

Really Need Both Current-LNA and Voltage-LNA to Measure LF Noise?

E4727B Advanced Low-Frequency Noise Analyzer
(A-LFNA)

Turnkey Solution for LF Noise Measurement

Keysight E4727B (Advanced Low-Frequency Noise Analyzer; A-LFNA) allows you to measure the LF (Low Frequency) noise of semiconductor devices very easily. The E4727B consists of hardware and software. The user can measure LF noise by just entering the expected measurement conditions and then the software will then set all parameters of custom hardware optimally. The most important and critical component in the hardware is LNA (Low Noise Amplifier) and very small noise and very high gain performances are required. The LNA in E4727B is designed to cover all device's measurements and all measurement conditions. Some commercial system is using both Voltage-LNA and Current-LNA for LF noise measurement, but this application note explains why the Voltage-LNA is enough in E4727B.



Comparison of Voltage-LNA and Current-LNA

The following table shows a comparison of Voltage-LNA and Current-LNA. These LNAs have both advantage and disadvantage each other, and it is required to select by the purpose.

	Voltage-LNA	Current-LNA
Noise Floor		
Bandwidth	 Decided by roll-off of input parasitic capacitance and resistance. A shorter cable and/or smaller value RLOAD are required.	 Decided by feedback resistance which defines I-V convert gain.

Specification

Frequency	<ul style="list-style-type: none">• 30 mHz – 100 MHz
LNA noise floor	<ul style="list-style-type: none">• -185 dBV²/Hz (Min)
LNA band width	<ul style="list-style-type: none">• LNA1: 30 mHz – 1 MHz• LNA2: 1 Hz – 1 MHz• LNA3: 1 Hz – 100 MHz
LNA voltage gain	<ul style="list-style-type: none">• LNA1: 59 dB• LNA2: 59 dB• LNA3: 47 dB
LNA corner frequency	<ul style="list-style-type: none">• LNA1: 15 Hz• LNA2: 100 Hz• LNA3: 200 Hz

Which Type of LNA is Better?

The disadvantage of Current-LNA is bad noise floor against Voltage-LNA. But the Current-LNA is good for LF noise measurement and is used in some commercial system. The reasons are it is good for smaller output resistance active devices and larger value resistors. The detailed reasons explain below.

Good for smaller output resistance active device

The output resistance of the active device, i.e. FET, BJT, and Diode depends on the bias conditions. Figure 1 shows the LF noise measurement circuit of FET and the equivalent output circuit.

