



5G Waveform Generation & Analysis Test Bed Reference Solution

5G Waveform Generation & Analysis Test Bed Reference Solution

Introduction

One of the most significant challenges research and development (R&D) engineers face in developing devices for today's 5G is the number and variety of waveforms, frequencies, and bandwidths. These test challenges include waveforms at frequencies below 6 GHz and at microwave and millimeter-wave (mmWave) frequencies which may involve wide bandwidths.

A flexible test environment is critical for 5G signal generation and analysis research to address many possible real-world scenarios.

5G Waveform Generation and Analysis Test Challenges

A flexible test platform is essential for 5G research. It enables you to perform different scenarios during the evaluation of early concepts using a variety of modulation schemes at many different frequencies and modulation bandwidths.

As developers conduct experiments, a highly flexible test bed enables the evaluation of waveforms with prototype algorithms and hardware. A flexible test environment makes it possible to quickly transition between what-if scenarios in simulation to the actual testing of the prototype algorithms and hardware.

More specifically, test flexibility is important in three key areas of 5G research and early testing:

- 5G New Radio (NR) and multiformat waveforms with high fidelity
- modulation bandwidths, from 100 MHz to more than 5 GHz
- frequency bands, from RF to centimeter wave to mmWave

5G NR waveform generation and analysis

To address these test challenges, Keysight's 5G waveform generation and analysis reference solution provides the essential components of a flexible 5G waveform generation and analysis test platform. This reference solution enables engineers and researchers to generate and analyze a variety of 5G NR waveforms at RF, centimeter wave, and mmWave frequencies. A range of modulation bandwidths is available up to 2.5 GHz, emphasizing 5G NR activity in the 28 GHz and 37 to 39 GHz bands.

The Keysight M9484C VXG microwave signal generator and Keysight's PathWave signal generation software give you various standards-compliant and custom 3GPP 5G NR waveforms. The dual-channel capability provides a variety of test use cases:

- Generating spatially multiplexed signals from each transmission antenna.
- Creating low power level wanted signals and high-power interfering signals.
- Producing phase-coherent signals to evaluate amplitude and phase shifts in phased array antenna systems with real-world modulated signals.

Keysight's PathWave vector signal analysis (89600 VSA) software enables signal demodulation and analysis within the simulation software. PathWave works using a signal analyzer, oscilloscope, or PC to control a variety of instruments or digitizers.

Figures 2 and 3 show the setup of Keysight hardware and software solutions which gives you a flexible 5G generation and analysis test bed.

The M8195A arbitrary waveform generator provides direct intermediate frequency (IF) signals to the external mixer. In contrast, the Keysight N5183B MXG X-Series microwave analog signal generator provides the local oscillator (LO) for upconversion to millimeter-wave frequencies. The Keysight N9042B UXA signal analyzer can directly digitize signal bandwidths up to 2 GHz for analysis. Using an oscilloscope, the UXA's wideband IF output enables you to analyze up to 5 GHz of bandwidth signal.

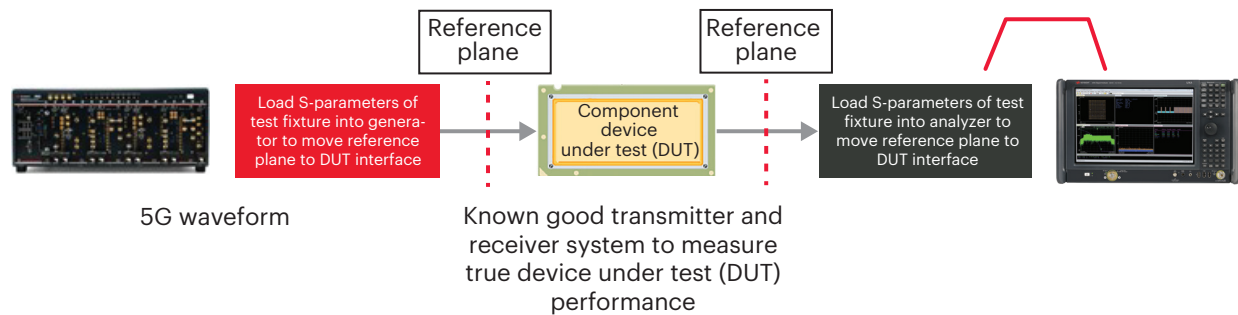


Figure 1. The 5G test bed provides a combination of hardware and software, giving the researcher flexibility and accuracy to explore and validate 5G designs



Figure 2. This 5G test bed configuration supports 3GPP NR signal creation up to 54 GHz with traditional bench top spectrum analysis up to 50 GHz. Both instruments support integrated 1 GHz bandwidth capability.

