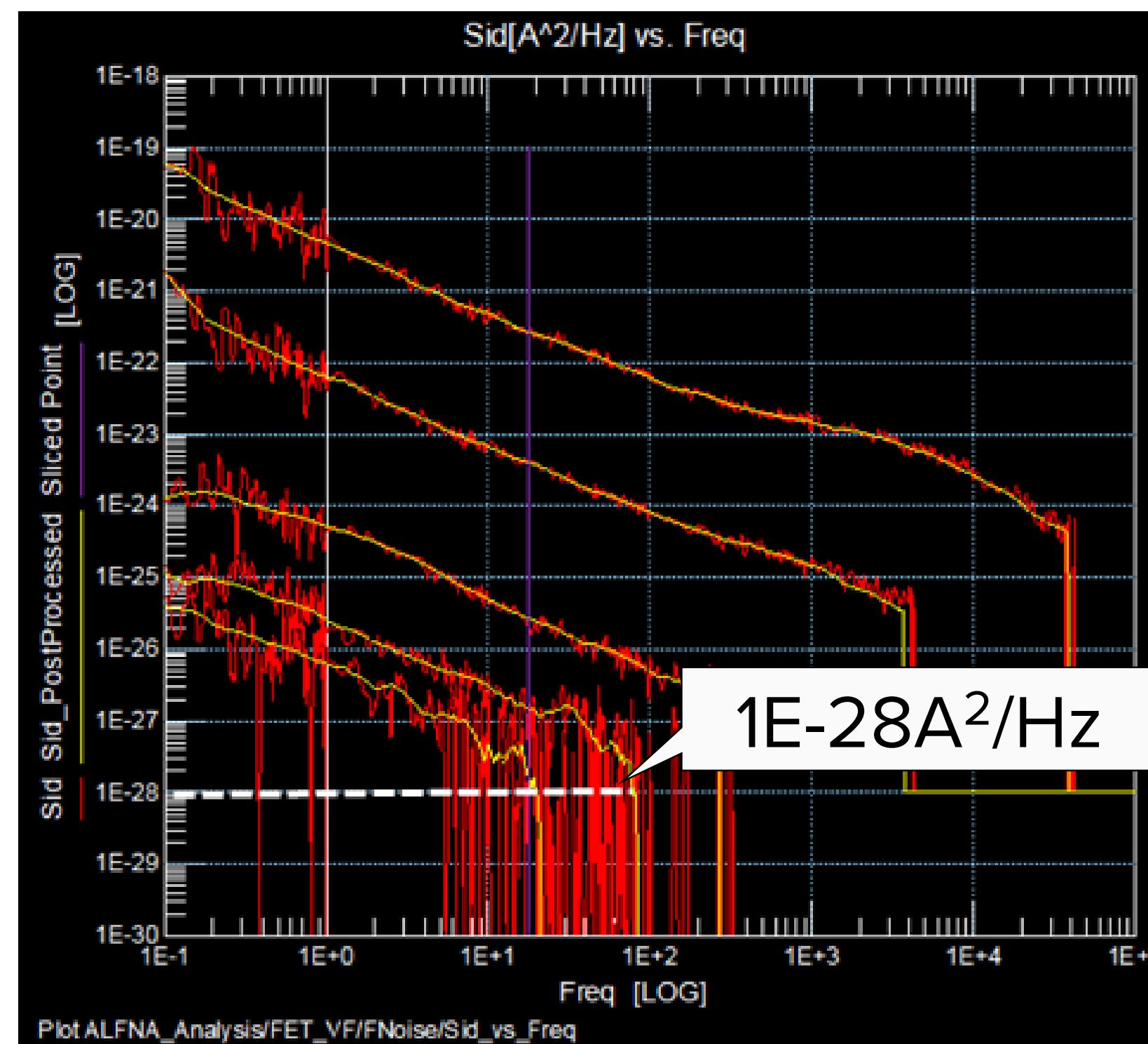


Challenge-2: Lower Noise Floor and Corner Frequency

System noise floor $1e-28A^2/Hz$

Challenge

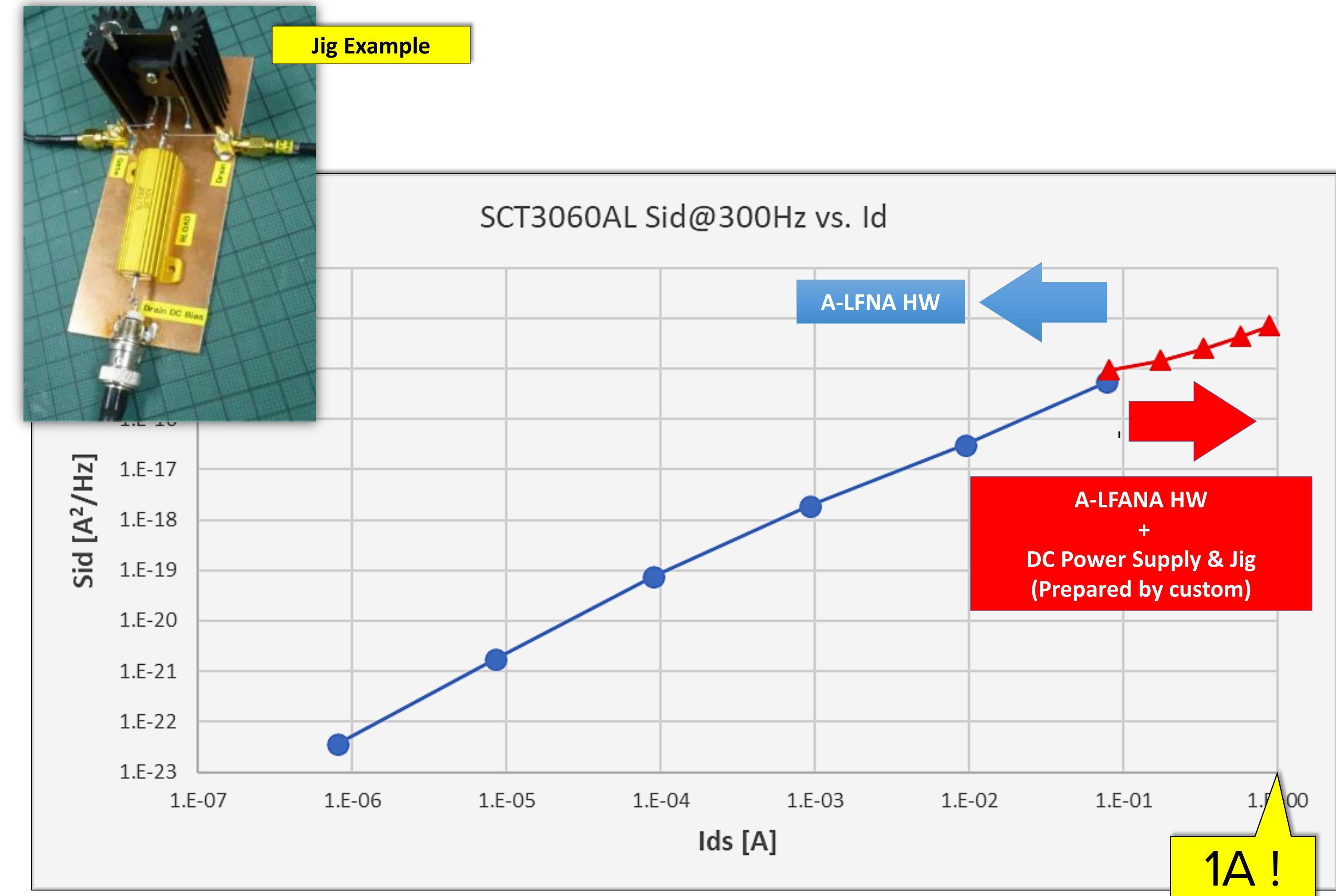
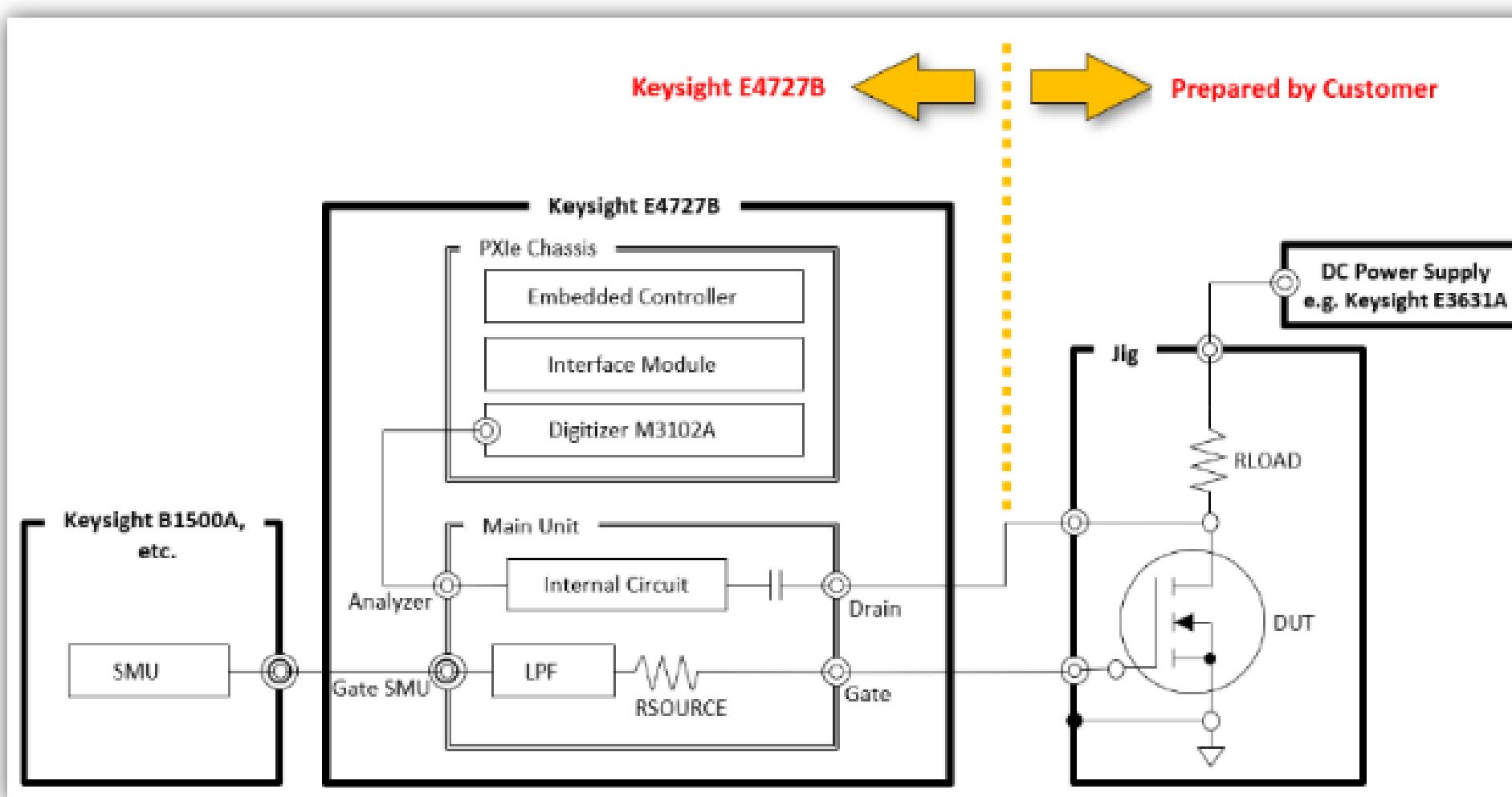
- Can't see very low noise like MOSFET linear region noise.....



