

Keysight Technologies and Skyworks Solutions

Applying a Very Wide-Bandwidth Millimeter-Wave Testbed to Power Amplifier DPD

White Paper

Acknowledgments:

The work presented in this whitepaper is the result of a joint collaboration between Skyworks Solutions, Inc. and Keysight Technologies. Keysight would like to acknowledge the following individuals who contributed to this work:

Skyworks Solutions:

Stephen J. Kovacic, Ph.D, Director,
Advanced Technology Group
Foad Arfarei Maleksadeh, Ph.D, Senior Designer,
Advanced Technology Group
Hassan Sarbishaei, Ph.D, Senior Designer,
Diversified Analog Solutions Group

Keysight Technologies:

Greg Jue, 5G System Engineer
Michael Millhaem, 5G System Architect
Jin-Biao Xu, Application Engineer
Michel Gagne, Senior Wireless Application Specialist
Jean-Marc Moreau, Solution Architect



Unlocking Measurement Insights

Introduction

Even as fourth-generation (4G) cellular systems—LTE and LTE-Advanced—are being deployed, research and active development has begun on fifth-generation or 5G systems. 5G mobile networks offer a vision of “everything everywhere and always connected.”

In a 5G system, key attributes may include a dense, highly integrated network comprised of small cells supporting data rates on the order of 10 Gbps with roundtrip latency of 1 ms or less. Most studies assume multiple air interfaces operating at microwave or millimeter frequencies – the new radio (NR). With 5G/NR there are three basic use cases: enhanced mobile broadband (eMBB), massive machine-type communications (mMTC) and ultra-reliable and low latency communications (URLLC). However, there are also 74 underlying use cases defined in TR 22.891 under the 3GPP, with many of these use cases stemming directly or indirectly from next-generation mobile networks (NGMN).

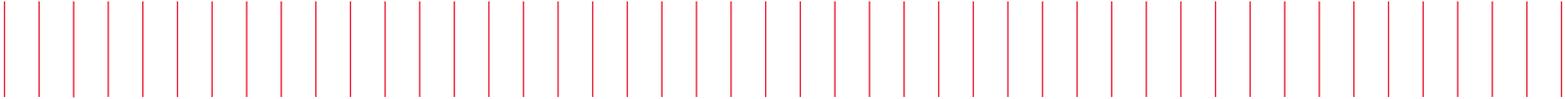
Achieving this vision will require a combination of evolution and revolution in technology, business models and policy. As a policy example, the U.S. Federal Communications Commission (FCC) recently announced new rules to enable rapid development and deployment of next-generation 5G technologies and services [1]. These rules create a new Upper Microwave Flexible Use service in the 28 GHz, 37 GHz, and 39 GHz frequency bands, as well as a new unlicensed band at 64–71 GHz. This new band, combined with the existing unlicensed band from 57–64 GHz, opens up a 14 GHz span of unlicensed spectrum from 57–71 GHz.

This expanse of unlicensed spectrum creates new possibilities for 5G applications that require high data throughput using wide-bandwidth digital modulation; however, in order to benefit from these very wide frequency bandwidths (e.g., 5 GHz of occupied bandwidth) within this unlicensed spectrum, new techniques are needed to achieve the highest system performance.

Testing these new designs will require advances in measurement technology. For example, today’s vector signal generators currently provide up to 2 GHz of modulation bandwidth. Different approaches to generating signals will be required to meet the wideband requirements allowed by the new spectrum allocations.

Digital pre-distortion (DPD) is a technique introduced in 3G and 4G that allows power amplifiers (PAs) to be run at a more efficient operating point by modifying the input signal to account for the AM/AM and AM/PM conversion that occurs as the amplifier operates at peak signal levels. By measuring the AM/AM and AM/PM conversion of the amplifier, the inverse of these functions can be applied to the input waveform, producing the ideal waveform at the amplifier output.

In contrast, AM/AM and AM/PM plots give only first-order insight into the behavior of the PA. It is important to also consider memory effects. Circuit models that are typically used for design and simulation of PAs cannot predict the memory effect, and the only practical way to deal with this issue is to test the PA and capture the time-domain modulated signal after passing through the PA [2].



Established techniques typically require that the input signal be generated and measured at three to five times the bandwidth of the signal. The test equipment that was available for testing 4G PAs could easily handle these sample rates, even for the widest 20 MHz LTE signals. For 5G and 802.11ad signals with bandwidths as wide as 2 GHz, the techniques used for 4G are beyond the capabilities of most vector signal generators and vector signal analyzers currently available.

This white paper explores and discusses a new wideband millimeter-wave testbed approach using digital technology and compact millimeter-wave converters to generate and analyze very wide-bandwidth millimeter-wave test signals (> 2 GHz to 8 GHz). While this approach may provide enough capability for some applications that require very wide bandwidths, it is not a replacement for a traditional vector signal generator and vector signal analyzer.

The testbed will be used to generate and analyze V-band (50-75 GHz) and E-band (60-90 GHz) test signals with up to 8 GHz of occupied bandwidth. The testbed solution software will then perform DPD on a Skyworks PA operating in the V-band. Improvements in adjacent-channel power (ACP) and error vector magnitude (EVM) will be shown utilizing simulated pre-distortion algorithms with the testbed. For this DPD application, 7.5 GHz of signal generation and analysis bandwidth was utilized, specifically 5x the 1.5 GHz symbol rate of the QPSK and 64QAM waveform used for the PA DPD.