Figure 3. An example of a 5G test bed configuration to enable signal generation and analysis of signals between 50 GHz and 110 GHz with wide bandwidths up to 5 GHz

Features

pre-5G and 5G NR candidate waveforms

scalable modulation bandwidths and frequency bands

factory-calibrated at all frequencies, amplitudes, and bandwidths

Benefits

evaluate designs for emerging waveforms to gain insights and reduce risk

flexibility to adapt as 5G evolves

measure the true performance of your device under test with metrology-grade test equipment

Signal Creation Configuration

For pre-5G and 5G NR signals in the 28 and 39 GHz bands, the M9484C VXG microwave signal generator offers less than 0.5% error vector magnitude (EVM) and up to 2.5 GHz bandwidth without external heads or components, as displayed in Figure 4.

An external arbitrary waveform generator (AWG) is required for bandwidths above 2.5 GHz. The Keysight M8190A AXIe AWG offers 5 GHz analog bandwidth. This solution can operate with a 14-bit resolution at up to 8 GSa/s or a 12-bit resolution of up to 12 GSa/s.

For signal generation above 54 GHz, the MXG X-Series microwave analog signal generators provide the local oscillators (LOs) for the mmWave upconverters.

Keysight's PathWave Pro signal generation software for 5G NR, pre-5G, and custom modulation quickly creates a variety of standards-compliant and custom waveforms for evaluating DUT characteristics over a wide range of signal configurations.

Figure 4 shows that the parameterized graphical user interfaces (GUI) make it easy to quickly create 5G NR, pre-5G, custom OFDM, and IQ waveforms. You can use PathWave software to save the VSA setup files to recall configurations for in-depth demodulation and analysis insights.

Calibration for our signal generators and signal analyzers covers frequency, amplitude, and modulation bandwidth. This method ensures metrology-grade measurements, so you see the true performance of your DUT rather than the test equipment. However, at wider modulation bandwidths and higher carrier frequencies, the test fixturing between the instrument and the DUT can significantly impact the amplitude and phase response across the signal bandwidth.

Typical test fixturing includes adapters, cables, couplers, combiners, and amplifiers. The generators and analyzers enable de-embedding of the test fixture by importing the S-parameters of the test fixture. This process effectively moves the calibration plane from the instrument to the input / output of the DUT. The network analyzer measures the S-parameters.



Figure 4. The M9484C VXG vector signal generator and N7630APPC PathWave Pro signal generation software creates a variety of 3GPP 5G NR signals

Signal analysis

For vector signal analysis, the N9042B UXA 50 GHz or N9041B 110 GHz signal analyzers can directly demodulate up to 1 GHz bandwidth using Option H1G. For backhaul and higher mmWave bands with wider bandwidths up to 5 GHz, use the N9041B as a precision downconverter to an S-Series Infiniium oscilloscope, which samples the IF.

For ultimate bandwidth, use a high-performance oscilloscope to digitize the signal at RF and mmWave frequencies. For example, in Figure 5, the Infiniium UXR-Series oscilloscopes feature sample rates up to 256 GHz with 10-bits of vertical resolution, enabling high fidelity measurements similar to a spectrum analyzer.

Additionally, the oscilloscope is available in four-channel versions for multichannel measurements like multiple-input and multiple-output (MIMO) spatial multiplexing measurements. Since the oscilloscope is phase coherent, measuring DUTs like phased array antennas and chipsets are simple and fast.



Figure 5. Wideband smart mixer, UXV signal analyzer, UXR-Series oscilloscope, and PathWave vector signal analysis (89600 VSA) software

Figure 6 shows a 73 GHz configuration for 5G RF, microwave, mmWave signal generation, and analysis. Easily alter the hardware configuration to address the actual frequencies, bandwidths, and waveforms of interest.

Figure 6 also includes the AWG and a **Virginia Diodes, Inc. (VDI)** upconverter, which upconverts the signal to 73 GHz. A low phase noise local oscillator drives the millimeter-wave upconverter. Optionally, add a waveguide amplifier, variable attenuator, and bandpass filter (not shown) at the VDI upconverter output to improve amplitude range to suppress out-of-band images.

