Testing Radio Receiver Performance with Noise Generators

Application Note / 202608-2A

Abstract

Every radio link includes noise. Laboratory validation therefore requires a repeatable way to add a known amount of noise to a wanted signal and measure how receiver performance changes as signal-to-noise conditions degrade. Maury Microwave noise generators provide controlled AWGN for radio receiver testing. This application note examines the key ratios, test architectures, measurement workflow, and practical considerations for establishing controlled noise conditions and measuring receiver response.

AWGN Fundamentals

Additive White Gaussian Noise (AWGN) is a type of noise commonly used in signal processing and telecommunications to model random noise that affects the transmission of signals. AWGN (Figure 1) can be explained as follows:

- **Additive:** The noise is added to the original signal. It does not alter the signal in any other way except by adding itself to it. The received signal can be represented as:

$$y(t) = x(t) + n(t)$$

where y(t) is the received signal, x(t) is the transmitted signal, and n(t) is the noise.

- **White:** The term 'white' refers to the noise having a flat power spectral density, meaning its power is uniformly distributed across all frequencies. It is analogous to white light, which contains all visible wavelengths equally. This property makes white noise uncorrelated across different frequencies.
- **Gaussian:** The noise amplitude follows a Gaussian distribution, also known as a normal distribution. This means that the noise values are random but have a bell-shaped probability distribution centered at zero (mean = 0).

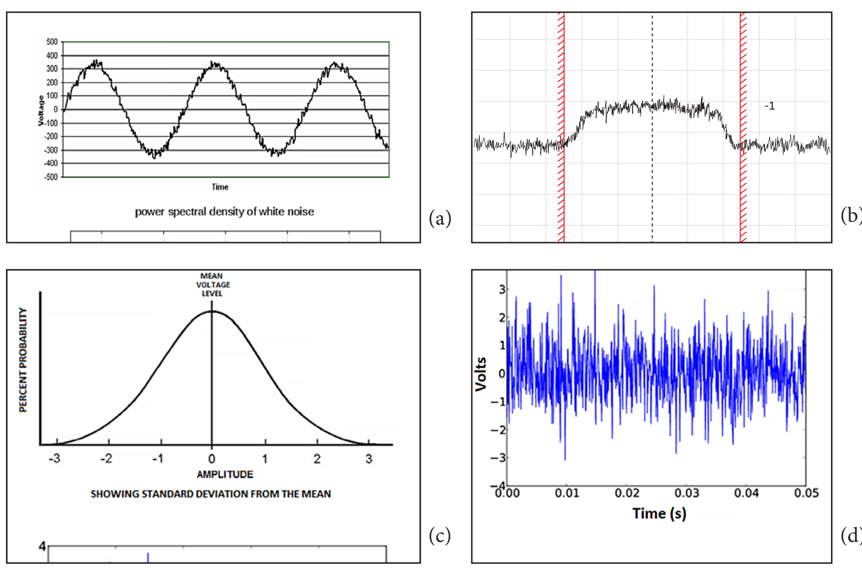

Figure 1. A breakdown of AWGN, illustrating additive noise on a signal (a); flat power spectral density (b); Gaussian distribution (c); and the random, independent nature of noise (d).

Noise Power and Density

Available thermal noise power over bandwidth B is N = kTB. At approximately 290 K, the commonly used reference density is about -174 dBm/Hz. For a flat noise density N0, integrated noise power increases with measurement bandwidth:

$$N(\text{dBm}) = N0(\text{dBm/Hz}) + 10 \log10(B \text{ in Hz})$$

Always define the bandwidth used for noise integration. A noise level without bandwidth or density information is incomplete.

Choosing the Control Quantity for Radio Receivers

When testing radio receivers under controlled noise conditions, the relationship between the desired signal and applied noise can be expressed using several different ratios. These quantities provide a repeatable way to characterize receiver performance as noise or interference increases. The most useful ratio depends on what the receiver or communication standard reports, as summarized in Table 1.

Ratio	Definition	Typical Use
C/N	Carrier power divided by integrated noise power in a stated bandwidth	Receiver tolerance and link-margin tests
C/No	Carrier power divided by noise power spectral density	Link-budget and satellite receiver work
Eb/No	Energy per information bit divided by noise density	BER waterfall and coding/modulation evaluation
C/I	Carrier power divided by interference power	Interference susceptibility when the impairment is represented as broadband noise

Table 1. Common ratios used to characterize receiver performance under noise and interference.