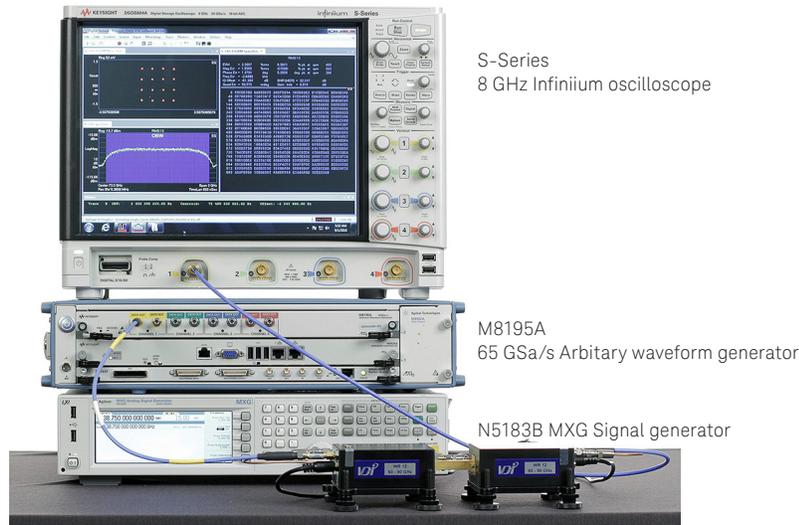
Applying a New Testbed Approach for Very-Wideband Signals at V Band and E Band

Traditional approaches to producing high-frequency wideband signals typically involve generation of analog I and Q waveforms, modulation of these onto an intermediate frequency (IF) or radio frequency (RF) carrier, and then frequency translation to millimeter-wave using an external upconverter.

For signal analysis, an external millimeter-wave downconverter would typically be used to shift the incoming signal down to IF or RF for characterization with either an RF signal analyzer or a digital oscilloscope. While this approach can work relatively well for moderately wide modulation bandwidths (e.g., 2 GHz), it can become problematic for very-wide modulation bandwidths (e.g., > 2GHz) due to impairments such as I/Q gain imbalance and amplitude or phase variation versus frequency.

The wideband millimeter-wave testbed shown in Figure 1 was designed to address very wide bandwidths at millimeter-wave frequencies. This testbed uses high performance digital technology for wideband IF signal generation and IF signal analysis to overcome analog RF impairments.

It also utilizes a set of compact up- and downconverters from Virginia Diodes, Inc. (VDI). These enable the IF input to be driven directly from an arbitrary waveform generator (AWG) and analyzed directly with a digital oscilloscope. The compact VDI up- and downconverters use an effective 2x multiplication factor for the local oscillator (LO) frequency, providing improved signal-to-noise (S/N) and substantially lower conversion loss for the upconverted signal, relative to traditional systems that use a 6x multiplication factor. In addition, the 2x multiplication factor enables use of a high quality LO source that ensures low phase noise at higher frequencies.



S-Series
8 GHz Infiniium oscilloscope

M8195A
65 GSa/s Arbitrary waveform generator

N5183B MXG Signal generator

Note: E-band converters shown here
V-band converters can also be used

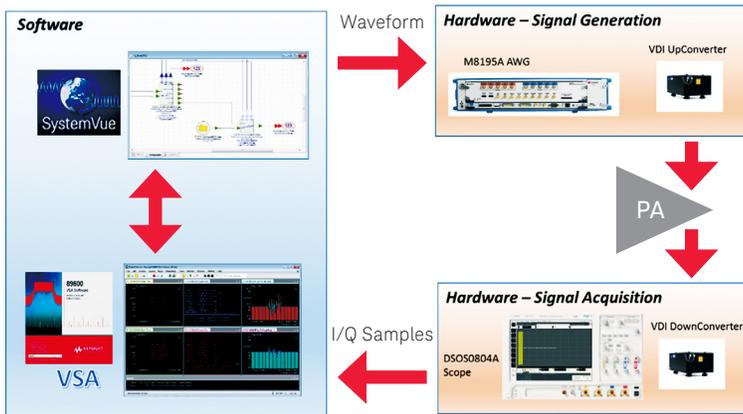


Figure 1. The proposed testbed includes a variety of powerful hardware and software elements.

The elements of the testbed fulfill several key roles:

- A multi-channel, eight-bit Keysight M8195A 65 GSa/s AWG is used to generate wideband modulated IF signals.
- A multi-channel Keysight Infiniium S-Series DSOS804A high-definition oscilloscope (8 GHz, 20 GSa/s, 10-bit resolution) is used to digitize and analyze wideband IF signals with the Keysight 89600 VSA software. A wider-bandwidth oscilloscope can also be used.
- The VDI E-band compact upconverter (N9029ACST-U12) and downconverter (N9029CST-D12) can both be driven directly with the AWG and connected directly to the high-definition oscilloscope. Compact VDI V-band converters could also be used.
- The compact Keysight N5183B MXG X-Series microwave analog signal generator is used to provide high quality LO signals to the compact VDI converters.
- The 89600 VSA software provides advanced demodulation and analysis of 5G candidate waveforms.
- Keysight SystemVue software supports waveform creation as well as DPD data processing and extraction.

Some of the key considerations for this testbed approach, relative to traditional approaches, are discussed next.

Wideband Signal Generation

In general, two different approaches can be used to generate wideband signals beyond the analog bandwidth of an AWG: analog I/Q modulation and digital upconversion.

Figure 2 shows simplified block diagrams of these two alternatives, and each approach has specific advantages and disadvantages that are discussed below.