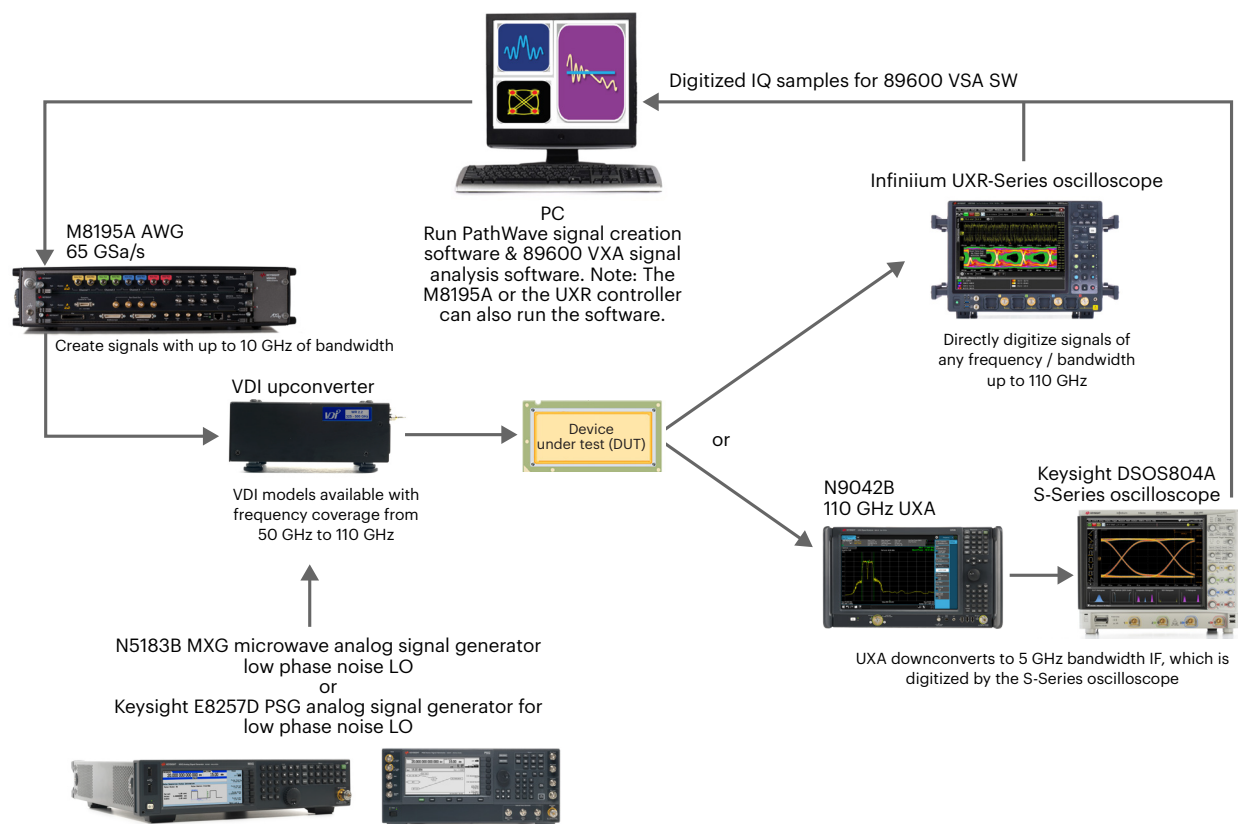


Figure 6. Example hardware configuration for millimeter-wave waveform generation and analysis at 73 GHz

For signal analysis below 50 GHz, the N9042B UXA signal analyzer can digitize and analyze up to 1 GHz of signal bandwidth to meet the requirements of 3GPP 5G NR in FR1 and FR2 bands.

Use the N9042B UXA to downconvert the mmWave signal to a wideband IF for signal analysis from 50 GHz to 110 GHz. With PathWave 89600 VSA software, the Infiniium S-Series oscilloscope digitizes the IF for quick 5 GHz wide bandwidth demodulation analysis.

This solution addresses FCC unlicensed bands in the 57 to 71 GHz range, and 71 to 76 GHz backhaul bands, including the 81 to 86 GHz ranges. The N90242B UXA can manage emerging applications that extend up to 110 GHz.

