

Zurich  
Instruments



# HDAWG Arbitrary Waveform Generator

2.4 GSa/s, 16 bit

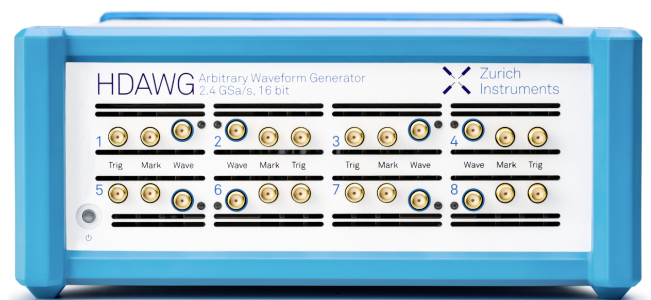
4, 8 and more channels

Product Leaflet

Release date: December 2019

## Key Features

- 2.4 GSa/s, 16 bit, 750 MHz
- 5 V<sub>pp</sub> maximum amplitude
- Scalable up to 144 output channels
- Highest channel density available
- Less than 50 ns trigger to output delay
- Digital modulation at multiple frequencies
- LabOne® AWG Sequencer and Compiler



## Summary

The Zurich Instruments HDAWG multi-channel Arbitrary Waveform Generator (AWG) has the highest channel density on the market and is designed for advanced signal generation up to 750 MHz bandwidth. The HDAWG comes with either 4 or 8 DC-coupled, single-ended analog output channels. The outputs can be individually switched between a direct mode, with maximized bandwidth and superior noise performance, and an amplified mode, that boosts the signal amplitude to up to 5 V<sub>pp</sub>. Two markers bits per AWG channel are available and allow precise setup synchronization.

LabOne® provides a state-of-the-art programming concept that combines the performance and flexibility of an AWG with the ease-of-use of a function generator. The platform-independent LabOne User Interface (UI) and a choice of APIs for LabVIEW®, .NET, MATLAB®, C, and Python enable easy measurement automation and fast integration into an existing control environment.

## Applications

The HDAWG is a high-end instrument designed to meet the requirements of demanding applications by extending the basic AWG functionality with additional waveform memory, function generator functionality, internal oscillators and a set of pulse counters.

### Quantum Computing and Phased-array Radar

Multiple HDAWG instruments can be controlled and automatically synchronized using a single user interface, enabling efficient scaling of radar and quantum computing systems while reducing complexity and lab space required. The short 50 ns reaction time to an external trigger signal enables quantum error correction methods with high fidelity. The internal oscillators minimize waveform upload times, ensure phase coherence and provide a simpler waveform definition. The integrated pulse counter helps simplify setups for trapped ion and N-V center experiments.

### NMR and Spectroscopy

Signals in NMR and other spectroscopy applications occur at timescales from nanoseconds up to seconds. The HDAWG can speed up these measurements by applying a variable sampling rate and/or parametric sweeping. Using digital modulation, an arbitrary envelope can be imposed on one or multiple carrier signals with minimal waveform upload time while phase-coherence is maintained over long times.

### Semiconductor Testing

Nested sequencing, waveform iteration, and dynamic sequencing with DIO control are ideal for realizing signals for extensive high-throughput testing. Multiplying or adding the AWG signal with a function generator signal extends the possibilities and helps simplify and speed up daily measurement routines.



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# Highlights

## High-level AWG Programming

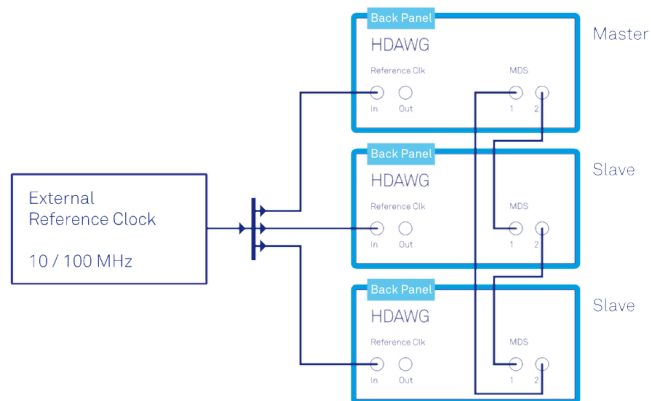
```
Sequence *pattern_1.seqc [ Examples... ]
1 const fs = 2.4e9; // sampling frequency
2 const n = 8000; // waveform length
3
4 wave w_chirp = chirp(n, 10e6/fs, 30e6/fs);
5 wave w_gauss = gauss
6
7 const A = 0x0f; // amplitude
8 const B = 0x1e; // position
9
10 repeat (1000) {
11   playWave(w_gauss, w_gauss, w_gauss);
12   if (getAnaTrigger(1)==0) {
13     playWave(w_chirp);
14     setDIO(config_A);
15   } else {
16     setDIO(config_B);
17   }
18   wait(400);
19 }
```

**gauss snippet**  
`wave gauss(const samples, const amplitude=1.0, const position, const width)`  
Gaussian pulse with arbitrary amplitude (a), position (p), width (w) and number of samples (N).