Analog I/Q Modulation vs. Digital I/Q Up-Conversion

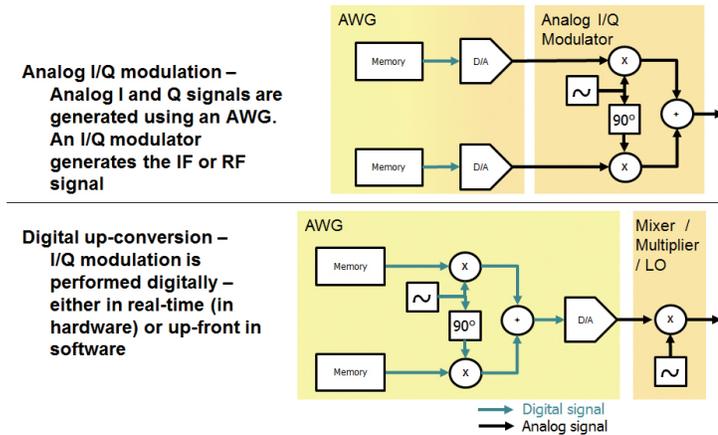


Figure 2. An AWG is the common element in the two possible approaches to generation of wideband signals.

Notice the blue and black arrows in the two diagrams: blue correspond to mathematical formulas or digital signals, whereas black arrows represent real analog signals and voltages.

The upper diagram shows analog I/Q modulation. In this case, an AWG generates I and Q signals that are fed into an I/Q modulator that is often built into a vector signal generator. One advantage of this approach: the analog bandwidth required at the output of the AWG is only one-half of the modulation bandwidth that can be achieved in the RF signal on the output. Thus, with a 500 MHz AWG, this approach can generate a signal with 1 GHz of modulation bandwidth. On the negative side, the analog I/Q modulator creates undesired distortion components such as images and carrier feedthrough that can be only partially offset. Also, I/Q gain imbalance versus frequency can become a dominant source of EVM error, especially as the modulation bandwidth increases.

In digital upconversion (lower part of Figure 2), the I/Q modulation is carried out as a mathematical operation—either in real-time by a digital signal processor or ahead of time in software. The result of this calculation is fed into a digital-to-analog converter (DAC) and upconverted using a mixer. With this approach, images and LO feedthrough can be filtered or rejected due to higher-frequency separation of the signal and the LO. Because this technique uses digital or software I/Q modulation, I/Q gain imbalance is not an issue as compared to analog I/Q upconversion. The modulated IF output of the AWG can be translated directly to millimeter-wave frequencies using an external upconverter, eliminating the need for an analog I/Q upconverter. One negative: this improved high-frequency signal-generation technique requires higher AWG bandwidth.

One type of impairment impacts both methods: non-ideal amplitude and phase variation over frequency. These variations occur along the signal paths from the AWG to the upconverter RF-output and from the RF-input of the downconverter to the digitizing oscilloscope. Contributors include variations due to the I/Q modulator, the converter mixers or multiplier stages, any passband filter or amplifier, and the flatness of the oscilloscope input channel.

Most of these frequency-response errors are linear and can be characterized using the available adaptive equalizer in the VSA software. Once equalized, the frequency response from the adaptive equalizer can then be used to pre-correct the waveform to compensate for the linear frequency response of the signal path (Figure 3).

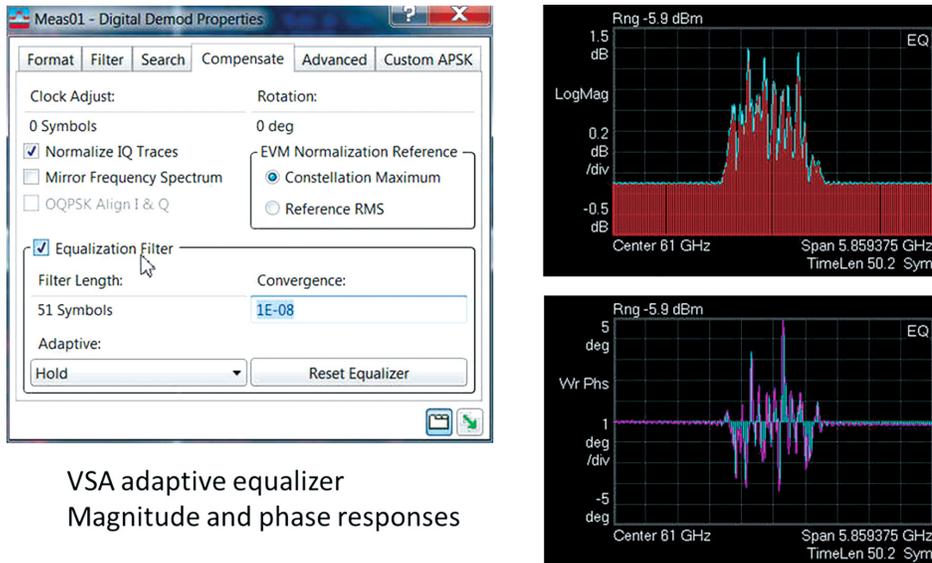


Figure 3. In this example, the adaptive equalizer is used to characterize the frequency response of the signal path at a 61 GHz center frequency.

For this testbed, the M8195A AWG was used to provide wideband IF modulated signals with digital upconversion. The M8195A AWG offers sample rates of up to 65 GSa/s with up to 25 GHz of analog bandwidth. As many as four channels can be used simultaneously in one AXle card, and a chassis can hold up to four cards. The extended memory option offers a total of 16 GB of waveform memory with a maximum access rate of 65 GSa/s. When more than one channel is used, the data rate for each channel is lowered. The DAC still runs at the full data rate, and the FIR filter in each channel is used to interpolate the data from divide-by-four or divide-by-two up to the DAC rate.

