Keysight Technologies
Solutions for Creating and Analyzing Custom OFDM Waveforms for Software-Defined Radio (SDR)

Application Brief

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Many of today's commercial wireless standards are based on a highly versatile transmission scheme: orthogonal frequency-division multiplexing (OFDM). Additionally, a method to enable multiple users on the same OFDM spectral channel is employed called orthogonal frequency-division multiple-access (OFDMA). Examples include 802.11a/g/n, 802.11ac/ad, 802.16e WiMAX, FDD-LTE, TDD-LTE and LTE-Advanced.

OFDM and OFDMA technologies provide important advantages in four areas: data throughput, spectral efficiency and scalability, data integrity, and waveform robustness in the presence of multipath fading. In addition, both technologies have the potential to be customized to suit the needs of proprietary applications.

For these reasons and more, OFDM and OFDMA are viewed as viable technologies for the development of communications systems including software-defined radio (SDR) and cognitive radio. The more successfully these technologies can be deployed, the easier it will be to achieve seamless communication and coordination between diverse public-safety agencies or military forces.

Because OFDM and OFDMA technologies are complex, they pose many challenges in the development process. Fortunately, development can be accelerated by design and test tools that simplify the creation, simulation, generation and analysis of standard or proprietary OFDM and OFDMA waveforms.

For device testing, waveforms can be created using the Keysight Technologies, Inc. SystemVue electronic system level (ESL) design software and downloaded to an Keysight high-precision arbitrary waveform generator (AWG). Vector signal generators such as the Keysight MXG offers an internal AWG with modulation bandwidth to 160 MHz that can be used to produce gigahertz-range carrier signals modulated with custom or standardized waveforms. On the analysis side, single-input/single-output (SISO) and multiple-input/multiple-output (MIMO) measurements are possible. For example, SISO measurements of custom OFDM waveforms can be made with an Keysight X-Series RF signal analyzer or an Infiniium 90000 X-Series high-performance digital oscilloscope coupled with the Keysight 89600 vector signal analysis (VSA) software. Additionally the oscilloscope and VSA software can be used for MIMO measurements of OFDMA standard waveforms like LTE or WiMAX.

This application note outlines the complexities of generating and analyzing standardized and custom waveforms, proposes solutions that address these problems, and presents the results of the suggested approaches. For those interested in deeper background about OFDM and OFDMA, a list of related information is included at the end of the note.

Problem

The use of custom OFDM waveforms presents several key challenges in both design and test. First, simulation environments need custom OFDM baseband simulation capabilities to generate and analyze the complex signals used in RF SDR designs. Second, simulation software and test equipment must be seamlessly integrated to create and analyze custom OFDM test signals not supported by off-the-shelf test equipment but needed for device testing.

The complexity of OFDM waveform generation is worth a closer look, and a quick walk-through of the diagram in Figure 1 will help illustrate the challenges. Signal generation proceeds as follows:

– Digitized voice or data bits are fed into baseband blocks.
– The baseband blocks encode and interleave the input bit stream, and maps the resulting bits "n" at a time onto the transmit constellation.
– In this example, the four bits "1011" correspond to a location with the I/Q coordinates 0.29 + j0.85 on a 16QAM constellation. This complex value is loaded into the next bin in an array of 52 complex values. The process is repeated until 192 bits have been converted

and the entire array has been filled with those values plus four bins that contain "pilot" signals.
– An inverse fast-Fourier transform (IFFT) is performed on the completed array, producing a new array containing 64 complex values.
– The resulting values are clocked out at a 20 MHz rate, yielding a 3.2-μs signal segment that represents a single "symbol" that, in this case, contains 192 bits of payload. Multiple symbols are joined to create a single "frame."

On the receiving end, an FFT is performed on each symbol waveform, recreating the original array of 52 complex values. These are mapped onto the constellation, converted back to bits, decoded, and so on.

