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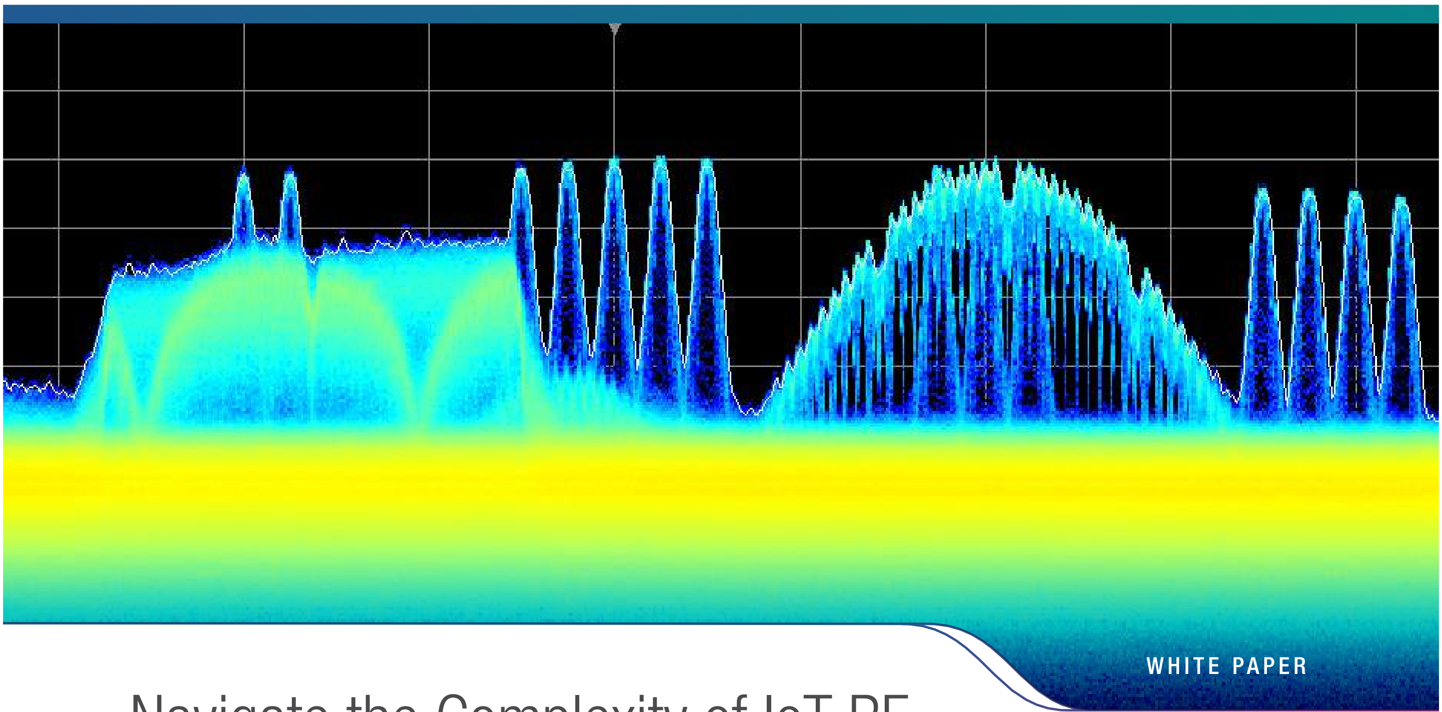


Navigate the Complexity of IoT RF Receiver Testing

In the next few years, billions of IoT devices will connect through many different and emerging wireless technologies. Each IoT device may integrate with two or more wireless standards. With multiple wireless standards using the same unlicensed bands, IoT device manufacturers need to verify that neither co-channel or adjacent-channel interference will adversely impact their designs. This situation presents challenges to device designers as design and verification testing becomes more complex, time- consuming, and expensive.

This white paper provides an overview of the major IoT wireless standards, common IoT RF receiver test cases, and tips for accurate receiver measurements.

