

5G Waveform Generation & Analysis Testbed, Reference Solution



Introduction

Flexibility required for 5G research – waveform generation and analysis

One of the biggest challenges faced by today's 5G researchers is the number and variety of waveforms, frequencies, and bandwidths being investigated. This includes waveforms at frequencies below 6 GHz, and at microwave and millimeter-wave frequencies which may involve wide bandwidths.

To address the multitude of possible scenarios, a flexible test environment is critical for this stage of 5G signal generation and analysis research.

5G Waveform Generation & Analysis Test Challenges

Flexibility is essential in 5G research. It enables “what if ?” analyses to be performed during evaluation of early concepts and potential 5G waveforms, using a variety of modulation schemes at many different frequencies and modulation bandwidths. The risk of potentially choosing the wrong path further reinforces the need for flexibility, especially in the form of signal creation and signal analysis tools that enable rapid changes in direction as strong waveform candidates emerge in the evolution of 5G.

As developers conduct experiments, a highly flexible testbed will enable them to evaluate proposed waveforms with prototype algorithms and hardware. It will also make it possible to quickly and easily transition between what-if scenarios in simulation and actual testing of the prototype algorithms and hardware.

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

- Generating and analyzing 3GPP 5G NR and multi-format waveforms with high fidelity
- Supporting a wide range of modulation bandwidths, from 100 MHz to over 5 GHz
- Supporting a wide range of frequency bands, from RF to centimeter-wave to millimeter-wave

5G 3GPP NR Waveform Generation and Analysis (28 - 39 GHz)

To help address these test challenges, the 5G waveform generation and analysis reference solution combines hardware, software and measurement expertise providing the essential components of a flexible 5G waveform generation and analysis test platform. The reference solution enables engineers and researchers to generate and analyze a variety of 3GPP 5G NR waveforms at RF, centimeter-wave, and millimeter-wave frequencies with modulation bandwidths of up to 2 GHz, with an emphasis on 5G 3GPP NR activity in the 28 GHz and 37 - 39 GHz bands.

The M9384B VXG Microwave Vector Signal Generator combined with Signal Studio software enable a variety of standards compliant and custom 3GPP 5G NR waveforms. The dual channel capability enables a variety of uses cases including: generating spatially multiplexed signals, creating low power level wanted signals and high power interfering signals, and creating phase coherent signals for use in evaluating amplitude and phase shifts in phased array antenna systems with real-world modulated signals. For signal demodulation and analysis, 89600 VSA software can be used either inside the simulation software, or on a signal analyzer, oscilloscope or PC controlling a variety of instruments or digitizers.

Figure 1 below shows a common arrangement of the software and hardware elements and Figure 2 shows a combination of Keysight Technologies, Inc. hardware and software for a flexible 5G generation and analysis testbed.

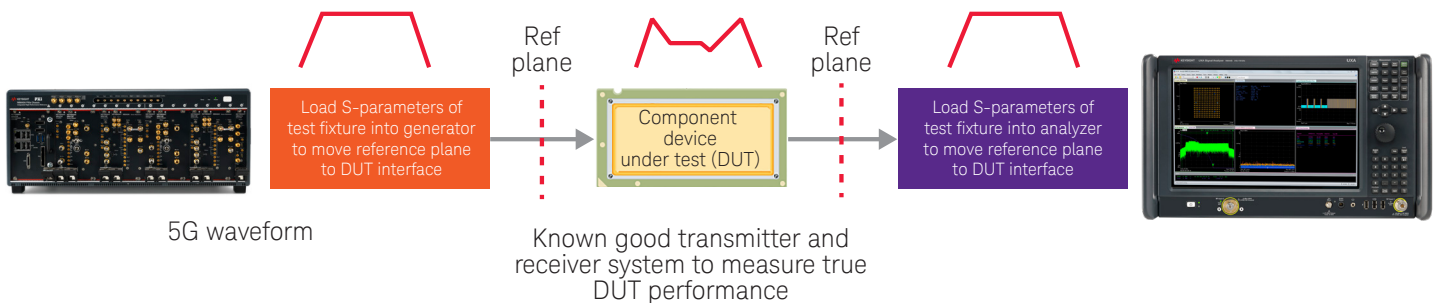


Figure 1. The 5G testbed provides combinations of hardware and software, giving the researcher flexibility and accuracy needed to explore 5G technologies, and then validate 5G designs.



