I/Q, IF/RF, and Serial waveform generation tools for Agilent arbitrary waveform generators

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# Overview

“IQtools” is a collection of MATLAB example applications for creating I/Q, IF/RF, and serial waveforms on the Agilent M8190A, 81180A, M933xA, 81150A and 81160A arbitrary waveform generators (AWG). MATLAB is a software environment and programming language for making your own arbitrary waveforms (multi-tone signals, pulsed radar signals, and multi-carrier modulated waveforms), measurement and analysis routines, and instrument applications. MATLAB is available directly from Agilent as an instrument option (option [N6171A](http://www.agilent.com/find/n6171a)) with many instruments, including the M8190A and M933xA, and also from MathWorks.

# Purpose

These example applications were created to demonstrate the waveform generation capabilities of these instruments, along with the value of using these instruments together with MATLAB software. While these applications are provided at no charge, they do require MATLAB software to operate. You can request a free trial of MATLAB software from your Agilent representative or directly at [www.mathworks.com/agilent/trial](http://www.mathworks.com/agilent/trial). Users who decide to order the MATLAB N6171A option together with their Agilent instruments will also receive access to the modifiable version of these example applications (in MATLAB .m format). These modiafiable examples will allow you to extend or customize the capabilities of these instruments for your specific setup.

# Requirements

These example applications require the MATLAB N6171A -M02 or MATLAB N6171A -M03 packages to operate (or the equivalent of these options which include MATLAB, Instrument Control Toolbox, Signal Processing Toolbox, and Communications System Toolbox). These example applications were developed with **MATLAB Version 7.12.0 (R2011a)** and might not work on older version of MATLAB.

Some of the analysis functionality works in conjunction with the **89600B VSA software**. It is required to have the “B” version of the 89600 software installed (Version 14.0 or higher). The “A”-Version of 89600A VSA is no longer supported. In this file, the 89600B VSA software will simply be referred to as “VSA”.

Installation

The MATLAB examples files are distributed in the form of a compressed .ZIP archive. Please choose an empty directory and unzip the files into this directory. Make sure that the directory structure of the unzipped files remains intact. It is recommended to use a subdirectory of your MATLAB working directory (e.g. c:\users\<username>\Documents\MATLAB\iqtools).

# Set the MATLAB search path to include the directory that you have chosen.Creating and downloading waveforms

Currently, the following types of waveform types can be created with these example applications:

1. **Multi-tone** (including single and dual-tone) signals with the ability to specify sampling rate, number of tones, tone frequency range and phase relationship as well as one or more notches with adjustable depth. The amplitude flatness can be automatically corrected using a spectrum analyzer. This tool can also be used to generate **band-limited gaussian noise** (with notches).
2. **Multi-Carrier Modulated Signals** (including single carrier) with the ability to specify the sampling rate, number of symbols, oversampling factor, modulation type, pulse-shaping filter, number of carriers and carrier spacing. Amplitude and phase correction can be performed from within this tool in conjunction with the VSA software. This will significantly improve the EVM performance.
3. **Pulsed frequency sweeps** with adjustable rise/fall time PW, PRI and pulse shape, frequency span and offset
4. **Frequency switching** between two or more frequencies with adjustable tone duration and phase continuous switching
5. **OFDM** signal generation with custom modulation schemes
6. **Serial data** with adjustable data rate, transition times, sinusoidal and random jitter, noise and inter-symbol interference (ISI).
7. **Function Generator**, which can generate various types of pulse shapes
8. **Load a waveform from a file.** With this function a MATLAB (.MAT), Binary (.BIN) or ASCII (.CSV) file containing sample and marker values can be downloaded to the AWG.
9. Setting up **Sequences** of waveforms
10. A number of M8190A demo examples for specific applications (e.g. CATV, Radar)

The waveforms can be created, displayed and downloaded to the AWG either as command typed in on the **command line** prompt or using a **graphical user interface** where parameters can be entered. To launch the graphical user interface, type

**iqtools**

on the MATLAB command line (or select them in the MATLAB file browser and press F9). Alternatively, the individual tools can be launched directly using the commands iqconfig, iqtone, iqmod, iqpulse, iqfsk, iqpulsegen, iqloadfile and iserial.

Each of these graphical user interfaces has a number of parameter fields as well as a "**Visualize in MATLAB**" and a "**Download**" button. Pressing the "**Visualize in MATLAB**" button shows the generated waveform in MATLAB plots (there is no hardware required). Some of the utilities also have an additional button called “**Visualize in VSA**”. This button starts the VSA software, sets it up with the appropriate parameters to show the calculated waveform. In order to use this function, no hardware connection is required.

The "**Download**" button loads the waveform into the AWG. In order for the download functionality to work properly, the connection to the AWG and optionally a few other parameters have to be configured. This can be done using the “Configuration” button in iqmain (or alternatively launching iqconfig).