IoT Wireless Standards Overview

There are specific wireless standards and technologies to support a wide variety of IoT applications; different applications require different RF characteristics. These applications include mission-critical service, mesh networks, short or long distance, and power-saving.

The IoT industry is spurring significant growth in wireless connectivity technologies. In fact, experts anticipate that new and emerging applications of low power wireless area network (LPWAN) and wireless personal area network (WPAN) technologies will propel even more growth in the wireless connectivity market in the coming years. Here are the major wireless connectivity standards that are in use in the IoT industry:

Bluetooth® Low Energy (BLE)

BLE is a WPAN technology designed and marketed by the *Bluetooth* Special Interest Group (SIG). BLE sharply reduces power consumption in *Bluetooth* devices, enabling them to run for 10 years using coin-cell batteries. The *Bluetooth* mesh profiles enable devices to pass the information forward to other BLE devices creating a “mesh” effect that is important for wireless IoT applications.

ZigBee

ZigBee is based on the IEEE 802.15.4 physical (PHY) and media access control (MAC) layers. Both specifications offer a great deal of functionality specifically designed to promote coexistence and mitigation of interference. ZigBee is built to support tree, star, and mesh networking so groups of devices can cooperatively pass data in short hops to thousands of control nodes.

LoRa

LoRa (Long Range) is a wireless technology that enables low data rate communications over long distances using sensors and actuators for machine to machine (M2M) and IoT applications. It operates at sub-1-GHz radio frequencies in the unlicensed spectrum at VHF, UHF, and 800-930 MHz frequencies. LoRa signals can penetrate deep into buildings and reach locations that are inaccessible to higher frequency equipment.

802.11ah (HaLow)

The IEEE 802.11 Wi-Fi protocol is the most widely used wireless internet connectivity technology today and has many variations. The 802.11ah (HaLow) standard was created for low data rates, long-range sensors, and controllers. HaLow uses time slot assignments to avoid collisions and ensure performance in crowded wireless environments.

3GPP NB-IoT

NB-IoT is a LPWAN radio technology standard developed by the Third Generation Partnership Project (3GPP) to enable a wide range of cellular devices and services. NB-IoT focuses specifically on indoor coverage, long battery life, and high connection density. NB-IoT uses a subset of the Long Term Evolution (LTE) standard but limits the bandwidth to a single narrow band of 200 kHz.

LTE Cat-M1

LTE Cat-M1 is an LPWAN air interface that allows you to connect IoT and M2M devices with medium data rate requirements. It uses cellular LTE-licensed spectrum and is well-suited for applications that require deep coverage where latency, mobility, and data speed requirements are less strict.

Vehicle-to-Everything (V2X)

There are two types of V2X communication technologies depending on the underlying wireless standard being used:

1. **Dedicated short-range communications (DSRC):** One-way or two-way short-range wireless communication for automotive use. DSRC uses the underlying radio communication provided by 802.11p.

2. **Cellular V2X:** 3GPP V2X specifications are based on LTE as the underlying technology. This specification supports wide area communication over a cellular network.

Table 1 below illustrates the key IoT wireless standards and their performance characteristics.

Name	Specification	Modulation	Frequency (MHz)	Bandwidth (MHz)	Range (m)
Bluetooth	*Bluetooth* SIG	GFSK, D8PSK	2400	1	50
ZigBee	IEEE 802.15.4	O-QPSK, BPSK	780, 868, 915, 920, 2450	2	10
WiSUN	IEEE 802.15.4g	MR-FSK, MR-OFDM	920	0.2-1.2	1000
LoRaWAN	LoRa Alliance	GFSK, CCS	169, 433, 470, 868, 915	0.5	10,000
Z-Wave	ITU-T G9959	FSK, GFSK	868, 915, 920	0.2	100
HaLow	802.11ah	OFDM	779, 868, 915, 920	1-16	1,000
DSRC/WAVE	802.11p	OFDM	5800, 5900	5, 10, 20	1,000
Cat-NB2 (NB-IoT)	3GPP Rel-13	BPSK, QPSK, 16QAM	GSM/LTE bands	0.18	1,000
Cat-M1	3GPP Rel-13	OFDM	LTE bands	1.4	1,000
C-V2X	3GPP Rel-14~16	OFDM	Band 3, 7, 8, 39, 41, 47	10	2,000