Bandwidth Conversion Reminder

The ratios used to characterize radio receiver performance depend on how the signal and noise are measured. If carrier power C and integrated noise N are measured at the same reference plane, C/N can be calculated as:

$$C/N = C(\text{dBm}) - N(\text{dBm})$$

Converting between C/N and C/No requires the applicable noise bandwidth. Converting to Eb/No also requires the information bit rate and an agreed definition of the measurement point.

Radio Receiver Noise Test Architectures

Once the appropriate test ratio and noise conditions have been defined, the desired RF signal and AWGN must be combined and applied to the radio receiver under test. This establishes a controlled signal-to-noise or carrier-to-interference condition at the receiver input, allowing receiver performance to be measured as the applied impairment is varied.

The following test architectures illustrate external RF combining, integrated ratio control, and AWGN signal conditioning for radio receiver testing.

Test Architecture A: External RF Combining

In this configuration, the desired RF signal and AWGN are generated by separate sources and combined through an RF combiner before reaching the radio receiver under test (Figure 2). This approach is used when the carrier source, power measurement, and impairment source are separate. The combiner insertion loss and port isolation must be included in the level plan. Carrier and integrated noise should be measured at the receiver reference plane whenever possible.

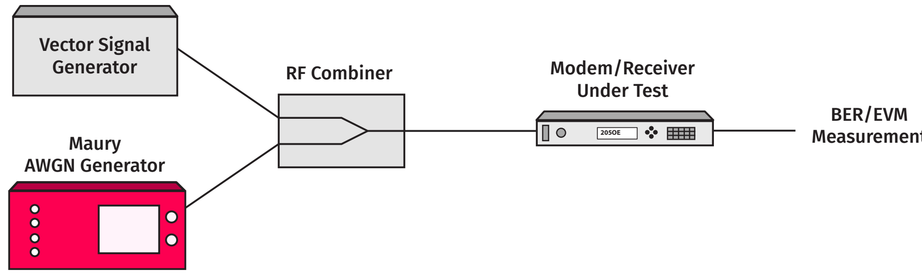

Figure 2. External RF combining architecture for controlled AWGN testing of a radio receiver.

Test Architecture B: Integrated Ratio Control

The CNG-EbNo simplifies receiver testing by generating precise, repeatable C/N, Eb/No and C/I ratios without requiring multiple external instruments (Figure 3). A user-supplied RF carrier is fed into the CNG-EbNo, where the carrier power is measured and the corresponding noise level is generated and added to the signal. The resulting carrier-plus-noise signal is then applied to the radio receiver under test at the ratio programmed by the user.

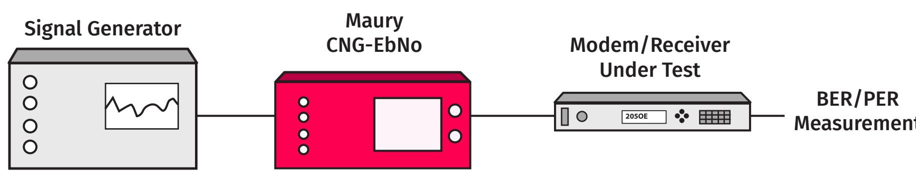

Figure 3. Integrated ratio-control architecture for radio receiver testing with controlled AWGN.

Programmable Noise Generator Architecture

Programmable noise generators provide a flexible architecture for generating and controlling AWGN by combining a noise source with variable attenuation, filtering, and amplification. This configuration provides control over noise power levels and frequencies to meet different test requirements. The attenuator controls the output noise level, filtering provides noise band limiting, and amplification provides the required output power (Figure 4).

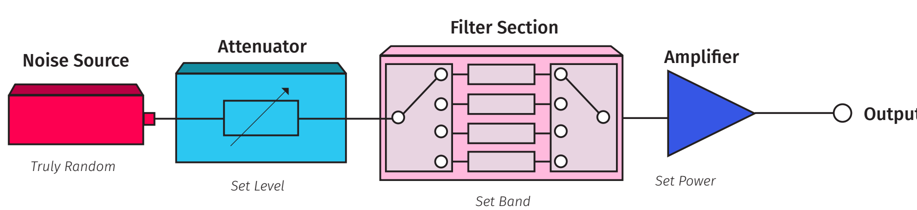

Figure 4. Programmable noise generator architecture for controlling noise level, bandwidth, and output power.

