

Zurich  
Instruments

# SHFSG 8.5 GHz Signal Generator

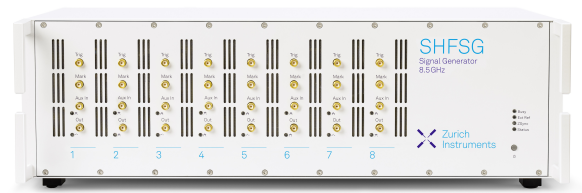
Qubit control with 4 or 8 channels  
and output frequencies DC to 8.5 GHz

Product Leaflet

Release date: 31.03.2023

## Key Features

- 4 or 8 output channels, control of up to 8 qubits
- Operation from DC to 8.5 GHz with 1 GHz bandwidth and free from mixer calibration
- Low phase noise and low spurious tones for high-fidelity gate operations
- High output power for short gate pulses without external amplification
- 14 bit output at 6 GSa/s
- 98 kSa waveform memory per channel
- Controlled through LabOne, LabOne Q, or APIs for Python, C, MATLAB®, LabVIEW™, and .NET



## Introduction

The Zurich Instruments SHFSG Signal Generator produces qubit control signals in the frequency range from DC to 8.5 GHz with a spurious-free modulation bandwidth of 1 GHz. The SHFSG uses a double superheterodyne technique for frequency up-conversion, which eliminates the need for mixer calibration and saves time on system tune-up. Each SHFSG comes with 4 or 8 analog output channels with 14-bit vertical resolution. Controlled by LabOne, its APIs or LabOne Q, the SHFSG supports quantum computing projects with sizes ranging from a few to several hundred qubits.

When synchronized by a PQSC, multiple SHFSGs can be combined within a Zurich Instruments QCCS to control many-qubit systems. Multi-qubit gate operations with minimal latency and high fidelity can be realized thanks to an advanced sequencer, a low-latency signal processing chain and low-phase-noise synthesizers. Combined with the SHFQA Quantum Analyzer for qubit readout, the SHFSG represents the second generation of instruments integrating microwave generation and analysis.

## Applications

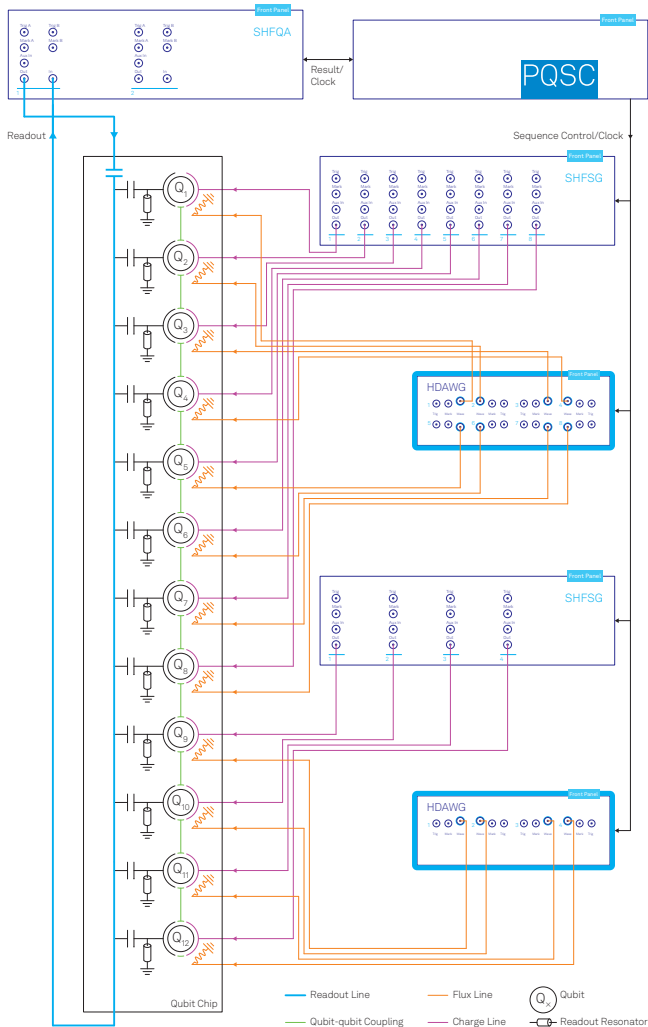
The DC-8.5 GHz output frequency range of the SHFSG is ideal for superconducting qubits, spin qubits, and NV centers, and is suitable for both single- and two-qubit gate operations. The SHFSG supports system sizes from single qubits up to 144 qubits when combined with a PQSC.