Table 1. IoT wireless connectivity standards performance attributes

Whether you need to test stimuli in R&D or manufacturing, Keysight PathWave Signal Generation simplifies creation of the IoT signals needed for characterization, verification, and pass/fail testing of components, devices, and receivers.

IoT RF Receiver Testing

The demand for ubiquitous wireless communications is challenging the physical limitations of current wireless communications systems. When IoT systems operate in a crowded wireless environment on the same shared spectrum, interference between the systems can occur. This makes the process of designing, testing, and isolating system problems more complex. As an example, consider the most commonly used 2.4-GHz ISM band, which includes wireless standards such as *Bluetooth*, WLAN, and ZigBee. These standards have been around for years and enjoy broad support in both the ICs and integrated modules that are integrated into IoT devices.

Figure 1 illustrates a crowded 2.4-GHz frequency band with multiple *Bluetooth* and WLAN devices simultaneously enabled. When you evaluate the receiver performance of your wireless IoT modules you need to take various interfering signals into account.

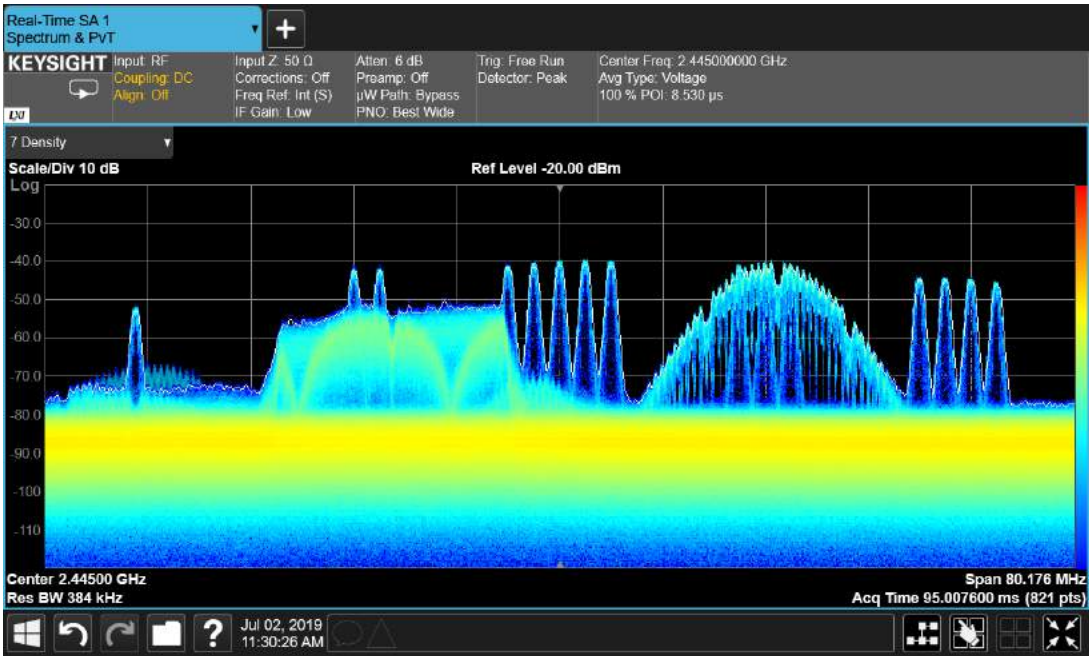


Figure 1. Real-time spectrum analysis at 2.4-GHz ISM band

Figure 2 is a digital radio receiver block diagram. The receiver must extract the RF signal in the presence of potential interference. A preselecting filter, the first component of the receiver, attenuates out-of-band signals received by the antenna. A Low-Noise Amplifier (LNA) then boosts the desired signal level while minimally adding to the noise of the radio signal. Next, a mixer down-converts the RF signal to a lower Intermediate Frequency (IF) by mixing the RF signal with a Local Oscillator (LO) signal. Finally, the IF filter attenuates the unwanted frequency components that the mixer generates along with signals from adjacent frequency channels. The variations in the receiver's design manifest themselves after they pass through the IF filter.