The LabOne UI is designed to get you going quickly by providing hardware control in an intuitive and easily readable form. After defining the waveforms and sequences in the LabOne AWG Sequencer, the LabOne AWG Compiler translates it into machine language and transfers it to the hardware in a minimum amount of time. LabOne sequencing supports loops with dynamically varying delay and conditional branching points.

In addition to the standard waveforms, e.g. Gaussian, Blackman, sinc, etc., LabOne contains all the essential math and array editing tools required for advanced waveform design. You can easily add, multiply, cut, and concatenate waveforms or organize them in segments. Importing measured signals or waveforms calculated in another tool like MATLAB is a simple drag-and-drop action.

## Multi-device Synchronization (MDS)



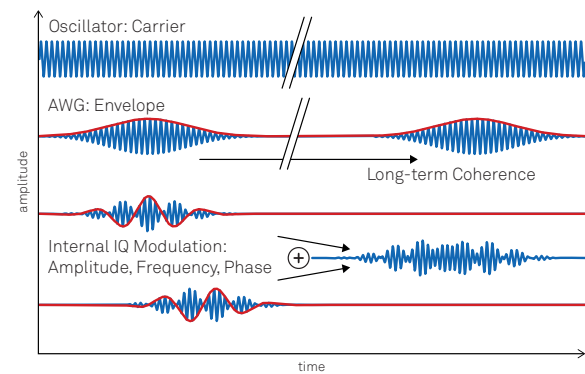
With MDS multiple HDAWGs can be operated much as a single multi-channel AWG:

- Operate all instruments from a single UI/API
- Absolute synchronization of all output channels
- Phase locking of all instrument clocks

When multiple HDAWGs are used, LabOne takes care of distributing your master sequence program across all instruments. An automated trigger exchange protocol ensures synchronized playback timing.

When combining the HDAWG with the Zurich Instruments PQSC, a system with up to 144 fully synchronized AWG channels can be realized. This system can be combined with measurement channels provided by the Zurich Instruments UHFQA.

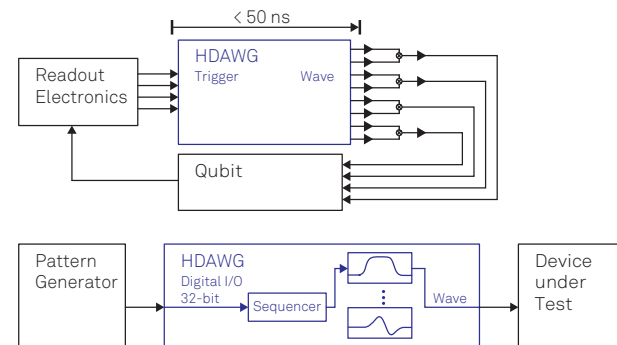
## Oscillators, Modulation and Phase Control



The HDAWG is equipped with digital oscillators to generate the sinusoidal carrier of a signal independently of the programmed AWG envelope signal. This means that long signals can be generated with very fast waveform upload and precise phase coherence across many pulses. Carrier frequencies and phases that would otherwise be written to a static waveform can be freely adjusted and swept.

The HDAWG-MF Multi-frequency option increases the number of oscillators and enables full digital I/Q modulation to implement frequency, phase, amplitude modulation techniques as well as frequency-domain multiplexing, or phase cycling.

## Low-latency Triggering and Sequence Branching



Thanks to the low-latency design, the HDAWG is able to generate its first sample on the output less than 50 ns after detecting an external trigger on one of the TTL inputs on the front panel. This is essential for feedback experiments in quantum computing where device properties are short-lived, and each nanosecond saved improves the experimental outcome tremendously. The 4 or 8 output channels of the instrument can be grouped in units of 2 or 4. Each of these groups can then be individually triggered which increases flexibility when distributing signals to separate parts of a device or setup.