### Quantum computing applications

- Coherent manipulation of qubits with single and multi-qubit gate operations
- Qubit spectroscopy and characterization
- Real-time, low-latency and global feedback for error correction

### Supported qubit types

- Superconducting qubits
- Spin qubit/superconducting resonator hybrids
- NV centers
- Qubits, qutrits, and ququads



Example setup showing how 12 superconducting qubits can be controlled and read out in a QCCS system. An SHFSG-8 and SHFSG-4 provide the microwave control signals for qubit gate operations, while the HDAWG-8 and HDAWG-4 provide flux pulses for tuning the qubit frequencies. By frequency multiplexing the readout, all 12 qubits can be read out using a single channel of the SHFQA-2. The data and measurement timing are synchronized across the instruments by the PQSC.

## Highlights

### High-fidelity qubit operation

The frequency range from DC to 8.5 GHz enables a single SHFSG to generate a variety of single- and multi-qubit gates. The SHFSG's superheterodyne frequency

conversion scheme operates over a wider frequency band and with better linearity and fewer spurious signals than standard IQ-mixer-based methods. This means that the SHFSG generates spurious-free, stable signals without requiring its users to spend time on mixer calibration or system maintenance. Building on the performance of synthesizers specifically designed for qubit control, the SHFSG offers low phase noise and low timing jitter across the output frequency range, ensuring that qubit gate operations realize the full potential of the quantum processor in terms of fidelity. Each SHFSG contains 4 low-phase-noise synthesizers, corresponding to 1 synthesizer per channel in the SHFSG-4 variant and to 1 synthesizer per channel pair in the SHFSG-8 variant.

### Advanced sequencer for efficient workflows

The SHFSG supports minimal use of waveform data even when complex signals are required. Users provide the desired signal in the form of a pulse description to LabOne Q, which then automatically programs the SHFSG in the most memory-efficient manner. Even for many-qubit systems that rely on multiple SHFSGs, this approach ensures that complex tune-up and calibration routines are completed with a minimum of instrument communication time. Support of loops and conditional branching points further enables the implementation of quantum error correction and active reset, while real-time phase updates make it possible to implement virtual Z gates. With up to 98 kSa waveform memory per channel, the ability to handle up to 32k sequence instructions, and a sampling rate of 2 GSa/s, the SHFSG offers customizable multi-channel AWG signals for qubit control.

### Scalable system approach

Each channel of the SHFSG has its own AWG core for creating phase- and timing-programmable waveforms, so that a single SHFSG-8 instrument can control 8 individual qubits. To carry out advanced protocols such as global error correction, several SHFSGs (for qubit control) can be combined with multiple SHFQAs (for qubit readout). The Zurich Instruments ZSync interface links the SHFSGs and SHFQAs to each other via the central PQSC Programmable Quantum System Controller; LabOne Q optimizes communication across instruments, thus simplifying protocol execution. Up to 18 SHFSGs can be synchronized through a PQSC, leading to coordinated control of up to 144 qubits. SHFSGs that are synchronized through a PQSC can be programmed with LabOne Q, with LabOne, or with its APIs for Python, C, MATLAB®, LabVIEW™ and .NET – so that users decide how they wish to incorporate the SHFSG into a new or existing setup.

# Frequently Asked Questions

## General

**Where can I get a live demonstration of the SHFSG Signal Generator?** Call us on +41 44 515 0410 or send us an email with your contact details and preferred time slot. We are happy to schedule an online demo to discuss your requirements and see whether there is a match with the SHFSG's capabilities.

**Do I need a computer to operate the SHFSG?** Yes, this instrument is operated from a computer connected via USB 3.0 or 1 GbE. The computer uploads waveform and sequence data to the SHFSG. Once the SHFSG is started, it generates its signal autonomously and does not strictly depend on the computer anymore.