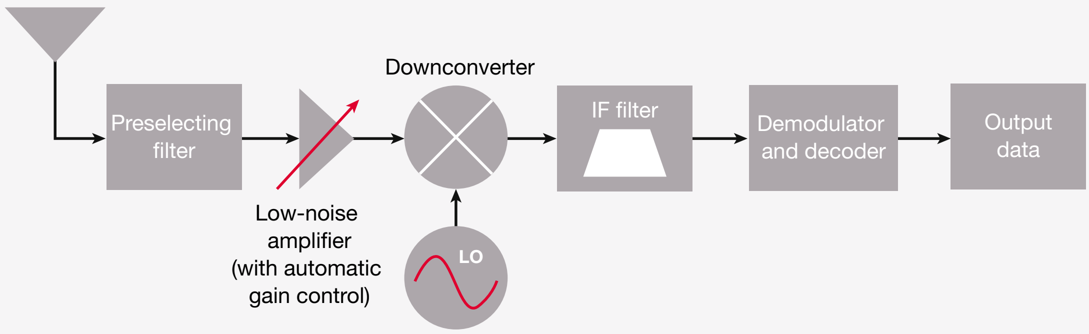


Figure 2. An RF receiver block diagram

Receiver design is challenging because the wireless device needs to handle a wide variety of input signal conditions and these conditions are difficult to predict. In addition, you need to inject noise and interfering signals in order to characterize the receiver's performance. Next, we will look at common receiver tests, their purposes, and how to set up the test systems.

Reference sensitivity level

The minimum input level test ensures the wireless device can receive data with a defined maximum packet-error-rate or bit-error-rate and be measured at the antenna port. In this test, a signal generator stimulates the antenna port of the receiver and works as an ideal transmitter as shown in Figure 3.

Figure 3. Receiver sensitivity test setup

Learn more

To learn more about why amplitude accuracy matters RF receiver tests and how to improve amplitude accuracy, download the white paper "Improving Amplitude Accuracy with Next-Generation Signal Generators."

Dynamic range

The dynamic range is specified as a measure of the capability of the receiver to receive a wanted signal in the presence of an interfering signal inside the received channel bandwidth. Noise is part of all communications channels. To simulate realistic channel conditions in a repeatable manner, you need to add random noise to the wanted signal. Additive White Gaussian Noise (AWGN) is a mathematical model to simulate the channel between the transmitter and receiver. The model is a linear addition of wideband noise with a constant spectral density and a Gaussian distribution of amplitude. The interfering signal for the dynamic range test requirement is an AWGN signal.

Figure 4 illustrates a common receiver's performance test setup for dynamic range. The first signal generator outputs the AWGN and the second generator generates the wanted RF signal. Use a hybrid combiner to mix the signals and connect to a DUT.

