As you reach toward terahertz frequencies, it’s easy to underestimate the challenges that arise in design, simulation, measurement, and analysis. Compared to signals at baseband, RF or microwave, those at 30 GHz, 300 GHz or 1 THz behave quite differently. At the respective wavelengths of 10 mm, 1 mm or 0.3 mm, propagation losses in the atmosphere are high, especially at the resonant frequencies of oxygen, water and carbon dioxide molecules. The differences also make it difficult to generate power, and it becomes increasingly challenging to make calibrated measurements and get useful results.

The ability to develop off-the-shelf tools for extremely high frequencies follows from Keysight’s proven blend of measurement science and millimeter-wave expertise. We deliver that expertise inside our hardware and software products, where we put those capabilities at your fingertips, and through specialized application engineers who are ready to work with you side-by-side. Helping you reach higher is our heritage—and we’re ready to help you succeed at 110 GHz and beyond with the Keysight N9041B UXA X-Series signal analyzer (3 Hz to 110 GHz).
Working at the Intersection of Technology and Demand

Millimeter-wave technology has been in use for decades, primarily in aerospace, defense and backhaul applications where the benefits have justified the high costs of development, manufacturing and support. In recent years, advancements in the fabrication of millimeter-wave devices have been reducing the cost of extremely high frequency (EHF) devices, making them more viable in commercial and consumer applications. For example, CMOS developers have produced devices with ft greater than 500 GHz, and some are aiming to push this cost-effective technology into the 1.0 to 1.5 THz range.

Keysight is also pursuing groundbreaking component-level R&D at extremely high frequencies. Specifically, our in-house expertise in microwave semiconductor technology has allowed us to develop a next-generation indium phosphide (InP) process that supports transistor switching frequencies above 300 GHz. This is opening up higher bandwidths in ICs and end products such as our upcoming oscilloscope that will deliver breakthroughs in real-time and equivalent-time performance (Figure 1).

Figure 1. The Keysight high-performance oscilloscope acquisition system, shown here, has already earned a PCG Technology Leadership Award from Mentor Graphics.

In the marketplace, millimeter-wave technologies such as 802.11ad are available today and consumer-grade WiGig routers currently sell for about US$350.00. The 802.11 standard is evolving to incorporate 802.11ay, a follow-up to 802.11ad that uses wider bandwidths. Looking ahead to 2020, development of 5G wireless communication is underway. The ability to meet the 5G vision of “everything everywhere always connected” will depend on successful utilization of wider bandwidths in the recently allocated spectrum at 28 GHz, 37 GHz, 39 GHz, and in the 64–71 GHz band. Other communications applications include millimeter-wave line-of-sight backhaul systems and satellite-to-satellite links.

Leveraging the resolution made possible by 1 mm wavelengths, imaging is another emerging application. Examples include the examination of pill coatings in pharmaceutical production, physical measurements of product content and texture in food production, and medical imaging that produces distinct spectral signatures for healthy and diseased tissues.
Weighing the Advantages and Challenges of mmWave

Developers of millimeter-wave-based systems may encounter a number of difficulties beyond propagation losses in the atmosphere. For example, when compared to RF and microwave designs, signal losses are greater through transmission lines such as coaxial cable and waveguide.

As frequencies increase, physical dimensions decrease. Thus, all the associated hardware becomes smaller and more fragile, and manufacturing tolerances become much tighter. This also means it is more difficult to fabricate and assemble delicate millimeter-wave devices.

All the same, EHF signals have a number of attractive properties. For example, antenna dimensions can be very small compared to microwave antennas and the resulting transmitter and receiver systems can be very compact. In addition, the antennas can be highly directional with small beam widths.

With wavelengths that range from 10 to 1 mm, millimeter-wave signals exhibit absorption properties that, at first, may seem problematic but can instead be turned into advantages. For example, in terrestrial applications these signals are rapidly absorbed as they propagate through the atmosphere.

Given these attributes, millimeter signals are most useful for short-range communications. Some of these rely on areas of low absorption: automotive radar (77 to 81 GHz), point-to-point radios, wireless backhaul links, and high-altitude radio-astronomy arrays.

Others utilize high absorption as a way to reduce interference between users. For example, the 802.11ad (WiGig) standard for high-speed audio and video links operates in the unregulated 60 GHz region. Unlike typical Wi-Fi signals, this frequency has a range of about 40 feet (about 12 meters) and is attenuated by wood, stone and glass, making it a good choice for home-entertainment installations in apartment buildings, condominiums or townhomes. Coupling high-absorption properties with highly directional antennas also enables creation of secure communication systems that minimize the chances of unauthorized eavesdropping.
Focusing on the Measurement Challenges

The two key issues mentioned above, guiding signals and generating power, are even more challenging in the creation of commercial, off-the-shelf test equipment that produces accurate, repeatable results.

As an example, waveguide must be as close to perfect as possible to ensure proper internal operation of any millimeter-wave instrument. Working within the range of frequencies between 100 GHz to 1 THz requires use of different waveguide bands. At millimeter wavelengths, any skew in a flange connection can cause unwanted reflections that degrade signal quality and power.