This process is even more complex with the "multiple access" capability of OFDMA. In concept, the subcarrier allocation could vary as a function of time (e.g. symbols, timeslots, frames) to support multiple users or multiple SDRs. Handling this additional complexity puts a greater burden on the devices, simulation software and test equipment.
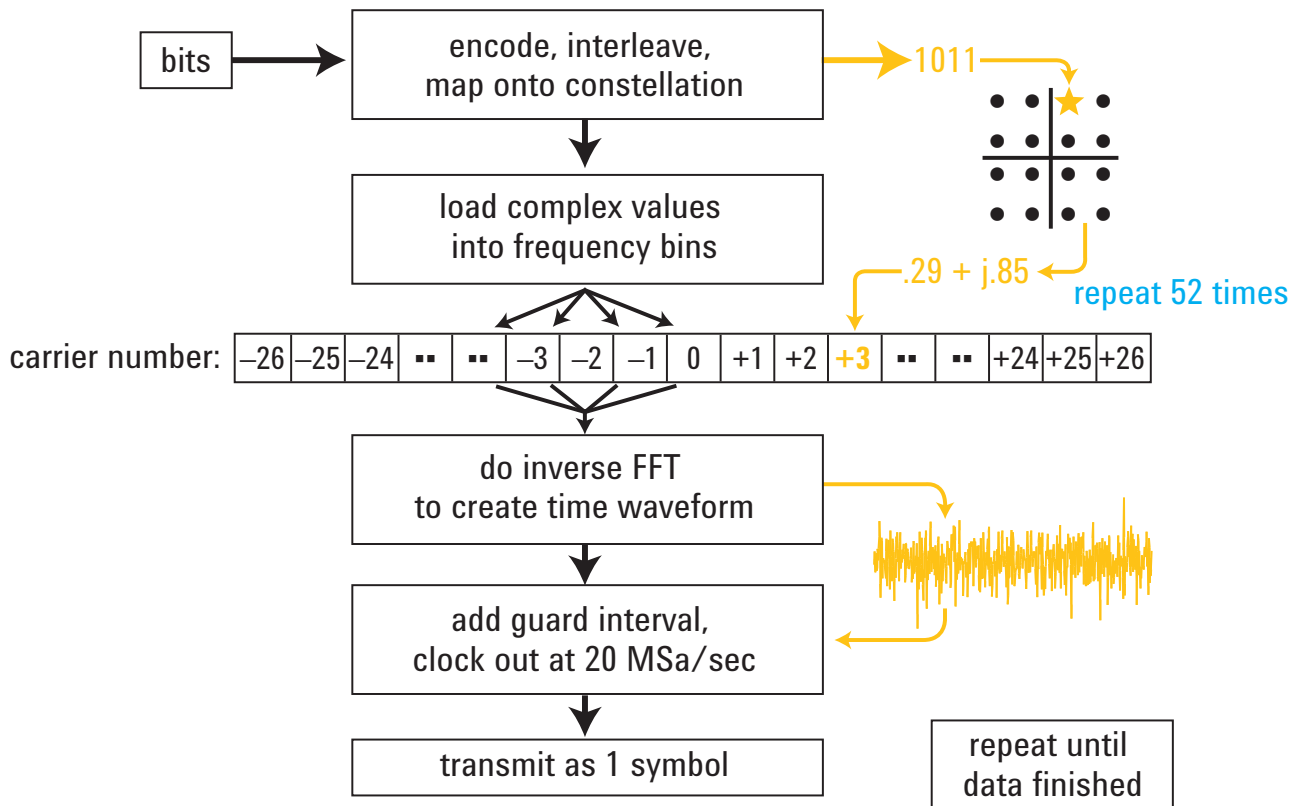

Figure 1. Generation of OFDM signals requires advanced baseband functionality.

Solutions and results: Custom OFDM

The custom OFDM solution has six major elements: simulation software, an AWG and a vector signal generator for signal creation; and a scope, signal analyzer and VSA software for signal characterization.

SystemVue and the 89600 VSA are both equipped to support SISO implementations of custom OFDM signals. For example, SystemVue includes a general-purpose OFDM library and application examples that can be used as the foundation of custom formats. A simulated OFDM signal, with I and Q components, can be created in SystemVue as either an ideal waveform or an impaired waveform that includes multipath, fading and other issues that are useful for testing SDR designs.