Using an AWG as a signal source has a tradeoff in that it lacks the signal conditioning and power control of a traditional RF signal generator. With the M8195A AWG, the eight-bit vertical resolution is another tradeoff. Fortunately, though, the M8195A has very low EVM, even for signals with bandwidth of up to 5 GHz at a 4 GHz IF frequency. Table 1 shows measured results for a single-carrier 16QAM signal and the associated symbol rates (SR) from 2 GHz to 4 GHz. The occupied bandwidth (OBW) is calculated using a root-raised cosine (RRC) filter with an alpha of 0.35 (e.g., 3.7 GHz SR * 1.35 = ~5 GHz of OBW). EVM measurements were performed with an S-Series high-definition oscilloscope and 89600 VSA software.

Table 1. The M8195A AWG provides good EVM performance across a variety of symbol rates.

	2 GHz SR (~2.7 GHz OBW)	3 GHz SR (~4 GHz OBW)	3.7 GHz SR (~5 GHz OBW)	4 GHz SR (~5.4 GHz OBW)
M8195A 4 GHz IF EVM (%)	1.1%	1.3%	1.4%	1.5%

Note: EVM results used constellation maximum as the EVM normalization reference, EQ is enabled for all EVM results.

Although the M8195A has eight-bit vertical resolution, the high maximum sample rate of 65 GSa/s provides oversampling processing gain at low IF frequencies, yielding low EVM results. Even so, EVM may vary with peak-to-average power ratio (PAPR) and may be different for multi-carrier and OFDM waveforms.

Up-/downconversion of Millimeter-wave Modulated Signals

The testbed was designed to use VDI's new compact millimeter-wave upconverters and downconverters. In the upconverter, the IF drive level is compatible with the M8195A AWG output voltage, enabling a direct connection. Because the downconverter IF output is conditioned with an IF gain stage, it can be analyzed directly with an S-Series high-definition oscilloscope. To generate signals in the V and E bands using the VDI converters, LO frequencies in the range of 30-40 GHz are required. These can be generated using Keysight's PSG, MXG or EXG signal generators.

Unlike the previous-generation VDI converter (N9029V12), which was reconfigurable, the compact VDI up- and downconverters used here are single-function devices. However, their compact size is beneficial in the Skyworks PA DPD application and others that require placement of the converters close to the probe tips.

Another key benefit of the compact converters is that the LO uses a 2x multiplication factor, and this enables use of a high quality LO source such as the MXG to ensure low phase noise at high frequencies. Residual LO phase noise is the sum of two basic noise mechanisms: additive noise and multiplicative noise (Figure 4).

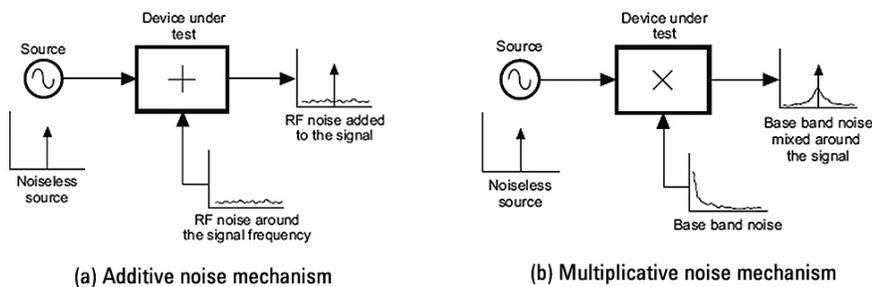


Figure 4. Within the test configuration, the DUT contributes additive and multiplicative noise.

Additive noise is the noise generated by the two-port device at or near the signal frequency, and this noise adds to the signal in a linear fashion. In contrast, multiplicative noise is often due to the intrinsic modulations to the input signal by the nonlinear behavior of the two-port DUT [3].

Since the previous converter multiplied the input LO by six, the multiplicative noise was increased by $20 \cdot \log(6)$ or 15.6 dB. The new converters have an effective multiplication factor of two, reducing the multiplicative noise to 6 dB ($20 \cdot \log(2)$). There will likely be some additive phase noise in the VDI LO path, but the effective 2x multiplication factor provides more flexibility in selecting a signal generator with the desired phase noise performance. For example, when excellent phase noise performance is crucial, a Keysight E8267D PSG vector signal generator with option UNY (enhanced ultra-low phase noise performance) might be used instead of the N5183B MXG.

The compact VDI converters are available for either V band (WR15) or E band (WR12). The E-band converters offer the following typical characteristics:

- RF: 60-90 GHz, WR12 UG-387/U flange
- LO: 30-45 GHz, 2.4 mm coax (f) flange
- LO power: 3-6 dBm required
- Typical performance: Lmix: 10 dB typical (SSB)

Because these converters operate in double-sideband mode, an external bandpass filter is generally recommended (e.g., 71-76 GHz bandpass filter) to attenuate or remove unwanted signal images. Some such filters are available from VDI.

Wideband Signal Analysis

Signal analyzers such as the N9040B UXA offer an integrated analysis bandwidth of up to 1 GHz and a frequency range of up to 50 GHz. Analysis of signals with more than 1 GHz of bandwidth is generally accomplished with a high performance digital oscilloscope such as the DSOS804A.

For this testbed, the Infiniium S-Series high-definition oscilloscope was used because it offers 8 GHz of analog bandwidth with 10-bit vertical resolution. The V-band and E-band VDI downconverters have IF bandwidths up to 9 GHz and 12 GHz, respectively, so the 8 GHz bandwidth is well-suited for a 4 or 5 GHz IF frequency. Wider bandwidth scopes such as the Keysight Infiniium Z-Series can be used to utilize the full IF bandwidth of the VDI downconverters.

