

Keysight Technologies

Enabling Noise Measurements on Magnetic Sensors

Application Note



KEYSIGHT
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Unlocking Measurement Insights



Introduction

Magnetic sensors are used in numerous applications requiring high sensitivity, ranging from brain function mapping to magnetic anomaly detection, magnetic compassing and mineral prospecting. Magnetic sensor sensitivity may be thought of as a signal-to-noise ratio, where the signal is reflected by the gain and the noise is indicated by the inherent noise of the sensor. Sensor manufacturers must characterize and track the inherent $1/f$ sensor noise, as this is a critical parameter typically represented in $\text{nT}/\sqrt{\text{Hz}}$. A new type of magnetic sensor has recently demonstrated higher sensitivity than the standard magnetoresistive sensors, presenting a new noise measurement challenge. Many noise sources may corrupt this measurement, including ambient magnetic field noise, supply noise, and the additive noise from the signal conditioning circuitry. Tunnel magnetoresistance (TMR) sensors offer better resolution, decreased power consumption, and smaller size than their Hall effect, anisotropic magnetoresistance (AMR) and giant magnetoresistance (GMR) counterparts². Thanks to new innovations in noise measurement hardware and software, accurate measurement of low noise levels in TMR sensors is now possible.

Magnetic Sensor Noise Measurements - An Introduction

Typically, magnetic sensor engineers will characterize noise as a function of applied magnetic field. The magnetic field is controlled using Helmholtz coils, as shown in Figure 1. Special care must be taken to avoid noise in the magnetic field environment.

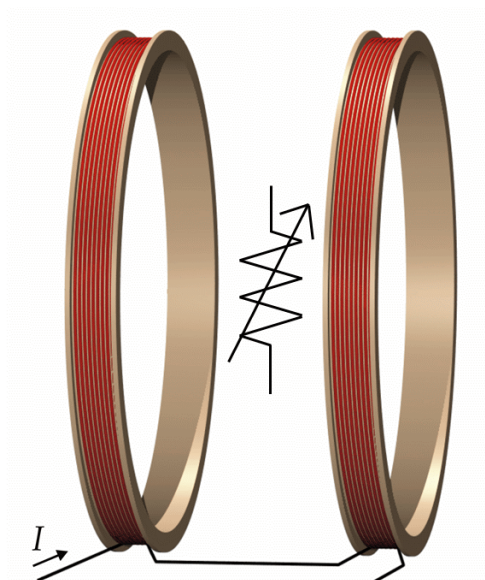


Figure 1. Helmholtz coils for single axis magnetic field control. ¹

A source measurement unit like the Keysight B1500A is then implemented to apply bias and measure resistance. So as to only measure variations in resistance, the SMU noise must be filtered out. The resistor noise manifests as current noise, which is converted to voltage noise using a load resistance and amplified by an ultra-low noise voltage amplifier. The resultant voltage noise is analyzed using a high-speed digitizer. As shown in Figure 2, all of these functions are included in the E4727A advanced low-frequency noise analyzer (A-LFNA) solution, which when combined with the A-LFNA software, leads to a powerful and accurate magnetic sensor noise measurement solution.

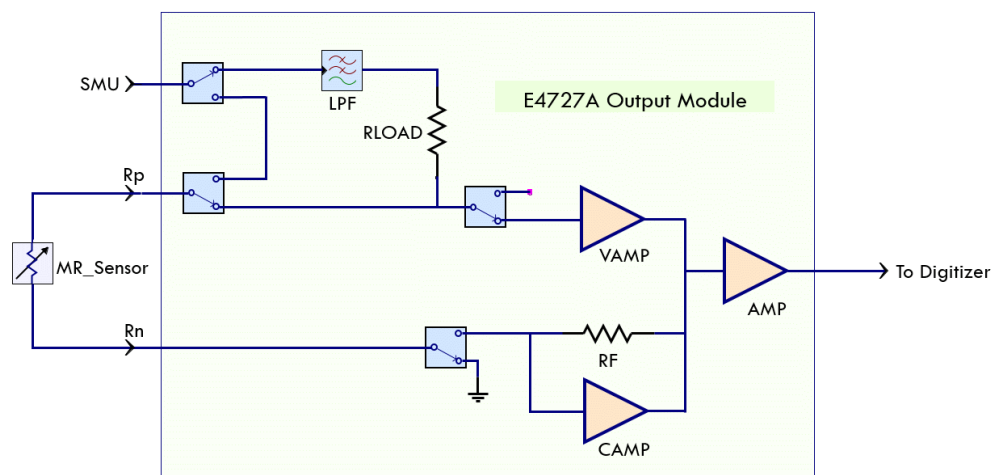


Figure 2. Variations in resistance are captured as voltage noise and then digitized.

