DATA SHEET

E4727A/E4727P3

Advanced Low-Frequency Noise Analyzer/Measurement Bundle Software

E4727E3

WGFMU Measurement Bundle Software

KEYSIGHT TECHNOLOGIES

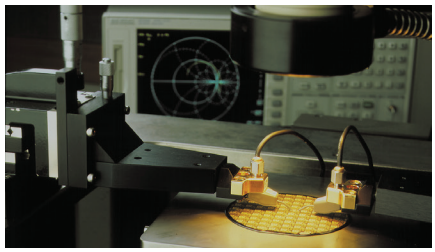
Introduction

Electrical noise is inherent in every circuit and may be caused by current flowing through a resistor or transistor, or even leakage current through a tantalum capacitor. As a classical limitation of electronics, this noise must be managed. A systems engineer must understand overall system sensitivity to noise, and then derive the key contributors. A typical key contributor might be a component like a semiconductor device, sensor or passive component. How do we quantify the noise of these constituent parts? The Keysight E4727A Advanced Low-Frequency Noise Analyzer (A-LFNA) enables a closer, deeper look at noise in components, individual devices and integrated circuits, both packaged and at the wafer level. A device modeling engineer may now leverage the A-LFNA's rare combination of industry-leading noise sensitivity (–183 dBV2/Hz) to characterize devices at high voltages (to 200 V) and down to ultra-low frequencies (to 0.03 Hz). Thanks to seamless integration with WaferPro Express software, one may program and sequence high-speed DC, capacitance and RF measurements, all the while automating wafer prober control using Cascade Microtech's software API.

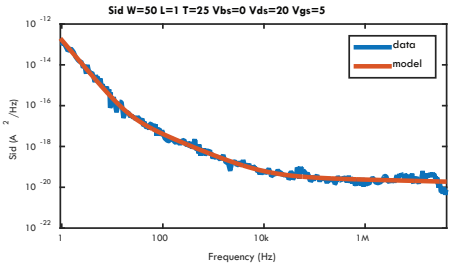
The applications for wafer-level 1/f noise measurements are numerous; however, a few important ones are listed as follows.

- **Process design kit development.** Semiconductor device foundries enable fabless design centers to design components such as transceivers for mobile phones, frequency synthesizers, analog-to-digital converters and much more. To make this possible, the foundries must provide Process Design Kits (PDK's) with simulation models of the primitive devices. The simulation models must include noise effects on transistors (BJT, CMOS, etc.) and resistors. The noise models must be across all possible bias currents, temperatures and device geometries.
- **Manufacturing statistical process control and reliability.** As an example, manufacturers of GaN devices may use noise measurements across their wafers as an early indicator of device reliability. Those devices that exhibit more noise are likely to fail sooner. Now we have a nondestructive way of assessing reliability, quite in contrast with standard accelerated life testing. Furthermore, for circuit applications where noise is a critical parameter, wafer level measurements may be used to track the evolution of noise performance across days, weeks and months of manufacturing.
- **IC noise specification.** Integrated circuit manufacturers of operational amplifiers and linear voltage regulators often need to characterize input referred voltage noise as a critical specification in their datasheets. One wafer may contain 20,000 such circuits. To efficiently measure and map circuit performance across the wafer (and even across lots of wafers), the probe and signal conditioning circuitry must be placed close to the device under test to improve grounding and minimize external noise influences.

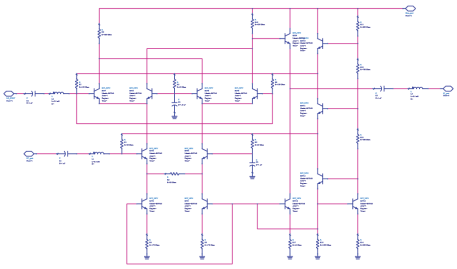
The resulting noise data may be used to develop device models with the help of state-of-the-art device modeling tools like Model Builder Pro (MBP) and Integrated Circuit Characterization and Analysis Program (IC-CAP). These models can then be passed along to circuit designers, who may then push the envelope in low noise circuitry.



