

# Noise-Related Technologies Climb Toward THz Territory

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Noise sources and noise analyzers are essential tools for testing and calibrating a wide variety of radar, communication and test systems. They are also vital for characterizing individual components and chip-scale electronic devices. At frequencies from MHz to THz, broadband noise sources are needed to measure the noise performance of amplifiers and receivers. They provide signals for testing digital radios and networks and they frequently support built-in test functions in radars and radiometric receivers. Amplified noise sources are commonly used as jamming signals in electronic countermeasures and emerging applications include gas and material composition detectors and broadband imaging systems.

At mmWave and sub-THz frequencies, electronic noise sources typically use an active device combined with a matching circuit and an attenuator or an isolator to match the output port to a standard impedance or waveguide type. In their most common configuration,

electronic noise sources provide two calibrated noise power levels for measuring the performance of receivers and various other types of components and systems. A "hot" noise level is generated when the active device is turned on, while a "cold" noise level is produced when the active device is off.

An ideal noise source generates Gaussian random noise over a flat frequency spectrum with a negli-

gible output mismatch to the reference termination.<sup>1-6</sup> Many coaxial and waveguide noise sources are available for mmWave frequencies with many reaching 110 GHz. A summary of representative noise sources from a variety of manufacturers is shown in **Table 1**.

At higher frequencies, fewer options exist. Fortunately, waveguide noise sources are now increasingly being offered at frequencies ex-

**TABLE 1**  
MMWAVE NOISE SOURCES

Manufacturer	Model	Frequency (GHz)	ENR (dB)	VSWR	Interface
Elva-1	ISSN-03	220 to 330	26 to 55	N/A	WR-03 waveguide
Eravant	STZ-22427410-03-IT2	220 to 270	7 to 13	1.6:1	WR-03 waveguide
Keysight	Q347B	33 to 50	9 to 17	1.5:1	WR-22 waveguide
NoiseCom	NC 3210M	2 to 110	>15	1.6:1	1.0 mm coaxial
NoiseWave	NW75G110-W	75 to 110	>15	1.6:1	WR-10 waveguide
VDI	WR5.1NS	140 to 220	8.5	N/A	WR-5.1 waveguide

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ceeding 200 GHz. **Figure 1** shows a noise source from Eravant that operates to 270 GHz. Electronic noise sources are commonly used with signal analyzers to perform noise

figure measurements. Important specifications include excess noise ratio (ENR) flatness and output return loss. Isolators are often included to improve the output match and stabilize the noise output level.

### THERMAL NOISE SOURCES

Thermal radiation sources have been used for calibration since Max Planck presented his theory of heat radiation in 1900. At mmWave and THz frequencies, matched terminations are often cooled with liquid nitrogen or heated with boiling water to produce primary noise references. However, “stem corrections” are typically applied to account for noise

contributed by transmission lines and anything else in the signal path between the thermal source and the noise receiver.<sup>6</sup> Despite such complications, thermal reference standards are widely used to calibrate noise sources and receivers.

Hot and cold thermal noise standards are available, either individually or integrated into more functional noise calibration systems.<sup>7</sup> Cold reference sources typically include a coaxial or waveguide termination placed inside an insulated Dewar flask. The flask is filled with liquid nitrogen maintained at its boiling point. A regulated heater controls the temperature profile of a coaxial or waveguide transmission line that connects the cold termination to a room temperature user interface. An example of this type of precision noise calibration system is shown in **Figure 2**.

Thermal noise standards are often characterized by an effective noise temperature that is slightly above or below the temperature of the termination. The noise contribution from an element in the signal path may be estimated as shown in Equation 1:

$$T_E * (1 - G) \quad (1)$$

Where:

$T_E$  is the temperature of the element

$G$  is the gain factor of the element

To illustrate, a transmission line with a gain factor of 0.99 (0.04 dB attenuation) held at a temperature of 200 K would add 2 degrees to the effective noise temperature of the source. A more rigorous analysis would model the signal path as a cascade of circuit elements with different temperatures.<sup>8</sup>

Cold thermal sources are also constructed from absorbing materials that are cooled with precision temperature controllers.<sup>9</sup> The thermal noise radiated by such structures is typically coupled to a receiver through an antenna with both units operating in a condensation-free environment. **Figure 3** shows a thermal noise source with a conical mmWave absorber. The temperature of the absorber is controlled with a circulating fluid.