Get real results up to 110 GHz



The new N9041B UXA X-Series signal analyzer delivers wider, deeper views of millimeter-wave signals with continuous frequency coverage from 3 Hz to 110 GHz. Its displayed average noise level (DANL) is as low as -150 dBm above 50 GHz, enhancing characterization of wideband modulated signals in the millimeter-wave band. Maximum analysis bandwidth is 5 GHz with the external IF output connected to a Keysight oscilloscope, and the fully integrated instantaneous bandwidth is 1 GHz.

To eliminate compromises, the N9041B UXA provides two input connectors. The dedicated 1.0 mm input connector is machined to exact tolerances to ensure continuous sweeps and valid measurements up to 110 GHz. A robust and economical 2.4 mm input connector covers measurements up to 50 GHz.

As you reach up to millimeter-wave frequencies, it's easy to underestimate the challenges. We're ready to help you get real results up to 110 GHz with the new N9041B UXA

Viewing Measurement Results at 73.5 GHz (E Band)

The wideband testbed was used to generate and analyze signals at 73.5 GHz with varying symbol rates and occupied bandwidths of up to 5 GHz. Figure 5 shows the measurement results for a single-carrier 16 QAM waveform with a 3.7 GHz symbol rate. The RRC utilized a 0.35 alpha, so the OBW is approximately 5 GHz (3.7 GHz SR * 1.35 = ~5 GHz of OBW). In the blue trace, the 89600 VSA software shows an OBW of 5 GHz. Figure 6 shows the EVM measurement results: the measured EVM value is approximately 2.15% with adaptive equalization applied.

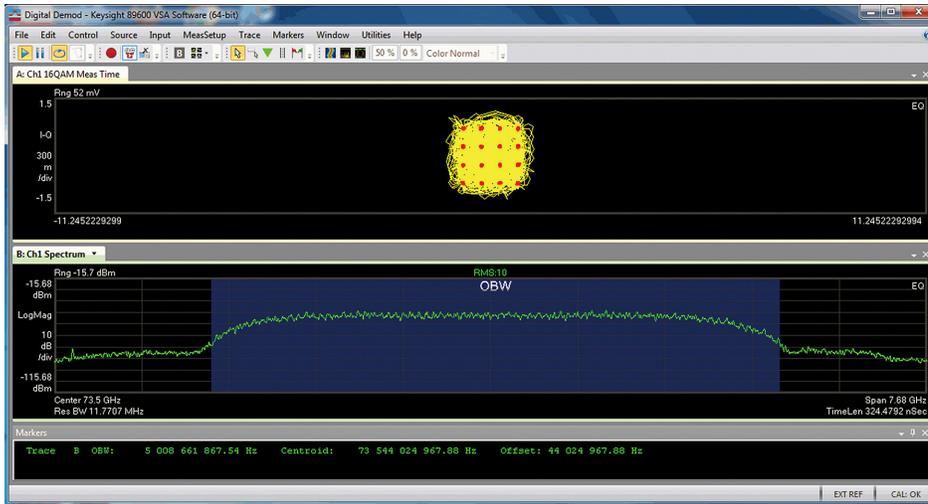


Figure 5. With the testbed, the 89600 VSA software measured an OBW of 5 GHz at 73.5 GHz.

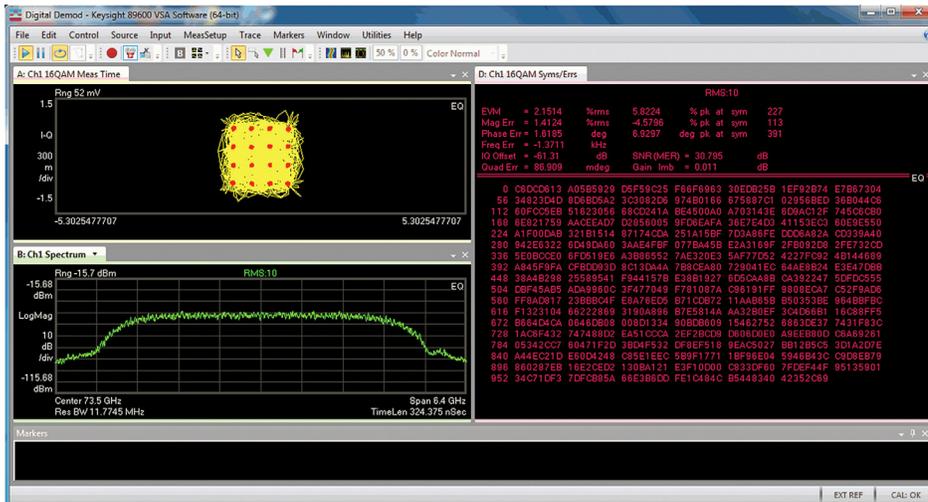


Figure 6. Also using the testbed, the 89600 VSA software measured an EVM of approximately 2.15% in a 16QAM waveform with a 3.7 GHz symbol rate.

Table 2 presents the measurement results for a single-carrier 16 QAM waveform after upconversion from 4 GHz IF from the M8195A AWG to 73.5 GHz, and after downconversion from 73.5 GHz to 4 GHz IF, as measured with the S-Series oscilloscope. The top row shows EVM results measured at the M8195A AWG output using the S-Series oscilloscope and VSA software. These are the same values shown in Table 1, and they are repeated here to enable comparison with the bottom row: the end-to-end EVM values are the results of upconverting and downconverting to and from 73.5 GHz. These were obtained using a 71-76 GHz waveguide bandpass filter connected between the VDI upconverter and downconverter. It can be seen that the residual EVM values are quite low for the digital-based approach to signal generation and analysis.

Table 2. Using the digital-based approach and a waveguide bandpass filter, the M8195A once again produced good EVM values.