Device characterization

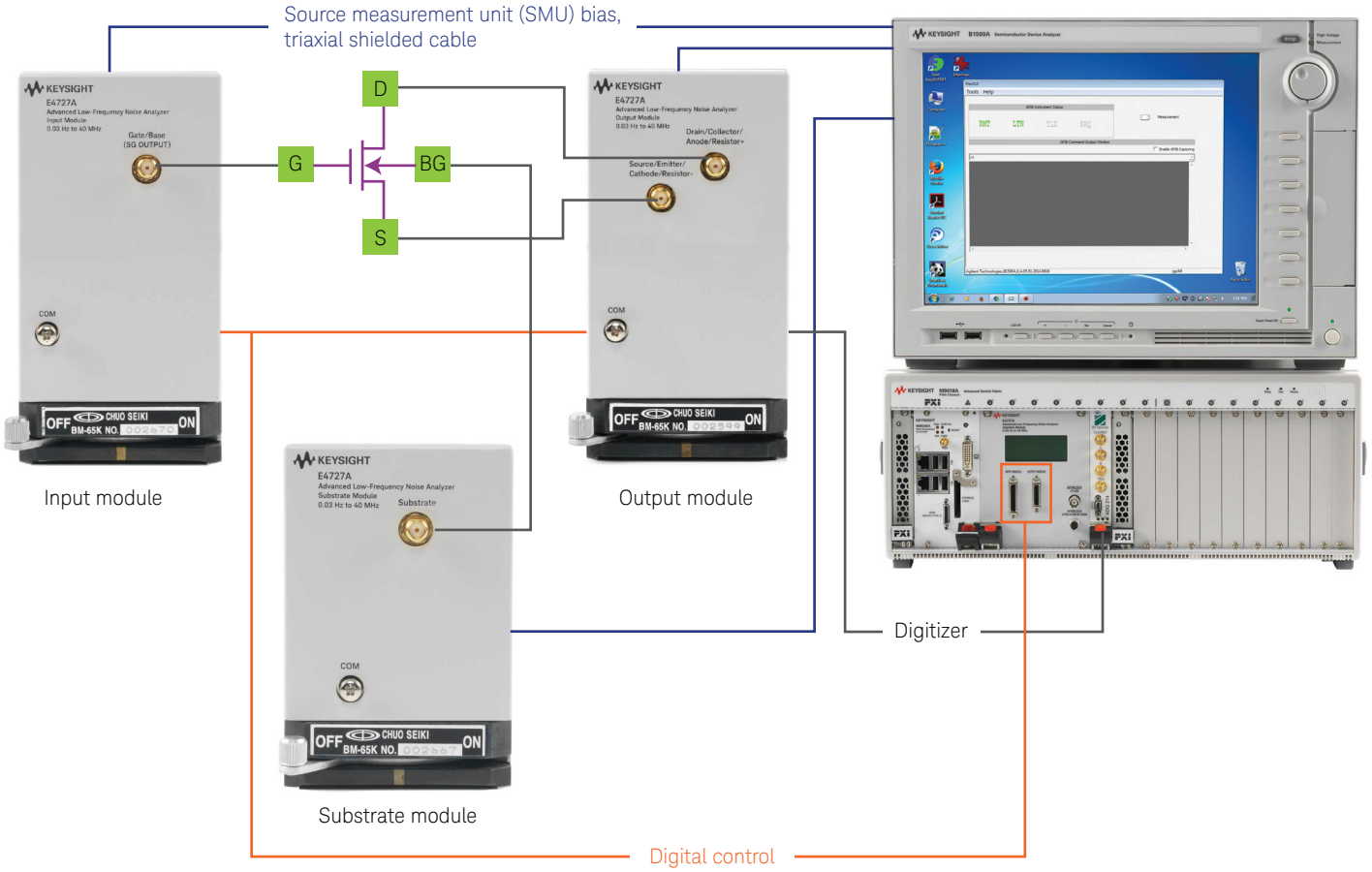


Modelling

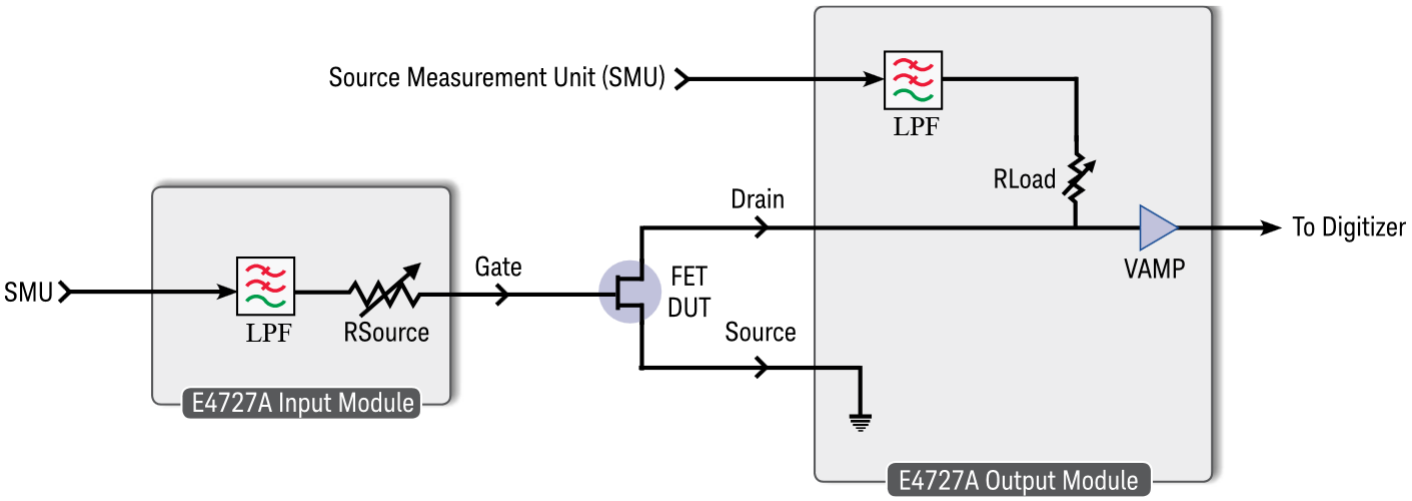


Circuit design in ADS

The E4727A hardware has been designed for both on-wafer and discrete device/circuit measurements, and consists of a series of modules paired with a PXI computer and digitizer. These modules are connected to a source measurement unit (SMU) such as the B1500A to enable both flexible and clean device biasing and noise signal conditioning.



An SMU is used to apply bias and measure DC operating points. However, when measuring noise, the noise contribution must be filtered out. The voltage noise taken from the device output is amplified and analyzed using a high-speed digitizer. One possible configuration of noise measurement is shown below, although many others are possible. The variable resistance, switching and filtering functions are included in the A-LFNA modules.



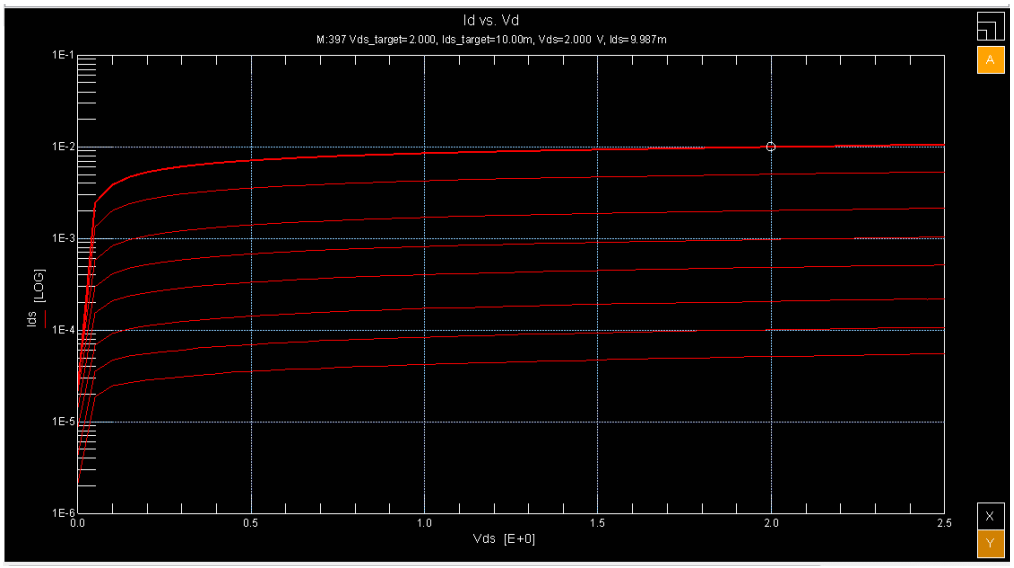
Different device types require different source and load impedance terminations. The E4727A is the only analyzer in the industry to offer 25 impedance values ranging from 0 ohms to 100 MΩ. The A-LFNA software is able to judiciously select RSource and RLoad based on device type (FET, diode, BJT, etc.) and measured DC characteristics.