Challenge-4: Speed-Up Noise Measurement

Challenge

- No way to see device noise at very high current like 1A.....



Challenge-4: Speed-Up Noise Measurement

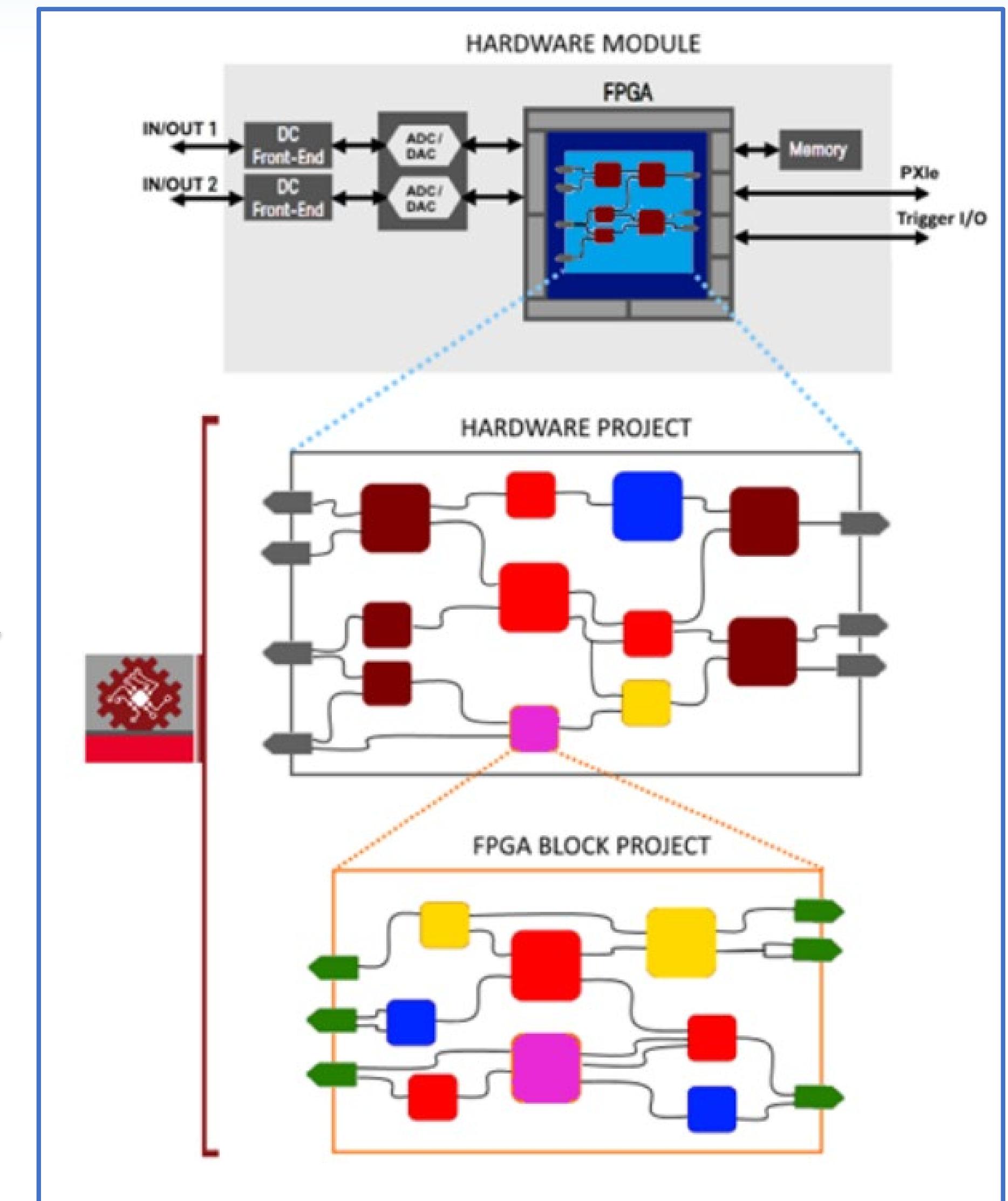
Challenge

- 1/f noise measurement takes very long time especially if we have many averaging....