Figure 2. This 5G Testbed configuration supports 3GPP NR signal creation up to 44 GHz with traditional bench top spectrum analysis up to 50 GHz. Both instruments support integrated 1 GHz bandwidth capability.



Figure 4. This 5G testbed configuration enables signal generation and analysis of signals between 50 GHz and 110 GHz with very wide bandwidths in excess of +5 GHz. The M8195A arbitrary waveform generator provides direct IF signals to the external mixer, while the N5183B MXG microwave analog signal generator provides the LO for up conversion to mmW frequencies. The N9041B UXA signal analyzer can directly digitize signal bandwidths up to 1 GHz for analysis. The UXA wideband IF output enables +5 GHz bandwidth signal to be analyzed with an oscilloscope.

| Features | Benefits |
|---|---|
| Pre-5G and 5G new radio candidate waveforms | Quickly evaluate designs for emerging waveforms to gain insights and reduce risk |
| Scalable modulation bandwidths and frequency bands | Provides flexibility to adapt as 5G evolves- reduce risk of choosing the wrong path |
| Factory calibrated at all frequencies, amplitudes, and bandwidths | Evaluate true performance of your device under test with metrology grade test equipment |

Reference Solution Configuration

Signal creation configuration

For pre-5G and 5G new radio signals in the 28 and 39 GHz bands, the new M9384B VXG Microwave Vector Signal Generator directly offers 1% EVM up to 2 GHz bandwidths, without external heads or components.

Above 2 GHz bandwidths, an external AWG is required. The M8190A AXIe AWG can operate with 14-bit resolution at up to 8 GSa/s or 12-bit resolution up to 12 GSa/s. It offers 5 GHz of analog bandwidth. For even higher modulation bandwidths, the M8195A (discussed later) may be considered.

For signal generation above 44 GHz, compact upconverters are available from Keysight and Virginia Diodes, Inc (50 to 110 GHz). MXG microwave analog signal generators provide the LOs for the mmWave upconverters. These are discussed in the next section.

The N7631C Signal Studio pro for 5G NR, N7630C for Pre-5G, and N7608C for custom modulation are flexible software tools for quickly creating a variety of standards compliant and custom waveforms for evaluating DUT characteristics over a wide range of signal configurations. The parameterized graphical user interfaces (GUI) make it easy to quickly create 5G NR, pre-5G, custom OFDM, and custom IQ waveforms. VSA setup files can be saved for quickly recalling configurations in the 89600 VSA software. The Keysight 89600 VSA software is used for in-depth demodulation and analysis insights.

Keysight signal generators and signal analyzers are calibrated over frequency, amplitude, and modulation bandwidth to enable metrology grade measurements ensuring you can 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 start to have a significant impact on the amplitude and phase response across the signal bandwidth. Typical test fixturing includes, adapters, cables, couplers, combiners, and even amplifiers. The generators and analyzers enable de-embedding of the test fixture by importing the S-parameters of the test fixture, effectively moving the calibration plane from the instrument to the input/output of the DUT. The S-parameters can be measured with a network analyzer or may be directly available from the manufacturer of the test fixture component.



Figure 3. The M9384B VXG Microwave Vector Signal Generator and N7630C Signal Studio software are used for creating a variety of 3GPP 5G NR signals.

Signal analysis configuration

For vector signal analysis, the UXA (N9040B 50 GHz or N9041B 110 GHz) can directly demodulate up to 1 GHz bandwidths using option H1G. For backhaul and higher mmW bands with wider bandwidths up to 5 GHz, the N9041B can be used as a precision downconverter to an S-Series Infiniium oscilloscope, which samples the IF. For the ultimate in bandwidth, a high performance oscilloscope can be used to digitize the signal directly at RF and mmWave frequencies. For example, the Infiniium UXR-Series scopes 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 multi-channel measurements like MIMO spatial multiplexing measurements. Since the oscilloscope is natively phase coherent, it makes measuring DUTs like phased array antennas and chipsets simple and fast.