▲ Fig. 1 Eravant noise source.



▲ Fig. 2 Noise calibration system with reference termination immersed in liquid nitrogen. Source: Maury Microwave.

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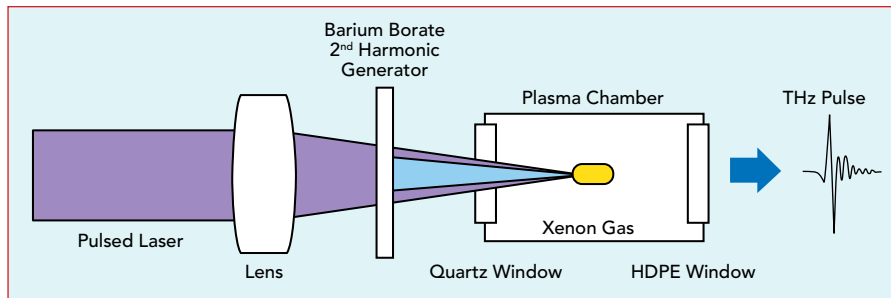
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▲ Fig. 3 Thermal noise source with conical mmWave absorber. Source: TK Instruments Ltd.

### ELECTRONIC NOISE SOURCES

Some of the earliest electronic noise sources were constructed with gas discharge tubes mounted inside waveguides.<sup>10</sup> Gas discharge tubes are still used today, but they are much less common. More recently, laser-induced plasmas in noble gases have produced extremely fast THz signal pulses.<sup>11</sup> Optical mixing in photodiodes also produces THz signals. A functional rendition of this idea is shown in **Figure 4**, where THz pulses are produced when optical power at different wavelengths excites a plasma in a chamber filled



▲ Fig. 4 Functional diagram for THz pulses created by optical excitation.

with a noble gas. Another type of THz noise generator applies multiple optical signals at different wavelengths to a high speed photodiode.<sup>12,13</sup> The photodiode mixes the spontaneous emission noise produced by a super-luminescent LED. While such technologies appear to be in early development stages, they offer hope that THz noise sources suitable for laboratory use are on the horizon.

By the late 1970s, solid-state devices started replacing gas discharge tubes.<sup>14,15</sup> The sources exploit the shot noise generated in avalanche diodes and other semiconductor devices. Recent developments with avalanche diodes in silicon carbide show promise for improved high frequency performance as signal sources.<sup>16</sup> Field-effect transistors of various types can also be used to generate controlled levels of broadband noise.<sup>17</sup> At mmWave and sub-THz frequencies, suitable transistors may include GaAs FETs, InP HEMTs and GaN HEMTs. When suitably bi-

ased, such devices can produce significant levels of broadband noise.

Noise sources used for noise figure measurements must be turned on and off repeatedly. The source mismatch should be small and more importantly, unchanged between the on and off states. Different noise temperatures are observed depending on whether the source is on (hot) or off (cold). Noise sources are generally characterized by their ENR, as well as a reference termination; either a nominal impedance or a standard waveguide size.

The ENR defines the hot noise level relative to the cold noise level when the source is held at a reference temperature of 290 K.<sup>18</sup> The ENR is generally a frequency-dependent quantity. For noise figure measurements and many other applications, the ENR should be as flat as possible and the source mismatch should be as small as possible.

The ENR is an important consideration when choosing a noise source. As a rule of thumb, a noise



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source is suitable for measurements of noise figures that are up to the ENR value plus about 10 dB.<sup>19</sup> For higher device under test (DUT) noise figures, the difference between measured power levels for the hot and cold noise signals becomes too small to yield accurate results. However, a lower ENR should be used when possible because it tends to avoid overdriving the DUT and the receiver. Available noise sources tend to have ENR values around either 6 or 15 dB.

### NOISE SOURCE CALIBRATION

Electronic noise sources are calibrated using a variety of instruments including spectrum analyzers, noise figure meters, signal analyzers and network analyzers. Any suitable instrument must have a sensitive receiver that can measure noise levels over an adequate bandwidth with sufficient linearity and dynamic range. For automated measurements, the instrument should also be capable of controlling a two-level noise source while simultaneously measuring the received power for each noise level.

