Improving 5G Millimeter-Wave Signal Analysis Accuracy

Unlocking the Potential of 5G

KEYSIGHT
Millimeter-wave (mmWave) frequencies unlock the true potential of 5G. The ultra-wide bandwidths enable faster wireless connection speeds and high capacity with low latency, providing the ideal solution to meet increasing industry demands. Many mobile network operators started deploying commercial 5G mmWave networks in 2020. All have massive mmWave deployment plans on their roadmaps. In response, 5G chipset, device, and base station makers are ramping up their design and manufacturing powers to bring more 5G mmWave products and services to market.

Millimeter-wave technology is a crucial element that sets 5G apart from 4G Long Term Evolution (LTE). The technology creates many challenges across the workflow in design, manufacturing, and deployment. At mmWave frequencies, significant path loss makes radio-frequency (RF) power limited and costly. And mmWave frequencies introduce a disruptive change in test methods. Measuring performance metrics using over-the-air (OTA) test methods makes achieving accurate and repeatable results more difficult. Wide bandwidths also introduce more noise and frequency responses. These challenges increase measurement complexity and uncertainty for chipset and device makers, network equipment manufacturers, and operators.

Improve 5G mmWave signal analysis accuracy by doing the following:

• reducing signal path loss
• improving signal condition
• calibrating at the reference plane
mmWave Testing Challenges

In wireless communication, increasing signal bandwidth and higher-order modulation enable faster data rates. However, wide bandwidths at mmWave frequencies cause unwanted reflections that degrade signal quality and power and make testing instruments more sensitive to noise. Significant path loss and frequency responses are the major challenges you need to overcome to perform accurate measurements at mmWave frequencies.

**Significant path loss**

Path loss represents the power loss of an electromagnetic wave propagating through space. Path loss increases as the frequency increases. This relationship remains true, even in noise-free conditions. Also, mmWave frequencies suffer from high path loss, limiting the range of signal transmission.

Path loss leads to a significant amount of lost power, resulting in a decreased signal-to-noise ratio (SNR) at the receiver. A low SNR makes signal analysis measurements, such as error vector magnitude (EVM), adjacent channel power (ACP), and spurious emissions, challenging.

Millimeter-wave spectrum provides access to wider, unoccupied bandwidths. However, widening signal bandwidth means that more noise is present, decreasing the SNR. Achieving high accuracy when the operating bandwidth is wide during the testing process is a challenge.

Figure 1 shows the setup of an OTA test at mmWave frequencies. The test system limits the number of components to reduce noise. It also requires precise calibration and control to eliminate as much noise interference as possible. As a result, performing accurate mmWave measurements is time-consuming.
Frequency responses

Frequency responses also impact the accuracy of 5G mmWave measurements. Frequency responses can occur at different frequencies and introduce amplitude and phase errors, which degrade modulation quality. Understanding the frequency responses of the receiver in a communication system is an important element of successful transmission. The signal analyzer acts as the receiver in a measurement system. Its internal circuitry includes many components — mixers, filters, amplifiers — that generate frequency responses. Outside of a signal analyzer, components such as switches, filters, and test fixtures also have frequency responses. Understanding all sources of frequency responses is important to optimizing measurement systems.

Frequency responses increase in signals with wide bandwidths at high frequencies. Figure 2 illustrates an orthogonal frequency-division multiplexing signal with poor frequency responses (on the left) and flat frequency responses (on the right).

![Figure 2. Frequency responses’ impact on frequency domain](image)

Reducing Signal Path Loss

Ideally, a signal analyzer gives you the flexibility to create optimum solutions for your application by selecting different signal paths. Tuning your signal analyzer’s signal path to your measurement needs enables you to assess transmitters, troubleshoot receivers, and analyze 5G mmWave OTA signals. For example, the signal analyzer can apply attenuation at higher power levels or a preamplifier at lower power levels to measure various input signals. Signal analyzers also provide several signal paths to reduce path loss and improve SNR and sensitivity.
Standard path

The standard path is ideal for measuring low-level signals with a bandwidth under 45 MHz. Figure 3 shows the standard path of a signal analyzer as a block diagram. The preselector limits the analysis bandwidth but gives excellent dynamic range for swept spectrum analysis, including spur searches.

![Figure 3. The standard path of a signal analyzer](image)

Microwave preselector bypass

Keysight’s UXA (such as the N9042B UXA X-Series) and PXA signal analyzers offer additional signal paths that benefit 5G measurements. 5G mmWave frequencies have wide bandwidths, but the standard path of the signal analyzer has a preselector that is better suited to narrow-bandwidth signals. A signal path with a microwave preselector bypass enables wideband analysis and a flat spectrum response over the bandwidth of the digitizer. Bypassing the preselector also improves amplitude accuracy by eliminating the amplitude drift and passband ripple of the preselector. Figure 4 shows a signal analyzer path with a preselector bypass.

![Figure 4. Signal path with a microwave preselector bypass](image)
Low-noise path

5G mmWave signals operate at high frequencies with high power. Amplifier gain, frequency response, and insertion loss can impact signal fidelity and measurement sensitivity. Selecting a low-noise path enables high-power-level testing by bypassing the preamplifier. This path reduces path loss and eliminates frequency responses. Figure 5 shows the low-noise path of a signal analyzer.