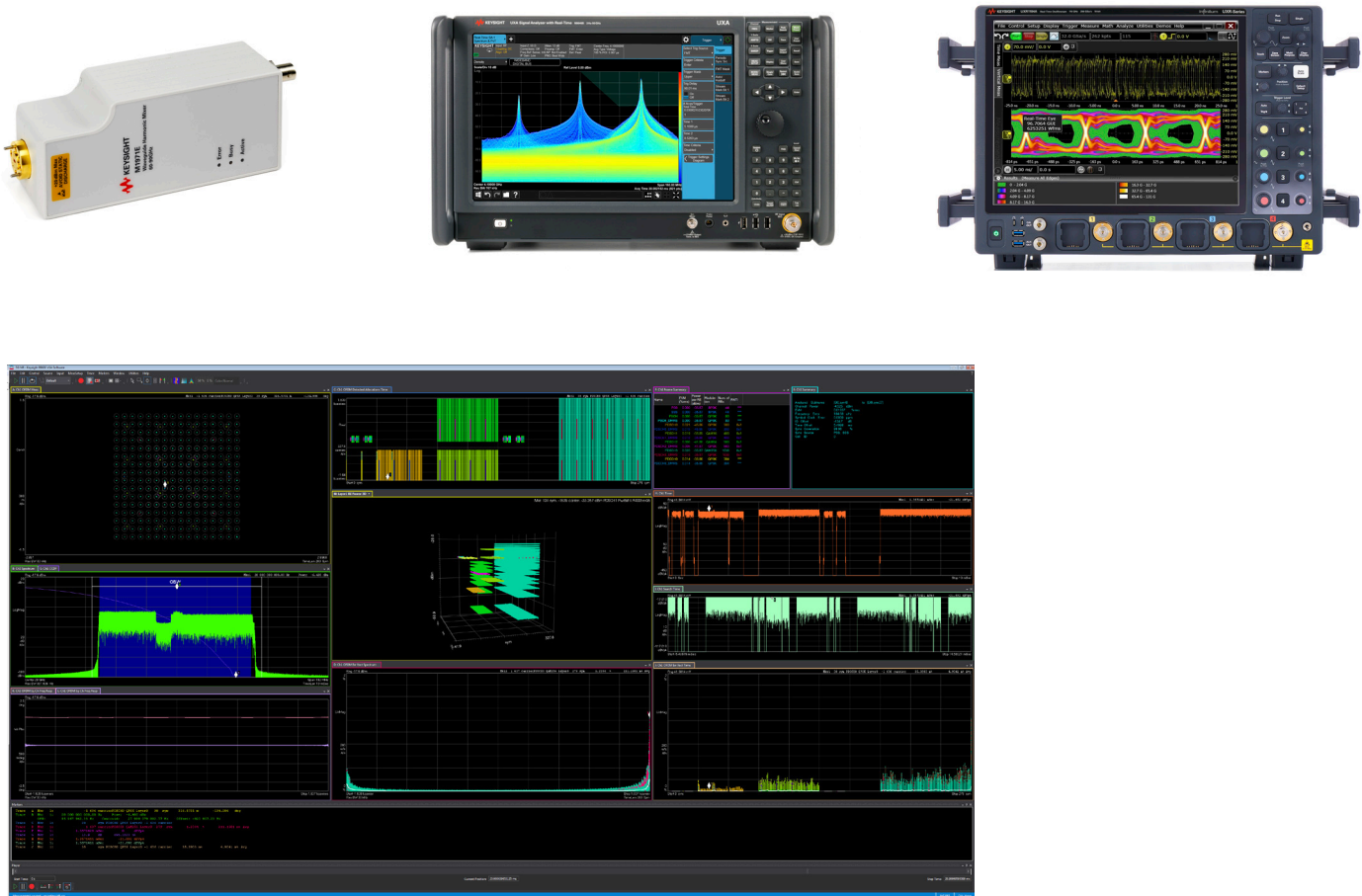


Figure 4. Wideband smart mixer, UXA signal analyzer, UXR-Series oscilloscope and 89600 VSA Software