Many older-model noise figure analyzers, such as the Agilent N8970 series, are essentially spectrum analyzers with additional built-in functions for measuring noise power levels and performing noise figure measurements. Newer signal analyzers, which combine the traditional functions of a spectrum analyzer with a wide range of other measurement capabilities, are rapidly becoming the tools of choice for performing noise measurements. Some of these newer signal analyzers


are shown in **Table 2**.

The Y-factor method is a well-established measurement technique for calibrating noise receivers and noise sources. It uses a pair of noise sources or a single source that provides two different noise levels. When the Y-factor is expressed linearly, it is equal to the hot noise power divided by the cold noise power, as measured by the receiver.

When a receiver is calibrated, its noise figure is obtained by performing a Y-factor measurement with a calibrated noise source connected to its input. The measurement is usually repeated each time the receiver is used and certainly whenever the measurement bandwidth changes or when the attenuation or gain settings are changed. The amplitude response of the receiver is separately calibrated using a reference signal generator, a reference power detector and/or a set of reference attenuators. Amplitude calibrations are typically performed infrequently according to a maintenance schedule or when the operating environment changes significantly.

After the noise receiver is calibrated, it can be used

Manufacturer	Model	Frequency
Anritsu	MS2850A	9 kHz to 44.5 GHz
Keysight	N9041B	2 Hz to 110 GHz
Rohde & Schwarz	FSW	9 kHz to 85 GHz



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to perform additional Y-factor measurements and determine the ENR of an uncalibrated noise source. The calibration accuracy of the reference standard is partially transferred to the noise receiver and then partially transferred to the uncalibrated noise source. Analyzing the cumulative effects of measurement uncertainty is one of the more difficult tasks associated with noise source calibration.

Advantages of the Y-factor calibration method include its relative sim-

plicity and its acceptable accuracy, in most cases. Power ratio measurements can be obtained quickly, minimizing the effects of temperature drift in the receiver response. However, basic Y-factor measurements typically do not compensate for mismatch effects and various other sources of measurement uncertainty.

Many studies have focused on analyzing and improving the accuracy of noise source calibrations.<sup>20-22</sup> Suggested enhancements can improve

calibration results by applying considerably more effort in both measurements and calculations. By compensating for the measured effects of mismatches, the receiver noise parameters and temperature drift, one study achieved a two-sigma calibration accuracy of 0.046 dB for a noise source with an ENR of 5 dB.

The cold source measurement technique was developed as an alternative to the Y-factor method.<sup>23</sup> Measurements are performed using a single reference noise level provided by a matched termination at room temperature. The cold source method relies on knowing the scattering parameters of the DUT.<sup>24,25</sup> The accuracy of cold source measurements is generally superior to that of Y-factor measurements when the latter includes mismatch compensation.<sup>26</sup> Additionally, the minimum noise figure and the noise parameters of a DUT can be obtained by performing multiple cold source noise figure measurements with different mismatches connected to the DUT input.

Cold source noise figure measurements require absolute noise power measurements, necessitating more accurate receiver calibrations. The measurement bandwidth must be known as well. Whereas the Y-factor method produces both the gain and noise figure of the DUT in one set of measurements, cold source noise figure measurements require independent gain measurements.

Because cold source noise figure measurements involve far more measurements and data manipulation than traditional Y-factor methods, they are usually performed using a fully integrated and automated test system. Some newer vector network analyzer (VNA) models include the ability to perform cold source noise figure measurements. Examples of these VNAs are shown



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Manufacturer	Model	Frequency
Anritsu	MS4647B	10 MHz to 70 GHz
Keysight	N5244B	10 MHz to 44 GHz
Rohde & Schwarz	ZNA67	10 MHz to 67 GHz

vide high-quality noise sources at THz frequencies. Meanwhile, high performance down-converters are available to extend the frequency coverage of existing noise measurement tools. ■

## References

1. ELVA-1, Web: <https://elva-1.com/products>.
2. Eravant, Web: <https://www.eravant.com/products/noise-sources>.
3. "Noise Figure Analyzers and Noise Sources," Keysight Technologies, Web: <https://www.keysight.com/us/en/products/noise->