You can use the Infiniium UXR-Series oscilloscopes to directly digitize RF and mmWave signals with frequencies / bandwidth up to 110 GHz. This solution works for bandwidths higher than 5 GHz at any frequency or multichannel phase-coherent demodulation.

Figure 7 shows the demodulation analysis of a vector-corrected waveform at 73 GHz with 2 GHz of modulation bandwidth. Demodulating a 2 GHz wideband signal is typically challenging without adaptive equalization due to hardware impairments across the wide bandwidth.

However, in this example, the linear amplitude and phase errors corrected during simulation generate a waveform that produces a low EVM without adaptive equalization.

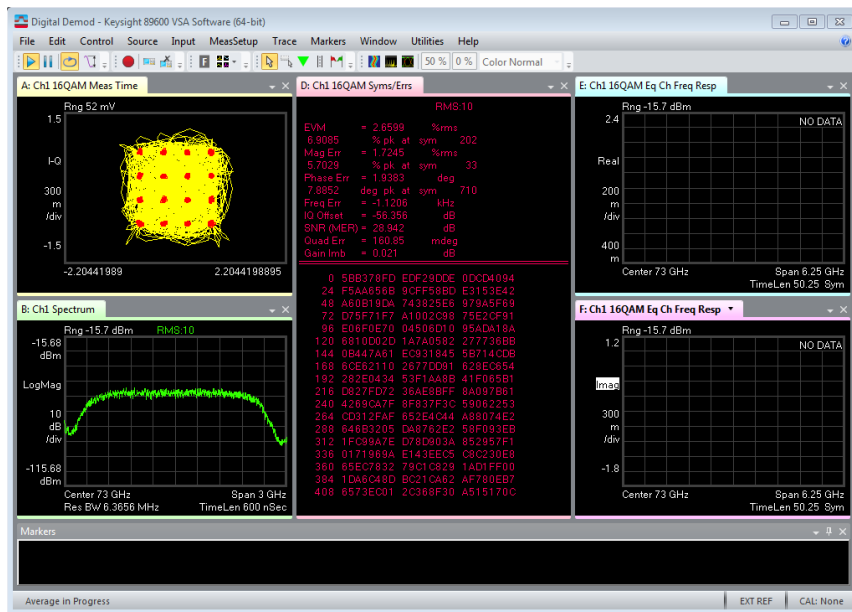


Figure 7. Demodulation of a 73 GHz waveform with 2 GHz of modulation bandwidth

Table 1 shows the available configurations you can create to address different frequencies and bandwidths with the Infiniium UXR-Series oscilloscopes.

Table 1. Available source and analyzer configurations

Carrier frequency	Modulation bandwidth	Source	Signal analyzer
< 6 GHz	< 160 MHz	MXG X-Series microwave analog signal analyzer	X-Series analyzers (MXA, PXA, UXA)
< 54 GHz	< 1 GHz	M9494C VXG microwave signal generator	N9042B UXA
50 to 110 GHz	< 5 GHz	M8195 AWG & N5183B MXG (LO) & VDI mmWave upconverter	N9041B UXA & Infiniium S-Series oscilloscope or UXR1104A Infiniium UXR-Series oscilloscope

Key Performance Characteristics

M8190A AXIe 12 GS/s arbitrary waveform generator

14-bit resolution up to 8 GSa/s for driving external IQ inputs

Analog bandwidth 5 GHz with direct digital-to-analog converter (DAC)

Up to 2 GSa arbitrary waveform memory per channel

M8195A AXIe 65 GS/s arbitrary waveform generator

8-bit resolution up to 65 GSa/s (but well oversampled)

Analog bandwidth at 25 GHz, capable of direct-to-IF synthesis

Expandable to 16 synchronized channels

M9484C VXG microwave signal generator

1 MHz to 54 GHz

2.5 GHz bandwidth, with <1% EVM typical on an 8CC 800 MHz 5G NR signal

Dual-channel with the phase-coherent operation

+24 dBm output power at 1 GHz

De-embedding with S-parameter file import

Integrated PathWave signal generation software

E8267D PSG vector signal generator

100 kHz to 20, 31.8, or 44 GHz

External I/Q inputs provide up to 2+ GHz modulation bandwidth when used with M8190A AXIe AWG