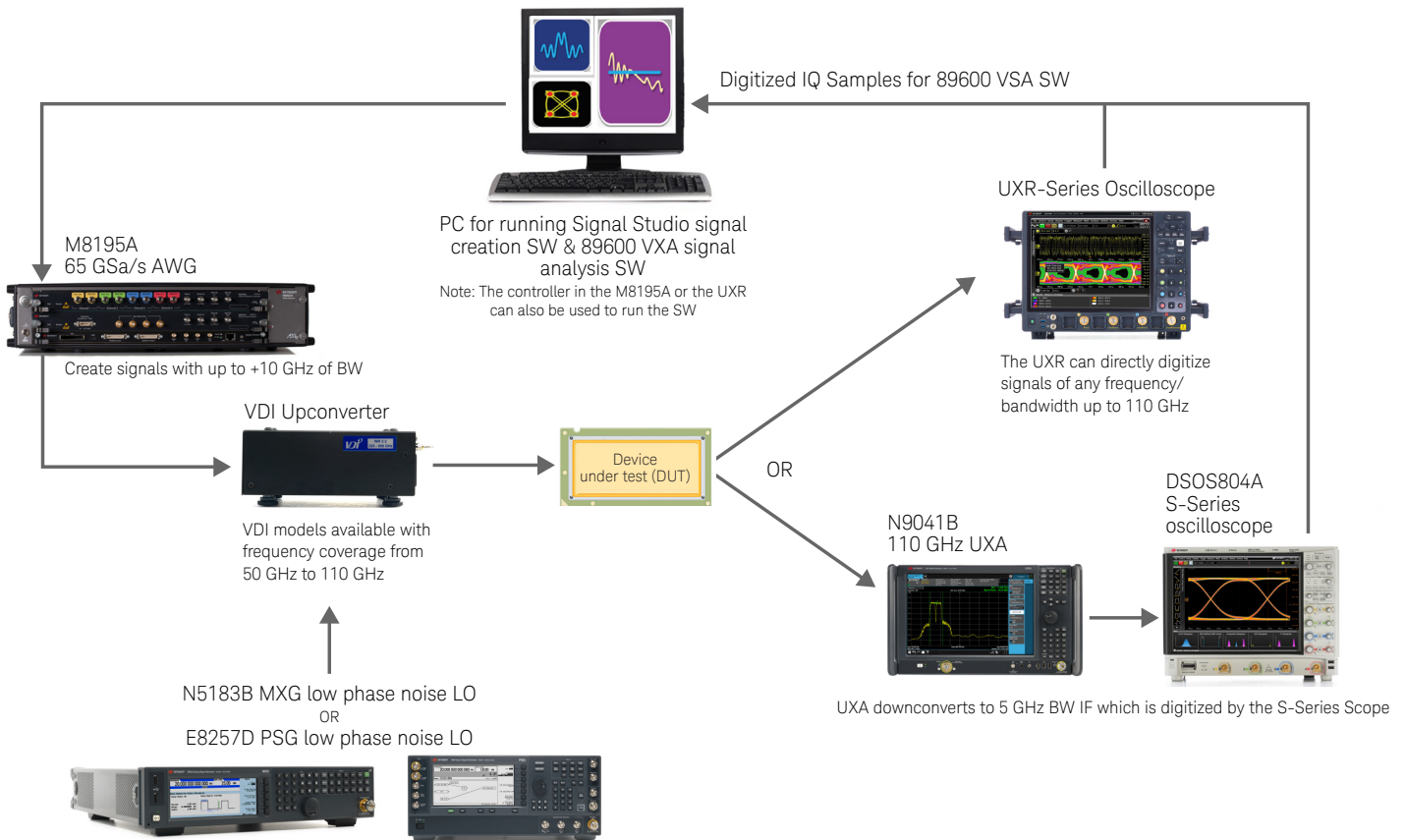


Figure 5. Example hardware configuration for millimeter-wave waveform generation and analysis at 73 GHz.

A simple block diagram of a 73 GHz configuration is shown in Figure 5 that can be used for 5G RF, microwave and millimeter-wave signal generation and analysis. The hardware configuration can be altered, to address the actual frequencies, bandwidths and waveforms of interest. Figure 5 includes the AWG previously described, along with a Virginia Diodes upconverter, which upconverts the signal to 73 GHz. A low phase noise local oscillator (MXG or PSG) drives the millimeter-wave upconverter. Optionally, a waveguide amplifier, variable attenuator, and bandpass filter (not shown) can be added at the VDI upconverter output, to improve amplitude range and suppress out-of-band images.

For signal analysis below 50 GHz, the N9040B UXA with Option H1G can directly digitize and analyze up to 1 GHz of signal bandwidth to meet the requirements of 3GPP 5G NR in the FR1 and FR2 bands. For signal analysis from 50 GHz to 110 GHz, the N9041B UXA is used to downconvert the mmWave signal to a wideband IF. This IF is digitized with an S-Series oscilloscope enabling 5 GHz wide bandwidth demodulation analysis with the 89600 VSA software. This solution addresses the FCC unlicensed bands in the 57-71 GHz range, backhaul bands in the 71-76 GHz and 81-86 GHz ranges, and emerging applications that extend up to 110 GHz. For any bandwidths higher than 5 GHz, at any frequency, and/or for multi-channel phase coherent demodulation, the Infiniium UXR-Series oscilloscopes can be used to directly digitize RF and mmWave signals with frequencies/bandwidth up to 110 GHz.