	2 GHz SR (~2.7 GHz OBW)	3 GHz SR (~4 GHz OBW)	3.7 GHz SR (~5 GHz OBW)	4 GHz SR (~5.4 GHz OBW)
M8195A 4 GHz IF EVM (%)	1.1%	1.3%	1.4%	1.5%
M8195A 4 GHz IF 73.5 GHz EVM End-to-End (%)	1.5%	1.75%	2.1%	2.2%

Note: EVM results used constellation maximum as the EVM normalization reference, EQ is enabled for all EVM results with BPF—used 71-76 GHz waveguide filter to connect Tx and Rx.

Applying the Testbed to Power Amplifier DPD

The testbed was used for a millimeter-wave DPD application, and the test requirement called for DPD on amplifiers operating at 60 GHz with modulation bandwidths of 2 GHz. The high-level hardware block diagram in Figure 7 shows the configuration used to perform DPD on a Skyworks PA.

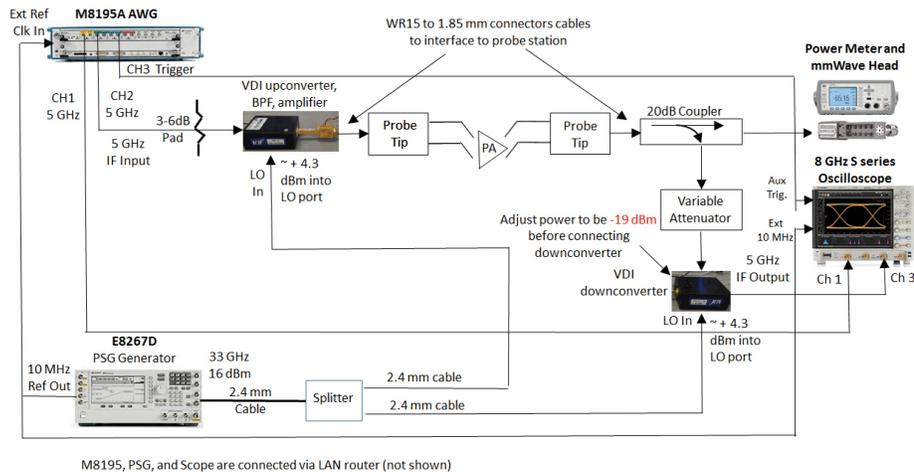


Figure 7. This configuration supports DPD-based measurements on millimeter-wave power amplifiers.

Several key points and connections are worth highlighting:

- The system uses three channels of the M8195A AWG:
 - Channel 1 is connected directly to channel 1 of the S-Series scope to provide a reference signal for the 89600 VSA software when computing gain compression and AM-to-PM conversion.
 - Channel 2 is connected to the IF input of the VDI upconverter and becomes the RF input to the DUT.
 - Channel 3 is connected to the auxiliary input of the S-Series scope to provide a trigger signal. The I/Q data acquired for the DPD model extraction is triggered to allow synchronization of the output I/Q data to the reference waveform.
- Three inputs are connected to the S-Series Scope:
 - Channel 1 and the auxiliary input are connected to channels 1 and 3 of the M8195A, as described above.
 - Channel 2 is connected to the IF output of the VDI downconverter, which is the DUT output signal.
- The LO signal for the up- and downconverters is provided by a 44 GHz E8267D PSG. A power splitter provides the LO to the VDI compact upconverter and downconverter.

A power meter was used to define a lookup table of millimeter-wave power at the probe tip versus AWG voltage level. This was done a priori and enabled the RF drive level to be controlled and varied into the PA DUT. The DUT itself is a PA with a power gain of 15 dB and Psat of 16 dBm, which happens at 5 dB of compression. The interface between the cables and the PA is an MPI ground-signal-ground (GSG) probe, with 100 μm pitch.

A 20 dB coupler was used at the DUT output to monitor the output power. The through path on the coupler was used to monitor the output power of the PA (the through-path insertion loss was compensated by entering a power offset into the power meter). The -20 dB coupled path was used to attenuate and protect the VDI compact downconverter module, given that the PA output power exceeded the module's maximum input power. A WR-12 variable attenuator was used to provide further adjustment of the RF power into the VDI downconverter.

Figure 8 shows an overall photograph of the test setup, and Figure 9 shows two close-up views.

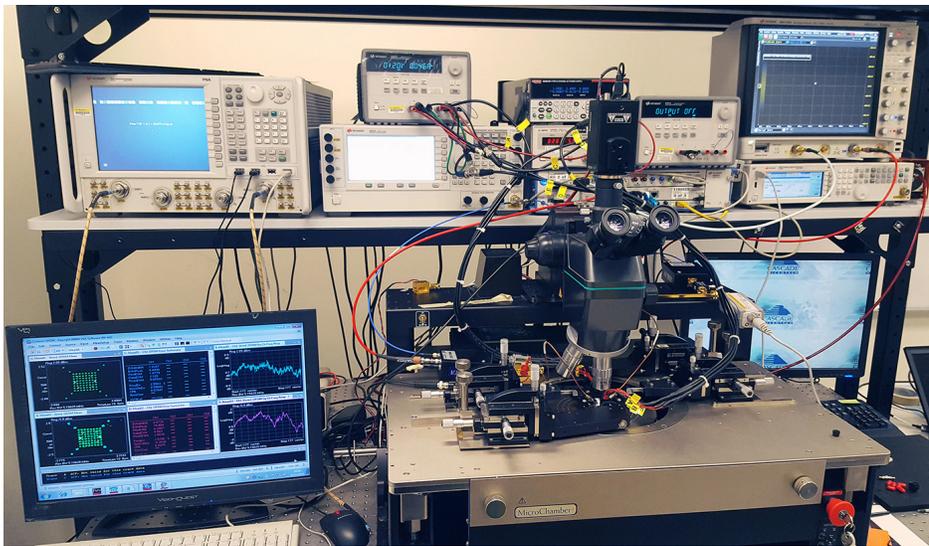


Figure 8. This overall photo of the testbed setup at Skyworks includes the millimeter-wave testbed as well as additional instruments such as a vector network analyzer and a variety of DC power supplies.