Recommended Measurement Workflow

A consistent measurement procedure is needed to produce meaningful, repeatable radio receiver performance results. This includes defining the performance metric, reference plane, signal and noise conditions, starting ratio, and sweep parameters before measuring the receiver response as the impairment is varied. The following workflow outlines the key steps for conducting and documenting the test.

1. **Define the pass/fail metric:** Select BER, PER, throughput, EVM, acquisition probability or receiver sensitivity. State the averaging interval and traffic pattern.
2. **Lock the reference plane:** Choose the physical plane at which carrier and noise are defined, normally the receiver input. Account for cables, combiners, couplers and adapters.
3. **Set the wanted signal:** Configure frequency, modulation, symbol or bit rate, coding and carrier power. Verify that the receiver is stable with low added noise.
4. **Configure the noise band:** Select a noise bandwidth that covers the occupied signal bandwidth and any receiver bandwidth relevant to the test.
5. **Establish the starting ratio:** Begin at a high C/N or Eb/No where errors are infrequent. Confirm that the measured carrier and noise levels agree with the level plan.
6. **Sweep the impairment:** Reduce the ratio in controlled steps. Near the receiver threshold, use smaller increments and sufficient observation time.
7. **Record the waterfall:** Plot BER or PER against Eb/No or C/N. Capture receiver lock behavior and any hysteresis during increasing and decreasing sweeps.
8. **Repeat and document:** Repeat critical points, record uncertainty contributors, instrument states, cable loss, bandwidth definitions and environmental conditions.

Test Configuration and Results

A complete test record should capture the conditions under which the receiver is evaluated as well as the resulting performance measurements. This includes the DUT and signal configuration, applied noise conditions, measurement reference plane, sweep parameters, results, and relevant uncertainty contributors, as summarized in Table 2.

Field	Information to Record
DUT/firmware	Model, serial number and software revision
Signal configuration	Frequency, modulation, occupied bandwidth, symbol rate, bit rate, and coding
Noise definition	AWGN band, density or integrated level, and ratio definition
Reference plane	Receiver input or other stated plane, including path-loss correction
Sweep	Start, stop, step size, dwell and direction
Result	BER, PER, EVM, throughput, lock state and threshold
Uncertainty/ conditions	Calibration status, power accuracy, bandwidth, averaging and temperature

Table 2. Example radio receiver noise test record.

Practical Engineering Considerations

Even with a well-defined measurement procedure, practical factors can affect the accuracy of radio receiver test results. Bandwidth, RF path losses, instrument operating range, measurement settings, and other test conditions can alter the noise level or signal-to-noise condition actually present at the receiver input. Key factors to consider when configuring and validating the test setup are outlined below.

- **Noise bandwidth and flatness:** Integrated noise depends directly on bandwidth. Verify that the generator is flat over the receiver band and that filters do not unintentionally reshape the impairment.
- **Combiner loss and isolation:** A passive combiner reduces both paths and can allow one source to load the other. Include insertion loss, return loss and isolation in the uncertainty budget.
- **Generator operating range:** Keep attenuators, amplifiers and measurement equipment within their linear operating regions. Excessive gain can compress noise peaks and alter the amplitude distribution.
- **Crest factor:** Gaussian noise contains occasional high peaks. Level planning must preserve enough headroom through amplifiers, switches, combiners and the DUT input.
- **Measurement detector and averaging:** Spectrum-analyzer detector type, resolution bandwidth, video bandwidth and averaging affect the indicated noise level. Use a documented method and consistent settings.
- **Receiver bandwidth:** The receiver may integrate a different noise bandwidth than the measurement instrument. Tie the ratio definition to the standard or test plan.
- **Calibration and repeatability:** Characterize path loss at the test frequency and over the occupied band. Repeat threshold points and monitor drift during long sweeps.
- **Safety and protection:** Before connecting the DUT, verify maximum output and transient conditions. Add attenuation, DC blocks or limiters where required by the hardware interface.