M3102A PXIe Digitizers

with Optional Real-Time Sequencing and FPGA Programming

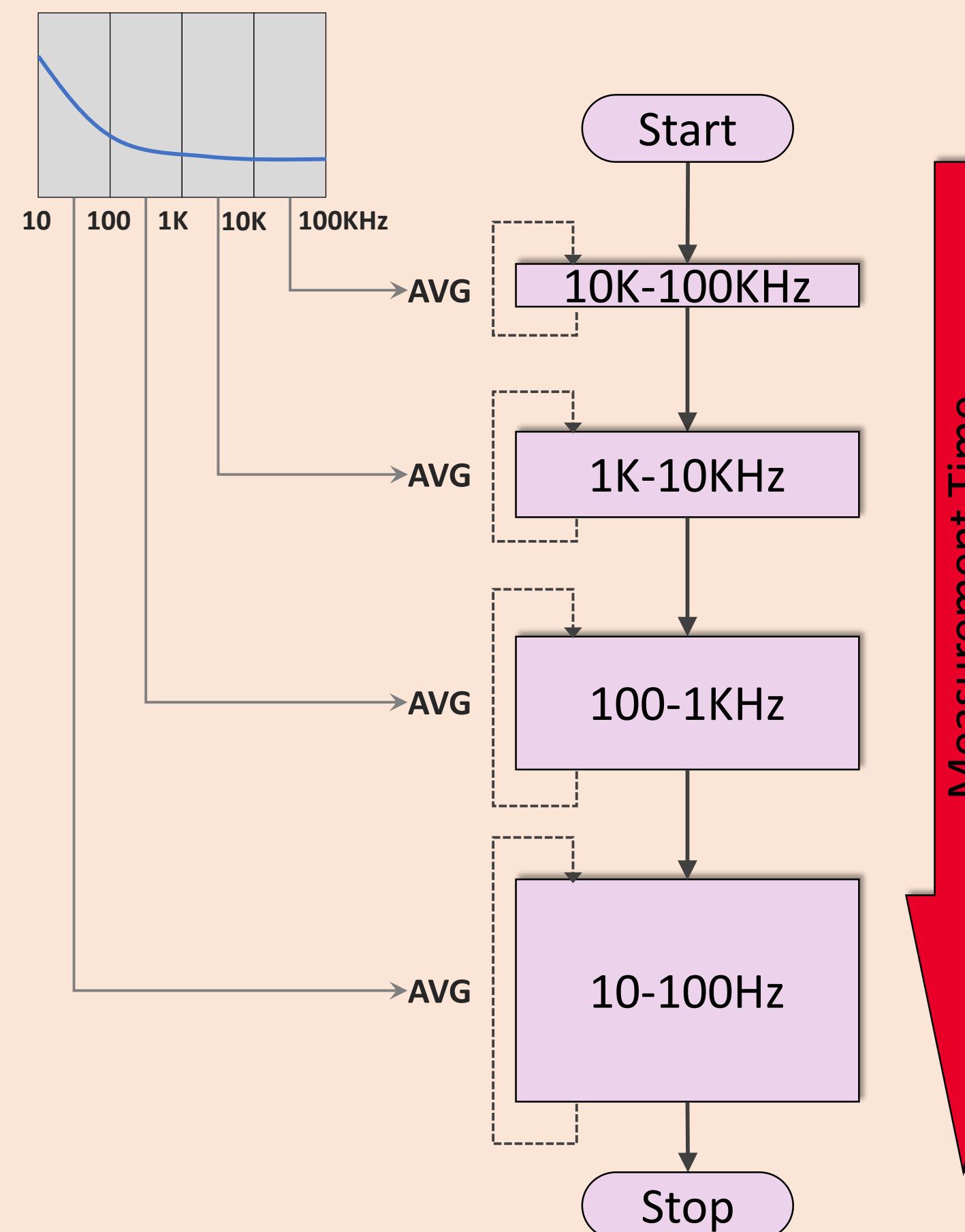
500 MSa/s, 14 Bits, 4 Channels



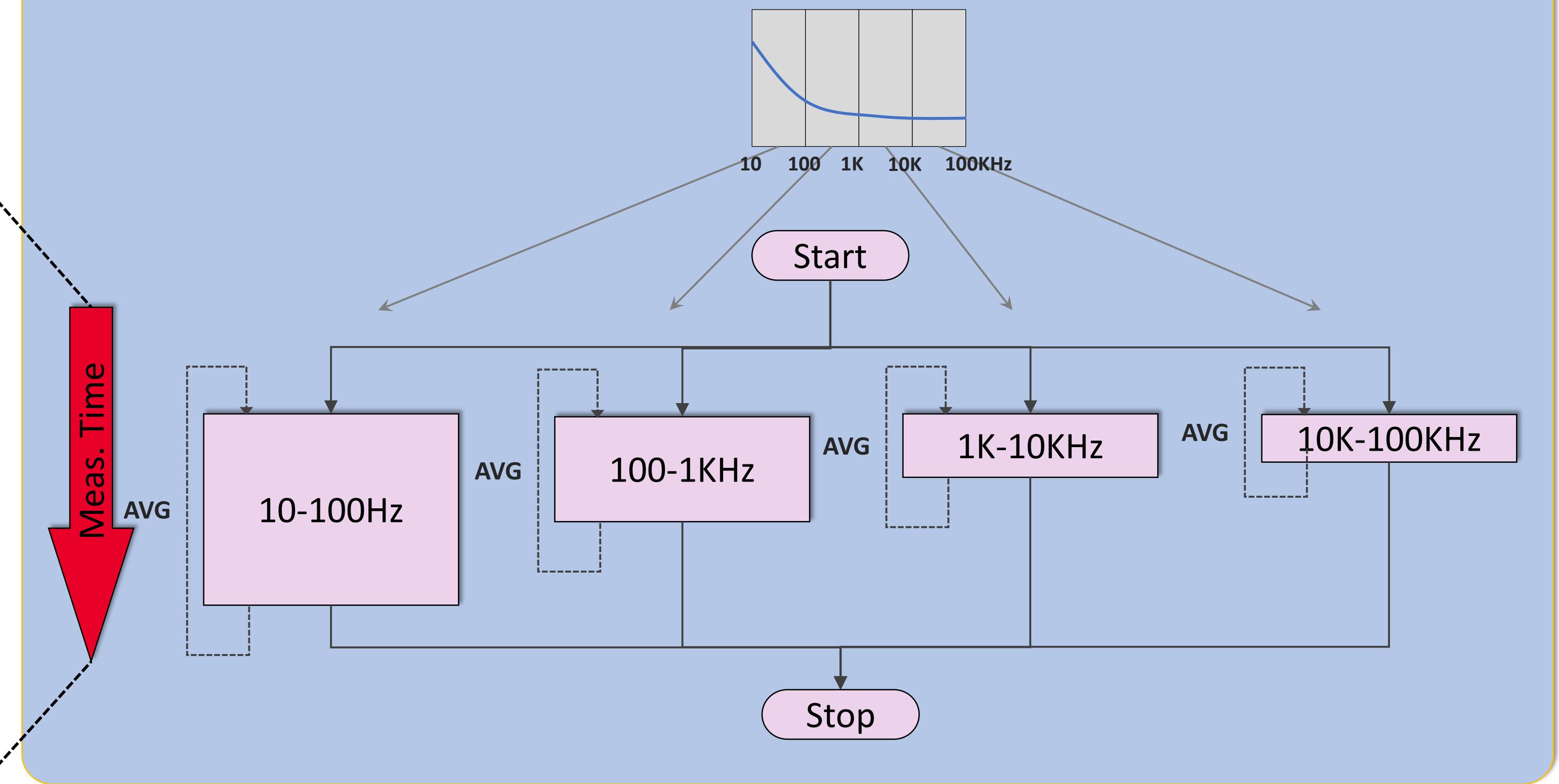
Challenge-4: Speed-Up Noise Measurement

DECIMATION CHAIN

E4727A = Series Measurement