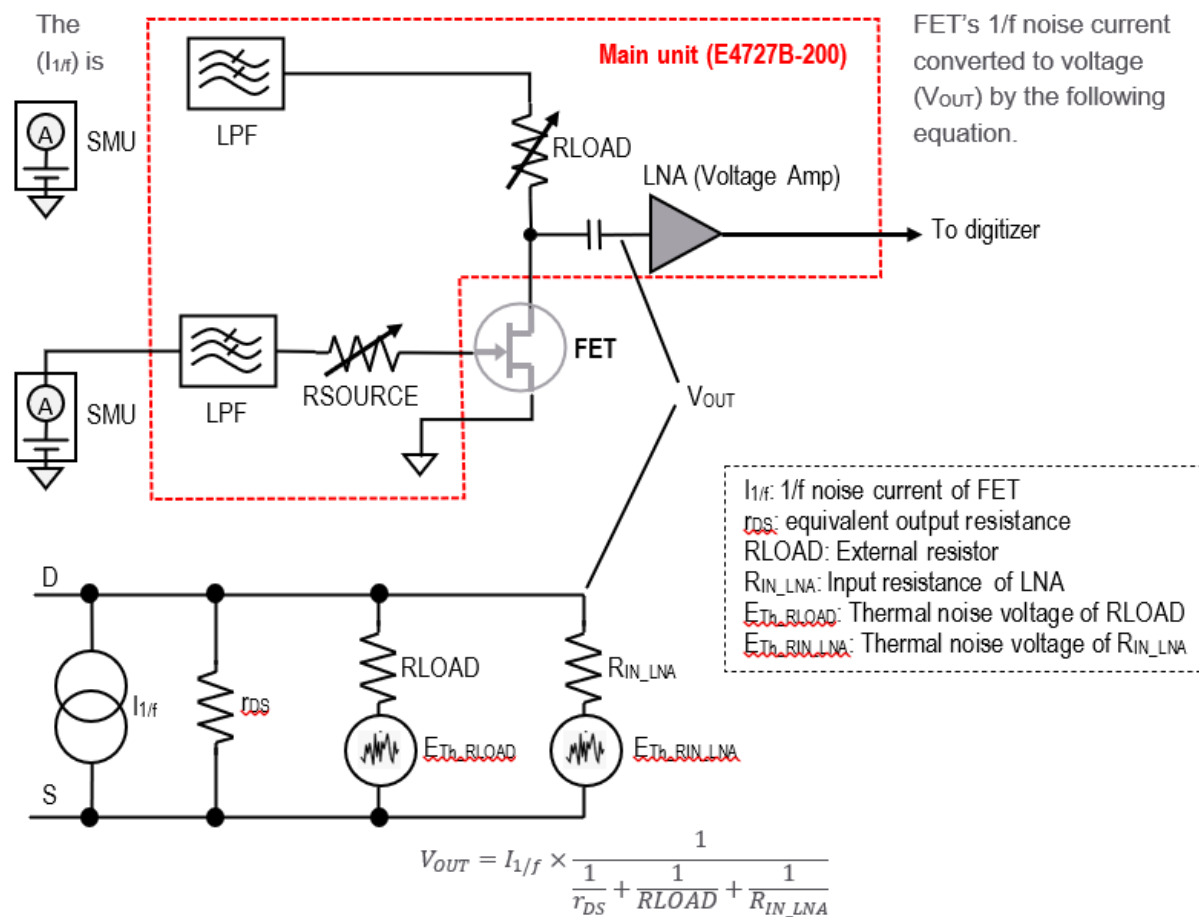


Figure 1. LF noise measurement circuit and the equivalent output circuit of FET

The external resistor RLOAD works as a current-to-voltage converter and amplifies 1/f noise current (I_{1/f}). The converted voltage follows basic Ohm's law and its value becomes large when the RLOAD value is large. However, in the linear region operation of FET, the equivalent output resistance (r_{DS}) value becomes very small compare to RLOAD (~kΩ) and R_{IN_LNA} (~MΩ). It means that V_{OUT} is limited by smaller r_{DS} and it is the system limitation of Voltage-LNA. Therefore, it is said that the Current-LNA is good for the smaller output resistance active device.

Good for larger value resistor

Figure 2 shows the equivalent measurement circuit of a resistor and the output voltage (V_{OUT}) is calculated by the following equation. The 1/f noise voltage of the resistor ($E_{1/f}$) is divided by R_{DUT} and R_{LOAD}/R_{IN_LNA} .

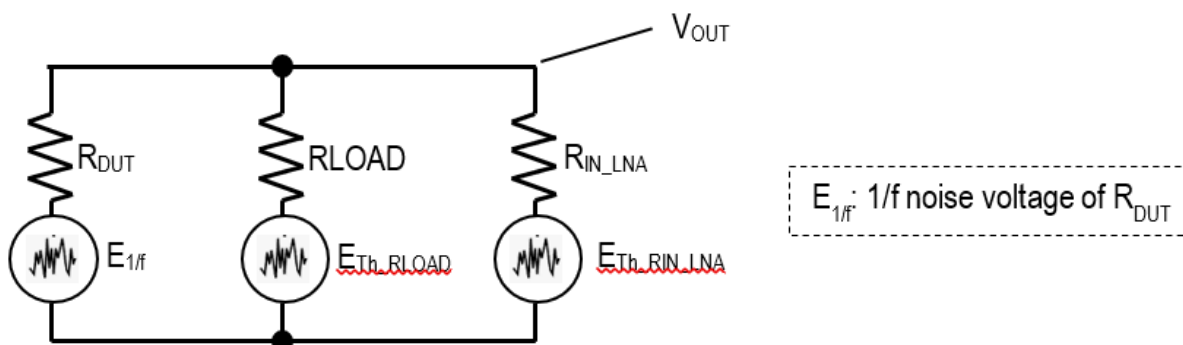


Figure 2. LF noise measurement circuit of resistor

$$V_{OUT} = E_{1/f} \times \frac{\frac{1}{\frac{1}{R_{LOAD}} + \frac{1}{R_{IN_LNA}}}}{R_{DUT} + \frac{1}{\frac{1}{R_{LOAD}} + \frac{1}{R_{IN_LNA}}}}$$