In order to generate signals with a high complexity and real-time control, the HDAWG is able to select from up to 1024 pre-stored waveforms in a programmable memory based on the bit-pattern applied to its 32-bit digital input. These could represent a digital modulation pattern, a device-specific test waveform, or a multi-qubit state readout result.

# Models and Upgrade Options

The HDAWG series comprises the 4 channel model HDAWG4 shown on the right and the 8 channel model HDAWG8. The two models are technically identical except for the channel number and features associated with individual channels, e.g. number of oscillators. Please note that 4 channel instruments cannot be upgraded to 8 channels. The following options can be added to enhance the basic functionality when purchasing the instrument or at any later time without sending the instrument back to Zurich Instruments.

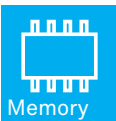
## HDAWG-PC Real-time Precompensation



- 4 filter methods
- In-situ tunability
- Precompensation Simulator

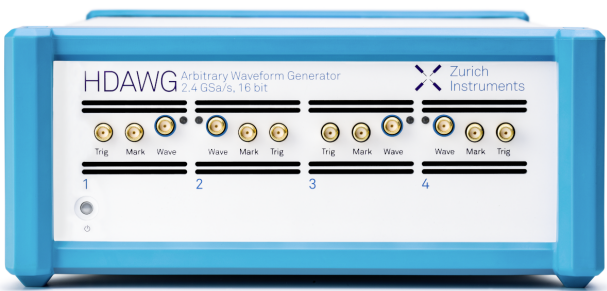
The HDAWG-PC Real-time Precompensation option ensures that the signal applied to the device under test equals the signal designed on the HDAWG. Widely configurable digital filters for each output allow the user to invert the effects of spurious capacitances and inductances, AC coupling, signal reflections, amplifier ringing, and others.

## HDAWG-ME Memory Extension



- 500 MSa waveform memory per channel instead of 64 MSa

The HDAWG-ME option enables playback of long signal patterns with sample-by-sample definition of the signal. This is particularly valuable when playing back waveforms with non-repetitive elements or replaying the signals recorded with a UHF instrument.



## HDAWG-MF Multi-frequency



- 4 oscillators per channel pair
- Independent envelopes for multiple carriers
- Output adder for 4 modulated signals

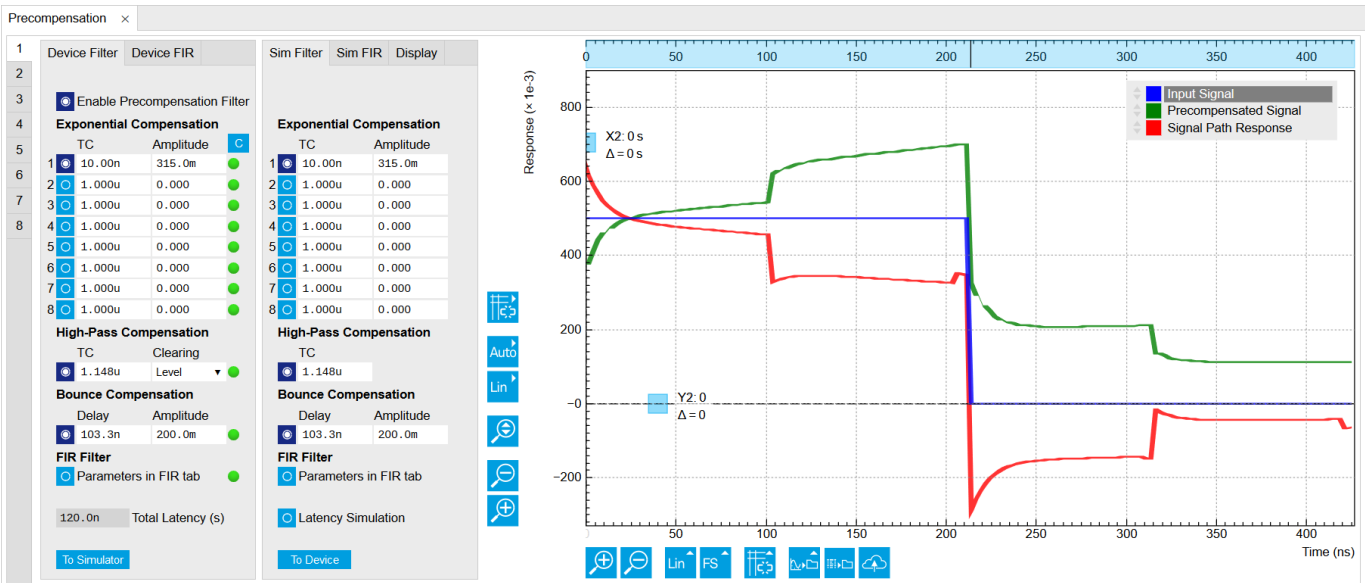
The HDAWG-MF option extends the number of oscillators and enhances the modulation capabilities of the HDAWG. This means faster waveform upload and more flexibility in applications where multiple superimposed carrier frequencies need to be tuned.