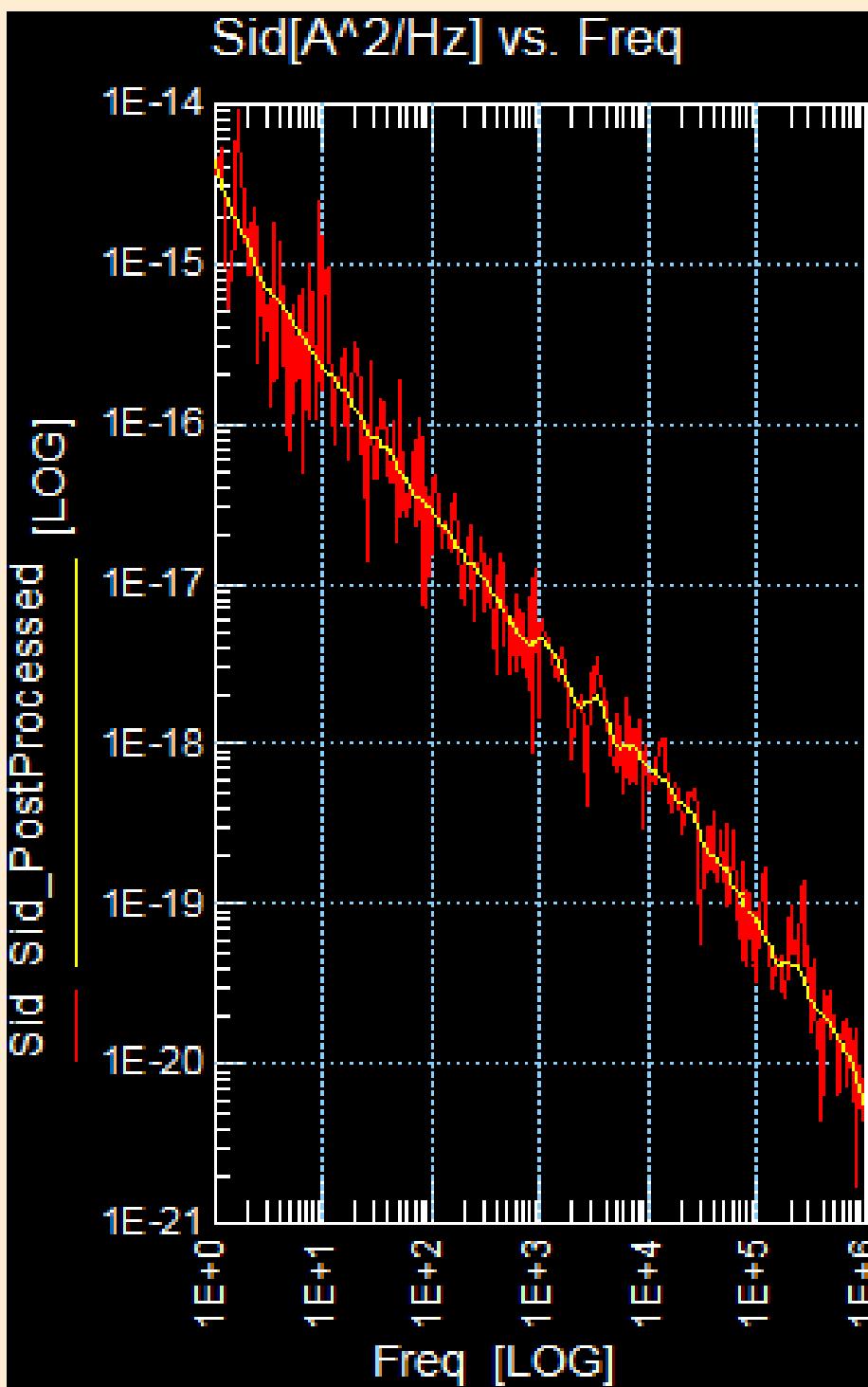
E4727B = Parallel Measurement



Challenge-4: Speed-Up Noise Measurement

COMPARISON OF MEASUREMENT QUALITY AND SPEED

E4727A



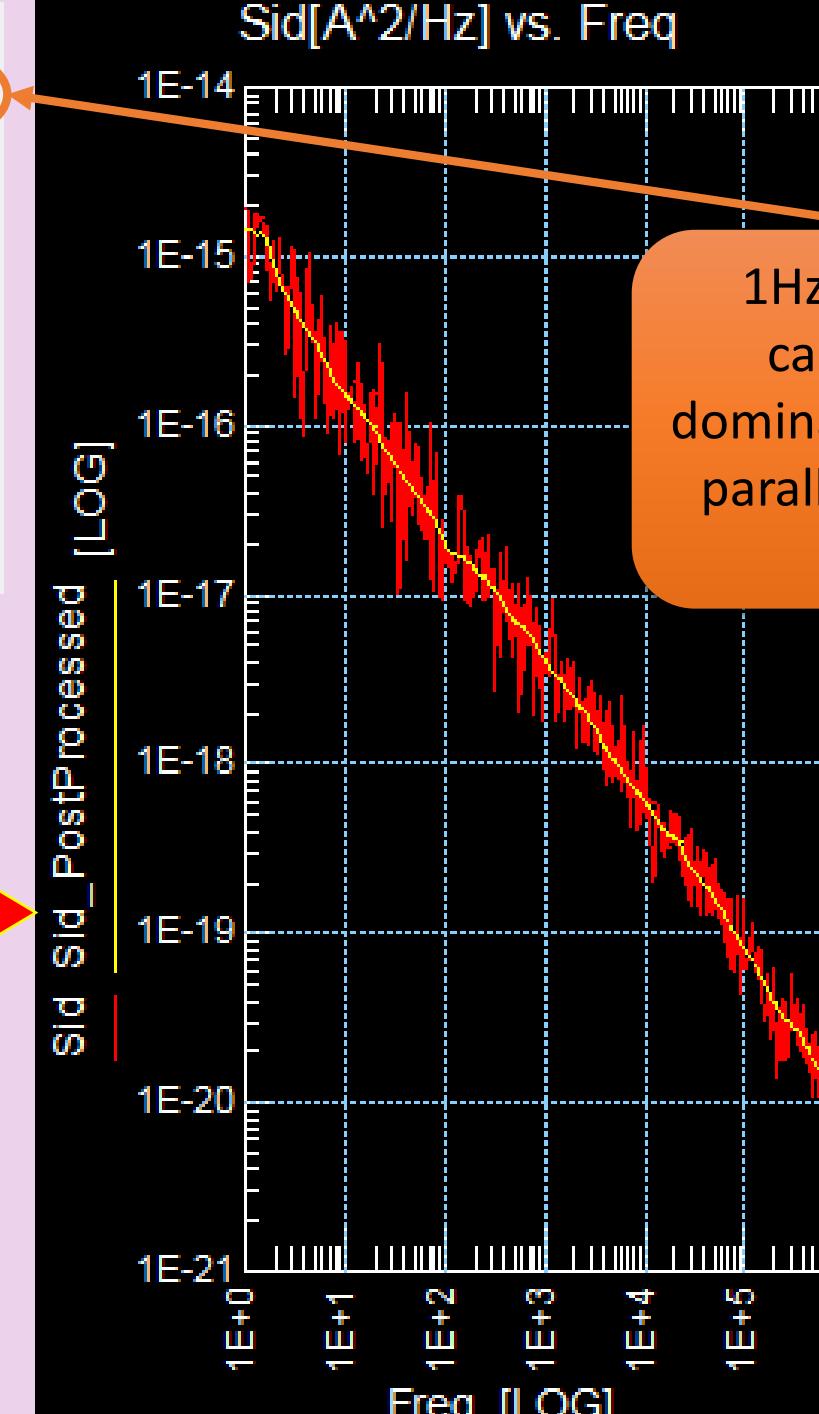
Precision Averaging = OFF

Averaging Factor
1Hz - 10Hz
10Hz - 100.0 Hz
100Hz - 1.000KHz