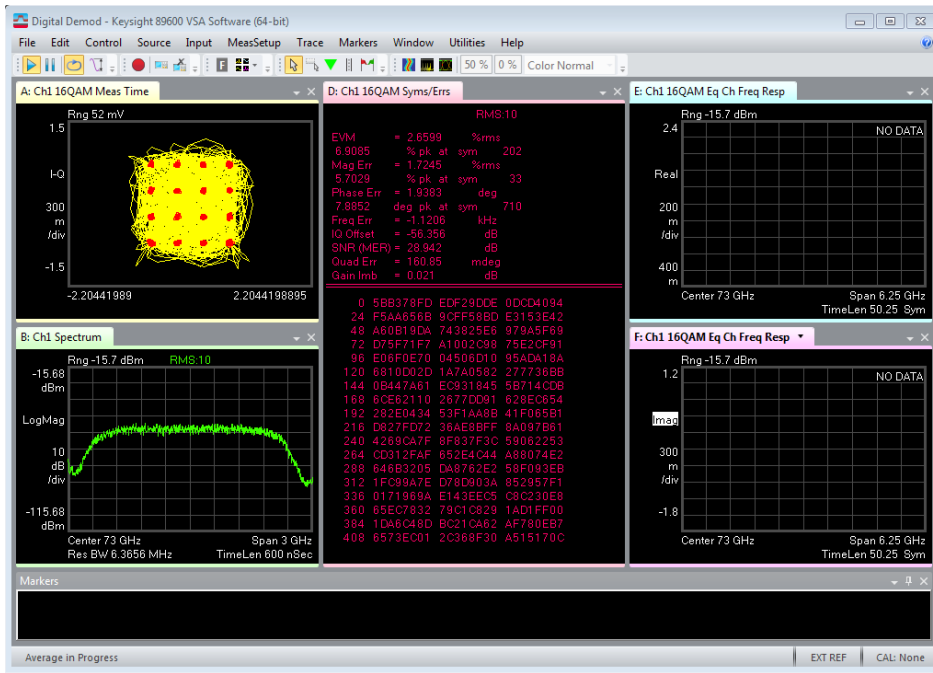


Figure 6. Demodulation of a 73 GHz waveform with 2 GHz of modulation bandwidth

Figure 6 shows the demodulation analysis of a vector-corrected waveform at 73 GHz with 2 GHz of modulation bandwidth, using 89600 VSA software. Demodulating a 2 GHz wideband signal is typically quite difficult without adaptive equalization due to hardware impairments across the wide bandwidth. However, in this example the linear amplitude and phase errors were corrected during simulation to generate a corrected waveform that produced a low EVM without adaptive equalization.

This 73 GHz example configuration is one of many possible configurations. Other configurations can be created to address different frequencies and bandwidths as shown in Table 1. A Keysight representative can recommend the best hardware configuration for your specific application requirements.

| Carrier frequency | Modulation bandwidth | Source configuration | Analyzer Configuration |
|-------------------|----------------------|---|---|
| < 6 GHz | < 160 MHz | MXG | X-Series Analyzer (MXA, PXA, UXA) |
| < 44 GHz | < 1 GHz | M9394B VXG Microwave Signal Generator | N9040B UXA |
| 50 - 110 GHz | < 5 GHz | M8195 AWG + N5183B MXG (LO) + VDI mmW Upconverter | N9041B UXA + S-Series Oscilloscope Or UXR1104A Infiniium Oscilloscope |

Table 1. General overview of source and analyzer configurations for different carrier frequencies and modulation bandwidths

Reference Solution 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 (direct DAC out)

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 25 GHz, capable of direct-to-IF synthesis

Expandable to 16 synchronized channels

M9384B VXG Microwave Vector Signal Generator

1 MHz to 44 GHz

2 GHz Bandwidth, with ~1% EVM typical on a 8CC 800 MHz 5G NR signal

Dual channel with phase coherent operation

+23 dBm CW output power

De-embedding with S-parameter file import

Integrated Signal Studio signal creation applications

Easy to use API, GUI for automation

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

N9040B UXA signal analyzer

3 Hz to 8.4, 13.6, 26.5 or 50 GHz

25 MHz (standard), 40, 255, 510, and 1GHz analysis bandwidths

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 DANL of < -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 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 Elements

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. A Keysight representative can help to recommend the best hardware configuration based on the specific application needs.