Low-Noise Amplifier Enables State-of-the-Art Measurement Sensitivity

The amplifiers illustrated in Figure 2 amplify the low-level noise signals so that the digitizer may accurately represent the spectral density, thus capturing magnetic sensor noise density. Since the noise of these amplifiers adds directly to the noise of the device under test, the additive amplifier noise becomes a critical specification for sensitivity. The previous generation 1/f noise measurement system amplifiers proved inadequate for magnetic sensor measurements, corrupting data with their own noise. The latest E4727A features a newly developed amplifier with $-183\text{ dBV}^2/\text{Hz}$ floor (equivalent to the noise of a $28\text{ }\Omega$ resistor) and a corner frequency of only 20 Hz (Table 1). This enables highly accurate characterization of magnetic sensor noise. Figure 3 presents the additive voltage noise of the LNA in the latest E4727A as compared to its predecessor, the E4725A. The E4727A has a much lower noise density, enabling industry-leading measurement sensitivity.

	E4725A	E4727A
Noise floor	$-177\text{ dBV}^2/\text{Hz}$	$-183\text{ dBV}^2/\text{Hz}$
	$1.4\text{ nV}/\sqrt{\text{Hz}}$	$0.67\text{ nV}/\sqrt{\text{Hz}}$
Corner frequency	10 kHz	20 Hz

Table 1. Tabulated LNA performance of predecessor E4725A and current E4727A measurement system.

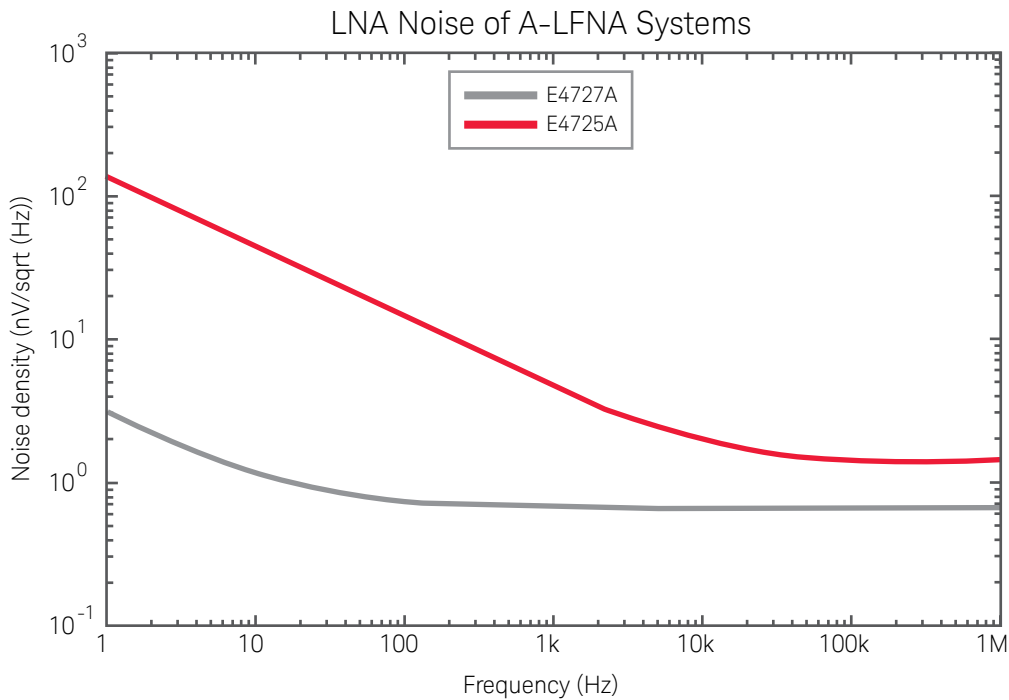


Figure 3. Noise floor comparison of E4727A and E4725A A-LFNA systems.