1KHz - 10.00KHz
10KHz - 100.0KHz
100KHz - 1.000MEGHZ

4
4
8
12
12
16

Same quality but faster measurement speed

E4727B

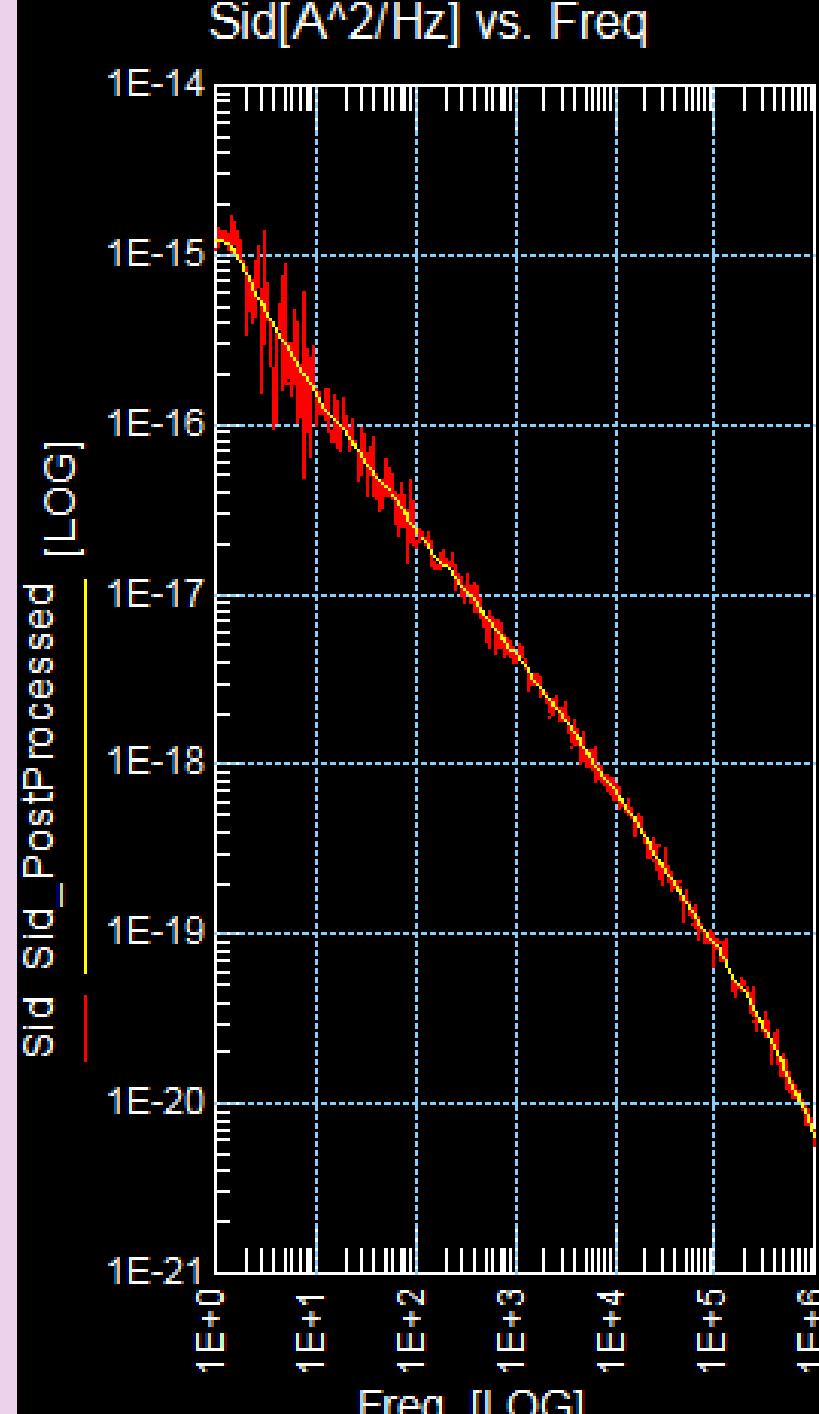


Precision Averaging = ON

Averaging Factor
1Hz - 10Hz
10Hz - 100.0 Hz
100Hz - 1.000KHz
1KHz - 10.00KHz
10KHz - 100.0KHz
100KHz - 1.000MEGHZ

