APPLICATION NOTE

How to Create Baseband Waveforms and Download Them to RF Vector Signal Generators

KEYSIGHT

Radio-frequency (RF) vector signal generators (VSG) use a dual arbitrary waveform generator (AWG) to generate baseband I (in-phase) and Q (quadrature) waveform signals. The dual AWG controls the playback sequence of waveform segments that have been written into the memory located in the internal baseband generator. Like an MP3 player that converts an audio file to an analog signal, the dual AWG enables you to play, rename, delete, store, and load waveform files in addition to building waveform sequences.

Baseband Waveform Data and Structure

Creating baseband waveform files for a VSG requires an understanding of the communication system and the waveform data requirements of the baseband generator. Before you create custom waveform files, you need to know the file formats the VSG supports and the waveform data required for playback.

AWG basics

A dual AWG is flexible and can generate many complex modulation signals. You can simulate your design and create the waveform files from a PC, then use the dual AWG to convert the files into analog signals. However, you need to understand the key specifications of AWGs first. Figure 1 illustrates the basic block diagram for an AWG. The key specifications appear below:

- **Sampling rate:** The maximum speed of conversion of the digital-to-analog converter (DAC). This parameter is equal to the speed at which the waveform memory reads samples.
- **Vertical resolution:** This is the number of DAC bits in the AWG. For a given vertical resolution, N, the DAC will be capable of generating 2N different levels. For an RF VSG, the number of bits of the DAC is 12 to 16.
- **Memory size:** The maximum number of samples that the waveform memory can store.
- **Output characteristics:**
  - Maximum voltage and DC offset ranges
  - Output impedance (typically 50 Ω)
  - Availability of differential outputs
  - Amplitude and phase flatness (frequency response)

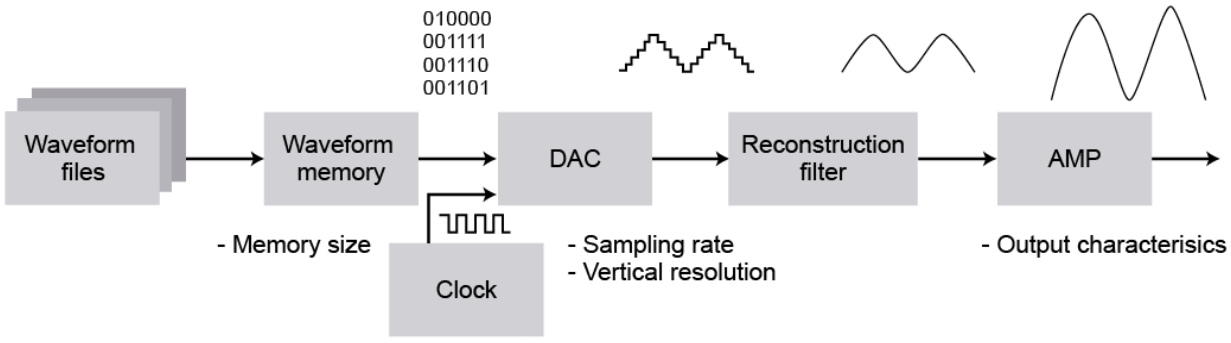

Figure 1. A basic block diagram for an AWG

RF VSGs use dual AWGs to generate baseband I and Q signals. For example, the maximum sample rate of Keysight MXG N5182B's baseband generator is 200 MSa/s, the number of bits of the DAC is 16, and playback memory size is up to 1024 megasamples. These specifications limit the signal's maximum RF bandwidth, dynamic range, and waveform length correspondingly. The output connectors are BNC single-end or differential outputs with impedance 50 Ω, DC coupled.

Understanding waveform data

A media player can play different types of digital audio formats, such as Waveform Audio File and MPEG Audio III (MP3). A sound card uses a DAC, which converts the digital data into an analog signal. You need to know if the media player supports the digital audio format that you want to play. Likewise, to generate baseband signals successfully, you need to understand what the AWG input data is and how to transfer a waveform file to the baseband generator. Let's explore the input data a DAC requires.

DAC input values

The DAC determines the range of input values for the I and Q data samples. A 16-bit (2 bytes) DAC means that you can divide the output range of the DAC into 0–65,535 (2^{16}) levels. A baseband generator divides the range with positive (32,767) and negative values (-32,768). Baseband generators accept binary or hex data formatted as shown in Figure 2.