Measurement Example of TMR (Tunnel Magnetoresistance) Sensor

Keysight Technologies collaborated with the Ando Laboratory in the Department of Applied Physics, Tohoku University, Japan, to show that $1/f$ noise of TMR sensors can be measured with high speed and excellent repeatability using the Keysight E4727A Advanced Low-Frequency Noise Analyzer (A-LFNA) in conjunction with the A-LFNA software. A B1500A semiconductor parameter analyzer is used to provide bias through the output module. The small size of the output module enables it to be placed very close to the device under test. To avoid crosstalk and electromagnetic interference, the other equipment may be located outside of the magnetic shield room. Figure 4 presents the complete measurement apparatus with the Helmholtz cage, output module, PXI controller and B1500A semiconductor parameter analyzer.

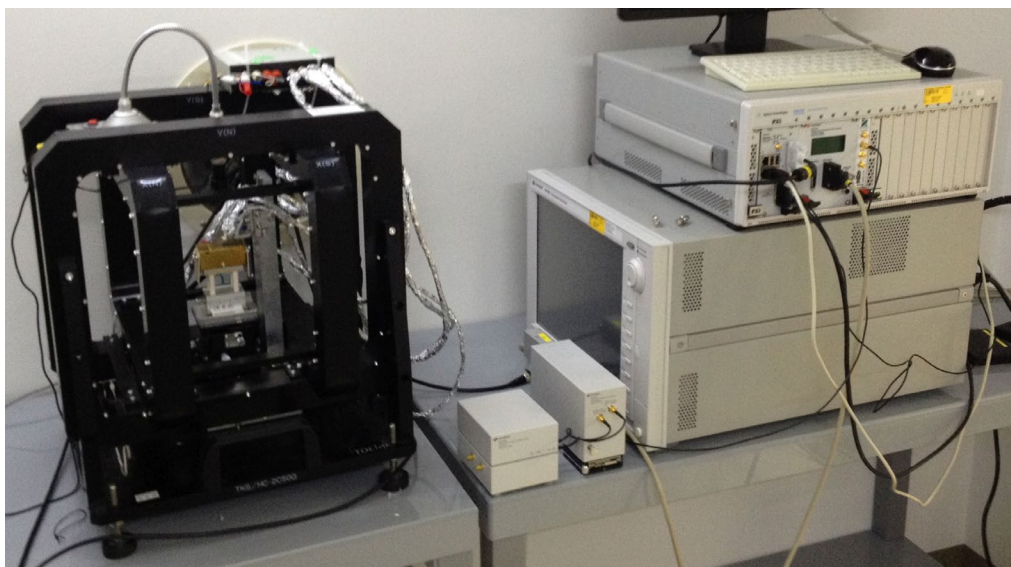


Figure 4. Helmholtz coils with magnetic sensor and device probe.

Figure 5 presents measured data on a TMR sensor. Given a constant 10 mV voltage applied across the sample, the Helmholtz cage was controlled to apply a magnetic field ranging from -20 Oe to $+20$ Oe. The resultant resistance is plotted on the left hand plot. The sharpest change in resistance occurs near 0 Oe. The middle plot shows $1/f$ noise S_i (A^2/Hz) measured at each magnetic field setting. Slicing this data at 100 Hz, one may plot $1/f$ noise as a function of applied magnetic field. This is presented on the rightmost plot, where the X-axis is applied magnetic field, and the Y-axis is $1/f$ noise at 100 Hz. Maximum $1/f$ noise is observed near 0 magnetic field, which is also where the resistance changes most rapidly.