4
27
100
100
100
100

1Hz-10Hz band calculation is dominant factor in all parallel calculation time



1Hz~1MHz

92 sec

-64%

33 sec

33 sec

0.03Hz~1MHz

1264 sec

-67%

412 sec

412 sec

21m 4s

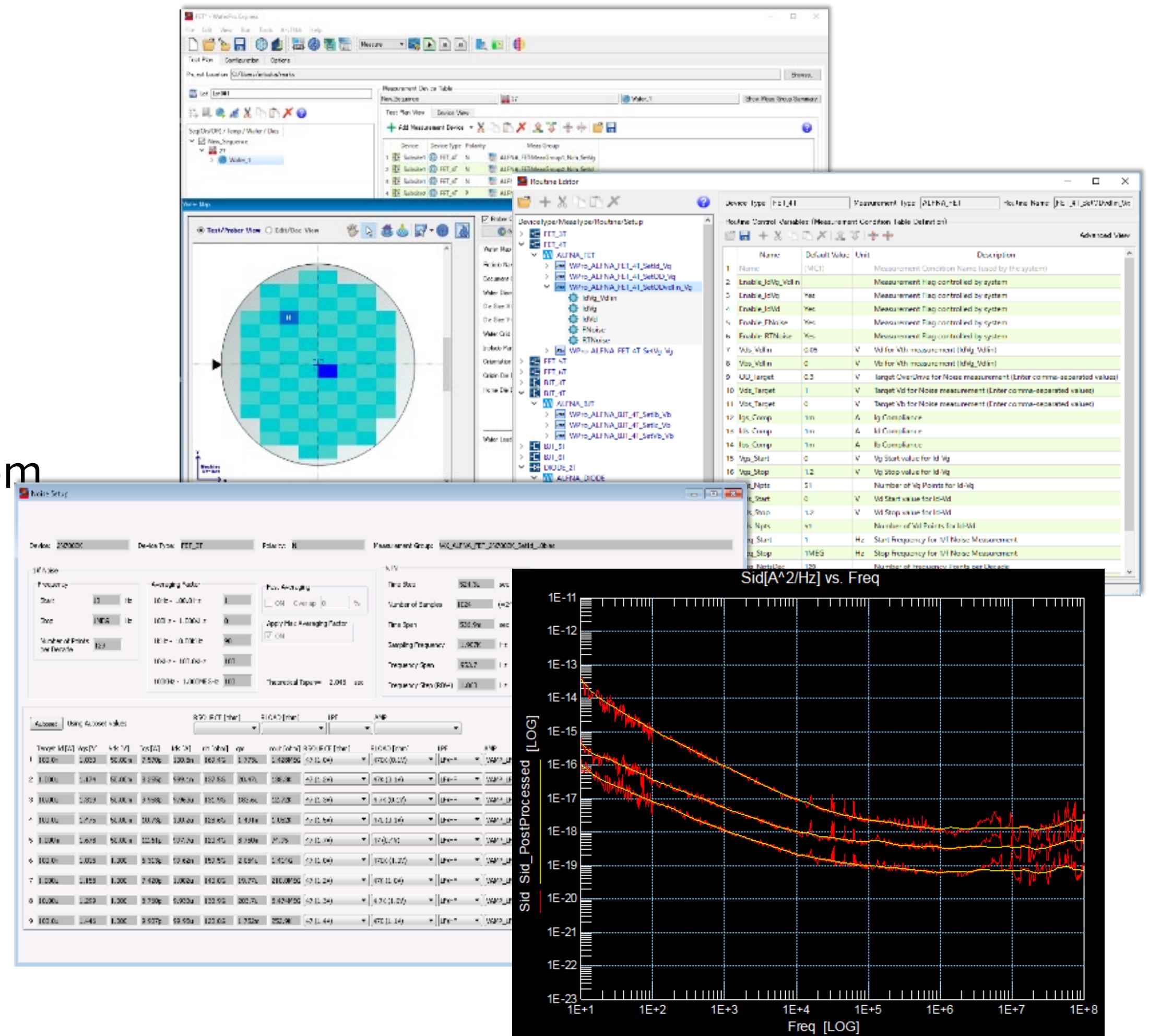
6m 52s

A-LFNA Bundle Software

E4727P3

Key features

- Seamless integration with WaferPro Express measurement platform
- Advanced data display and analysis, enabling noise data comparisons and modeling with respect to bias current
- Automated control of all major wafer probing systems
- A-LFNA module features DC measurements, 1/f noise, random telegraph noise and data analysis
- Flexible hardware averaging for throughput-accuracy tradeoffs
- Multiple built-in biasing schemes for flicker noise characterization
- Measured data compatible with Keysight device modeling software
- Guided system calibration procedure
- PEL and Python measurement routine language support



Order Information

KEYSIGHT SYSTEM CONFIGURATION

1. A-LFNA Hardware

	Bundle kit 1 Z2082E-309 <i>System with 10 slots small PXI chassis</i>	Bundle kit 2 Z2082E-310 <i>System with 18 slots standard PXI chassis</i>	Bundle kit 3 Z2082E-311 <i>System for upgrade customer from E4727A A-LFNA</i>	Bundle kit 4 Z2082E-312 <i>For customer who has all necessary Keysight instruments</i>
A-LFNA Custom HW				
PXIe Chassis	 M9010A	 M9019A		
PXIe Embedded PC	 M9037A		Re-use M9018A/B & M9036A from E4727A	Re-use customer's own Keysight instruments
PXIe Digitizer		 M3102A		
Function Generator		 33621A		

Included:
• Accessory (cable, etc.)