Voltage	DAC Range	Input Range	Binary Data	Hex Data
Vmax	65535	32767	01111111 11111111	7FFF
	32768	1	00000000 00000001	0001
0 Volts	32767	0	00000000 00000000	0000
	32766	-1	11111111 11111111	FFFF
Vmin	0	–32768	10000000 00000000	8000

Figure 2. 16-bit DAC input values correspond to output voltages

Waveform Files and Sequences

Waveform files are the most fundamental element for baseband waveform generation. Specific application software or general software tools, such as MATLAB, C++, or Keysight's waveform generation software, can generate waveform files. There are two types of waveform files: segment and sequence.

Waveform segment

A segment is a waveform file that you download to the signal generator's memory. It consists of I/Q data, marker data, and a file header.

File header

The file header contains key parameters of the waveform segment, including the DAC sample rate, marker polarity, and runtime scaling. Figure 3 shows a file header of a waveform file, including a header field and setting. In this example, the "sample rate" of this waveform is 200 MHz.

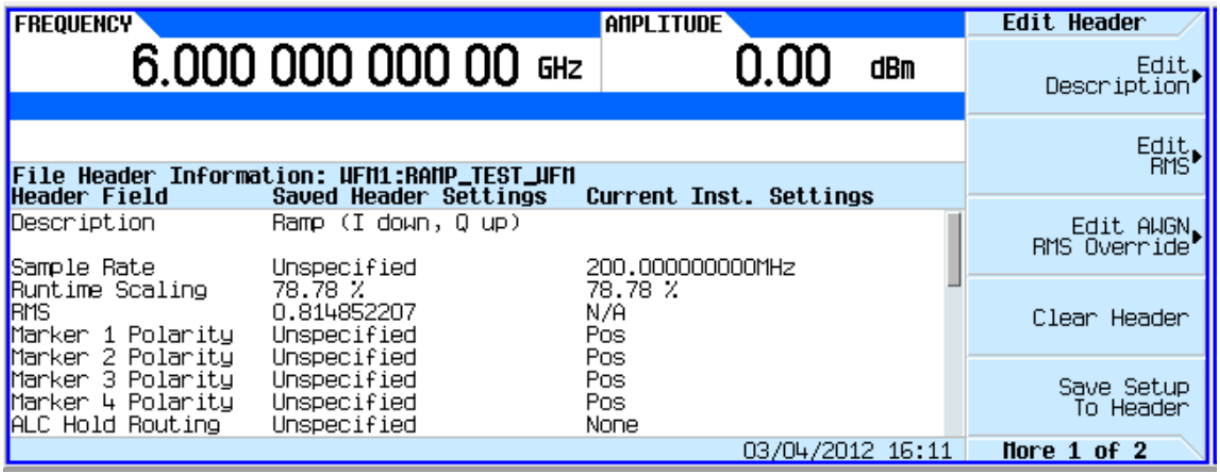

Figure 3. Waveform header information on Keysight MXG signal generator

Marker file

VSGs provide waveform markers to label specific points on a waveform segment. You can turn on markers at specific sample points manually or download a marker file with the waveform file together with the baseband generator. When the signal generator encounters an enabled marker, it routes an auxiliary signal to a real panel event output that corresponds to the marker number. The Keysight X-series signal generator provides four markers set at each waveform sample. A marker point consumes 1 byte. Figure 4 illustrates I/Q waveforms and markers 1–4. Using an oscilloscope to examine the Q channel and marker 1 signal, the waveforms appear at the bottom of Figure 4.