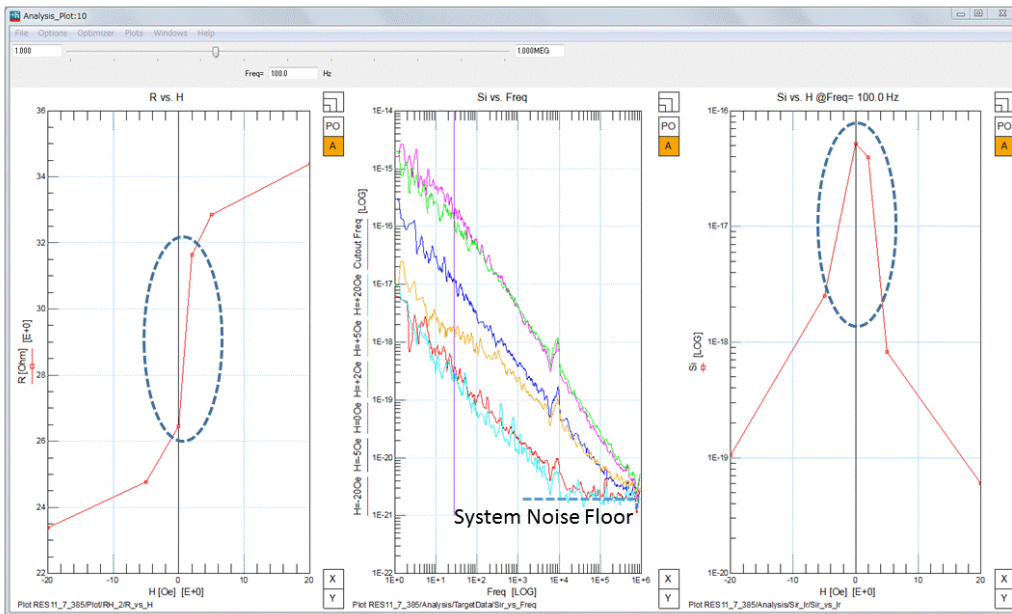


Figure 5. Measurement results from Ando Laboratory, Department of Applied Physics, Tohoku University, Japan.

Magnetic Sensor 1/f Noise Measurement Solution

The module used for magnetic sensor measurements is called an “output module.” Its two terminals will connect to the two ports of the magnetic sensor. However, they may also be connected across the drain and source of an FET or collector and emitter of a bipolar transistor. A “fixture module,” included with the E4727A, facilitates measurements on discrete components. On-wafer testing of bipolar transistors, CMOS devices, and even power devices is controlled by an easy-to-use software interface. The resultant data may then be ported over to powerful device modeling software like Model Builder Pro (MBP) and Integrated Circuit Characterization and Analysis Program (IC-CAP).



Figure 6. Modules of E4727A: interface module, input module, output module and substrate module.

Conclusion

The Keysight E4727A Advanced Low-Frequency Noise Analyzer is the next-generation system for characterization and analysis of 1/f flicker noise and random telegraph signal noise (RTN). Designed for on-wafer probed devices, discrete package devices, and low noise integrated circuits, it uniquely allows for versatile noise measurement under diverse conditions, including: ultra-low frequency, ultra-low current, high current, high voltage, or high power. Given its state-of-the-art noise sensitivity and modular design, the E4727A is well suited for magnetic sensor 1/f noise measurements. For device modeling, characterization and statistical process control, this solution features an easy-to-use software platform built on top of Keysight's powerful device modeling software. Measurements ranging from 0.03 Hz to 40 MHz are now possible, enabling new sensor designs that push the frontier in sensitivity and noise.

Items		Specifications
Measurement devices		FET, BJT, Diode, Resistor, Circuit
Maximum frequency range		0.03 Hz ~ 40 MHz
AMP		Voltage AMP x3, Current AMP x2
Voltage AMP	Noise floor	-183 dBV ² /Hz (0.67 nV/ $\sqrt{\text{Hz}}$)
	Corner frequency	20 Hz
Current AMP	Noise floor	1E-23 A ² /Hz
	Corner frequency	200 Hz
Maximum bias range		200 V/0.1 A (10W max)

Table 2. Key specifications for E4727A advanced low-frequency noise analysis system.

References

1. Hellwig, Ansgar, "Helmholtz Coils for Single Axis Magnetic Field Control", Creative Commons Licence, CC-BY-SA-2.0 and GFDL, <http://bit.ly/1LS5k9X>. Web. 8 Mar. 2016.
2. "Introduction to TMR Magnetic Sensors." MultiDimension. MultiDimension Technology, Co. Ltd., 12 Mar. 2015. Web. 9 Mar. 2016.

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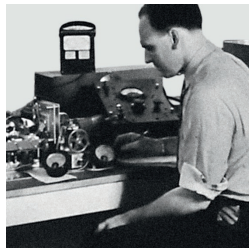
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