![Diagram of Low-noise path of a signal analyzer](image1)

**Figure 5. Low-noise path of a signal analyzer**

Full-bypass path

With a Keysight UXA or PXA signal analyzer, you can also combine the low-noise path with the microwave preselector bypass to achieve low path loss, high signal fidelity, and high measurement sensitivity. At 5G mmWave frequencies, the full-bypass path has up to 10 dB less loss than the default path. The trade-offs are potential in-band imaging and low SNR at lower power levels. Figure 6 shows the circuitry of the full-bypass path in a signal analyzer.

![Diagram of Full-bypass path of a signal analyzer](image2)

**Figure 6. The full-bypass path of a signal analyzer**
Improving Signal Condition

Wideband noise and significant path loss at 5G mmWave frequencies between transmitter and receiver are key challenges that test engineers need to overcome. These factors result in a lower SNR for the digitizer. Low SNR may impair the EVM and ACP ratio performance in transmitter measurements. In a measurement system, a signal analyzer acts as the receiver. An optimal input mixer level is key to improving signal condition when making EVM measurements. Figure 7 shows a simplified block diagram of a vector signal analyzer (VSA).

There are two ways to optimize the input mixer level. The first method is to attenuate the power level at the first mixer to ensure that the high-power input signal does not distort the signal analyzer. The input signal level can be lower than the optimum mixer level. The built-in preamplifier in Figure 7 provides a better noise figure but a poorer intermodulation-distortion-to-noise-floor dynamic range. This method is suitable for low-input-level test scenarios.

Alternatively, you can add an external low-noise amplifier (LNA) at the front end, with or without the internal preamplifier, to the Figure 7 configuration. This method is better suited for high-input-level test scenarios and offers a more robust solution for testing 5G mmWave devices. The Keysight UXA X-Series signal analyzer offers an internal LNA in the signal path along with the internal preamplifier, providing the benefits of the LNA without the external setup.
Calibrating at the Reference Plane

A test system’s key objective is to characterize a device under test (DUT). The instrument specifications are not the only factor determining the accuracy of the test results. The location of the reference plane plays an important role. A test setup includes many cables, connectors, and switches between the signal analyzer and the DUT, as shown in Figure 8. You need to calibrate the amplitude and phase of the test receiver path to offset the impact from frequency responses.

5G mmWave technology relies on wide bandwidths and high frequencies. In wide-bandwidth 5G transceivers, phase errors across the analysis bandwidth degrade EVM performance. Also, path loss is a key contributor to the signal attenuation between the DUT and the signal analyzer. As frequencies increase, high path loss can be multiple decibels per meter rather than the tenths of a decibel at lower frequencies. When you are making RF signal analyzer measurements where path loss is a few decibels or more, you can benefit from moving the test plane from the signal analyzer input to the output of your DUT. This process ensures that your design parameters apply only to your device design and are not burdened by the cables and fixtures in between.

Amplitude correction

Signal analyzers allow you to manually configure complex corrections, including amplitude and phase corrections, to offset frequency responses. A signal generator and a power meter can flatten amplitude accuracy. You can also improve your test receiver system’s absolute amplitude accuracy by using Keysight’s U9361 RCal receiver calibrator (see Figure 9). It automatically calibrates out linear impairments from fixtures, cables, and adapters in the test system.
Complex corrections

Use of a vector network analyzer (VNA) is the traditional method of correctly measuring the amplitude and phase values of the frequency response for complex corrections. The VNA then shares the measurement data with the signal analyzer, which stores and applies the corrections as needed.

The Keysight U9361 RCal receiver calibrator offers a new calibration alternative for complex corrections using a patented comb generator. The comb generator functions as a receiver system calibrator that can inject tones at the desired calibration plane, which becomes the new reference plane. The calibrator generates continuous wave tones of known amplitude and phase. The signal analyzer measures each tone’s amplitude and phase at the output of the test network and compares them to the known amplitude and phase. The signal analyzer then corrects differences, stores the corrections, and applies them as needed.
Improving mmWave Measurement Accuracy

Using mmWave technology in 5G networks brings many benefits and possibilities, driving the 5G ecosystem to adopt mmWave networks and products.

Despite the benefits and market potential of mmWave technology, 5G faces many challenges. High frequencies and wide bandwidths create more path loss, noise, and frequency responses, impacting measurement accuracy. Instrument calibration is key to improving mmWave signal analysis accuracy. Selecting the appropriate signal path for your signal analyzer can reduce path loss. Adjusting the input power level can improve signal condition. And moving the reference plane can eliminate frequency responses. These new strategies significantly improve mmWave measurement accuracy for 5G.

Learn More

Find out more about Keysight’s signal analysis solution for 5G:

- N9042B UXA X-Series Signal Analyzer
- U9361 RCal

Find information on 5G challenges and solutions:

- 5G chipset manufacturers
- 5G device manufacturers
- 5G network equipment manufacturers
- 5G service providers