Using the “**Ok**” button in Configuration Window, the parameters are stored in a file called “arbConfig.mat” in the current folder and they **effect all following download operations**. In addition to the AWG configuration, Configuration can set up the communication parameters for a spectrum analyzer as well. The spectrum analyzer connection is needed for the Multi-tone amplitude correction as described below.

# Entering numerical values

All of the numeric input fields in all of the tools will accept number is fixed point or engineering notation. Units are always seconds or Hertz and unit indicators are NOT allowed. E.g.:

* 12e9 - to indicate 12 GHz
* 6.2e-6 - to indicate 6.2 Microseconds
* 3 MHz - NOT allowed (must be specified as 3e6)
* 1ps - NOT allowed (must be specified as 1e-12)

Some fields which are marked with (\*) in the graphical user interface also accept lists of values (i.e. MATLAB vectors). Lists can simply be specified by multiple values separated by spaces or commas. E.g.:

* 100e6, 200e6, 500e6 - to indicate 100, 200 and 500 MHz
* 1e-6 3.5e-6 1e-4 - to indicate 1 us, 3.5 us and 100 us

In addition to numbers and lists of numbers, the fields also accept formulas using MATLAB syntax. E.g.:

* 1e9-5e3 - to indicate 5 kHz less than 1 GHz (or 999.5 MHz)
* 100e6:10e6:200e6 - a list of values from 100 MHz to 200 MHz in steps of 10 MHz
* linspace(100e6,200e6,11) - different way of describing the same as above: 11 values  
   evenly spaced between 100 and 200 MHz
* 100e6\*rand(1,10) - a list of 10 random numbers between 0 and 100 MHz  
   (“rand” is a built-in MATLAB function)

In addition to that, all of the input fields will evaluate variable names that are defined in the MATLAB workspace and formulas using MATLAB workspace variables. E.g.

* Fs - can be used e.g. in the sample rate field if the variable “Fs”  
   is defined in the MATLAB workspace
* 1e6\*f - can be used to specify a list of frequencies assuming that “f”  
   contains the list of frequencies in MHz
* fc-5e3 - center frequency minus 5 kHz – assuming that the variable “fc”  
   is defined in the MATLAB workspace

# Programmatic interface

Instead of using the graphical user interfaces of the scripts, the waveforms can also be generated, displayed and downloaded using text commands. This can be useful to generate more complex waveforms that e.g. consist of multiple signals added together. An example program for a multi-tone signal looks like this:

fs = 4.2e9; % sample rate  
 data = iqtone('sampleRate', fs, 'tone', linspace(-250e6, 250e6, 21));  
 iqplot(data, fs);  
 iqdownload(data, fs);

The input parameters of iqtone, iqmod, iqpulse, iqfsk, iqpulsegen and iserial are specified as parameter/value pairs. All parameters have default values if they are not specified. Please look at the headers of the individual script for available arguments and ranges.

# Downloading your own data

The **iqplot** and **iqdownload** scripts are used to display resp. download I/Q data into the AWG. You can use these functions to display and download I/Q data that has been generated by your own MATLAB functions. For both **iqplot** and **iqdownload**, the first parameter is the desired signal represented as a vector of complex numbers in the range [-1…+1] and the second parameter is the sampling rate in Hz.

Please DO NOT call the download routines for individual AWGs directly, since the interface might change over time. (e.g. iqdownload\_M8190A, iqdownload\_81180A, etc.)

**iqdownload** also accepts additional parameters as name/value pairs. These are explained in the header section of iqdownload.m

# Generating RF / IF waveforms

All of the tools (except iserial) will generate I/Q of RF waveforms. The “I” signal is downloaded to channel 1 of the AWG; the “Q” signal in channel 2. The output of the two channels are intended to be connected to an I/Q modulator, such as the wideband I/Q inputs of a Vector PSG (E8267D). They can also be connected directly to an oscilloscope for analysis of the I/Q waveform using the VSA software.

However, the tools can also be used to generate an IF/RF signal directly (digital up-conversion). In that case, either channel 1 or channel 2 outputs can be used. The output amplifier should be switched to "AC" using the configuration utility. In order to generate an RF signal, make sure that:

For **Multi-Tone**, both start and stop frequency are positive

For **Digital Modulation signals**, the carrier offset is positive and larger than ½ of the bandwidth of the modulated signal

For **Radar chirps**, frequency offset is positive and larger than ½ the frequency span.

For **Frequency Switching**, all frequencies in the list must be positive

The simulated spectrum that is shown when the "Display" button is pressed should only show positive frequency components.