Selecting a Maury Noise Generation Solution

The appropriate noise-generation solution for radio receiver testing depends on the requirements of the application. Key considerations include the application and pass/fail metric; carrier frequency; required noise bandwidth; noise density or total noise-power range; and desired C/N, C/No, Eb/No or C/I range and resolution. Additional considerations include maximum carrier and combined output levels, RF interface, and system configuration requirements such as manual versus automated control, number of paths and switching needs.

Maury offers a range of noise-generation solutions, from noise diodes and amplified modules to manual and programmable noise generators, to address varying radio receiver test requirements. Solutions can be configured to meet application-specific needs based on factors such as frequency, bandwidth, noise level, test ratio, interface, and level of automation. Table 3 summarizes the available solution types and their typical applications.

Solution	Typical Application	Configuration
Noise diodes/ calibrated sources	Reference and receiver-noise measurements; embedded source designs	Component or connectorized source
Amplified noise modules	Higher-noise-level injection, built-in test and custom subsystems	Module requiring external level control or switching as needed
NC6000A / NC8000A manual generators	Benchtop impairment tests where manual attenuation and straightforward setup are preferred	Manual instrument
UFX7000B programmable generator	Broadband and custom AWGN impairment using configurable attenuation, filtering, switching and amplification	Programmable, flexible architecture
CNG-EbNo precision SNR generator	Automated ratio-based tests such as C/N, C/No, Eb/No and C/I for communication receivers	Integrated precision SNR test instrument

Table 3. Maury noise-generation solutions for radio receiver testing.

Conclusion

Controlled AWGN injection provides a repeatable method for evaluating radio receiver performance under defined noise conditions. Meaningful results depend on selecting the appropriate test ratio and bandwidth, establishing the carrier and noise levels at a defined receiver reference plane, and accounting for the practical factors that can affect measurement accuracy.

By controlling these conditions and measuring receiver response as the applied noise is varied, engineers can characterize performance metrics such as BER, PER, EVM, and receiver sensitivity under controlled noise and interference conditions representative of real-world operating environments.

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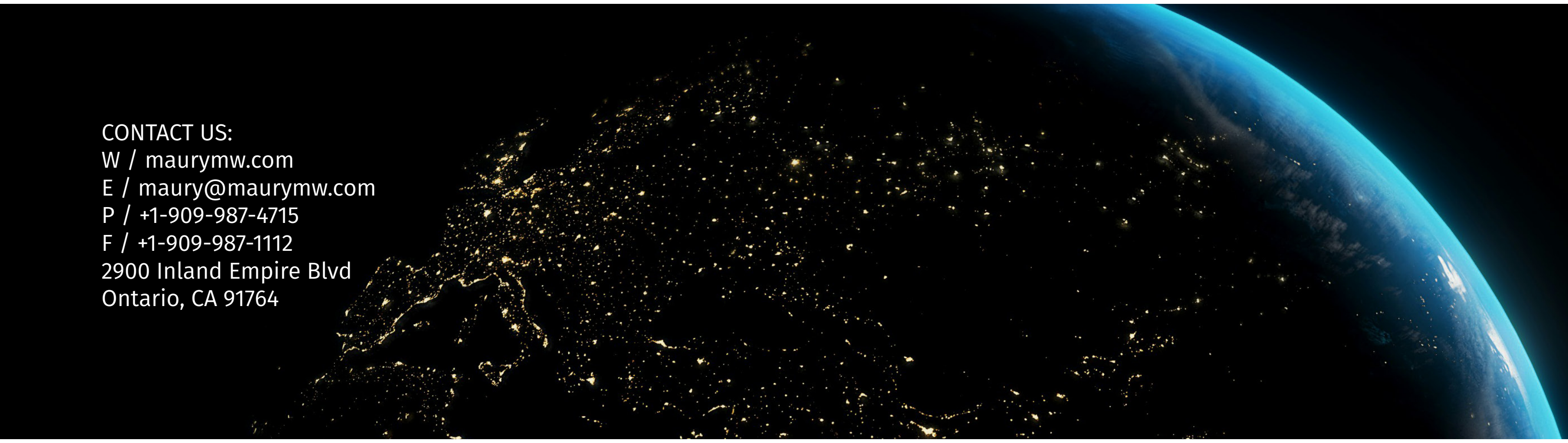

CONTACT US:
W / maurymw.com
E / maury@maurymw.com
P / +1-909-987-4715
F / +1-909-987-1112
2900 Inland Empire Blvd
Ontario, CA 91764