# Testing Next-Generation Optical Systems with Simulated OFDM Signals

## Application Note

## Overview

Orthogonal frequency-division multiplexing (OFDM) has become widely used for wideband digital communication in wired and wireless systems. Recently, it has also attracted the attention of researchers developing long-haul optical transmission systems.

In optical applications, OFDM has the capability to overcome a variety of limitations commonly associated with optical transmission systems: modal dispersion, relative intensity noise, chromatic dispersion, polarization mode dispersion, and self-phase modulation. Attracted by these inherent advantages, researchers are experimenting with two forms of OFDM in optical systems: coherent-optical OFDM (CO-OFDM) and direct-detected optical OFDM (DDO-OFDM).

The main differences between CO-OFDM and DDO-OFDM are in the ways optical signals are generated and received. For example, a typical CO-OFMD architecture uses in-phase/quadrature (I/Q) modulation with coherent detection. In contrast, a typical DDO-OFDM architecture uses single-sideband (SSB) transmission and direct detection.

These details are worth mentioning because they have implications for the required test system. During the early phases of development, one of the most important implications is the need for flexibility in both the software and hardware used to create and generate suitable test signals.

The measurement solution presented here includes software and hardware that is flexible enough to handle a wide range of modulation schemes, channel spacings, spectral widths, and detection methods. As is described later, the major elements are the Agilent SystemVue software environment and an Agilent M8190A 12 GSa/s arbitrary waveform generator (AWG).

## Problem

The root problem is the ever-growing need among businesses and consumers to consume more data in less time. Today, a typical long-haul optical transmission system carries data at a 10 Gb/s and uses direct detection. Next-generation systems have taken data rates to 40 Gb/s and 100 Gb/s, and rates of 1 Tb/s and higher are currently under investigation.

In day-to-day development work, the combination of higher data rates, new architectures and complex modulation schemes makes testing more challenging—especially when the relevant standards are evolving, or when experiments include proprietary modulation schemes. One of the key challenges is in the digital version of "cut and try" as it relates to the creation of highly realistic test signals. The two main elements of the test solution are a software environment for signal creation and an AWG capable of producing complex modulated signals.

For signal creation, the range of possibilities includes programming languages, general-purpose mathematical environments and dedicated signal-creation applications. In general, the use of programming languages and math environments requires a larger time investment than a purpose-built application. Of course, a dedicated signal-creation application must support the required modulation types—OFDM in this case. It must also provide sufficient flexibility to enable experimentation with parameters such as subcarriers, pilots, preambles, data, symbols, and more. Once the signal has been created, direct support of high-performance AWGs—including easy downloading of waveforms—can save time.

In signal generation, most AWGs require a compromise between resolution and bandwidth. Also, when I/Q modulation is being used, precise synchronization of two separate AWGs—or two independent outputs in a single AWG—is essential.

## Solution

You can create highly realistic test signals by combining the Agilent SystemVue environment with an Agilent M8190A AWG and an analog signal generator. For signal analysis, combining a real-time scope or high-performance signal analyzer with the Agilent 89600 vector signal analysis (VSA) software enables advanced modulation analysis of transmitted and received signals. All this can be accomplished with a system configuration created by members of Agilent's application engineering organization (Figure 1).

In the example system, the I and Q components of a time-domain signal were created in SystemVue and then downloaded to the M8190A AWG. With its pair of synchronized output channels, the AWG provided the analog signals at 10 GSa/s for both the I and Q components. The AWG was phase-locked to the synthesizer through a 10 MHz reference.

In the device under test, the optical I/Q modulator directly imposed the baseband OFDM signal onto four optical tones. The modulator was biased at its null point to completely suppress the optical carrier before performing linear baseband-to-optical upconversion. The optical output of the I/Q modulator consists of four-band orthogonal band-multiplexed (OBM) OFDM signals and each band was filled with the same data.

To improve the spectrum efficiency, 2x2 multiple-input/multiple/output (MIMO) OFDM was also used. The two OFDM transmitters were emulated by splitting the transmitted signal and recombining it on orthogonal polarizations with a one-symbol delay.

These were detected by two OFDM receivers, one for each polarization. Within the receiver, each signal was coupled out of the recirculation loop and received with an optical receiver that included a polarization beam splitter, a local laser, two optical 90° hybrids, and four balanced photoreceivers.

In this example the complete OFDM spectrum had four sub-bands, and the entire bandwidth was only 32 GHz for an OFDM signal running at approximately 100 Gb/s. The local laser was tuned to the center of each band and the RF signals from the four balanced detectors were passed through anti-aliasing low-pass filters. The performance of each band was measured independently by sampling the detected RF signals with an Agilent 90000 X-Series oscilloscope and then processing the sampled data with the Agilent 89600 VSA software.

1. *SystemVue and the 89600 VSA software were both running on the PC; however, the VSA software can also run inside a variety of Agilent oscilloscopes and signal analyzers.*

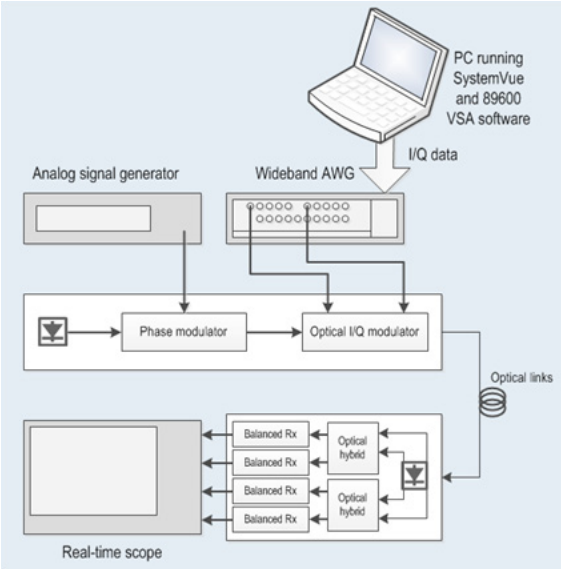


*Figure 1. Block diagram of system that provides OFDM signal generation and analysis*

## Creating custom OFDM waveforms with SystemVue

The W1461 SystemVue Communications Architect environment includes a general-purpose OFDM reference block set and application examples that can be used to create a variety of formats. The software also provides a parameterized OFDM reference source—with full framing and preambles—built out of the OFDM block set.