SystemVue also provides a parameterized OFDM reference source, with full framing and preambles, built from the custom OFDM library models. The OFDM source also provides configuration information to the "custom OFDM" personality of the 89600 VSA software (option BHF), enabling convenient demodulation and analysis of custom or proprietary signals.

The 89600 VSA software supports more than 70 signal standards and modulation types, and its advanced troubleshooting tools enable measurements in the time, frequency and modulation domains. To help reveal what's happening inside complex wireless devices, the state-of-the-art graphical user interface provides virtually unlimited trace views and markers for each trace. Because the software runs on more than 30 Keysight measurement platforms—scopes, signal analyzers and logic analyzers—vector signal analysis can be applied virtually anywhere within a block diagram. This enables evaluation of the SDR waveform at RF, IF or I/Q, and within an FPGA implementation by using a logic analyzer with Dynamic Probe.

With this range of capabilities, SystemVue and the 89600 VSA software provide a developer's suite that can be used for both the design and verification of customized OFDM-based communication formats.

Working with SISO custom OFDM

In this scenario, SystemVue was used to create custom OFDM waveforms, and the VSA software was used (with an oscilloscope) to demodulate the resulting waveforms. Alternatively, a PXA signal analyzer with the VSA software could be used for demodulation and analysis.

Figure 2 shows the system configuration. The OFDM waveform from SystemVue was downloaded to the AWG within the MXG vector signal generator. The internal AWG/ real time baseband generator (BBG) of the MXG vector signal generator has an RF modulation bandwidth of up to

160 MHz.The modulated 5.8-GHz carrier signal can be used as an input to a hardware DUT.

The custom OFDM signal was analyzed using a 13-GHz high-performance scope, which was running the 89600 VSA software. As shown in Figures 3 and 4, the software demodulated the OFDM signal and performed 256- or 512-point FFTs, respectively, to produce the corresponding frequency spectra (lower-left corner of each trace). Constellations and error-vector magnitude (EVM) values were derived from the demodulated waveforms.