The PXI chassis system controller comes equipped with the A-LFNA software integrated with WaferPro express, enabling fast and flexible instrument and prober control. Thus, the engineer may now automate multi-bias, multi-device DC and noise measurements. Measurement speed and accuracy may be adjusted by setting the degree of hardware averaging. The factory provided measurement routines offer a rich set of biasing schemes that can be copied and modified to suit specific needs.

Measurement Capabilities

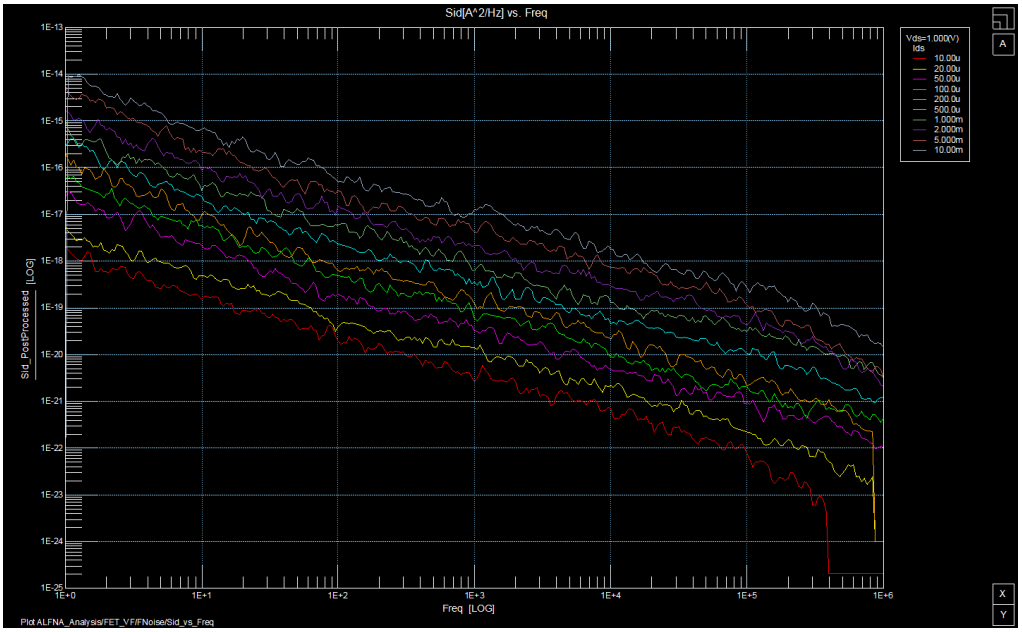
DC measurement

- Accurate DC measurement when used with supported semiconductor parameter analyzers - up to 0.1 A and 200 V
- Device types supported: BJTs, FETs, diodes, and resistors.



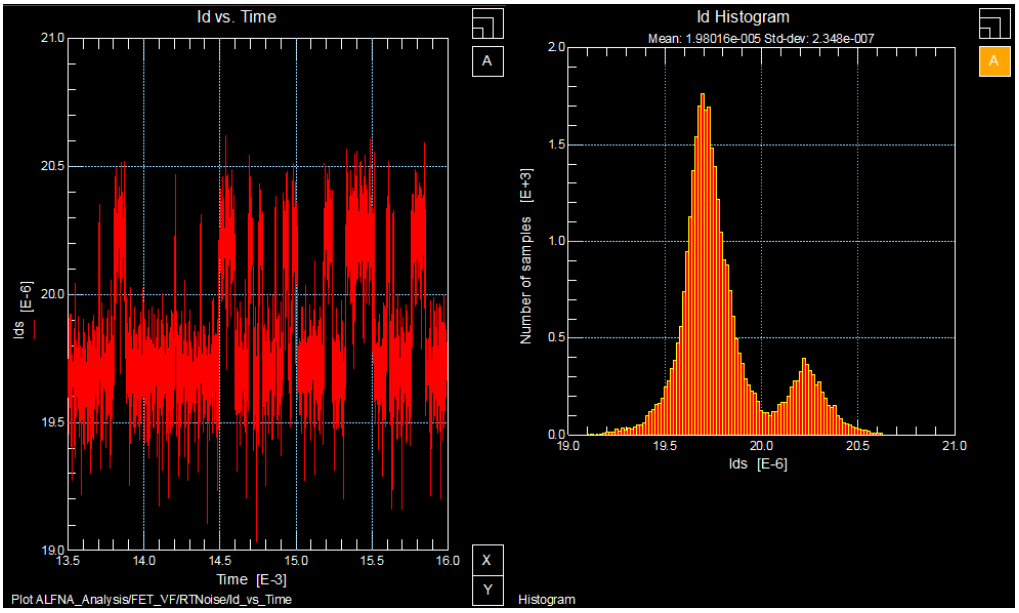
1/f (flicker) noise measurement

- Device types supported: BJTs, FETs, diodes, resistors and circuits (Op-Amps, comparators, etc.)
- Analysis frequency range from of 0.03 Hz to 40 MHz
- Measures noise down to 0.67 $\frac{\mathrm{nV}}{\sqrt{\mathrm{Hz}}}$ at 10 kHz
- Current/voltage/power range of up to 0.1 A/200 V/10 W, respectively



Random telegraph signal noise (RTS or RTN) measurement

- Time domain representations of noise
- Histograms of current and voltage
- Device types supported: BJTs, FETs, diodes, resistors and circuits (Op-Amps, comparators, etc.)
- 2.5 nsec minimum time step
- Up to 16 million points sampling size



E4727A Specifications

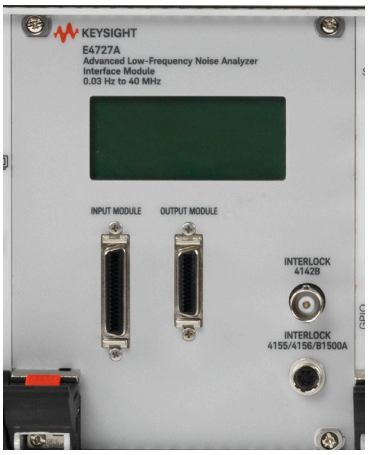
Main modules

The E4727A adopts an innovative modular architecture to minimize system noise.