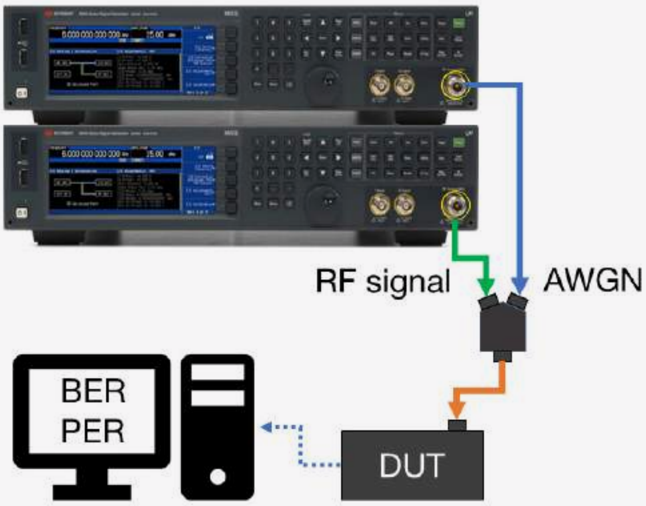


Figure 4. Receiver sensitivity test with AWGN setup

Signal isolation between signal generators

Ensure the isolation of the power combiner between the two signal generators (SGs) is good enough (> 60 dB) so that they will not impact the other unit's automatic leveling control (ALC) operation. If not, the ALC may feedback a wrong value in one SG due to the reverse power from the other SG. The wrong value will cause the SG to output a wrong amplitude.

Figure 5 depicts the bandwidth and power between the carrier (wanted signal) and AWGN. Carrier bandwidth is the occupied bandwidth of the carrier. The noise bandwidth is the flat noise bandwidth. The actual flat noise bandwidth should be slightly wider than the carrier bandwidth (typically 1.6X the carrier bandwidth). When you combine the carrier and AWGN signal for receiver tests, the carrier now appears larger because of the added noise power.

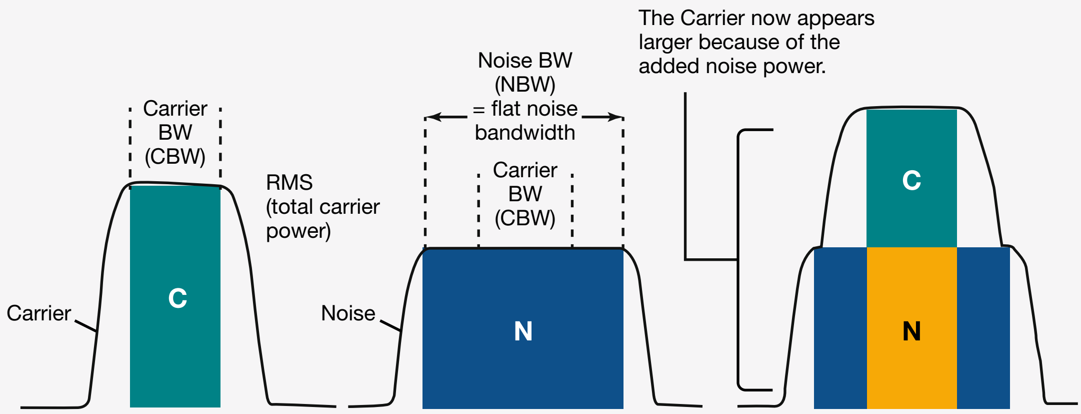


Figure 5. AWGN added to the wanted signal for receiver tests

In-channel selectivity

In-channel selectivity (co-channel immunity) is a measure of the receiver's ability to receive a wanted signal in the presence of an interfering signal received in the same RF channel. The interfering signal can be a continuous wave (CW), narrowband, or the same type as the wanted signal.

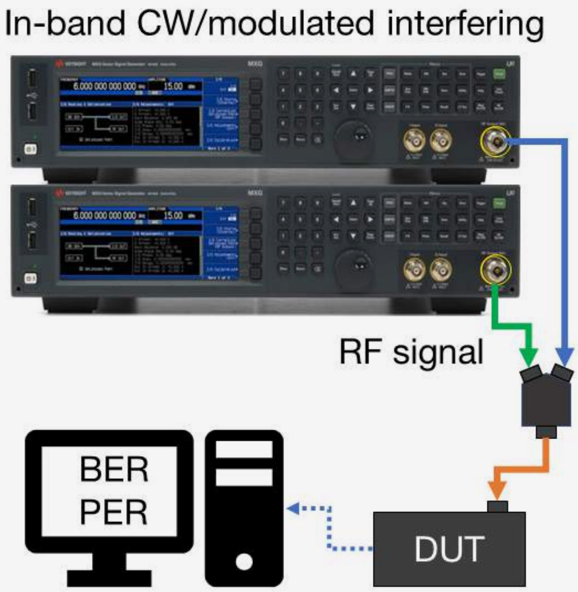


Figure 6. In-channel selectivity measurement setup

Learn More

To Learn more about how to simplify AWGN Signal Generation, download the white paper "Making Noise in RF Receivers."