The value of R_{IN_LNA} is very large and the equation can be simplified to the next equation. It means the larger value R_{LOAD} compare to R_{DUT} is required to get enough V_{OUT} . Also, the larger R_{LOAD} value is required not to hide $E_{1/f}$ by E_{Th_RLOAD} and $E_{Th_RIN_LNA}$. Therefore, if the target R_{DUT} value is large like 10 M Ω , then the R_{LOAD} value is required around ~100 M Ω . This causes difficulties in hardware design and this is the reason to select Current-LNA for this application.

$$V_{OUT} \approx E_{1/f} \times \frac{R_{LOAD}}{R_{DUT} + R_{LOAD}}$$

But E4727B Can Measure by Only Voltage-LNA, Why?

The following list is a summary of a good application of Current-LNA.

- Linear region operation for FET (=small equivalent output resistance; r_{DS})
- High current region for Diode (=small equivalent resistance; r)
- Large value Resistor (=Large R)

The E4727B supports only Voltage-LNA but it can cover all LF noise measurement for any devices and any measurement conditions. The reason is the optimized LNA circuit design and optimal total system design. The following 2 examples show the evidence of reasons.

The first example is the linear region operation of FET to verify smaller output equivalent resistance active device. Figure 3 shows the measured data of S_{id} at $I_D=1\ \mu\text{A}$ to $2\ \text{mA}$ and $V_{DS}=0.01\ \text{V}$. The equivalent output resistance at $I_D=2\ \text{mA}$ is very small ($\sim 4\ \Omega$), but the E4727B can get very reasonable data in all bias conditions. The right plot shows the bias dependency of S_{id}/I_D^2 , and its reasonable curve explains evidence of reasonable measurement.

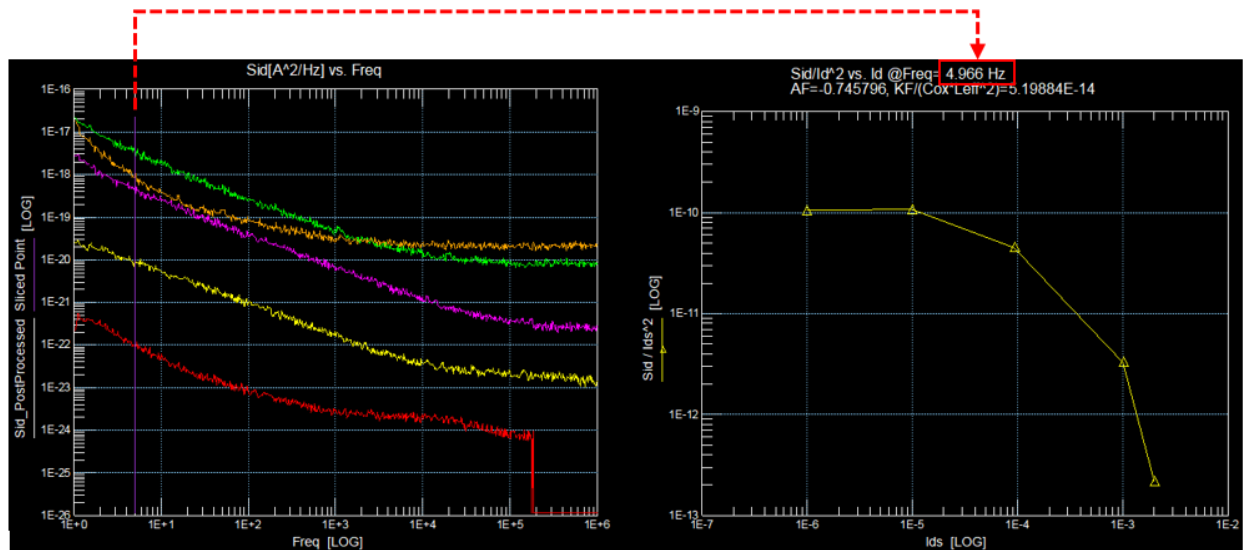


Figure 3. Measured Drain noise current density (S_{id}) of $V_{DS}=0.01\ \text{V}$ for FET, 2N7002K (Left), and bias dependency of normalized S_{id} at 5 Hz (Right)