Module name	Key features	
M9018A PXIe mainframe	18-slot chassis, providing central control of E4727A	
	M9036A embedded PC	Windows 7 64-bit (in English)
	E4727A(K01) interface module	LCD display
		Digital control of input and output modules
	Digitizer	A/D converter (digitizer)
E4727A(K02) input module	Connects to DUT input port	
E4727A(K03) output module	Connects to DUT output port	
E4727A(K04) substrate module	Connects to DUT substrate/backgate	
E4727A(K05) test fixture module	Fixture for through-hole packaged devices	
Module enclosure	Grounding enclosure for input, output and substrate modules	

E4727A(K01) interface module specifications

Residing in the PXI chassis, the interface module controls the E4727A (K02) input module for gate or base bias and the E4727A (K03) output module for drain or collector bias.



Input module (K02) control	
Connector type	36-pin miniature delta ribbon (f)
Output module (K03) control	
Connector type	26-pin miniature delta ribbon (f)
Interlock connections	
Interlock for 4142B	BNC(f)
Interlock for 4155/4156/B1500/E5260/E5270	16493J

E4727A(K02) input module specifications

The input module accepts a voltage or current input from the SMU generates an input bias output signal that is suitable for noise measurements. 3 output configurations are possible:

- Straight pass-through of the SMU input signal for DC characterization
- Low pass filtering of the SMU signal followed by a controlled input impedance for noise measurement
- With a 0.01 Hz to 40 MHz signal generator output for device or circuit gain characterization

LPF		
Number of LPFs	2	
	LPF1	LPF2
Cut-off frequency	0.03 Hz	0.53 Hz
Series resistance (Rlpf_input)	5 kΩ	300 Ω
Maximum voltage	± 50 VDC	± 50 VDC
Maximum current	± 0.1 A	± 0.1 A
Input resistances		
Resistor values	0 to 100 MΩ (25 selections)	
Accuracy	± 0.5%	
Signal generator circuit		
Output signal	Sine wave	
Frequency range	0.01 Hz to 40 MHz	
Frequency resolution	233 µHz (fout ≤ 30 Hz); 29.1 mHz (fout > 30 Hz)	
Output amplitude	–50 dBm, –60 dBm, or –70 dBm, all ± 5 dB typical	
Output impedance	50 Ω	
Connector types		
DC Source Measure Unit (SMU) inputs	Tri-axial(f) Force and Tri-axial(f) Sense	
Interface module digital control input	36-pin miniature delta ribbon (f)	
Gate/Base (SG output) port	SMA(f)	

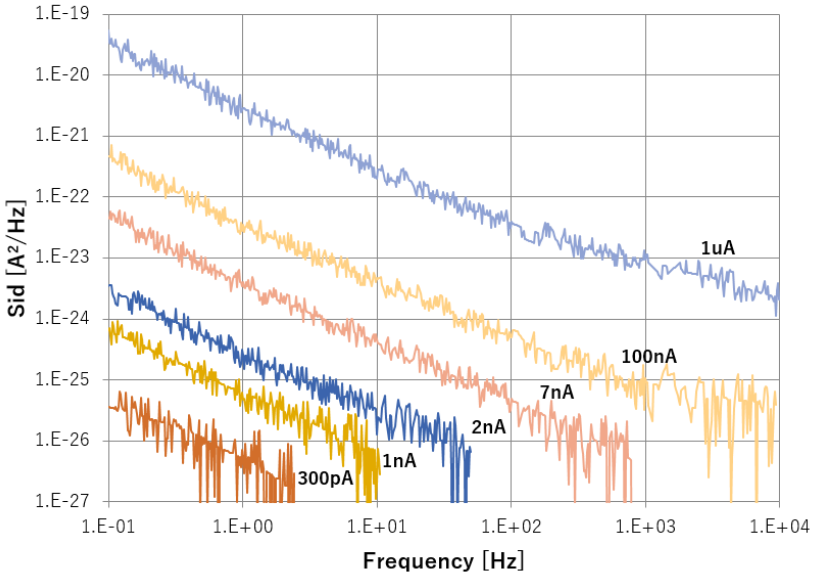
E4727A(K03) output module specifications

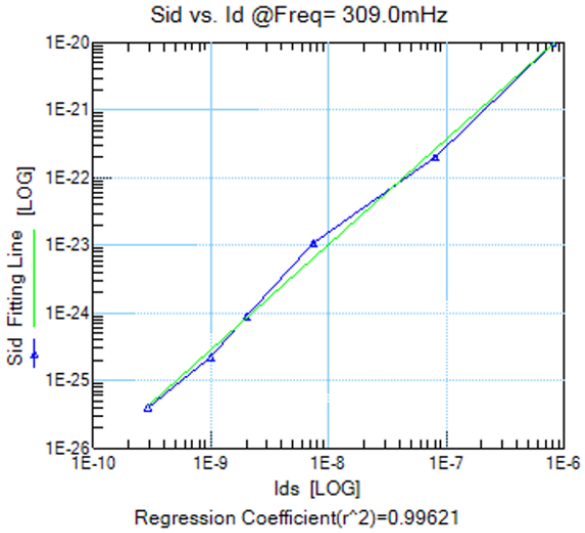
The output module accepts tri-axial force and sense inputs from the SMU, applies low-pass filtering and a variable and controllable load impedance. The same output module output connector serves as the noise receiver input. In the noise receiver path to the digitizer, the output module is equipped with 5 possible low-noise amplifiers to maximize flexibility in the types of devices measured.