N5182B MXG

RF DUT
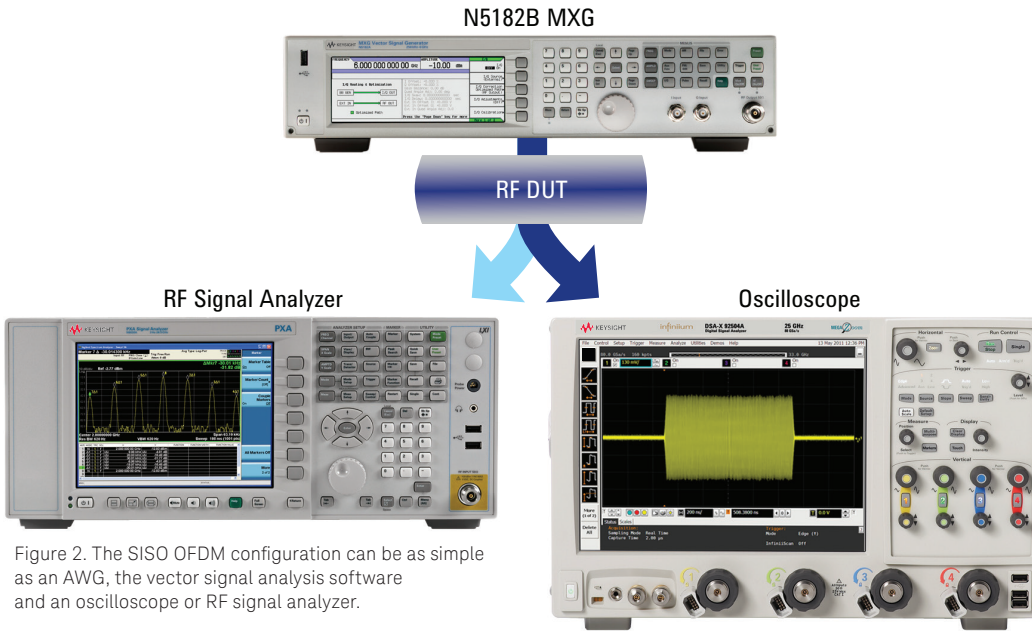
RF Signal Analyzer

Oscilloscope

Figure 2. The SISO OFDM configuration can be as simple as an AWG, the vector signal analysis software and an oscilloscope or RF signal analyzer.
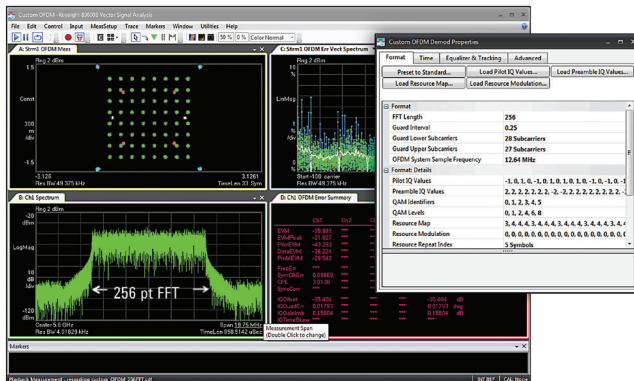

Figure 3. These results show demodulation of the custom OFDM signal: constellation (upper left), spectrum from 256-point FFT (lower left), EVM versus subcarrier (upper right) and EVM (lower right).
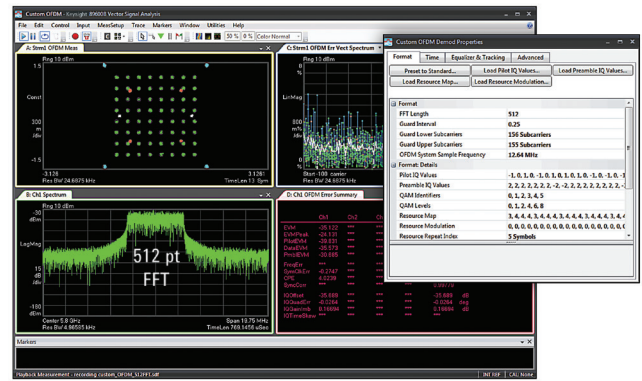

Figure 4. These results show demodulation of the custom OFDM signal: constellation (upper left), spectrum from 512-point FFT (lower left), EVM versus subcarrier (upper right) and EVM (lower right).
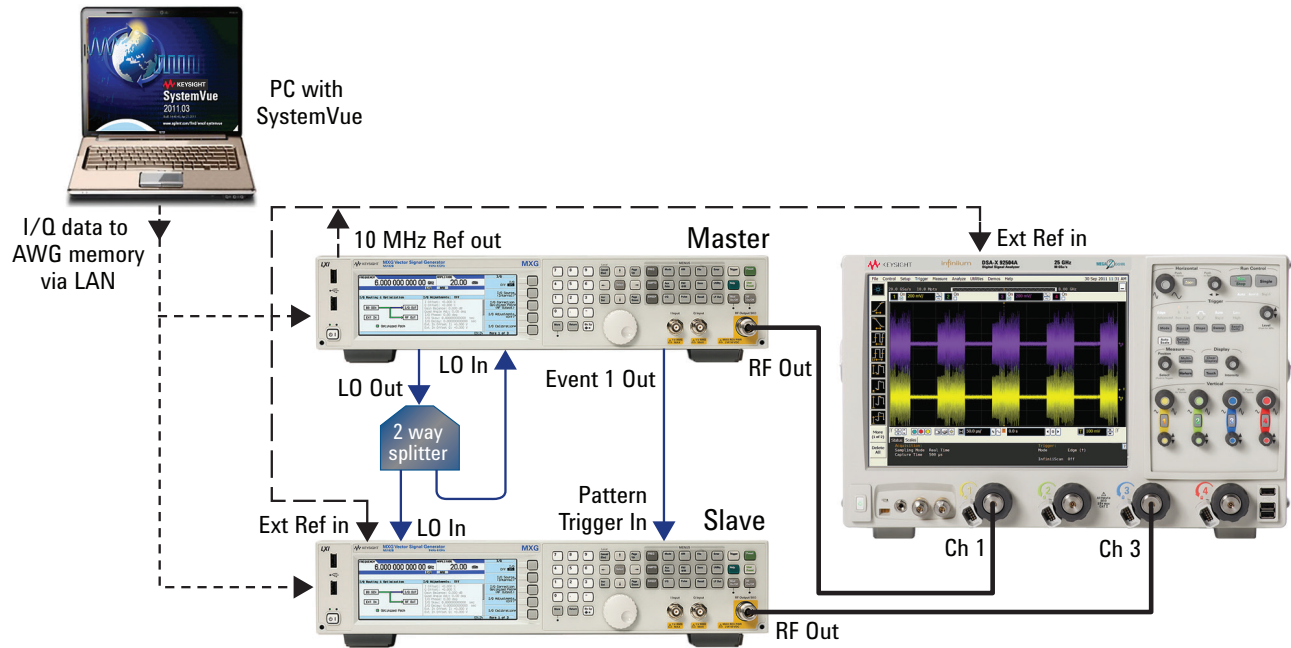
Working with MIMO OFDMA