Generating adequate signal power is a challenge because it is difficult to simultaneously maintain amplifier efficiency and linearity at these frequencies. This tends to limit the top-end power that can be produced with a signal generator or network analyzer. Related to this, wider bandwidth is an alluring feature of millimeter-wave; however, a wideband measurement introduces more noise into the instrument and thereby raises the noise floor. The net effect: lower maximum power and a higher noise floor will reduce the available dynamic range in wideband spectrum measurements.

Once you get past these difficulties, the next crucial challenge is in calibration of the instrument and the test setup. In addition, it is difficult to accurately calibrate power levels at extremely high frequencies, but precise control of power is essential to ensuring measurement accuracy and avoiding damage to the device under test (DUT).

Measurements themselves are very different at these frequencies—and this will prompt even the most experienced engineers to set aside trusted methods and adjust their expectations. From spectrum analysis and the assessment of distortion or spectrum emission mask (SEM) to network analysis and the characterization of passive (S-parameters) or active devices (X-parameters), every stage—instruments, cables, accessories—must be right: pristine connections, clean upconversion of output signals, precise downconversion of incoming signals, low-level internal spurious signals, well-managed internal harmonics, and more.

Finally, one more critical difference adds to the challenges: in some cases the connection between instrument and DUT must be made over the air (OTA) rather than through cables or waveguide. In an OTA situation, it is necessary to control and calibrate the radiated environment around the test setup. There must also be a way to consistently control or lock down any directional element in the DUT to ensure repeatable measurements.
Extending Signal Analysis to mmWave Frequencies

Developing off-the-shelf tools for extremely high frequencies requires Keysight’s proven blend of measurement science and millimeter-wave expertise. The N9041B UXA X-Series signal analyzer exemplifies the company’s unique expertise, and the development team focused on meeting three key challenges in mmWave signal analysis: sensitivity, frequency range and analysis bandwidth (Figure 2).

In the UXA, advanced front-end circuitry achieves low loss and efficient mixing, providing a displayed average noise level (DANL) as low as –150 dBm/Hz when characterizing wideband modulated signals in the millimeter-wave band. To eliminate compromises, the analyzer provides two input connectors. A robust and economical 2.4 mm input connector covers measurements up to 50 GHz, and the dedicated 1.0 mm input connector is machined to exact tolerances to ensure continuous sweeps and valid measurements up to 110 GHz.

The UXA provides continuous frequency coverage from 3 Hz to 110 GHz in a single sweep. Unlike solutions that use banded measurements, the UXA enables you to sweep the entire range without spurious signals and therefore full sensitivity. The result: you can investigate unknown or unexpected signals with high sensitivity, and this provides greater confidence that you’re seeing problematic signals, not artifacts from the analyzer. Coverage to 110 GHz in one box also provides the future flexibility needed to adapt your measurements to suit evolving spectrum allocations.

Fully integrated instantaneous bandwidth is 1 GHz, and an IF output supports a maximum analysis bandwidth of 5 GHz when connected to an external Keysight oscilloscope. For those who are pursuing fleeting or elusive signals, the optional real-time spectrum analysis (RTSA) capability has a maximum bandwidth of 250 MHz.
Enabling Deeper Analysis of Complex Signals

Tight integration between the analyzer and Keysight applications and software puts advanced analysis and fresh insights at your fingertips—literally. The touch-enabled X-Series applications are proven, ready-to-use measurements for signal analysis. By capturing Keysight measurement expertise and delivering repeatable results, the applications make it easy to see and understand the performance of devices and designs. Currently, the N9041B supports a variety of useful options and measurement applications including real-time analysis up to 255 MHz with basic or optimum detection (options N9041B-RT1 and N9041B-RT2, respectively; Figure 3).

Figure 3. In RTSA mode, configurable windows make it easy to quickly identify transient and spurious signals (red box).
Keysight 89600 VSA software is a comprehensive set of tools for demodulation and vector signal analysis. To help pinpoint the root cause of signal problems, the 89600 VSA also provides capture/playback capabilities that enable detailed post-processing analysis with advanced triggering and post-capture tune-and-zoom measurements (Figure 4). These tools enable you to explore virtually every facet of a signal and optimize your most advanced designs.

![Figure 4. The 89600 VSA software provides powerful visualization and measurement tools that can highlight subtle and transient events such as this radio turn-on event.](image)

**Conclusion**

For more than 75 years, engineers have counted on Keysight to give them easier access to accurate, repeatable measurements at ever-higher frequencies and wider bandwidths. Today, we’re extending the leading edge for R&D engineers performing design, simulation, test and analysis at millimeter-wave frequencies. Innovations such as the N9041B UXA signal analyzer are testament to our ongoing leadership in creating solutions for millimeter-wave applications.
Related Information

- Data Sheet: UXA X-Series Signal Analyzer, Multi-Touch, N9041B, publication 5992-1822EN
- Configuration Guide: UXA X-Series Signal Analyzer, Multi-Touch, N9041B, publication 5992-2112EN
- Brochure: X-Series Signal Analyzers, publication 5992-1316EN
- Application Brief: Characterization of LTE Devices Made Simple, publication 5992-1361EN
- Application Brief: Optimize Wireless Designs in Less Time, publication 5992-1591EN
- Application Brief: Simplifying Wideband Pulsed Signal Characterization, publication 5992-1502EN
- Application Brief: Overcoming the Challenges in Satellite Testing and Interference Detection, publication 5992-1469EN
- Application Brief: Noise and Noise Figure Measurements Made Simple, publication 5992-1360EN
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