N5183B MXG microwave analog signal generator for uW LO

9 kHz to 13, 20 31.8 or 40 GHz

+ 15 dBm output power at 20 GHz

-124 dBc / Hz phase noise at 10 GHz and 10 kHz offset

N9029AV12-UDC millimeter-wave upconverter / downconverter

60 to 90 GHz frequency range

M1971E waveguide wideband smart mixer

55, 60 to 90 GHz

27 dB maximum conversion loss

N9042B UXA signal analyzer

3.6 Hz to 8.4, 13.6, 17.1, 26.5, 34.5, or 50 GHz

10 MHz (standard), 25, 40, 255, 1 GHz, 1.5 GHz, 2 GHz, and 4 GHz analysis bandwidths
(expandable up to 11 GHz with external digitizer)

Multi-touch interface

N9041B UXA signal analyzer

3 Hz to 90 GHz or 110 GHz

25 MHz (standard), 40, 255, and 1 GHz internal analysis bandwidths

Up to 5 GHz external IF analysis bandwidth

Low displayed average noise level (DANL) at < -150 dBm to 110 GHz

UXR1104A Infiniium UXR-Series oscilloscope

110 GHz bandwidth with high fidelity

256 GSa/s maximum sample rate

10-bit analog-to-digital (ADC) vertical resolution

DSOS804A Infiniium S-Series oscilloscope

8 GHz bandwidth with flat frequency response for high signal fidelity

20 GSa/s maximum sample rate

10-bit analog-to-digital converter (ADC) vertical resolution

Hardware Solutions

The combination of this test equipment provides waveform generation and analysis up to millimeter-wave frequencies with very wide bandwidths and frequency coverage up to 110 GHz. Your local Keysight representative can help to recommend the best hardware configuration for your specific application needs.

M9484C VXG Microwave Signal Generator

www.keysight.com/find/VXG



The M9484C VXG microwave vector signal generator enables high-performance and wideband mmWave signal creation. Key features include two channels for MIMO spatial multiplexing for creating wanted and interfering signals with a wide amplitude dynamic range to overcome over-the-air (OTA) losses.

This solution enables de-embedding using S-parameter import to see true DUT characteristics. The integrated PathWave software enables fast signal creation and factory calibration of signals at all frequencies, amplitudes, and signal bandwidths to give you metrology-grade measurements.

M8190A AXIe 12 GS/s Arbitrary Waveform Generator

www.keysight.com/find/m8190a



Use the M8190A AWG to drive vector signal generators with wideband external I/Q inputs to produce modulation bandwidths of up to 2 GHz. It has 5 GHz of analog bandwidth, a high-quality spurious-free dynamic range (SFDR), and 2 GSa of memory per channel.

M8195A AXIe 65 GS/s Arbitrary Waveform Generator

www.keysight.com/find/m8195a



The M8195A AWG drives a millimeter-wave upconverter to produce modulation bandwidths up to 10 GHz wide, required to explore higher mmWave backhaul and unlicensed bands. The M8195A is a precision 1, 2, or 4 channel AWG with 8-bit resolution up to 65 GSa/s, enabling it to synthesize directly to an IF frequency. This solution eliminates common IQ modulator errors, flatness, and the first stage of upconversion, improving delivered EVM.

E8267D PSG Vector Signal Generator

www.keysight.com/find/e8267d



The E8267D PSG vector signal generator includes wideband differential external I/Q inputs for modulation bandwidths up to 2 GHz or 44 GHz to use your existing investment for 5G.

N5183B MXG X-Series Microwave Analog Signal Generator



www.keysight.com/find/n5183b

Use the N5183B MXG X-Series microwave analog signal generator to provide LOs for the mmWave upconverters and downconverters.

N9029AV12 Millimeter-Wave Upconverter / Downconverter



www.keysight.com/find/SA_mmwave

Use Keysight Option UDC as a millimeter-wave upconverter for the E, V, and W bands covering 50 to 110 GHz. It easily reconfigures as a downconverter that works directly with the X-Series signal analyzers.

M1971E Waveguide Harmonic Smart Mixer



www.keysight.com/find/smartmixer

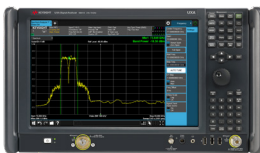
Combine the Keysight M1971E wideband smart mixer with the Keysight N9030A PXA X-Series signal analyzer and the DSOS804A S-Series Infiniium oscilloscope for wideband signal analysis from 60 to 90 GHz.