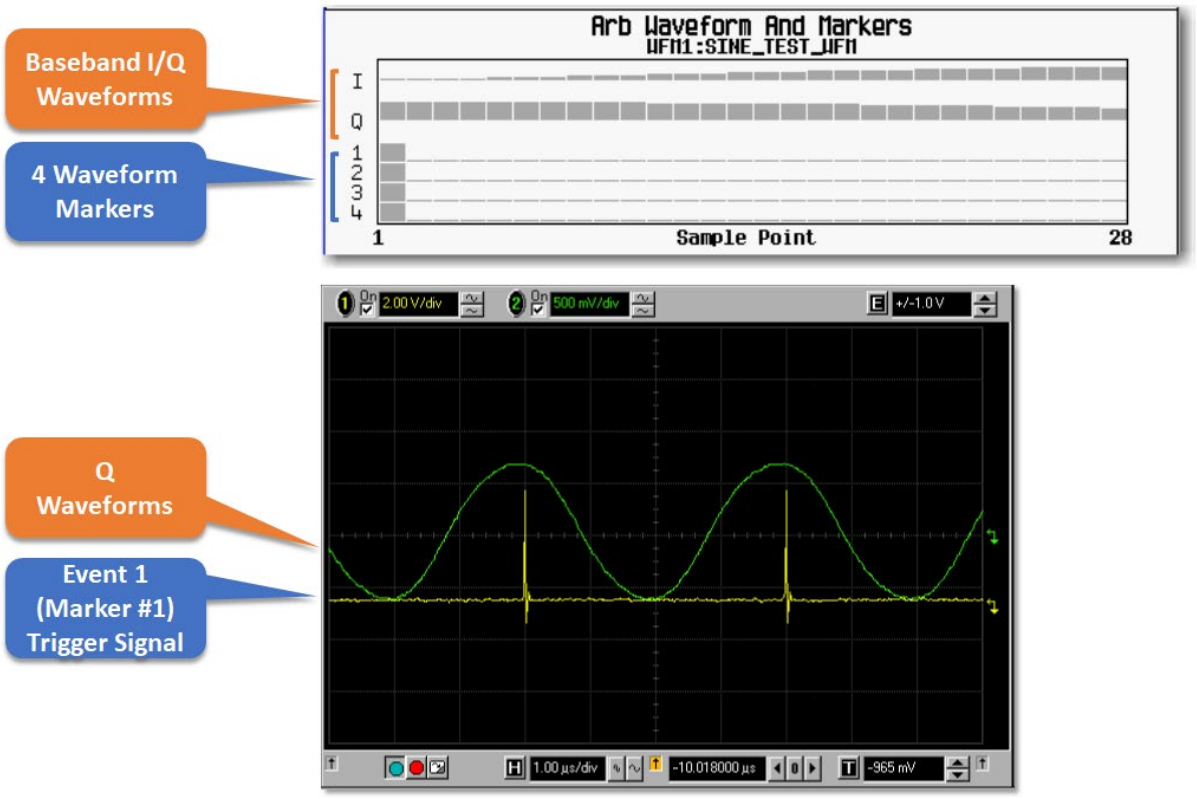

Figure 4. The I and Q components of the waveform and the marker points

You need to set the marker polarity (positive or negative) and routing for each marker (1–4). You can also configure markers to enable or disable internal hardware, such as automatic leveling control hold and RF blanking.

I/Q file

An I/Q waveform consists of samples. A sample contains I and Q data (2*2 bytes) and marker data (1 byte), 5 bytes in total. When you create the waveform data, the I and Q data samples typically reside in separate arrays or files. You can also use a single file with I and Q data samples interleaved; the Q data follows the I data.

Waveform sequence

A waveform sequence is a file that contains pointers to one or more waveform segments, other waveform sequences (nested sequences), or both. This enables you to play multiple waveform segments or sequences. The signal generator allows you to set the number of times the segments and sequences repeat during playback.

Figure 5 shows the structure of waveform segments and sequences. A segment includes a file header, I/Q waveform samples, and marker files. Use a sequence to play back segments or other sequences.