4. figure-analyzers-noise-sources. "Calibrated Sources," *Noisecom*, Web: <https://noisecom.com/products/calibrated-sources>.
5. NoiseWave, Web: <https://noisewave.com>.
6. E. Maxwell and B. J. Leon, "Absolute Measurement of Receiver Noise Figures at UHF," *IRE Transactions on Microwave Theory and Techniques*, Vol. 4, No. 2, April 1956.
7. "Precision Calibration Noise Calibration System," *Maury Microwave*, Web: <https://maurymw.com/product-category/precision-calibration/noise-calibration>.
8. C. T. Stelzreid, "Microwave Thermal Noise Standards," *IEEE Transactions on Micro-*

9. *wave Theory and Techniques*, Vol MTT-16, No. 9, September 1968.
9. "Calibrated Thermal Targets," *TK Instruments*, <https://www.terahertz.co.uk/tk-instruments/products/calibratedthermaltargets>
10. W. W. Mumford, "Broad Band Microwave Noise Source," U.S. Patent No. 2,706,782, April 1955.
11. Y. Chen, M. Yamaguchi, M. Wang and X.-C. Zhang, "Terahertz Pulse Generation From Noble Gases," *Applied Physics Letters*, Vol. 91, No. 25, December 2007.
12. B. Vidal, "Broadband Photonic Microwave Noise Sources," *IEEE Photonics Technology Letters*, Vol. 32, No. 10, May 2020.
13. Y. Zhang, W. Liu, Y. Guo, J. Liu, Z. Jia, Y. Sun, A. Wang and Y. Wang, "Generation of Flat Terahertz Noise by Mixing Incoherent Light Fields," *Photonics*, Vol. 2023, No. 10, p. 778.
14. N. J. Keen, "Avalanche Diode Noise Sources at Short Centimeter and Millimeter Wavelengths," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 24, No. 3, March 1976.
15. M. M. Radmanesh and J. M. Cadwallader, "Solid State Noise Sources at mm-Waves: Theory and Experiment," *Microwave Journal*, October 1991.
16. S. J. Mukhopadhyay, S. Kanungo, V. Maheshwari and M. Mitra, "Terahertz IMPATT Sources Based on Silicon Carbide," *Lecture Notes in Electrical Engineering*, Vol. 727, February 2021, Web: [https://link.springer.com/chapter/10.1007/978-981-33-4489-1\\_5](https://link.springer.com/chapter/10.1007/978-981-33-4489-1_5).
17. R. S. Roeder, M. C. Smith, L. P. Dunleavy and S. . Lardizabal, "Variable Microwave Cold/Warm Noise Source," U.S. Patent No. 6,439,763, August 2002.
18. "Fundamentals of RF and Microwave Noise Figure Measurements," *Keysight Technologies*, Application Note, 2019.
19. "Noise Figure Measurement Accuracy: The Y-Factor Method," *Keysight Technologies*, Application Note, 2021.
20. J.-M. Collantes, R. D. Pollard and M. Sayed, "Effects of DUT Mismatch on the Noise Figure Characterization: A Comparative Analysis of Two Y-Factor Techniques," *IEEE Transactions on Instrumentation and Measurement*, Vol. 51, No. 6, 2002.
21. L. Belostotski, "A Calibration Method for RF and Microwave Noise Sources," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 59, No. 1, January 2011.
22. K. Wong, J. Gorin and G. Lu, "Quantifying the Error Contribution of Noise Parameters on Y-Factor Noise Figure Measurements," *ARFTG Microwave Measurement Conference*, 2017.
23. N. Otegi, J. M. Collantes, and M. Sayed, "Cold-Source Measurements for Noise Figure Calculation in Spectrum Analyzers," *ARFTG Microwave Measurement Conference*, 2006.
24. "The Cold Source Technique for Noise Figure Measurements," *Rohde & Schwarz*, Application Note, 2021.
25. "Performing Differential Noise Figure Measurements," *Anritsu*, Application Note, 2018.
26. J. Dunsmore, "Noise Figure Verification of Y-Factor and Cold Source Methods," *International Conference on Noise and Fluctuations*, 2017.

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