Excluded:
• DC Analyzer
• Probe Station

2. A-LFNA Software

- W7802B

3. A-LFNA Onsite Installation & Training

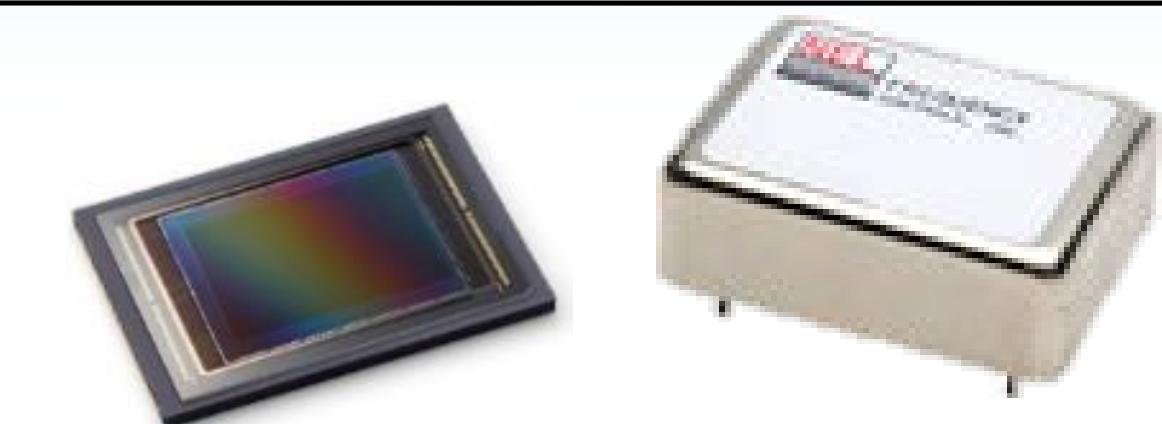
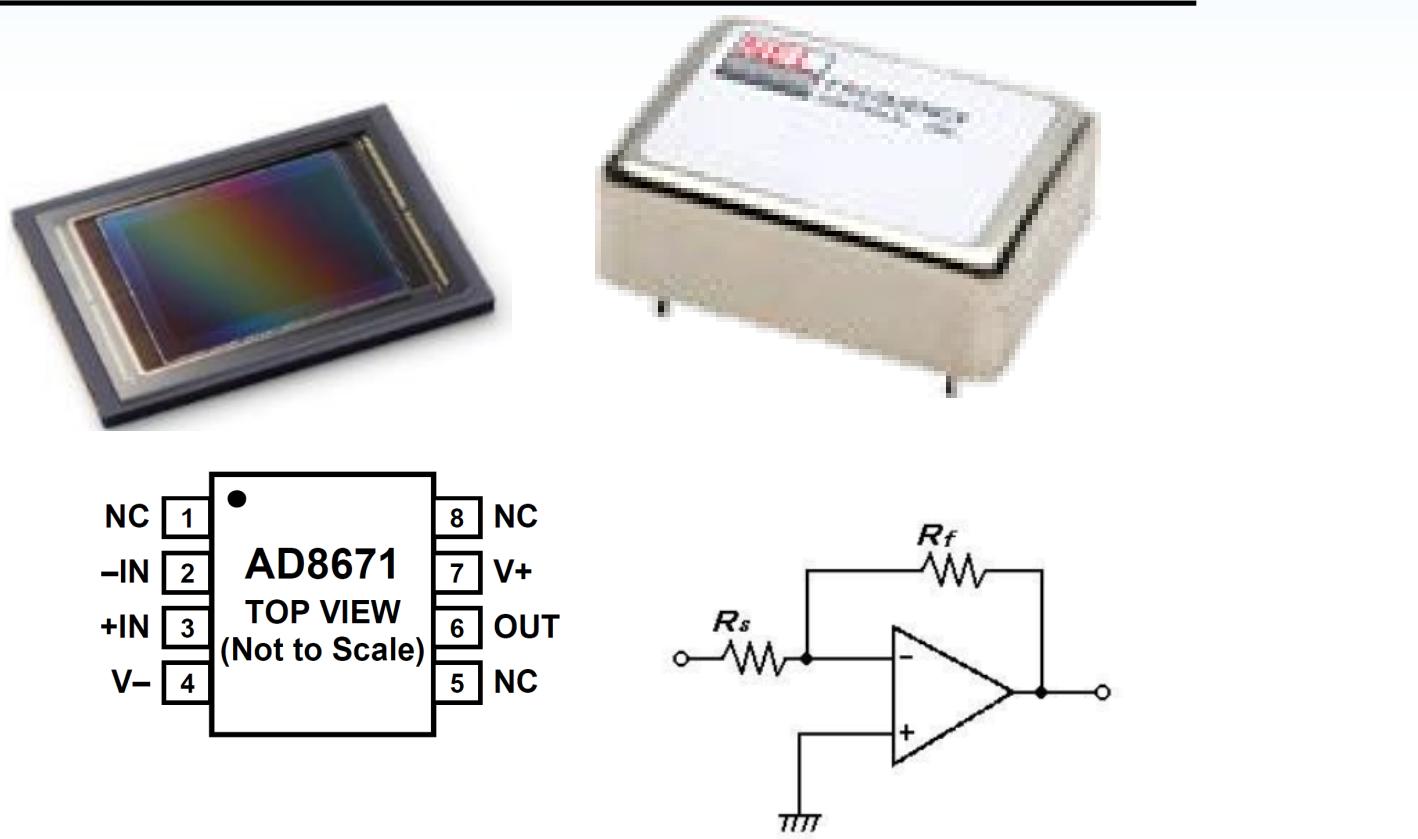
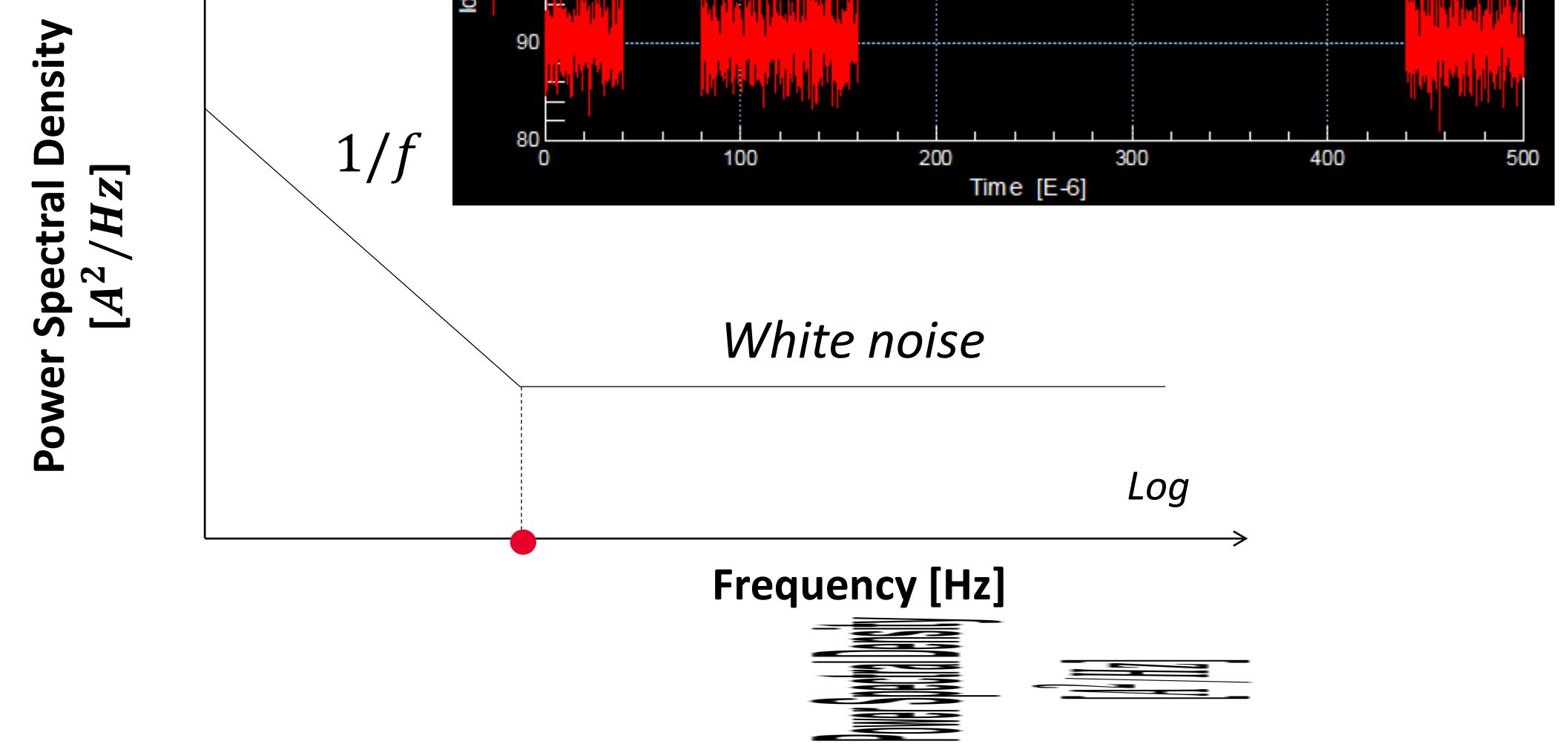
- E4727S

Wafer-level Measurement Solutions Collaboration with FormFactor Inc.

Physical Origins

CM300xi-ULN

- New system for 5G & 7,5,2nm device IC technologies
- **1/f, RTN, low frequency phase noise** (CIS,PLL, VCO, etc..)
- Revolutionary next-gen Pureline™ 3 Technology
- Wide temperature (-60 to +300°C)
- Semi / Full auto
- Autonomous DC probing (24/7 operation)