LPF					
Number of LPFs			2		
	LPF1		LPF2		
Cut-off frequency	0.03 Hz		0.53 Hz		
Series resistance (Rlpf_output)	5 kΩ		300 Ω		
Maximum voltage	± 200 VDC		± 200 VDC		
Maximum current	± 0.1 A		± 0.1 A		
Output resistances					
Resistor values	0 to 100 MΩ (25 selections)				
Accuracy	± 0.5%				
LNAs					
Number of LNAs			5		
	LNA1	LNA2	LNA3	LNA4 [1]	LNA5 [1]
LNA type	Voltage	Voltage	Voltage	Current	Current
Frequency range	0.03 Hz to 1 MHz	1 Hz to 1 MHz	1 Hz to 40 MHz	0.03 Hz to 100 kHz	1 Hz to 100 kHz
Input voltage noise density	0.67 $\frac{nV}{\sqrt{Hz}}$ at 10 kHz	0.67 $\frac{nV}{\sqrt{Hz}}$ at 10 kHz	1.5 $\frac{nV}{\sqrt{Hz}}$ at 1 MHz	–	–
Input current noise density (max)	100 $\frac{fA}{\sqrt{Hz}}$ at 10 kHz	100 $\frac{fA}{\sqrt{Hz}}$ at 10 kHz	100 $\frac{fA}{\sqrt{Hz}}$ at 10 kHz	0.7 $\frac{pA}{\sqrt{Hz}}$ at 10 kHz	0.7 $\frac{pA}{\sqrt{Hz}}$ at 10 kHz
Corner frequency	20 Hz	200 Hz	200 Hz	200 Hz	200 Hz
Maximum input voltage	± 200 VDC	± 200 VDC	± 200 VDC	± 5 VDC	± 5 VDC
Maximum input current	–	–	–	± 30 mA	± 30 mA
Output impedance	220 Ω	220 Ω	220 Ω	220 Ω	220 Ω
Connector types					
DC Source Measure Unit (SMU) inputs	Tri-axial(f) Force and Tri-axial(f) Sense				
Interface module digital control input	26-pin miniature delta ribbon (f)				
Drain/collector/anode/resistor+ port	SMA (f)				
Source/emitter/cathode/resistor- port	SMA (f)				

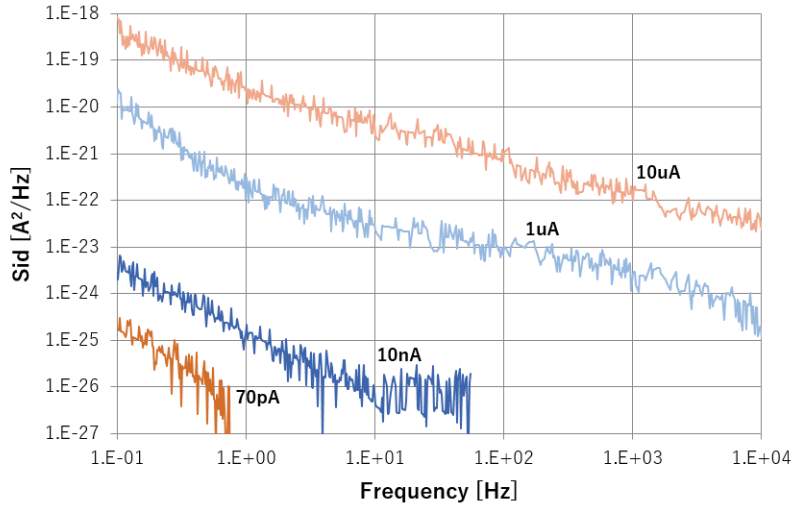
1. Ground-Signal (GS/SG) or Ground-Signal-Ground (GSG) probes are incompatible with the current mode amplifiers.

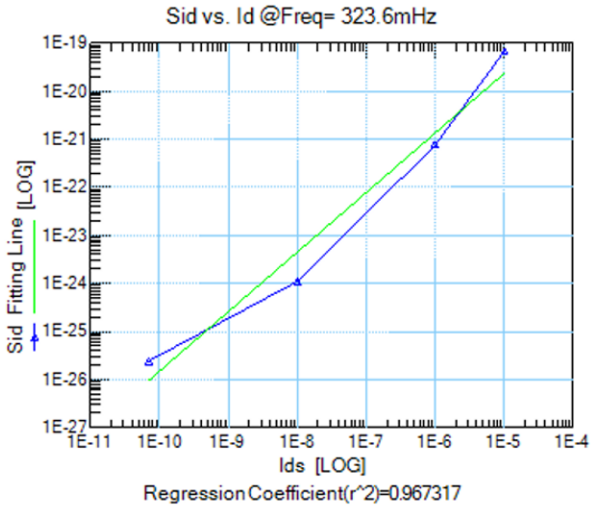
Actual Measured Data for Sid=2E-27A^2/Hz





Actual Measured Data for Ids=70pA





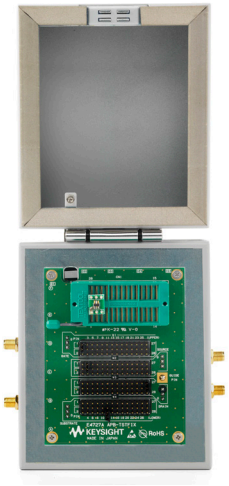
E4727A(K04) substrate module specifications

The substrate module is a passive device used to pass along a filtered version of the DC bias to a substrate or back-gate node of a device.

LPF	
Number of LPFs	1
Cut-off frequency	0.08 Hz
Series resistance (Rlpf_substrate)	2 kΩ
Maximum voltage	± 50 VDC
Maximum current	± 0.1 A
Connector	
DC Source Measure Unit (SMU) inputs	Tri-axial(f) Force and Tri-axial(f) Sense
Substrate terminal	SMA(f)

E4727A(K05) test fixture module specifications

The test fixture module is used to facilitate testing of packaged through-hole devices.