**iserial** is an exception and always generates an identical signal on channel 1 and 2

# Multi-tone amplitude correction

In order to improve amplitude flatness for multi-tone signals, the “iqtone” utility comes with an amplitude correction (or calibration) function. Amplitude correction is performed by measuring a multi-tone signal with a spectrum analyzer and feeding back the correction curve into the waveform calculation routine. This amplitude correction can later on also be used by the other waveform creation utilities to improve the flatness. The amplitude flatness correction can be used to compensate non-flatness on the output of the AWG or to perform correction after I/Q up-conversion.

To perform an amplitude correction:

1. Use the “Configure Instrument Connection” tool to set up the communication parameters for the spectrum analyzer (visa is recommended). Choose whether you want to use the **Zero Span** or **List sweep** mode. The LIST SWEEP commands are only available on MXA (N9020A) and PXA (N9030A). The LIST SWEEP measurement is a little faster, but less accurate. If in doubt, use the “Zero Span” mode. Don’t forget to click “Ok”.
2. Use “Multi-tone” to generate a multi-tone signal that spans the entire frequency range that need to be corrected later on. A good starting point is the Preset “101 tones, +/- 1 GHz, asymm.” (can be found in the menu bar) if you are generating I/Q data. For a direct IF/RF signal (not using I/Q), choose a range of frequencies that are all positive. A larger number of tones will improve the accuracy, but increase the measurement time. Around 100 – 200 tones produces reasonable results. For demo purposes, 30 or 40 tones are good enough. To get optimal results, the “Phase” should be set to “Random” and when using I/Q up-conversion, the tones should be selected such that the images don’t fall on top of generated tones. (i.e. don’t use symmetrical intervals around 0 Hz)
3. You might want to click “Download” once to see how the un-corrected waveform looks like. The multi-tone calibration works either with direct AWG output or with I/Q output going into the wideband modulation inputs of a PSG and measuring the PSG output. (Make sure the “Apply Correction” checkbox is off).
4. Set the center frequency (“Fc – for calibration only”) in the Multi-Tone GUI to zero if you are analyzing the direct AWG output. If you have the I/Q signals connected to a PSG and you are correcting the flatness of the final RF output, enter the Carrier frequency that is set in the PSG.
5. Make sure the “Apply correction” checkbox is OFF to start a new correction measurement.  
   Now press the “Calibrate” button. Depending on the selected measurement mode, the spectrum analyzer will perform a measurement and the correction curve is written to the file “ampCorr.mat” in the local directory. The measured frequency response is also displayed as a MATLAB plot. This plot is just for your information and can be closed if it no longer needed.
6. To further improve the calibration, you can run it again, taking the previous correction factors into account. Experience shows that after running the calibration about 3 times, no further improvement can be achieved. The red graph indicates the measured deviation for each tone from the average tone power. It should get close to the zero line as you perform repeated calibrations.
7. The saved correction factors can be used by the other utilities (iqmod, iqpulse, iqfsk) as well. Just turn on the “Apply correction” in the respective utility. Note: When performing the amplitude correction, make sure that the start and end frequencies span at least the same range of frequencies that you will use later on in other utilities.

# Amplitude and Phase corrections for Digital modulation waveforms

When generating a digitally modulated signal with the “Digital Modulation” utility, you can improve the EVM by performing a amplitude and phase calibration in conjunction with the VSA software. The VSA software has to be installed on the same PC that runs the MATLAB scripts. The connection to the oscilloscope that captures the signal has to be established before using the calibration function in the MATLAB script. The calibration routine uses the Equalizer that is built into the VSA software to determine the channel frequency response. After generating an (un-corrected) signal, the MATLAB script launches the VSA software, turns on the equalizer and uses the frequency response of the equalizer to calculate a pre-distorted waveform. Unlike the flatness correction using multi-tone, this method corrects magnitude and phase of the signal.

Please follow these steps to generate a pre-distorted signal:

1. Set the desired parameters in the “Digital Modulation” tool and press download to generate a digitally modulated signal. Make sure that the “Apply Correction” checkbox is turned OFF.  
   Do **NOT** start the VSA software manually – the script will do that.
2. Press the “Calibrate (VSA)” button. This will start an instance of the VSA software and set up the parameters to demodulate the signal that has been configured.
3. When you see the dialog “VSA measurement running. Please press OK when Equalizer has stabilized”, you should first check the Input range in VSA and then observe the Equalizer stabilizing. If it does not converge, you might have to modify the Equalizer parameters.
4. Once the equalizer is stabilized, press “Ok” to continue in the calibration process. The MATLAB script will read the current equalizer frequency response, display it as a MATLAB plot, download the pre-distorted waveform and turn the equalizer in VSA off.
5. Optionally, you can press the “Calibrate” button again (it will now be labeled “Re-Calibrate”) to further improve the EVM performance.
6. If you make changes to your iqmod parameters, please un-check the “Correction” checkbox, press “Download” and then “Calibrate (VSA)”.
7. The connection between the MATLAB script and the VSA software remains intact until you either close VSA or exit MATLAB. So, for consecutive calibration runs, the VSA software will not be launched again, but the already running instance will be re-used.