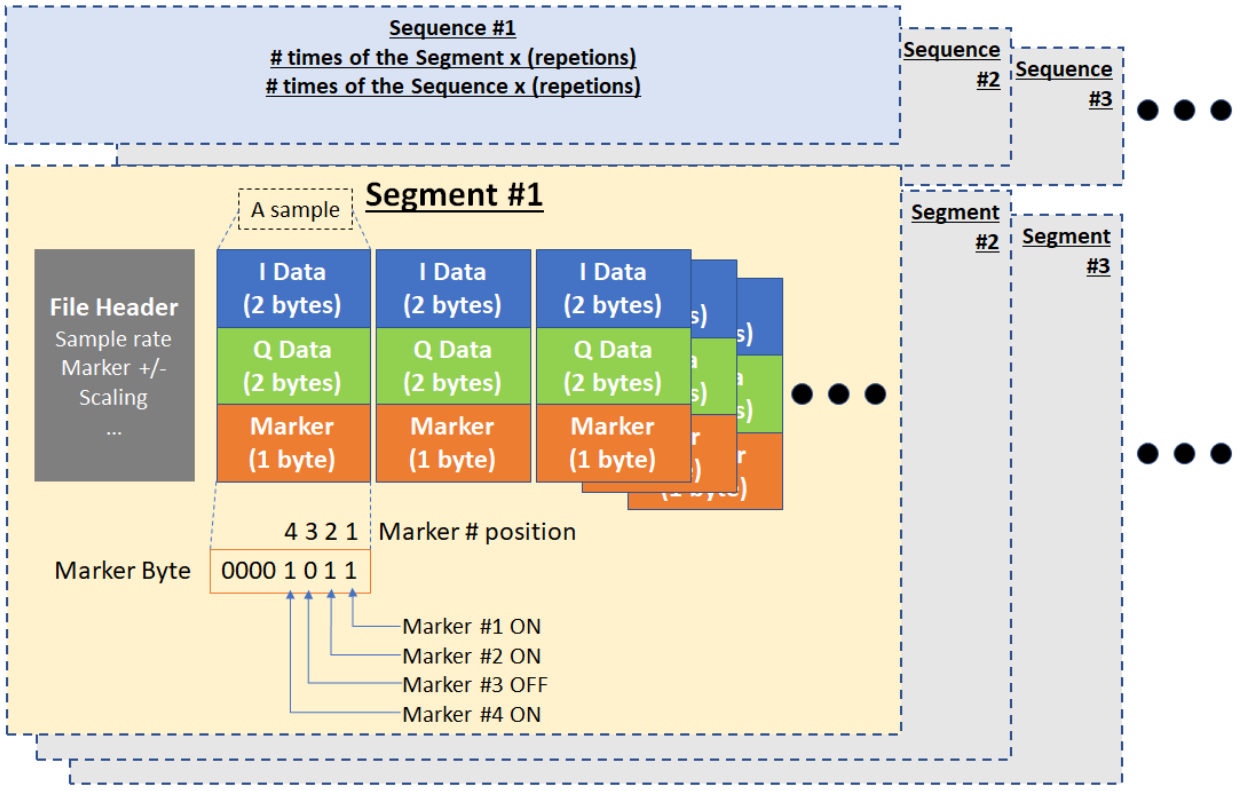

Figure 5. Waveform files, waveform segments, and sequences

Download I/Q Waveforms into a Vector Signal Generator

Once you have created the waveform files, you need to download the files to the VSG's memory for playback. A VSG has two types of memory: volatile memory (VM) and nonvolatile memory (NVM).

Waveform memory

VM requires continuous power to retain stored data. When the power is off, data stored in VM is lost quickly. The baseband generator plays the waveform files from VM, so it is commonly known as waveform memory. Rebooting the signal generator deletes the files in VM. The restriction of waveform memory size can be a bottleneck for waveform playback.

In contrast to VM, NVM can retrieve stored data even after the power has cycled through. The storage medium can be an internal hard drive or a USB drive. Remember to copy waveform files to NVM so that you do not need to regenerate the waveforms from an external computer. Whenever you download waveform files to memory, you need to be aware of your signal generator's remaining memory.

How to download waveform files

Waveforms must reside in the signal generator's waveform memory before you play, edit, or include them in a sequence. There are three ways to download waveform files to the Keysight signal generator's waveform memory: by File Transfer Protocol (FTP), programmatically, or through Keysight waveform download tools.

Load waveform files from NVM

If the waveform files are in the signal generator's NVM, you can load the waveform files directly from NVM to VM through the signal generator's user interface or send commands via a programming environment.

Using FTP

You can use FTP to transfer waveform files. There are three ways to transfer files:

1. Use the Microsoft Internet Explorer FTP feature.
2. Use the PC or UNIX command window.
3. Use the signal generator's internal web server.

As mentioned earlier, there are two types of waveform files — segment and sequence. The segment file consists of a header, markers, and I/Q data stored in the different folders in VM and NVM. The sequence file is in VM. Figure 6 shows the file folder map for the Keysight VSG. Ensure that you place waveform files in the right folders. The "SECUREWAVE" directory is not an actual storage directory, but rather a portal for the encryption and decryption process.