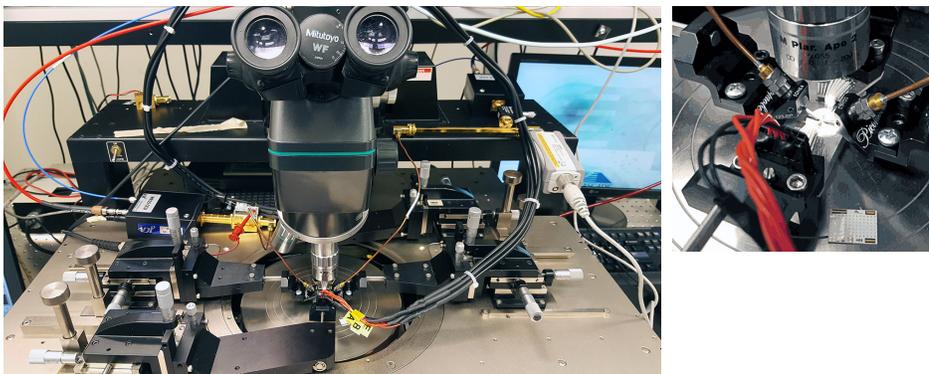


Figure 9. These close-up photos of the test setup show the probe station microscope (left) and the PA itself (right).

The software for the DPD measurement system utilized SystemVue and the 89600 VSA. SystemVue was used to generate the test waveforms, perform the DPD model extraction, and then apply the DPD model to generate pre-distorted waveforms. The VSA software was used to measure EVM and ACPR, visualize AM-to-AM and AM-to-PM distortion, and extract the measured I/Q data used for the DPD model extraction. A C# program was used to coordinate the software applications and control the M8195A AWG and LO signal generators. The block diagram in Figure 10 shows the structure of the software.

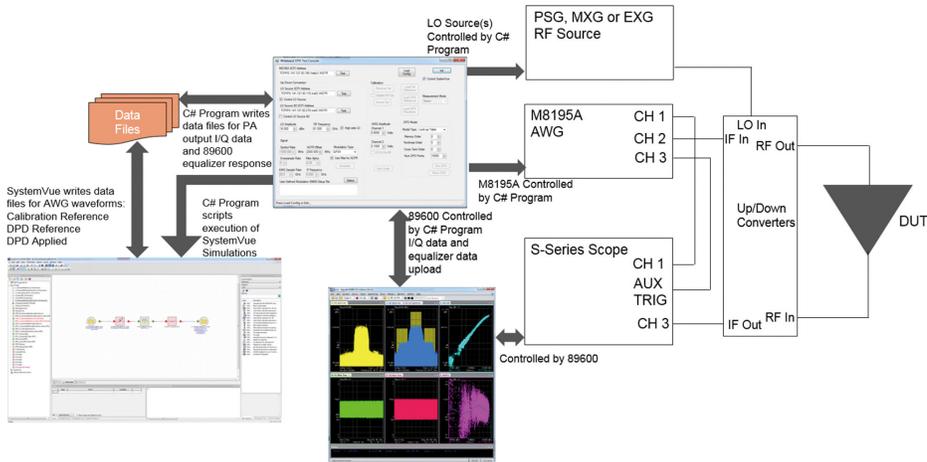


Figure 10. The system uses a combination of off-the-shelf and custom-coded software, working together as shown in this diagram.

The core of the process is to generate the reference waveform at the same sample rate that will be used for DPD model extraction (e.g., 7.5 GHz, or 5x the 1.5 GHz symbol rate). Calibration data was applied to this waveform and it was further upsampled to the ~64 GHz sample rate of the M8195A AWG.

The C# program performs the I/Q modulation in software and downloads the IF waveform into the AWG. The 89600 VSA software is configured to extract I/Q data at the 7.5 GHz analysis sample rate. The VSA is also configured to measure EVM, ACPR gain compression and AM/PM conversion.

The I/Q data measured at the DUT output is sent to SystemVue for DPD model extraction and waveform pre-distortion; the resulting waveform is loaded into the AWG. The various 89600 measurement modes can then be used to observe the improvements that result from the DPD process.

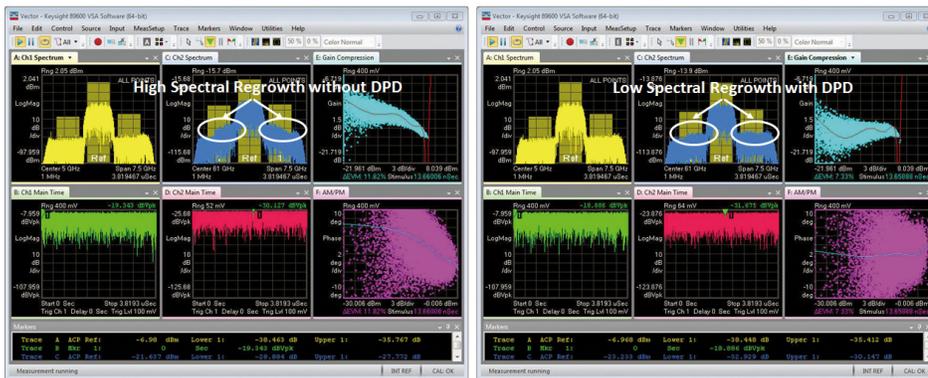
The DPD model extraction can be configured to use a lookup table, memory polynomial or volterra series. In addition, parameters including lookup table size and polynomial order can be configured. These values are adjustable through the C# program, simplifying the process of determining the optimal DPD model parameters.