The smart mixer is an economical, banded signal analysis option providing a medium level of spur and noise performance. Although un-preselected, it offers more than 2 GHz of down conversion bandwidth when extending the X-Series signal analyzers to mmWave.

N9042B UXA Signal Analyzer

www.keysight.com/find/n9042b

Use the Keysight N9042B UXA X-Series signal analyzer for spectrum and demodulation analysis. This solution provides frequency coverage up to 50 GHz. Extend the coverage up to 110 GHz with Keysight's V3050A frequency extender to ensure present and future flexibility through optional measurement capabilities and hardware scalability.



N9041B UXA signal analyzer

www.keysight.com/find/n9041b

Use the Keysight N9041B UXA signal analyzer for high-performance spectrum and demodulation analysis from 3 Hz to 110 GHz — where low noise, low spurs, single sweep, and wide demodulation bandwidth are requirements. For example, 5G, 802.11ax/ay, satellite, radar, electronic warfare (EW), and more.

The UXA signal analyzer's performance enables you to characterize today's most challenging signals — fast-hopping, wideband, transient.

UXR1104A Infiniium UXR-Series oscilloscope



www.keysight.com/find/uxr

The Keysight Infiniium UXR-Series oscilloscopes directly digitize RF and mmWave signals with high bandwidths and frequencies up to 110 GHz. The 256 GHz sample range combined with 10-bit ADC, an internal preamplifier, and attenuators that enable high-fidelity measurements on all channels simultaneously.

The multichannel capability helps you with MIMO spatial multiplexing measurements or comparing individual element paths in phased array antennas and chipsets. Connectivity with the 89600 VSA software enables a wide range of analyses, including 4G and 5G, and future requirements as the standards evolve.

DSOS804A Oscilloscope



www.keysight.com/find/oscilloscopes

An Infiniium S-Series high-definition oscilloscope performs wideband demodulation analysis when paired with the N9030A PXA signal analyzer as a wideband downconverter and the M1971E waveguide harmonic smart mixer.

A 10-bit ADC, low-noise front end, correction filters, vertical scaling support down to 2 mV / division, and a precise time base produce high-fidelity measurements. In addition, its advanced frame and a broad range of capabilities enable the S-Series oscilloscopes to generate a wide range of test needs.

Software Solutions

PathWave signal generation software is a comprehensive PC-based software for flexible signal creation in cellular, wireless connectivity, aerospace / defense, broadcasting, and general-purpose applications. This solution supports a wide variety of signal generation hardware.

N7631APPC PathWave Signal Generation for 5G New Radio

www.keysight.com/find/n7631appc

Use this PC-based application to generate, export, download, and playback Verizon Pre-5G waveforms. Create Verizon pre-5G standard (5GTF) compliant signal for BTS and UE testing with LDPC channel coding and multi-antenna port

N7630APPC PathWave Pro Signal Generation for Pre-5G, PC Application

www.keysight.com/find/n7630appc

Create signals that conform to pre-5G (5GTF) standards with Keysight signal generators. This software generates Verizon pre-5G fully standard-compliant signal creation for BTS or UE testing at 28 GHz and single-carrier or multi-carrier support with a graphical UI.

Export the N7630APPC PathWave Pro signal generation VSA setup file for custom OFDM modulation analysis (Option 89600B-BHF) or pre-5G modulation analysis (Option 89600B-BHN) when making demodulation measurements on your signal.

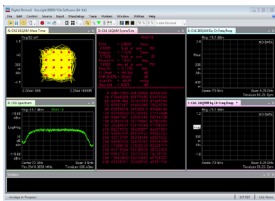
PathWave Signal Generation



www.keysight.com/find/pathwave

Get signal creation for a wide range of general-purpose or standards-based signals. Create calibrated signals validated by Keysight that conform to industry standards to help enhance the characterization and verification of your devices with or without impairments.

PathWave Vector Signal Analysis (89600 VSA)



www.keysight.com/find/pathwave

Experience software tools to explore every facet of a signal to optimize your designs. Measure a broad range of signals, including 5G, IoT, radar, and more. Gain greater insight into frequency, time, and modulation domains. These tools enable you to assess design trade-offs and see through the complexity.

For more information on Keysight Technologies' products, applications, or services, please visit: www.keysight.com