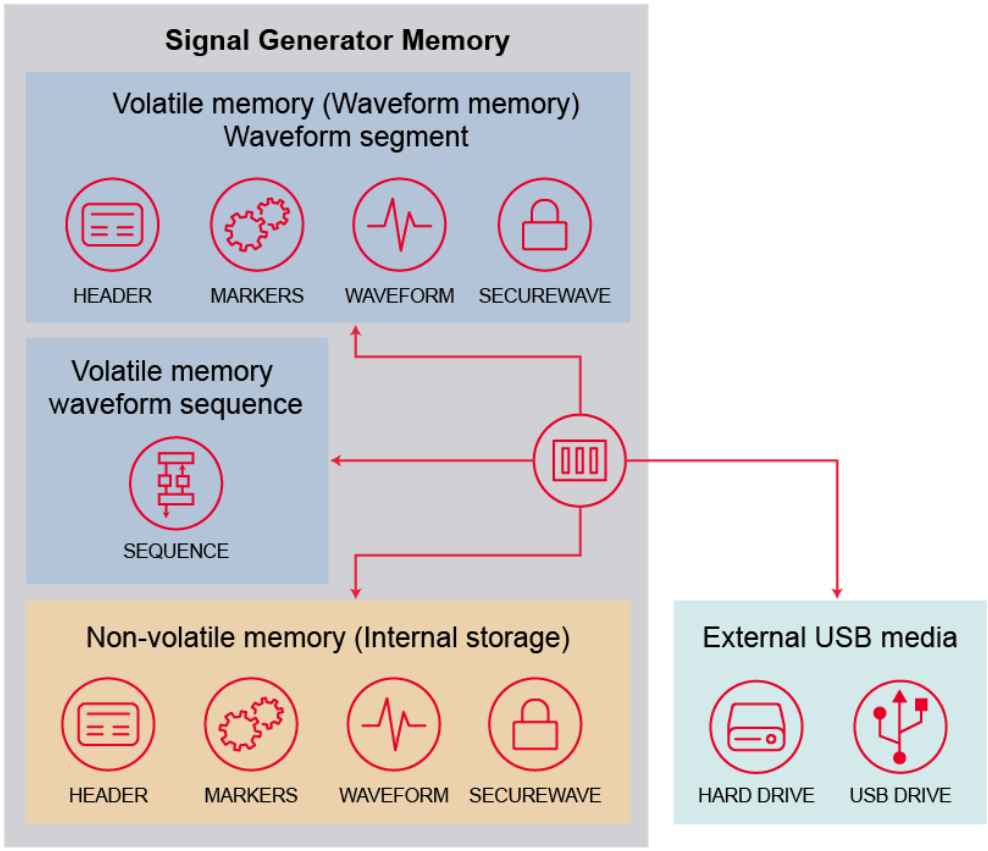

Figure 6. File structure map for the Keysight MXG signal generator

Waveform download tools

Keysight provides download utilities to simplify the downloading of waveforms into the signal generator by automatically converting waveforms into the file format required by the baseband generator.

Keysight Waveform Download Assistant

The Waveform Download Assistant software is a free software utility that enables you to download your custom I/Q data into the baseband generator of any VSG and use a single MATLAB command to play it back. In addition, you can send Standard Commands for Programmable Instruments (SCPI) commands to control your signal generators from the MATLAB command line.

Keysight BenchVue software

Keysight BenchVue is PC-based software. You can quickly configure the most commonly used measurements and setups for multiple instruments, including signal generators, as shown in the left of Figure 7. Select the folder of waveform files and download them to the signal generator. Also, BenchVue includes an easy-to-use test flow to control instruments automatically, as shown in the right of Figure 7.