Lowest Noise & Expanded Test conditions

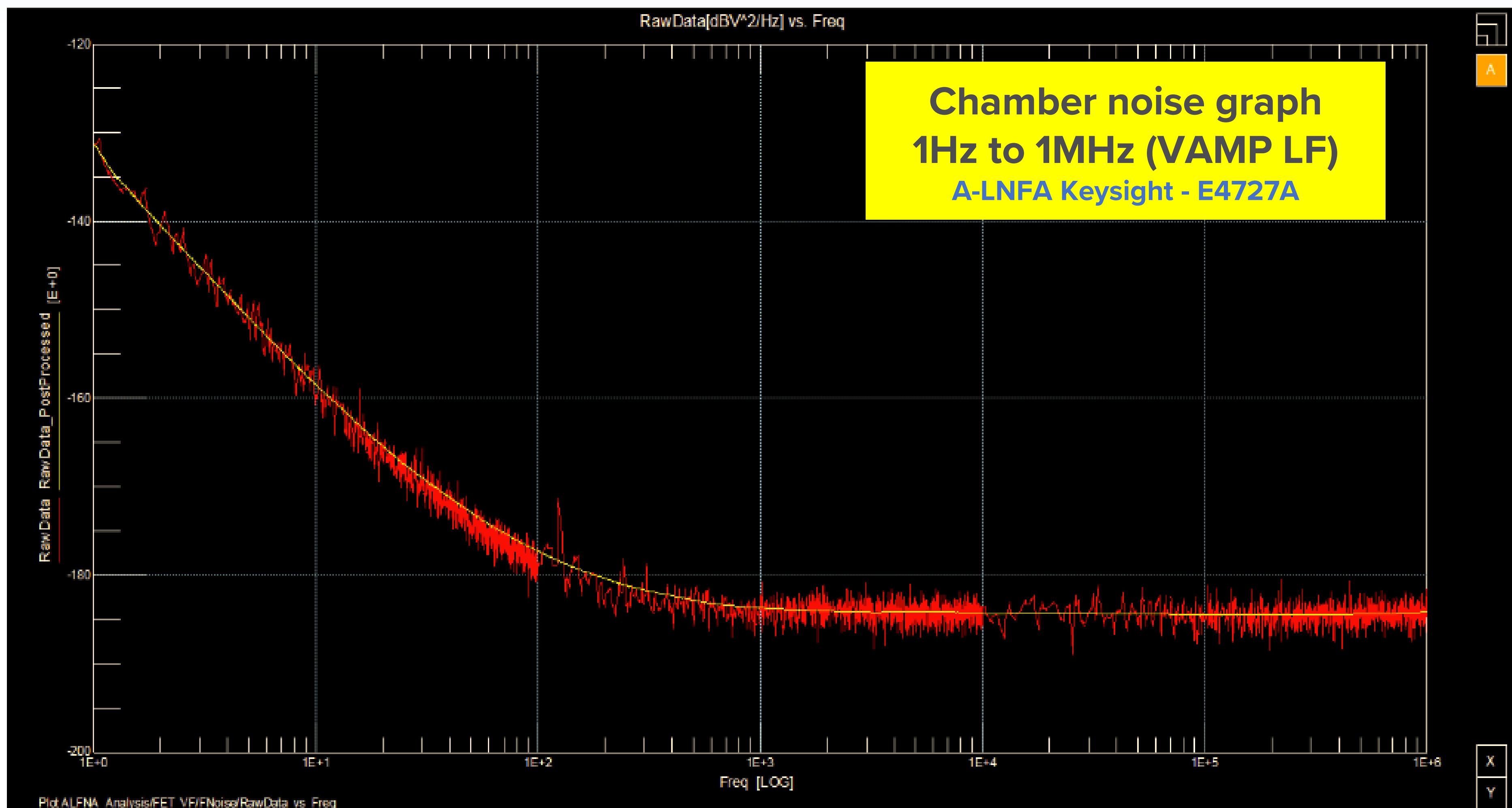
	PA300 S300	Elite300	CM300	NEW CM300-ULN
Noise Specs For Prober System				
-150 dBVrms/ $\sqrt{\text{Hz}}$ (10kHz to 1MHz)	✓			
-170 dBVrms/ $\sqrt{\text{Hz}}$ (10kHz to 1MHz)	✓	✓	✓	✓
Low Frequency optimized (1Hz – 1kHz)		✓	✓	✓
-184 dBVrms/ $\sqrt{\text{Hz}}$ broadband (~1kHz to 20MHz)*				✓
Test Conditions (1/f flicker noise)				
Minimal temp range (+25 to +200°C)	✓			
Full temperature range (-60 to +300°C)	✓	✓	✓	✓
With Auto wafer loading unit (MHU)		✓	✓	✓
With motorized DC probes for Unattended Testing over Multiple Temperatures on 30um pads			✓	✓



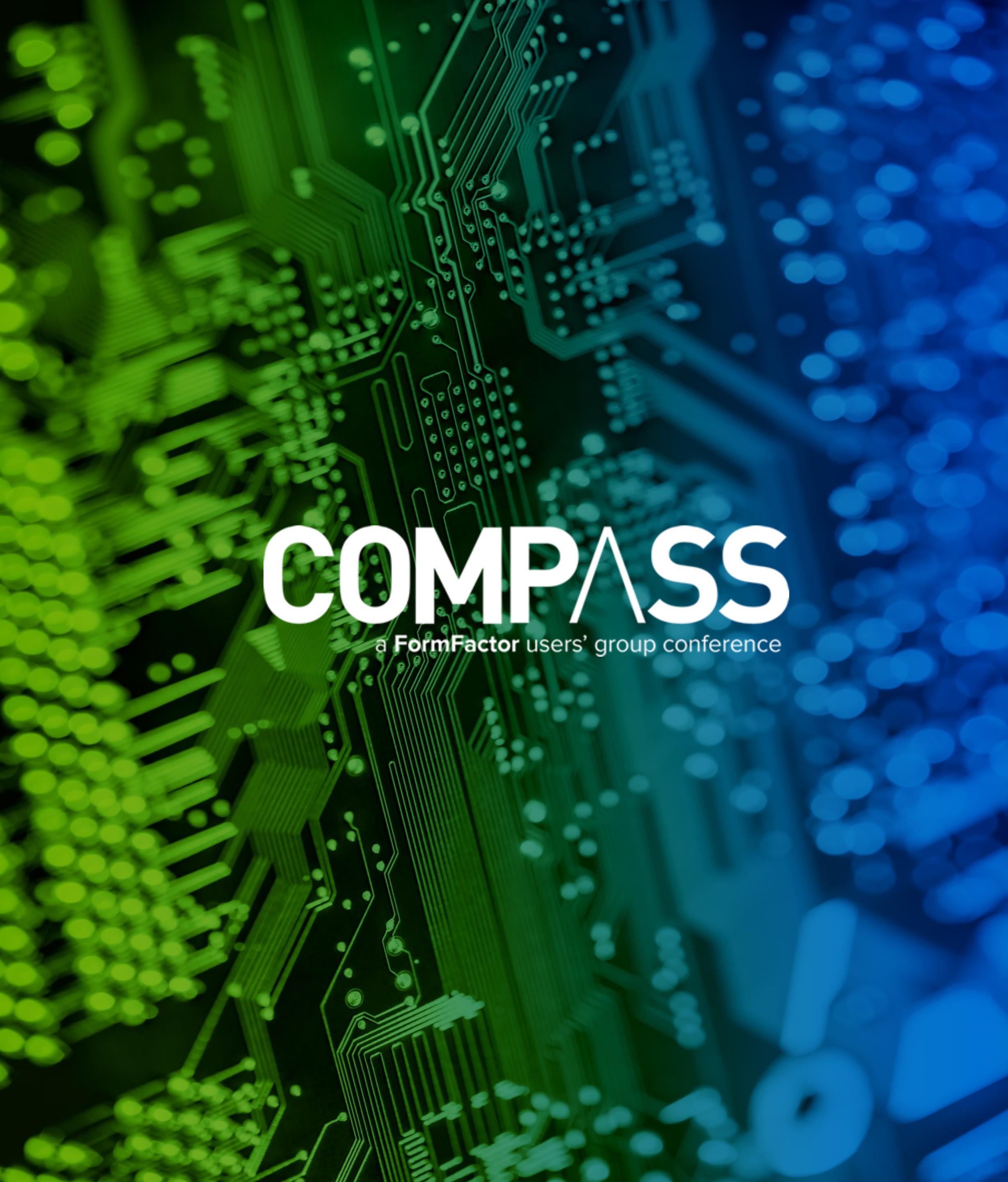
Expanded test conditions,
AND
best low noise specs, in the new 300mm ULN solution

* Typical result, final spec may vary 1-2 dB

Industry Best “Chamber Noise” - CM300xi ULN



NOTE: Using DCP-HTR probe, and all AC power using
CM300xi-ULN Power Conditioning Unit



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THANK YOU