IC socket	
Type	DIP (300 mil and 600 mil)
Lead pitch	2.54 mm (100 mil)
Maximum number of leads	28
Connector	
Drain/collector/ anode/resistor+	SMA(f)
Source/emitter/cathode/resistor-	SMA(f)
Gate/base terminal	SMA(f)
Substrate terminal	SMA(f)

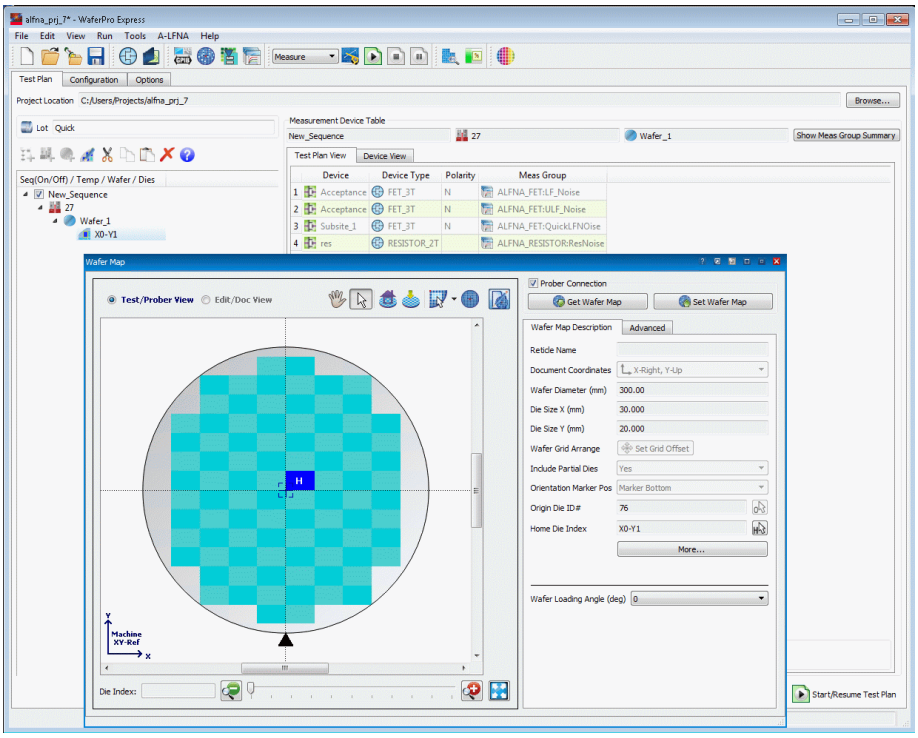
E4727A Software

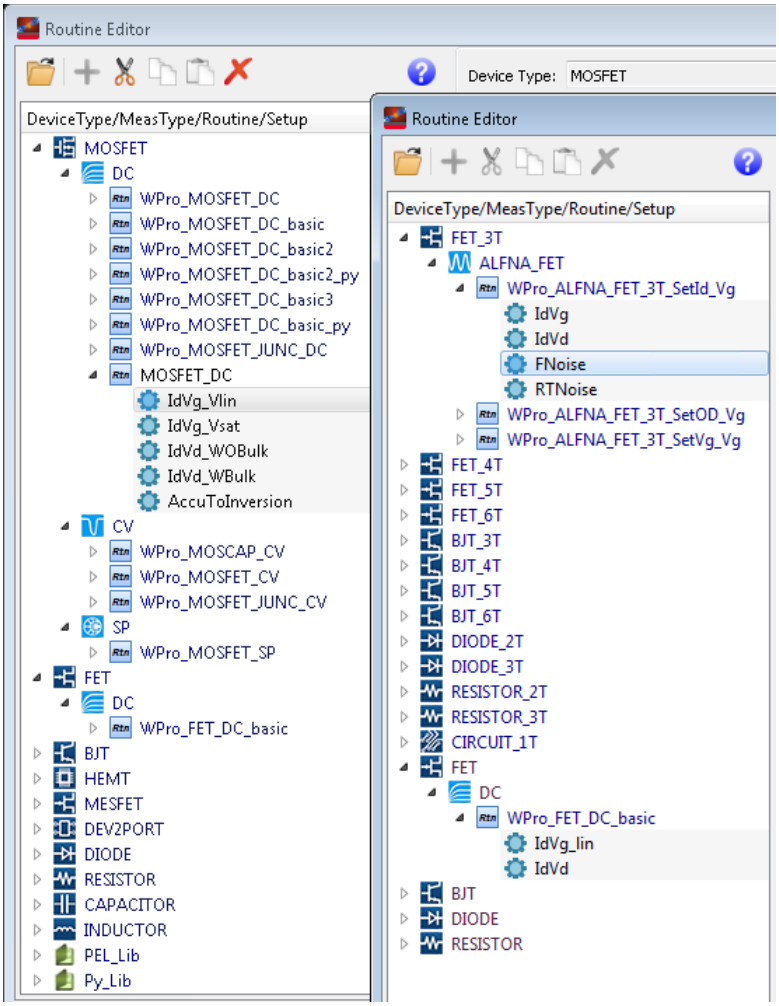
The A-LFNA software and user interface is built on top of the WaferPro Express measurement platform. Engineers may now manage and automate the full wafer level characterization in a measurement system that is both flexible and expandable. Just as before, those using WaferPro Express can program and sequence high-speed DC, capacitance and RF as parameter measurements, all the while automating wafer prober control. Now with the noise measurement module, they can add noise measurements and analysis to the test suite.

The A-LFNA's built-in measurement routines make DC and noise measurements turnkey. For example, to measure noise on an N-Type MOSFET, the system automatically chooses the source and load impedances that will best expose the intrinsic device noise. The engineer can accept these recommended settings or make changes, and a noise measurement is initiated. The A-LFNA then measures noise power spectral density (1/f noise) and noise in the time domain (RTN). Resulting data is plotted using a "multiplot" data display window. Various windows tabs help facilitate common tasks such as evaluating device DC operating point and measuring the slope of the power spectral density curve.