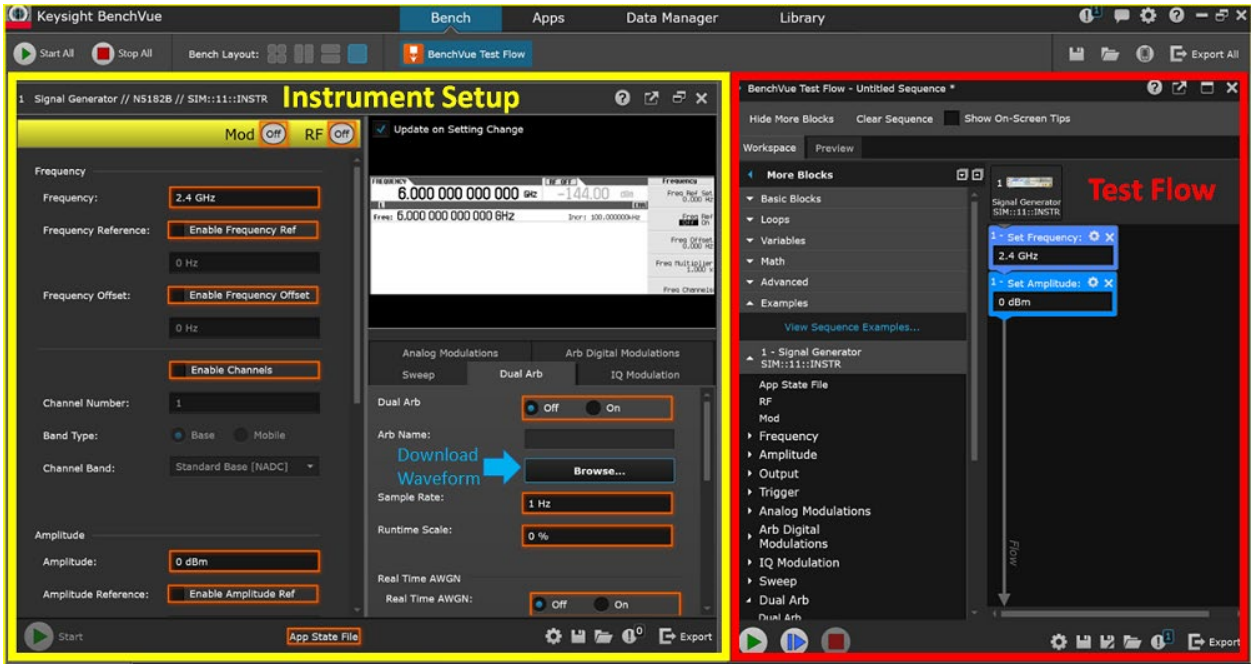

Figure 7. Keysight BenchVue user interface for signal generators

Keysight N7622B PathWave Signal Generation for waveform download toolkit

N7622B PathWave Signal Generation for IQ waveform download toolkit is a free software utility for Keysight VSGs that downloads and plays back custom I/Q waveforms. The toolkit can translate the I/Q waveforms created in common development environments, such as MATLAB and C++, into the proper file format for the target baseband generator, as shown in Figure 8. Once the toolkit has translated the I/Q waveforms, you can download and play back the waveforms. The toolkit also supports Microsoft .NET and component object model (COM) application programming interfaces (APIs). These APIs enable you to develop a custom user interface.

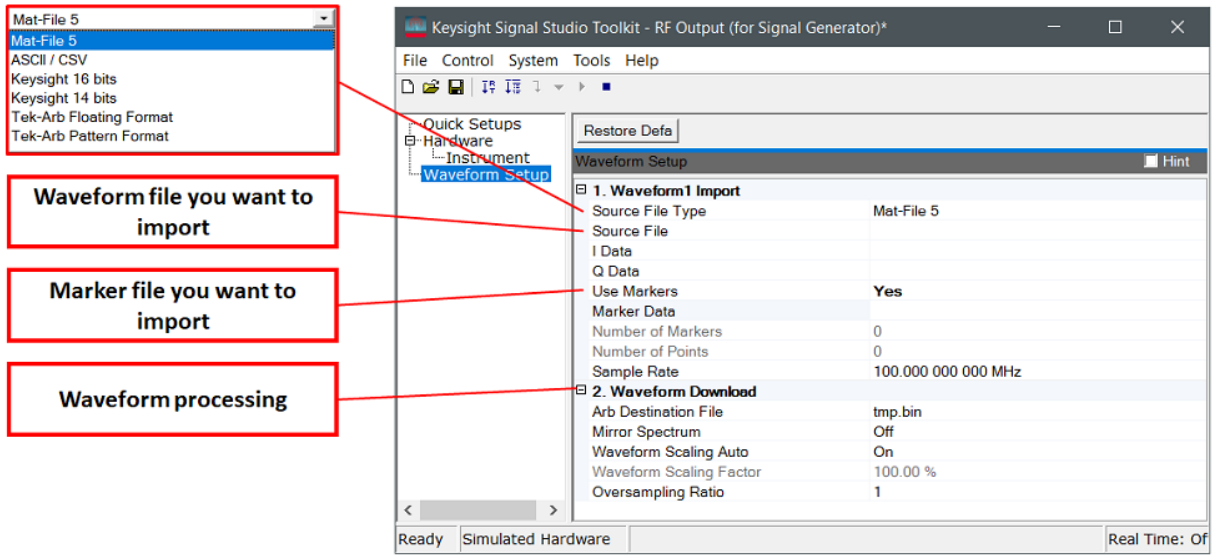

Figure 8. The user interface for the N7622B PathWave Signal Generation for Toolkit