M9384B VXG Microwave Vector Signal Generator

www.keysight.com/find/VXG



The M9384B VXG microwave vector signal generator enables high performance, wideband mmWave signal creation. Key features include 2-channels for MIMO spatial multiplexing or creating wanted and interfering signals with wide amplitude dynamic range, high power option to overcome OTA losses, de-embedding with S-parameter import to see true DUT characteristics, integrated Signal Studio software enables fast signal creation, and factory calibration of signals at all frequencies, amplitudes, and signal bandwidths enabling metrology grade measurements.

M8190A AXIe 12 GS/s arbitrary waveform generator

www.keysight.com/find/m8190a



The M8190A AWG is used to drive vector signal generators equipped with wideband external I/Q inputs to produce modulation bandwidths of up to 2 GHz. It has 5 GHz of analog bandwidth, with very high quality SFDR, and 2 GSa of memory per channel.

M8195A AXIe 65 GS/s arbitrary waveform generator

www.keysight.com/find/m8195a



The M8195A AWG is used to drive a millimeter-wave upconverter to produce modulation bandwidths up to 10 GHz wide, required to explore higher mmW 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 eliminates common IQ modulator errors, flatness, and the first stage of upconversion, improving delivered EVM, despite its lower precision.

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, up to 44 GHz. Leverage your existing investment for 5G.

N5183B MXG microwave analog signal generator

www.keysight.com/find/n5183b



N5183B MXG microwave analog signal generators are used to provide LOs for the millimeter-wave upconverters and downconverters.

N9029AV12-UDC Millimeter-wave upconverter / downconverter*

www.keysight.com/find/SA_mmwave



The N9029AV12 millimeter-wave signal analyzer frequency extension module is one of the mixer/amplifier/multiplier chain series (WRxx SAX series) from VDI Inc. Option UDC enables it to be used as a millimeter-wave upconverter for the E, V, and W bands covering 50-110 GHz. It can also be re-configured as a downconverter, designed to work directly with the X-Series signal analyzers.

*Note: Other frequency bands may be available, depending on the application. VDI VDI12.0AMP amplifier and WR12BPF71-76 filter are not shown. Please contact VDI for further information (www.vadiodes.com).

Hardware Elements (continued)

M1971E Waveguide harmonic smart mixer

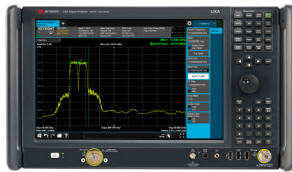
www.keysight.com/find/smartmixer



The M1971E wideband smart mixer is combined with an X-Series signal analyzer, such as an N9030A PXA signal analyzer, and DSOS804A S-Series oscilloscope for wideband signal analysis from 60 to 90 GHz. The smart mixer is an economical, banded signal analysis option, at a medium level of spur and noise performance. Although un-preselected, it offers more than 2 GHz of downconversion bandwidth when extending X-Series signal analyzers to millimeter wave.

N9040B UXA signal analyzer

www.keysight.com/find/n9040b



A Keysight N9040B UXA signal analyzer is used for spectrum and demodulation analysis. The UXA signal analyzer, a high-performance member of the X-Series, provides frequency coverage up to 50 GHz, and ensures present and future flexibility through optional measurement capabilities and hardware expandability. A UXA may also be used, depending on application requirements. www.keysight.com/find/n9040b

A Keysight N9040B UXA signal analyzer is used for spectrum and demodulation analysis. The UXA signal analyzer, a high-performance member of the X-Series, provides frequency coverage up to 50 GHz, and ensures present and future flexibility through optional measurement capabilities and hardware expandability. A PXA may also be used, depending on application requirements.

N9041B UXA signal analyzer

www.keysight.com/find/n9041b

A Keysight N9041B UXA signal analyzer is used 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 required. The N9041B is uniquely capable of adapting to new frequency bands, troubleshooting R&D issues, and validating sensitive spectral emissions masks (SEM) for regulatory compliance in emerging backhaul and high mmW bands.