Adjacent and alternate channel selectivity

Adjacent and alternate channel selectivity are a measure of the receiver's ability to receive a wanted signal in the presence of an adjacent channel signal with a specified channel offset. This verifies that a receiver can establish and hold a connection if other channels are in use. The measurement setup for adjacent channel selectivity is similar to in-channel selectivity setup.

Blocking

The blocking characteristic is a measure of the receiver's ability to receive a wanted signal at its assigned channel in the presence of an unwanted interferer. The first signal generator provides the wanted signal to the receiver at a certain power level. The second signal generator delivers the specified modulated or CW interfering signals, typically at a high output power level. The modulated signals simulate co-location with other wireless devices, but in a different wireless format.

TIP: Select better phase noise performance of signal generators

The spectral characteristics of the test and interfering signals are important. For many receivers, the phase noise of the signal generator that is used to produce the interfering signal is a critical spectral characteristic. If the phase noise energy inside the passband of the IF filter is excessive, the receiver may appear to fail the test.

For some cases, the maximum interfering signal frequency is up to 12 GHz for a 2.4-GHz ISM band wireless device. The measurement setup is similar to an in-channel selectivity setup, but at a higher frequency range.

Receiver spurious emissions

The receiver spurious emissions power measures the power of emissions generated or amplified in a receiver that appear at the antenna connector. The test's purpose is to limit the interference caused by receiver spurious emissions to other systems. For measurement setup, you need to connect the receiver's output to a spectrum analyzer with a transmitter notch filter and terminate all transmitters and untested receivers as shown in Figure 7.

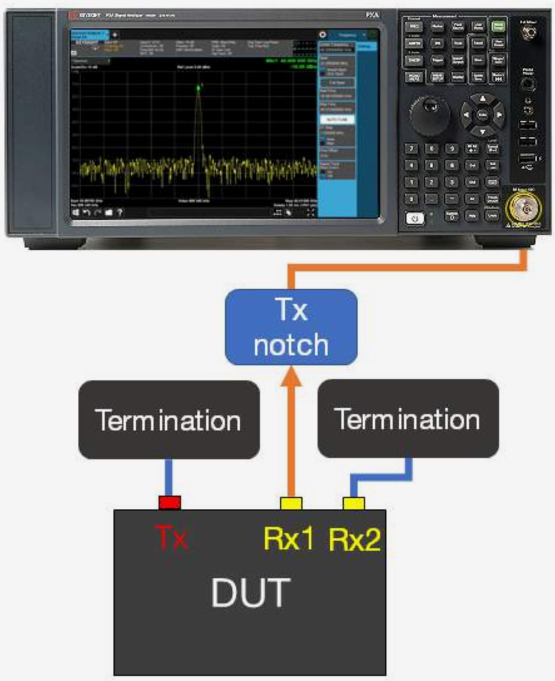


Figure 7. Measuring receiver spurious emission

FDD versus TDD System

For frequency division duplex (FDD) systems, the spurious measurement is performed when transmit and receive are ON.

For time division duplex (TDD) systems, the test requirements apply during the transmitter OFF period.

Receiver intermodulation

Third and higher-order mixing of the two interfering RF signals can produce intermodulation signals in the band of the desired channel at a receiver. The intermodulation signals may degrade the receiver's sensitivity performance. In this test case, you need one signal generator for the wanted signal and two signal generators as interfering signals as shown in Figure 8.