Figure 5. This configuration supports signal creation, generation and analysis for 2x2 MIMO designs.

In this 2x2 MIMO example, the system included two AWGs, two vector signal generators and one multi-channel oscilloscope (Figure 5). The accuracy of MIMO measurements depends on a stable phase relationship across all signals. To generate a phase coherent signal for a 2x2 MIMO configuration with the MXG, Master MXG LO Out is connected to the Slave LO In. The LO Out provides a sufficient amplitude LO signal when connected directly, to drive the Slave MXG, thus providing phase coherency for the RF signal output signals. The 10-MHz reference from the "master" vector signal generator was connected to each of the other instruments. Also, an optional special-purpose cable was used to establish time synchronization between the two AWGs, enabling the instruments to share the same sampling clock.

From SystemVue, LAN connectivity was used to download the I and Q waveforms to each AWG. The I/Q outputs of the master and slave AWGs were connected to the wideband I/Q inputs of the master and slave vector signal generators.

As a demonstration of MIMO measurement and analysis, the modulated 5.8-GHz carrier signals were connected to channels 1 and 3 of the four-channel scope. Because all four channels are phase-coherent, the Infiniium X-Series scope can be used to perform RF MIMO measurements with the 89600 VSA software.

The 13-GHz scope was used to verify proper synchronization of the two MIMO waveforms, as shown in Figure 6. With the oscilloscope's phase-coherent inputs, the VSA software was able to properly demodulate both signals and provide the results shown in Figure 7. In the figure, the two constellations are at the upper left, the two spectra (centered at 5.8 GHz) are at the lower left, and the EVM results are on the right in the upper and lower traces. In this case, EVM was approximately -40.4 dB for channel 1 and -40.6 dB for channel 2 with the software's equalizer training set to "preamble, pilots and data."

I/Q impairments can impact a device's residual EVM performance. In this example, I/Q imbalance was manually adjusted using front-panel controls on the AWG. This was done by first downloading SISO signals to each AWG and then using a PXA signal analyzer running the 89600 VSA software to measure the I/Q imbalance while adjusting the AWG settings.
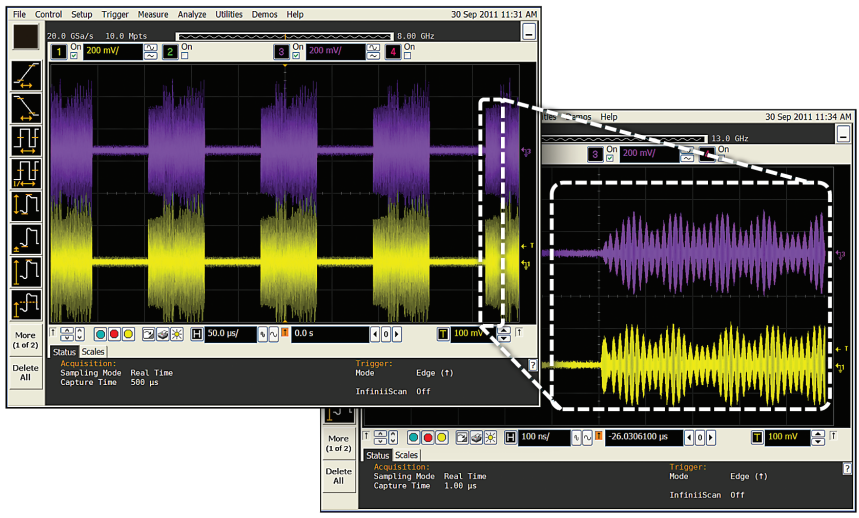

Figure 6. These time-domain waveforms show the synchronization of the wideband MIMO waveforms.