UXR1104A Infiniium UXR-Series Oscilloscope

www.keysight.com/find/uxr



The Infiniium UXR-Series oscilloscopes can be used to directly digitize RF and mmW signals with high bandwidths and frequencies all the way to 110 GHz. The 256 GHz sample range combined with 10-bit ADC, internal preamp and attenuators, enable high fidelity measurements on all channels simultaneously with signal analyzer like performance. The multi-channel capability is suited for MIMO spatial multiplexing measurements or comparing individual element paths in phased in array antennas and chipsets. Connectivity with the 89600 VSA software enable a wide range of analysis including 4G and 5G and future needs as the standards evolve.

DSOS804A Oscilloscope

www.keysight.com/find/oscilloscopes



An Infiniium S-Series high-definition oscilloscope is used to perform wideband demodulation analysis when paired with the N9030A PXA signal analyzer used 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 broad range of capability enable the S-Series oscilloscopes to tackle a wide range of test needs.

Software Elements

The combination of this signal generation and analysis software provides waveform generation and analysis of candidate 5G waveforms with the hardware configuration listed above.

N7631C Signal Studio Pro for 5G NR

www.keysight.com/find/n7631c

N7631C Signal Studio Pro for 5G NR creates 5G 3GPP NR standards compliant signals for BTS, UE, or component (amplifier) testing at sub-6 GHz or in the uW bands. Quickly create signals with multiple component carriers with modulation bandwidths up to 400 MHz per component carrier. Customize the resource block allocations per user with modulation capability up to 256QAM.

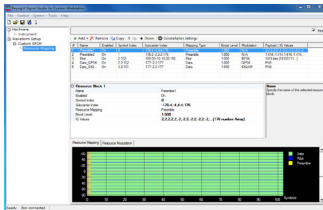
N7630C Signal Studio for pre-5G

www.keysight.com/find/n7630c

N7630C Signal Studio for pre-5G generates Verizon pre-5G fully standard-compliant signal creation for BTS or UE testing at 28 GHz, as well as single-carrier or multi-carrier support with a graphical UI. It also exports set-up files for demodulation analysis using the 89601B VSA software (Option BHN).

N7608B Signal Studio for custom modulation

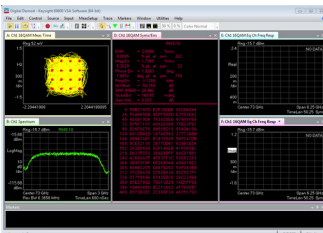
www.keysight.com/find/n7608b



N7608B Signal Studio for custom modulation is a flexible suite of signal-creation tools that will reduce the time you spend on signal simulation. Custom FBMC, OFDM, and IQ signals can quickly and easily be generated for component, transmitter, and receiver test of emerging 5G applications.

89600 VSA Software

www.keysight.com/find/89600



The 89600 VSA software is a comprehensive set of tools for demodulation and vector signal analysis. These tools enable you to assess design tradeoffs and see through the complexity. Option BHN (3GPP NR and pre-5G) enables standards based signal analysis while option BHF enables custom OFDM analysis.

Recommended Reference Solution Base Configuration

This reference solution is flexible and scalable. Buy what you need today and add more capabilities as the 5G measurement requirements evolve.

The following is a summary of the 5G waveform generation and analysis base configuration. This configuration is designed for RF modulation bandwidths less than 1 GHz and frequency bands between 100 kHz and 44 GHz. This is a minimum configuration and additional test equipment and/or options may be needed based on the specific application requirements.

Note that other configurations may be available depending on specific application requirements. A Keysight representative can recommend the best hardware configuration based on the specific application requirements.

| Model | Description |
|------------------|--|
| M9384B | VXG Microwave Signal Generator |
| M9384B-001 | Add channel 1 (required) |
| M9384B-002 | Add channel 2 |
| M9384B-F44 | Frequency range, 1 MHz to 44 GHz |
| M9384B-D21 | RF bandwidth, 2 GHz with 256 MSa memory |
| M9384B-600 | Enhanced high performance reference |
| M9384B-ST6 | Enhanced low phase noise |
| M9384B-1EB | High output power from 20 GHz to 44 GHz |
| M9384B-M10 | Baseband generator memory upgrade to 10 MSa |
| M9384B-EXT | Wideband differential external IQ inputs |
| M9384B-PCH | Phase coherency for N channels |
| N9040B* | UXA X-Series signal analyzer |
| N9040B-550 | Frequency range, 3 Hz to 50 GHz |
| N9040A-H1G | Analysis bandwidth, 1 GHz |
| N9040A-P50 | Preamplifier 50 GHz |
| UXR0252AP | Infiniium UXR Real-Time Oscilloscope, 25 GHz, 1mm, 256 GSa/s, 2 Channel |
| UXR0000-610 | 10 GHz mmWave configurable bandwidth window |
| UXR0000-02G | 2 Gpts/CH memory option |
| Y1901B | Ruggedized 1mm to 1.85mm adapter |
| DSOS804A* | S-Series high-definition oscilloscope, 8 GHz |
| DSOS000-400 | Memory- 400 Mpts/ch |