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
- Convenient connectivity to instruments via GPIB and prober systems via LAN IP address
- Automated control of all major wafer probing systems, thanks to Keysight's close collaboration with Cascade Microtech (auto-align, wafer map, die indexing, etc.)
- 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





Measurement Functions

Built-in biasing schemes

Device type	Biasing scheme	Description
FET	SetVg	Defines Vgs, Vds, and Vbs as bias conditions
	SetId	Defines Ids, Vds, and Vbs is as bias conditions. Vgs is determined automatically to achieve target Ids
	SetOD	Defines threshold voltage (Vth) based on constant-current or gm_max and an offset voltage. Vgs will be automatically set offset from Vth.
BJT	SetVb	Defines Vbe ,Vce and Vse as bias conditions
	SetIb	Defines Ib and Vc and Vse as bias conditions. Vbe is determined automatically to achieve target Ib.
	SetIc	Defines Ic, Vc and Vse as bias conditions. Vbe is determined automatically to achieve target Ic.
Diode	SetVa	Defines Vac and Vsub as bias conditions
	SetIa	Defines Iac (diode current) and Vsub as bias conditions. Vac is determined automatically to achieve target Iac.
Resistor	SetVr	Defines Vr and Vsub as bias conditions
	SetIr	Defines Ir and Vsub as bias conditions. Vr is set automatically.

External instrument control

Supported parameter analyzers

- Keysight 4142B (41420A HPSMU, 41421B MPSMU)
- Keysight 4155B/C (MPSMU)
- Keysight 4156B/C (HRSMU)
- Keysight B1500A (B1510A HPSMU, B1511A/B MPSMU, B1517A HRSMU)
- Keysight E5260A (E5290A HPSMU, E5291A MPSMU)
- Keysight E5270B (E5280B HPSMU, E5281B MPSMU, E5287A HRSMU)

Supported semi-automated probe stations

The choice of which prober to work with the A-LFNA is an important decision. Conducted noise from the probe station, either from thermal Chuck or servo motors controlling the microscope or positioners may introduce noise in the A-LFNA measurement. Thanks to a close collaboration between Keysight and Cascade Microtech, we are pleased to present semi automatic control of the following probe stations.

- Cascade Summit 12000, lowest noise
- Cascade S300
- Cascade Elite300, lowest noise
- Cascade PA300
- Cascade CM300, etc.

Note that any probe station not listed above (manual or otherwise) is perfectly acceptable for A-LFNA measurements. The only consideration is that the prober will not be controlled by the A-LFNA software.

Interfaces

Interface	Description
LAN	2 LAN connectors for connection with embedded PC
USB	4 USB ports at front of PXIe chassis for connection with embedded PC
GPIB	GPIB interface built into M9036A embedded PC
VGA video output	External display connector to embedded PC
Interlock	High-voltage safety mechanism for Keysight 4142B, 4155B/C, 4156B/C, E5260A, E5270B, B1500A and test fixture module (K05)

System Specifications

Number of DUT terminals		4 for FET and BJT (expandable to 5 or 6 by Opt.022 or Opt. 023)	
		3 for diode and resistor	
		1 for circuit	
Maximum bias applied to DUT		Voltage AMP	Current AMP
	Gate/Base	50 V – (Rlpf_input+RSource)*I_{PORT1}	
	Drain/Collector/ Diode	200 V – (Rlpf_output+RLoad)*I_{PORT2}	± 5 V
	Substrate	50 V – 2 KΩ *Isubstrate	
	Resistor	200 V – (Rlpf_output+RLoad+Rdut)*I_{PORT2}	
		Maximum RDUT = 10 MΩ	N/A
Minimum noise floor		2E-27 A^2/Hz	
Minimum bias current		70 pA (typ)	
1/f noise measurement accuracy		± 1.5 dB	
1/f noise measurement repeatability		± 2.0 dB	

General Specifications

Specification conditions			
Temperature			23 °C ± 5 °C
Humidity			30% ~ 80% RH
Warming up time			Minimum 40 minutes
Calibration period			1 year
Temperature range			
Operating			10 to 40 °C
Storage			–30 to 70 °C
Humidity range			
Operating			20 to 70% RH, no condensation
Storage			20 to 90% RH, no condensation
Power requirement			
AC voltage			100 to 240 V (± 10%)
Line frequency			50/60 Hz
Maximum volt-amps (VA)			1000 VA
Regulatory compliance			
EMC			IEC/EN 61326-1
			CISPR Pub 11 Group 1, class A
			AS/NZS CISPR 11
			ICES/NMB-001 This ISM device complies with Canadian ICES–001. Cet appareil ISM est conforme a la norme NMB-001 du Canada.
			KCISPR11
Safety			IEC/EN 61010-1
			Canada: CSA C22.2 No. 61010-1
			USA: UL std no. 61010-1
			KSCIEC61010-1/
			KSCIEC60950-1/
Acoustic Statement: (European Machinery Directive)			Acoustic noise emission
			LpA < 70 dB
			Operator position
			Normal operation mode per ISO 7779
Compliance marks	CE	CE	Conformité Européenne
	C SP US	CSAus	CSA Group Certification for US and Canada
		RCM	Electromagnetic compatibility, Australian Communications Media Authority
	KC	KCC	South Korean Certification Compliance (KCC) mark. MSIP-REM-Kst-RP15129

Dimensions and weight

Part	Dimensions W x H x D (mm) (excluding protruding object)	Weight (Kg)
PXIe unit	444.4 x 177.8 x 466	17.1
E4727A(K02) input module	65.0 x 125.0 x 180.0	2.3
E4727A(K03) output module	65.0 x 125.0 x 180.0	2.4
E4727A(K04) substrate module	65.0 x 98.0 x 99.4	1.5
E4727A(K05) test fixture	100.0 x 85.0 x 120.0	0.8
E4727A(K06,07) oscillation block filter (type 1, 2)	50.0 x 20.0 x 30.0	0.04
4-terminal module enclosure	279.0 x 140.7 x 194.0	3.0