Figure 7. These 89600 traces show the RF MIMO demodulation results at 5.8 GHz: two constellations, two frequency spectra, and the EVM.

Conclusion

OFDM and OFDMA provide important advantages in data throughput, spectral efficiency and scalability, data integrity, and waveform robustness in the presence of multipath fading. In addition, OFDM can be easily customized to suit the needs of proprietary applications, such as SDR and cognitive-radio systems.

The SISO and MIMO solutions presented here simplify the creation, simulation, generation and analysis of proprietary OFDM waveforms and standard-based COTS OFDMA waveforms. The flexibility and convenience of Keysight instruments and software accelerate development and, ultimately, help ensure successful communication between diverse public-safety agencies or military forces.

Related information

SystemVue ESL software: www.keysight.com/find/SystemVue
  – Application note: *Custom OFDM Signal Generation Using SystemVue,* publication 5990-6998EN
    http://cp.literature.keysight.com/litweb/pdf/5990-6998EN.pdf
  – Application note: *Flexible OFDM Signal Generation,* Analysis and Troubleshooting, publication 5990-9757EN
    http://cp.literature.keysight.com/litweb/pdf/5990-9757EN.pdf
  – Brochure: *Keysight SystemVue System-Level Design & Verification Environment,* publication 5990-9412EN
    http://cp.literature.keysight.com/litweb/pdf/5990-9412EN.pdf
  – Technical overview: *Keysight EEsof EDA SystemVue 2013*, publication 5990-4731EN
    http://cp.literature.keysight.com/litweb/pdf/5990-4731EN.pdf
89600 VSA software: www.keysight.com/find/89600
  – Brochure: *Keysight 89600 VSA Software: See through the complexity,* publication 5990-6553EN
    http://cp.literature.keysight.com/litweb/pdf/5990-6553EN.pdf
  – Technical overview: *89601B/BN-105 Link to EEsof ADS/SystemVue 89600 VSA Software,* publication 5990-6410EN
    http://cp.literature.keysight.com/litweb/pdf/5990-6410EN.pdf
M8190A 12 GSa/s arbitrary waveform generator: www.keysight.com/find/M8190A
  – Brochure: *Enhance your reality, Keysight M8190A AWG,* publication 5990-7516EN
    http://cp.literature.keysight.com/litweb/pdf/5990-7516EN.pdf
81180B 4.6 GSa/s arbitrary waveform generator: www.keysight.com/find/81180
  – Data sheet: *Keysight 81180B Arbitrary Waveform Generator,* publication 5991-0364EN
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Infiniium 90000 X-Series oscilloscopes: www.keysight.com/find/90000X-series
  – Data sheet: *Keysight Infiniium 90000 X-Series Oscilloscopes,* publication 5990-5271EN
    http://cp.literature.keysight.com/litweb/pdf/5990-5271EN.pdf
N9030A PXA signal analyzer: www.keysight.com/find/PXA
  – Brochure: *Drive your evolution, PXA X-Series Signal Analyzer N9030A,* publication 5990-3951EN
    http://cp.literature.keysight.com/litweb/pdf/5990-3951EN.pdf
  – Data sheet: *N9030A PXA X-Series Signal Analyzer,* publication 5990-3952EN
    http://cp.literature.keysight.com/litweb/pdf/5990-3952EN.pdf
  – Brochure: *X-Series Signal Analysis,* publication 5990-7998EN
    http://cp.literature.keysight.com/litweb/pdf/5990-7998EN.pdf
N7109A multi-channel signal analyzer: www.keysight.com/find/N7109A
  – Data sheet: *Keysight N7109A Multi-Channel Signal Analyzer,* publication 5990-6732EN
    http://cp.literature.keysight.com/litweb/pdf/5990-6732EN.pdf
Wideband PXI MIMO vector signal analyzer: www.keysight.com/find/PXI-VSA

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