## HDAWG-CNT Pulse Counter



- 4 or 8 counter modules
- 300 MHz maximum count rate
- Adjustable discriminator level
- Background subtraction

The HDAWG-CNT Pulse Counter option adds a photon detection capability for experiments using photo-multiplier tubes or APDs. Multiple pulse trains on the trigger inputs or the DIOs can be analyzed with five modes of operation including time-tagging for statistical analysis. AWG sequences can be branched based on counter data, enabling ultra-fast feed-forward loops for quantum error correction.



The Precompensation tab in the LabOne UI provides a simulator to display the effect of imperfections of the transmission lines and how to compensate them. Then the correction parameters can be easily transferred to the device.

# Specifications

## General

|                             |                                                |
|-----------------------------|------------------------------------------------|
| Dimensions including bumper | 23.2 × 10.2 × 43.0 cm<br>9.2 × 4.0 × 16.9 inch |
| Weight                      | 4.6 kg; 10.2 lbs                               |
| Power supply                | AC: 100 – 240 V; 50/60 Hz                      |

## Arbitrary Waveform Generator

|                             |                                                                       |
|-----------------------------|-----------------------------------------------------------------------|
| Channels                    | 4 or 8, depending on model                                            |
| Markers                     | 2 per waveform, 1 SMA output per channel, 32 bit real-time DIO output |
| D/A converter resolution    | 16 bit                                                                |
| Waveform memory per channel | 64 MSa<br>500 MSa (HDAWG-ME option)                                   |
| Sequence length             | 8,192 instructions                                                    |
| Waveform granularity        | 16 samples                                                            |
| Minimum waveform length     | 32 samples                                                            |

## Wave Output

|                            |                                                 |
|----------------------------|-------------------------------------------------|
| Output modes               | amplified, direct                               |
| Output ranges (into 50 Ω)  | ±0.1 V to ±2.5 V (amplified)<br>±0.4 V (direct) |
| Output impedance           | 50 Ω, DC coupled                                |
| Offset voltage (into 50 Ω) | ±1.25 V (amplified)<br>0 V (direct)             |

## Time & Frequency Domain Characteristics

|                                                   |                                                                                        |
|---------------------------------------------------|----------------------------------------------------------------------------------------|
| Base Sampling rate                                | 100 MSa/s to 2.4 GSa/s                                                                 |
| Sampling rate division                            | 2 <sup>0</sup> to 2 <sup>13</sup>                                                      |
| Sampling rate res.                                | 7 digits                                                                               |
| Bandwidth (–3dB, corrected for sin(x)/x roll-off) | 0 – 600 MHz (ampl. ±0.5 V)<br>0 – 300 MHz (ampl. ±2.5 V)<br>0 – 750 MHz (direct)       |
| Rise time (20% to 80%)                            | 400 ps (ampl., 1 V step)<br>1000 ps (ampl., 5 V step)<br>300 ps (direct, 0.8 V step)   |
| Output noise > 200 kHz                            | <35 nV/√Hz (ampl., high Z)<br><12 nV/√Hz (direct, high Z)                              |
| Output noise at 1 Hz                              | 4 μV/√Hz (amplified, high Z)                                                           |
| Phase noise (100 MHz)                             | <–135 dBc/Hz (Δf 10 kHz)<br><–148 dBc/Hz (Δf 1 MHz)                                    |
| SFDR (100 MHz)                                    | 80 dBc (excl. harmonics)                                                               |
| Worst harmonic component                          | –65 dBc (HD2) (ampl. ±0.5 V)<br>–47 dBc (HD3) (ampl. ±2.5 V)<br>–53 dBc (HD2) (direct) |
| Output period jitter                              | 3 ps RMS (synchr. trigger)                                                             |
| Trigger uncertainty                               | 3.3 ns (asynchr. trigger)                                                              |
| Trigger delay to output                           | <50 ns                                                                                 |
| Skew between channels                             | <200 ps                                                                                |
| Skew control (HDAWG-SKW option)                   | 10 ns (range)<br>10 ps (resolution)                                                    |