Automated RTN Solution Using E4727E3 and B1500A

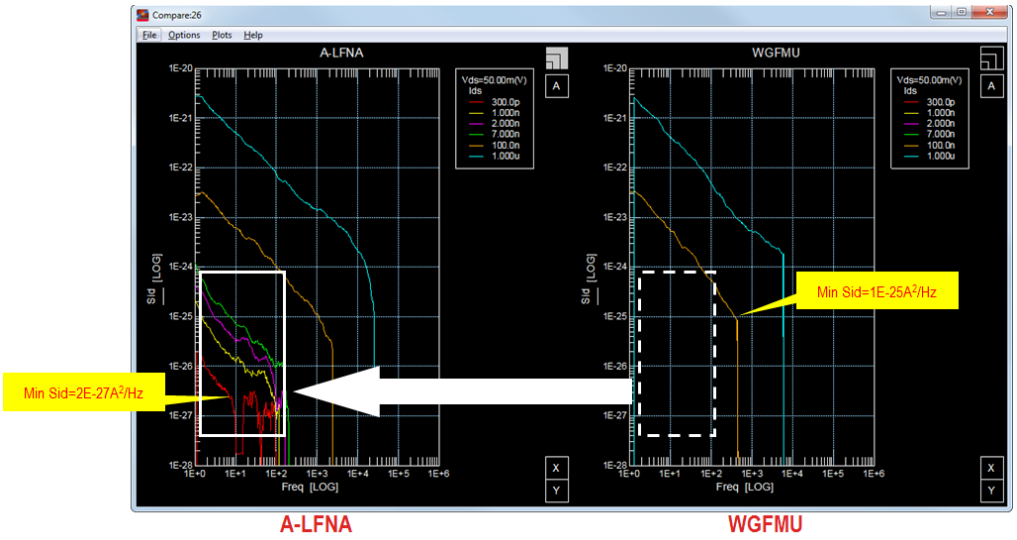
E4727E3 efficiently performs at a low cost an automated RTN measurement on the wafer using the B1500A Semiconductor Device Analyzer with the B1530A Waveform Generator/ Fast Measurement Unit (WGFMU). It can improve the efficiency of RTN measurement and data analysis including wafer prober control.

Key features
- Automated measurement without programing
- Auto prober control
- Wafer mapping
- Single data display for multi decade in frequency domain
- Upgradeable from your existing B1500A

RTN and 1/f noise measurement system comparison

		E4727A Advanced Low-Frequency Analyzer		**E4727E3 Automated RTN software for B1500A**
Measurement software		E4727P3 A-LFNA measurement and programming bundle software		E4727E3 WGFMU measurement bundle software
License type		Floating		Node-locked
Supported instrument		E4727A A-LFNA	B1500A with B1530A WGFMU (Optional)	B1500A with B1530A WGFMU
Target device		FET, BJT, Diode, Resistor, Circuit		FET
Device terminal number		3, 4, 5, 6		3
Maximum bias voltage		± 200 V		± 10 V
Maximum bias current		± 100 mA		± 10 mA
Bias Mode for FET		SetVg, SetId, SetOD, SetODvdlin		
Noise floor		2E-27 A^2/Hz		1E-25 A^2/Hz
Analog frequency bandwidth		30 m to 40 MHz		1 m to 16 MHz
Frequency domain measurement	Minimum frequency	30 mHz		1 mHz
	Maximum frequency	40 MHz		16 MHz
Time domain measurement	Maximum sampling frequency	400 MHz		200 MHz
	Minimum sampling interval	2.5 nsec		5 nsec
	Maximum sampling number	2^{24}=16,777,216		2^{21}=2,097,152
Controller PC		M9036A PXIe embedded controller		Windows PC
GPIB interface		M9036A built-in GPIB interface (Micro-D 25 pin)		USB GPIB interface (Keysight 82357B, NI GPIB-USB-HS)

Measurement example



- Device: JFET
- Bias:
  - Ids = 300p/1n/2n/7n/100n/1uA
  - Vds = 50mV

For more information on WGFMU, please see the link below.

- https://www.keysight.com/en/pd-1443698-pn-B1500A-A30re/
- http://literature.cdn.keysight.com/litweb/pdf/5991-2443EN.pdf

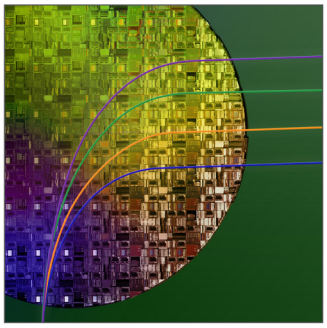
Ordering Information

Automated noise measurement with A-LFNA	
E4727A	Advanced low-frequency noise analyzer
E4727A-022	Add one extra substrate module for 5-terminal device characterization
E4727A-023	Add two extra substrate modules for 6-terminal device characterization
E4727A-031	Connection plate for PA300
E9000S	12 month hardware warranty
E4727P3	WaferPro Express A-LFNA and WGFMU measurement and programming bundle software license
R-35E-001-B	Floating single site license
R-36E-002-L	12M upgrades and support contract - Floating single site
R-36E-002-X	24M upgrades and support contract - Floating single site
R-36E-002-Y	36M upgrades and support contract - Floating single site
Automated noise measurement with WGFMU (Typical configuration example)	
B1500A	Semiconductor device analyzer mainframe
B1500A-A00	Empty package for custom solution
B1500A-A30/A31	WGFMU add-on package or WGFMU add-on package with connector adapters
B1500A-A3P	WGFMU probe cable kit
E4727E3	WaferPro Express WGFMU measurement bundle software license
R-35E-001-A	Node-locked License
R-36E-001-L	12M upgrades and support contract - Node-lock
R-36E-001-X	24M upgrades and support contract - Node-lock
R-36E-001-Y	36M upgrades and support contract - Node-lock

IC-CAP

Keysight IC-CAP

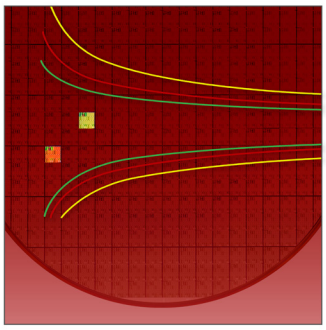
- Device Modeling Software
- www.keysight.com/find/eesof-iccap



MBP

Keysight MBP

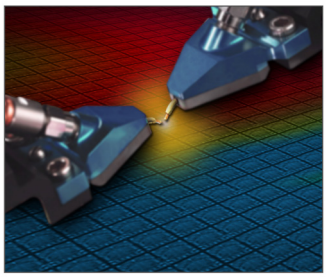
- Turn-key Device Model Extraction Solutions
- www.keysight.com/find/eesof-mbp



MQA

Keysight MQA

- Device Model Validation Software
- www.keysight.com/find/eesof-mqa



WaferPro Express

Keysight WaferPro Express

- On-wafer Measurement Program
- www.keysight.com/find/eesof-waferpro-express

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