*Note:

A high performance oscilloscope such as a DSAZ504A or DSAZ634A may also be used for high frequency wide bandwidth measurements (e.g. 2 GHz modulation bandwidth). Please consult with a Keysight representative for more information.

Recommended Reference Solution Base Configuration (continued)

| Software | |
|---------------|--|
| N7631C | Signal Studio Pro for 5G NR |
| N7631APPC | 5G NR signal creation |
| N7630C | Signal Studio for Pre-5G |
| N7630APPC | Pre-5G signal creation |
| N7608C | Signal Studio for Custom Modulation |
| N7608CAPPC | Custom IQ, Custom OFDM, Candidate 5G signal creation |
| 89601B | 89600 VSA Software N7608APPC |
| 89601B-200 | Basic vector signal analysis and hardware connectivity |
| 89601B-BHF | Custom OFDM modulation analysis |
| 89601B-AYA | Digital modulation analysis |
| 89601B-BHK | Custom IQ modulation analysis (requires AYA) |
| 89601B-BHN | 5G 3GPP NR and Pre-5G analysis |

Configurations for 50 to 110 GHz and up to 5 GHz Bandwidth

The following is a summary of the additional equipment needed to extend the base configuration for RF modulation bandwidths up to 5 GHz between 50 and 110 GHz. The test equipment configuration may vary depending on the frequency mixing scheme (e.g. LO frequencies required). This is a minimum configuration and additional test equipment and/or options may be needed, based on the specific application requirements.

| Model | Description |
|------------------------------|--|
| N5183B | MXG X-Series signal generator (used for upconverter LO) |
| N5183B-520 | Frequency range, 9 kHz to 20 GHz |
| N5183B-UNY | Enhanced low phase noise |
| N9029AV12-UDC* | Millimeter-wave upconverter/downconverter |
| M8195A | AXIe AWG (replaces M8190A) |
| M8195A-001 | AWG - 1-channels |
| M8195A-16G (recommended) | Upgrade to 16GSa memory (optional) |
| M8195A-BU1 | Bundle 1 (5-slot chassis and controller) |
| N9041B | UXA signal analyzer (N9040B) |
| N9041B-590 (5CX optional) | Signal analyzer up to 90 GHz (110 GHz optional) |
| N9041B-H1G | Signal analysis bandwidth of 1 GHz |
| N9041B-P50 | Pre-amp below 50 GHz |
| N9041B-CRW | 5 GHz using external IF output |

*Note: N9029AV12-UDC can also be configured as a downconverter. If the N9029AV12-UDC is used instead of the M1971E waveguide smart mixer, then an additional N5183B MXG is recommended for the downconverter LO. Additional hardware may also be required if the N9029AV12-UDC is used as an upconverter, such as the Virginia Diodes, Inc. VDI12.0AMP amplifier and WR12BPF71-76 filter for 73 GHz applications. This additional hardware depends on application requirements and are not listed here. Please contact VDI for further information.

Hardware Support and Warranty

Keysight provides its standard warranty on all hardware products. The warranty service provides standard coverage for the country where product is used, including:

- All parts and labor necessary to return to full specified performance
- Recalibration for products supplied originally with a calibration certificate
- Return shipment

Standard hardware warranty includes 3 year warranty on each product with a typical turn-around time of 15 days.

Keysight has optional upgraded warranty services on each product including:

- Extended warranty from 3 years to 5 years
- Express warranty for faster turnaround time. Available upgrade for 3 and 5 year warranties.

Learn more at: www.keysight.com

For more information on Keysight Technologies' products, applications or services, please contact your local Keysight office. The complete list is available at: www.keysight.com/find/contactus