# Creating sequences

For some of the AWG models (currently M8190A and 81180A), IQtools also support the sequencer that is built into these AWGs. To set up a sequence, you must first define the individual **waveform segments** that will later be combined into a sequence. Then you can define the sequence itself. The sequence is a table that describes which waveform segment to use, how often it will be looped and under which condition the next segment will follow.

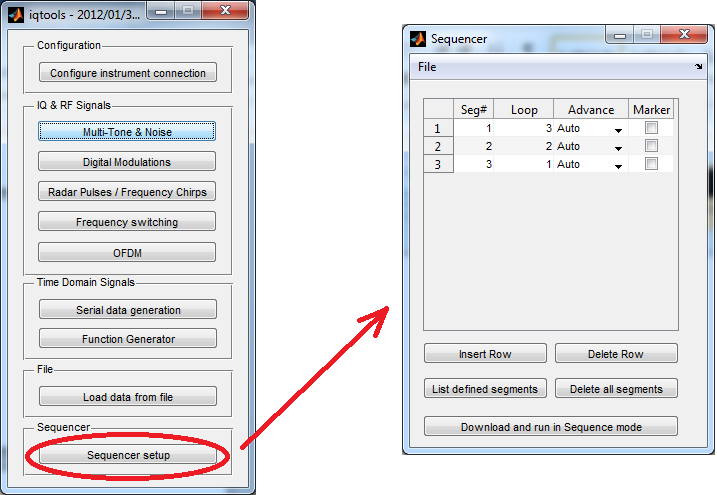
To define the individual waveform segments, you use the “Segment Number” field that is available in each of the individual waveform tools (Multi-Tone, Digital Modulation, Radar Pulse, etc.)



The default segment number is 1, meaning that the waveform will be downloaded to that segment. (Waveform segments are numbered starting from 1 up to the AWG model-specific limit).

In order to set up a number of waveform segments, you choose one of the waveform creation tools (multi-tone, digital modulations, radar chirps, etc.), define the desired parameters, set segment number to “1” and press “Download”. Now you can change any of the parameters (or use another waveform tool), set segment number to “2” and press “Download” and so on until you have defined all the individual segments that you would like to use in your sequence.

Next, you open the “Sequencer Setup” tool from the IQtools main window and edit the sequence table:



In each row of the sequence table, you can specify the waveform segment that you would like to be generated, how many times this waveform segment will be looped, under which condition the sequencer will advance to the next segment and finally whether the marker outputs that you have defined for this segment will be output.

You can insert and delete rows from the table with the respective buttons and also display all the available segments (M8190A only) or delete all of them. Note that when you delete all segments, you have to go back to the waveform tools and download the segments again.

Once you press the “Download and run in Sequence mode” button, the sequence table will be downloaded and the AWG starts to generate the programmed sequence. In the example above, segment#1 will be played three times, followed by segment 2 twice and segment 3 once, then back to segment#1 three times and so on. After the last segment has been generated, the sequence will automatically loop back to the beginning of the table.

The “Advance Modes” offers the following choices:

* “Auto” – the waveform segment will be looped for the programmed number of times. Then, the sequence will automatically proceed to the next table entry
* “Conditional” – the segment will be looped until an external signal is applied to the “Event” input (or SCPI command is sent to the instrument to simulate such an event). A segment will always be completed - independent on when the Event signal is asserted
* “Repeat” – the waveform segment will be looped for the programmed number of times and then the output is paused as that last sample value. The sequence proceeds once the “Event” input is asserted.
* “Stepped” – similar to “Repeat”, except that processing is paused after each loop.

The sequencer allows you to do much more complicated setups using SCPI programming, but the IQtools utility currently only supports those “simple” sequences. There are some more sophisticated sequencer examples in the “M8190A specific examples” section. Please click on the individual examples and take a look at the MATLAB source code for these examples to see how to program the sequencer.

# Next Steps

1. Learn more about the Agilent M8190A arbitrary waveform generator (used in this document) at [www.agilent.com/find/m8190a](http://www.agilent.com/find/m8190a)
2. Learn more about MATLAB software and ordering it directly from Agilent with the M8190A, other arbitrary waveform generators, and other instruments at: [www.agilent.com/find/matlab](http://www.agilent.com/find/matlab)
3. Information on all Agilent signal and waveform generators can be found at [www.agilent.com](http://www.agilent.com)
4. Additional information on using MATLAB with Agilent instruments is available at [www.mathworks.com/agilent](http://www.mathworks.com/agilent)