Measurable device

The E4727B A-LFNA can use for FET, BJT, Diode, Resistor, and Circuit. All devices are measured by Voltage-LNA which is designed optimally for LF noise measurement.

The next example is to verify the larger value resistor. Figure 4 shows the measured thermal noise of the resistor from 10 Ω to 20 M Ω . The Y-axis is noise current density (S_{ir}) and the blue dotted line is the theoretical ideal line of thermal noise ($4kT/R$). The black dotted line is 20 Ω thermal noise and it is equivalent to LNA noise floor, -185 dBV²/Hz. This data explains the evidence that E4727B can measure from 30 Ω to 10 M Ω resistor.

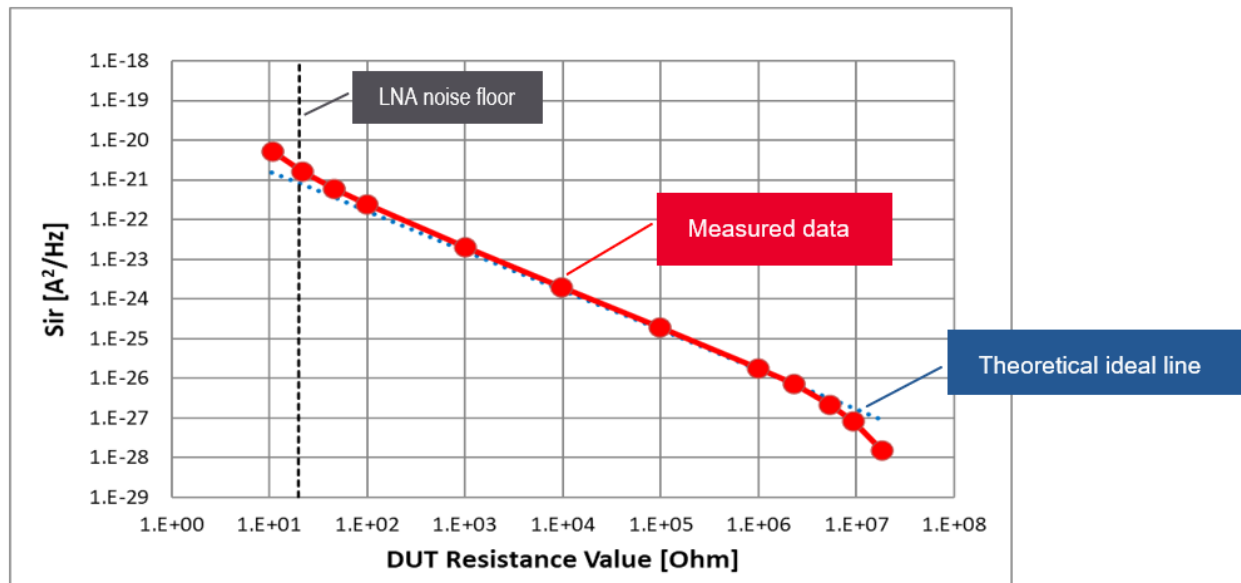


Figure 4. Measured noise current density (S_{ir}) of resistor's thermal noise

Summary

Some commercial system is using both Current-LNA and Voltage-LNA for LF noise measurement, but this application note indicated the evidence that it is possible to measure LF noise by only Voltage-LNA. However, it is required to design optimally, and an optimized system design is required, too. Keysight E4727B has these capabilities and it is a unique technique of Keysight. The E4727B can provide a very stable and accurate LF noise measurement for all devices and all measurement conditions.

Literature

E4727B / W7802B Advanced Low-Frequency Noise Analyzer / Measurement Bundle Software
- Data Sheet, [3120-1435.EN](#)

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