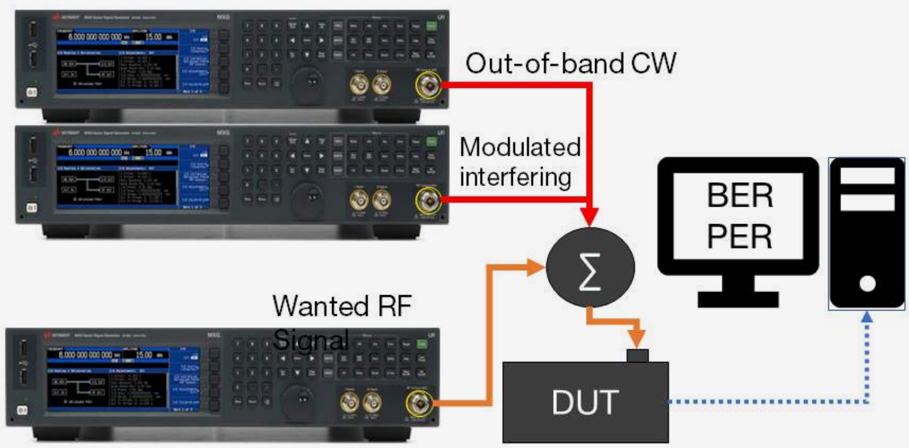


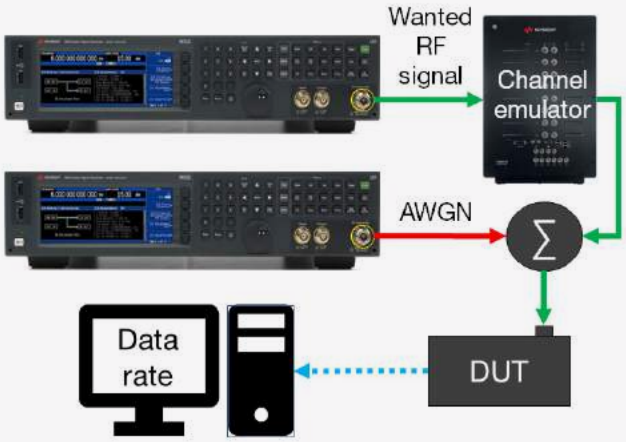
Figure 8. Receiver intermodulation measurement setup

Avoid intermodulation products from signal generators

Whenever two signals are input to a combiner, the nonlinearities of the signal generators may create intermodulation products. There are several techniques for reducing signal generator intermodulation products:

- Maintain a frequency separation between the interfering signals that is greater than the bandwidth of the ALC of the signal generators.
- Add attenuators to the outputs of the signal generators.
- Use hybrid combiners.
- Use isolators.
- Turn off the ALC of the signal generators.

Note that all of these techniques may be applied simultaneously to reduce intermodulation products.



Dedicated signal generator for AWGN signal generation

AWGN simulates the system noise between the transmitter and receiver. You cannot generate the wanted signal and AWGN with a vector signal generator for receiver performance tests. AWGN does not apply to fading, intermodulation, and interference receiver tests.

Figure 9. Functional setup for receiver performance with a channel emulator

Choosing the Right Tools

Whether you are working on a single radio format or integrating multiple formats into an IoT device, easy access to the right test signals streamlines validation and helps ensure interoperability. Accelerate your work with Keysight PathWave Signal Generation software, a flexible suite of signal-creation tools that reduces the time you spend on signal simulation.

Keysight X-Series Signal Generators (CXG, EXG, and MXG) are designed to work with dozens of Keysight PathWave Signal Generation software products, many of which address the complex and rapidly proliferating IoT wireless connectivity standards. Keysight's involvement in and leadership role in standards committees ensures that PathWave Signal Generation is at the forefront of evolving standards.

With the right signal generators, you can trust that the signals you generated align with the latest IoT technologies and wireless standards.