Assessing Actual DPD Measurement Results

DPD measurements were performed for QPSK and 64 QAM with a 1.5 GHz symbol rate. With the excess bandwidth of the RRC filter, this corresponded to an OBW of approximately 2 GHz. The measurement bandwidth was five times the symbol rate, or 7.5 GHz. Achieving that bandwidth required use of an M8195A AWG as the wideband source, and an 8 GHz S-Series scope was used as the wideband digitizer.

Two different DUTs were measured. One was a single-stage PA based on a 45 nm SOI CMOS technology with approximately 7.5 dB gain and a continuous wave (CW) 1 dB compression point (P1dB) of approximately 11 dBm and Psat of around 15 dBm. The other DUT (based on the same semiconductor platform) was a three-stage PA with 14 dB gain and a CW P1dB of approximately 15 dBm. In designing the PA, the goal was to render an amplifier with minimum AM-AM and AM-PM distortion with little or no memory effect. AM/PM variation across the design frequency band is a measure of the amount of memory effect of the amplifier, and sudden variations in AM/PM vs. frequency are symptoms of linearization problems [2].

The DPD measurements were performed at several RF input powers for the single-stage PA, and over a range of RF-input powers for the three-stage PA. The three-stage PA was of higher importance to the customer. In general, DPD provided 2 to 4 dB of improvement in adjacent channel power and 1 to 2 percent improvement in EVM, relative to results without application of DPD. Figures 11 and 12 show ACP and EVM results for a single test case of the three-stage PA. Several approaches were used to properly model the PA and, ultimately, it was found that a third-order memory polynomial with one memory span most accurately represented PA behavior. This eliminated the need to use more complicated Volterra models, even at high compression values.



PA Output- No DPD
 Lower ACP = -28.8 dB
 Upper ACP = -27.7 dB

PA Output- With DPD
 Lower ACP = -32.9 dB => **4.1 dB improvement**
 Upper ACP = -30.2 dB => **2.5 dB improvement**

Figure 11. As shown on the right, applying DPD yields improved ACP in the three-stage PA.

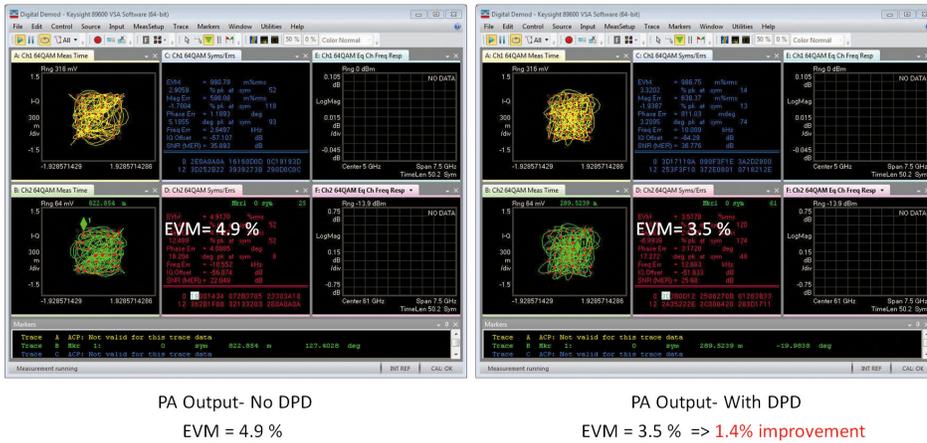


Figure 12. As shown on the right, applying DPD also improves EVM in the three-stage PA.

Summary

The availability of newly-allocated frequency spectrum creates new possibilities for 5G applications that will provide high data throughput using wide-bandwidth digital modulation. Working at increased bandwidths will challenge test methods, and a paradigm shift from analog to digital technology will accelerate the validation of 5G designs.

An example is the wideband millimeter-wave testbed described in this white paper. This innovative approach uses digital technology and compact millimeter-wave converters to generate and analyze very wide-bandwidth millimeter-wave test signals (> 2 GHz to 5 GHz). Low EVM performance was presented for test signals up to 5 GHz of occupied bandwidth.

A joint PA DPD collaboration with Skyworks successfully demonstrated this wideband millimeter-wave testbed applied to a millimeter-wave PA. This DPD application required 7.5 GHz of signal generation and analysis bandwidth, or 5x the 1.5 GHz QPSK and 64QAM symbol rate. Two different power amplifiers were successfully linearized with the test bed, with single carrier QPSK and 64QAM modulations.

References

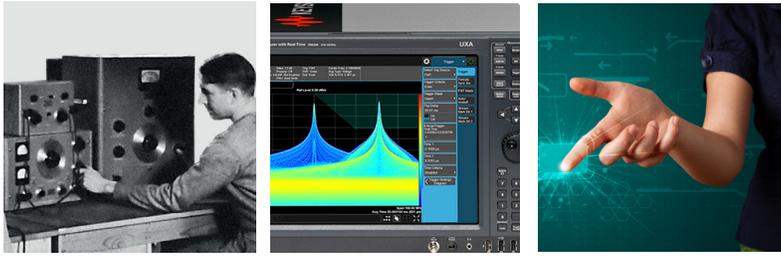
[1] Press release: FCC Takes Steps to Facilitate Mobile Broadband and Next-Generation Wireless Technologies in Spectrum Above 24 GHz, https://apps.fcc.gov/edocs_public/attachmatch/DOC-340301A1.pdf

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