Keysight PathWave Signal Generation software — general-purpose or standard-based signal creation

Keysight PathWave Signal Generation is signal-creation software that runs on PCs and enables you to generate application-specific test signals at baseband, RF, and microwave frequencies. A fast and streamlined user interface features tree-style navigation and graphical, parameterized signal configuration. Figure 9 illustrates the signal creation setups for 5G New Radio, such as instrument, waveform, resource allocation, and logical channel setups. It also displays the simulated waveform results, including complementary cumulative distribution function (CCDF) power curve, spectrum, and I/Q traces.

In addition to signal creation and download, PathWave Signal Generation provides interactive control of your signal generation through direct hardware connection with a variety of Keysight instruments. It also offers APIs so you can develop a custom user interface.

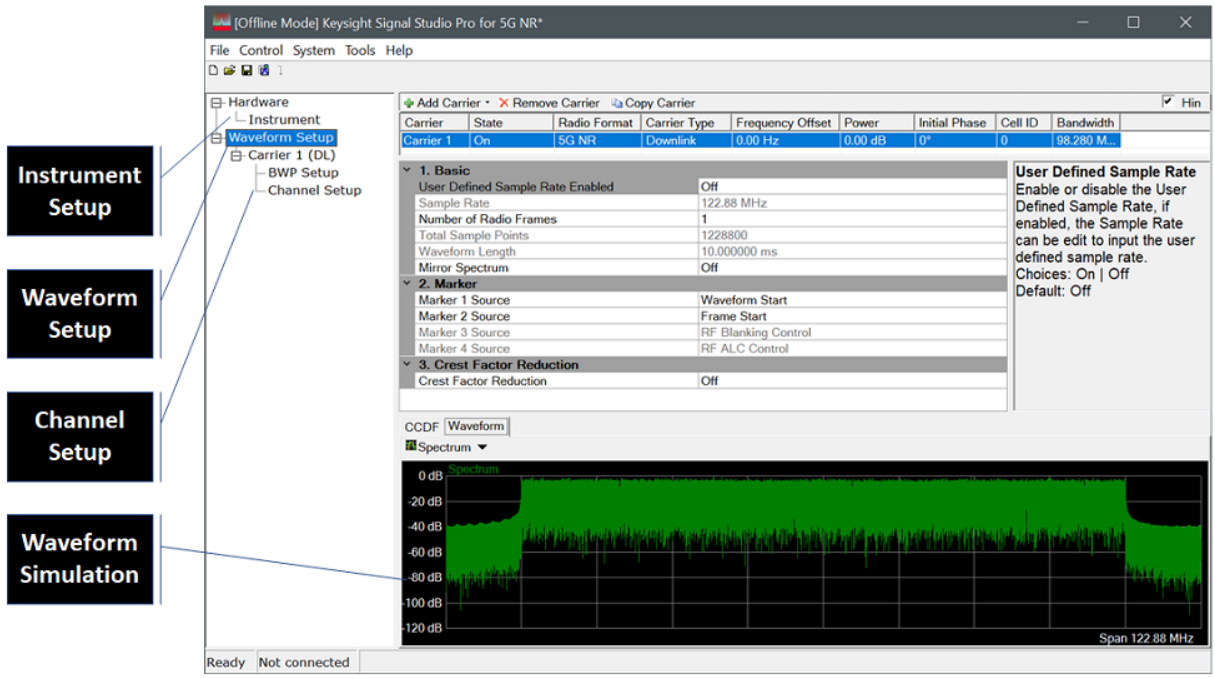

Figure 9. Simplify signal creation with PathWave Signal Generation software

Programming environment

You can use various programming environments to create the waveform data and download it to the baseband generator. Programming environments include:

- Simulation software such as MATLAB and Keysight SystemVue
- Advanced programming languages such as C++, Visual Basic, Keysight VEE, Microsoft Visual Studio.Net, Labview

You can use either the SCPI, tools' APIs, or FTP command to download waveform files to the baseband generators. Be sure to download the files to the right folders.

Accelerate Your Test and Design Workflows

The dual AWG is a flexible way to generate complex baseband waveforms. However, you need to understand the hardware structure and requirements for waveform data so that you can generate correct waveforms. Keysight offers several tools to help you generate and download waveforms to the signal generators with ease.