SystemVue provides a convenient, tabbed user interface that resides atop the OFDM source, simplifying simulation and component validation (Figure 2). The software also supports the downloading of waveforms to Agilent AWGs such as the M8190A, 81180 and M9330A, and signal generators including the Agilent ESG and MXG families.

The SystemVue OFDM source can also send configuration information to the Agilent 89600 VSA software through its Custom OFDM personality (option BHF). This makes it possible for the VSA software to demodulate and analyze real or simulated OFDM signals.

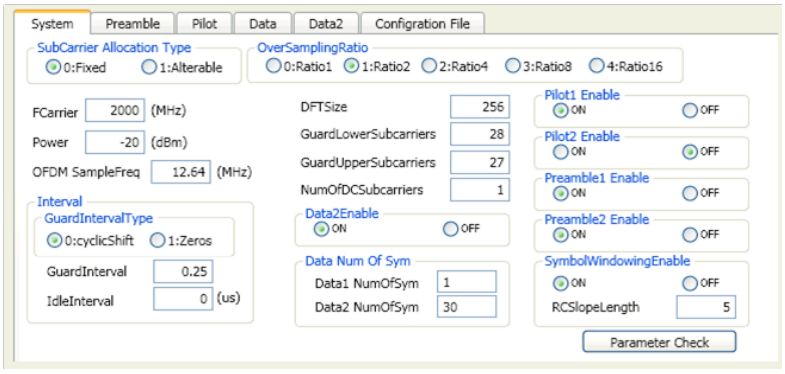


*Figure 2. The convenient tabbed interface provides tremendous flexibility in the creation of OFDM signals*

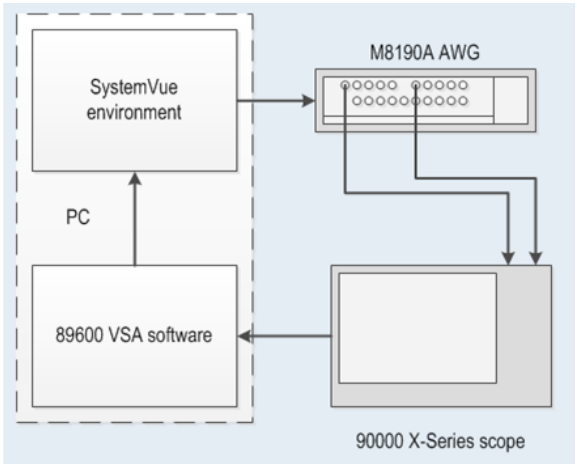


*Figure 3. Wideband calibration of the AWG output is possible with SystemVue and the 89600 VSA software running on the same PC*

## Applying I/Q baseband flatness correction

When generating an OFDM signal, you can significantly improve the error vector magnitude (EVM) by performing an amplitude and phase calibration in conjunction with the 89600 VSA software. To do this, the VSA software must be installed on the same PC as SystemVue.

Procedurally, the connection to the oscilloscope that captures the signal must be established before applying the FIR filter in SystemVue. The calibration routine uses the 89600's built-in equalizer to determine the channel frequency response. The SystemVue MathLang code uses the complex frequency response of the equalizer to calculate a pre-distorted waveform.

Without some form of compensation, there will be variations in the magnitude of the output response that are a function of frequency. These are the result of the sinc function (i.e., (sin x)/x) roll-off of the AWG's digital-to-analog converter (DAC) and the frequency response of the reconstruction filter. The correction method uses finite impulse response (FIR) filters to level the amplitude response and create a linear phase response at the AWG output.

This process attenuates the signal as a function of frequency, but cannot increase the signal above the maximum output voltage. As a result, it is necessary to attenuate the lower frequency signals. In turn, this causes reduced output voltage and dynamic range at all frequencies, but with uniform response across the full frequency range.

## Conclusion

Whether your optical transmission system is using CO-OFDM, DDO-OFDM or another approach, the solution described here provides convenience and flexibility in the creation and generation of highly realistic test signals. The SystemVue environment offers unique advantages to RF, DSP and FPGA/ASIC implementers who rely on both RF and digital signal processing to achieve the full value of their hardware platforms. The M8190A AWG enables realistic testing by providing high resolution and wide bandwidth simultaneously. And the 89600 VSA software provides a window into what's happening inside complex modulated signals and the devices that produce them. Working in concert, these tools provide an excellent development suite for the design and verification of OFDM-based communication signals in optical applications and elsewhere.

## Related Literature

- *Data Sheet: Agilent M8190A 12 GSa/s Arbitrary Waveform Generator*
  Publication 5990-7516EN
- *Technical Overview: Agilent EEsof EDA SystemVue 2011*
  Publication 5990-4731EN
- *Brochure: 89600 Vector Signal Analysis Software*
  Publication 5990-6553EN
- *Application Note: Custom OFDM Signal Generation Using SystemVue*
  Publication 5990-6998EN

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