**What kind of support will I receive if the instrument is purchased from a local partner and not from Zurich Instruments directly?** All users receive support from Zurich Instruments independently of where the purchase took place. Local sales partners, where available, also provide first-level support in the local language. For extended support, instrument calibration or service, please check our Support page.

## Functionality

**Does the SHFSG support amplitude modulation (AM), frequency modulation (FM), phase modulation (PM), and double sideband modulation (DSB)?** The SHFSG readily supports modulation of the in-phase and quadrature internal oscillator by a dual-channel waveform signal. Based on this functionality, AM, FM, PM, and DSB can be realized. The SHFSG does not support modulation by an external source.

**How many markers does the SHFSG have? How can I access them?** The SHFSG has 1 marker per channel (4/8 in total). The markers are located on the front panel. Using any of the markers does not reduce the 14-bit resolution of the output.

**How can I use the 4 (8) trigger input connectors?** Each channel has a trigger input on the front panel. A single sequence program can incorporate several trigger inputs, and can use the state of a trigger as an input for sequence branching.

**Can I synchronize multiple SHFSG instruments?** Yes, up to 18 SHFSGs can be synchronized through a PQSC, leading to coordinated control of up to 144 qubits. SHFSGs that are synchronized via a PQSC can be programmed by LabOne Q, by LabOne, or by its APIs for Python, C, MATLAB®, LabVIEW™ and .NET, giving flexibility in how best to incorporate the SHFSG into a new or existing setup.

**What tools are provided to help me with my experiments?** With every release of our LabOne software, we provide new tools and features. For example, the fast resonator spectroscopy helps you to measure and characterize your readout line in the minimal amount of time. We also offer a library of python notebooks and tutorials that help you setup and control your SHFSG as quickly as possible.

## Hardware

**Do I need additional mixers external to the instrument to be able to control a set of qubits using the SHFSG?** No. The output of the SHFSG is designed to be directly usable for qubit manipulation, so long as the operation frequencies are within the bandwidth DC - 8.5 GHz. This is possible thanks to the super-heterodyne frequency conversion scheme of the SHFSG, designed to bring stability and simplicity to qubit setups.

**Do I need additional amplification after the signal outputs?** This depends on the specific application. The SHFSG can supply up to 10 dBm of output power, which allows for very short (5 ns) gates with superconducting transmon qubits.

## System integration

**Can I integrate the SHFSG into my existing control software?** If you rely on custom Python, C, MATLAB®, LabVIEW™, or .NET software, the integration is straightforward with the LabOne APIs. Additionally, LabOne helps you to find the right API command for a given instrument setting thanks to its command log feature.

**How can I connect the SHFSG with other instruments of the QCCS?** The SHFSG is intended to be interfaced with the PQSC through the Zurich Instruments ZSync link that provides both system-wide clock synchronization and data distribution. Furthermore it also provides a 32-bit DIO VHDCI interface that can be used to directly connect the SHFSG to other instruments of the QCCS for fast feedback, e.g. the HDAWG Arbitrary Waveform Generator, the PQSC, or to third party instruments.

**Do I need the PQSC to operate the SHFSG?** No. The SHFSG can be controlled with a conventional computer only. However, for optimal synchronization with other instruments of the QCCS Quantum Computing Control System, we strongly recommend using a PQSC.

**Do I need an HDAWG and/or HDIQ to operate the SHFSG?** No, the SHFSG can be used as a stand-alone system and provides everything needed to control multi-qubit systems, including frequency conversion up to 8.5 GHz. It can be triggered through an internal trigger source or any conventional TTL-signal generator.

**Can I replace one or more HDAWGs with an SHFSG directly?** Sometimes. The SHFSG is a specialized signal generator that covers many of the capabilities of a system comprising HDAWG and HDIQ. The HDAWG, however, offers larger waveform memory. The HDAWG also offers a larger signal amplitude at DC than the SHFSG, which makes it suitable for flux bias pulses.

**Can I mix HDAWGs and SHFSGs in a single setup?** Yes. In a QCCS setup, the SHFSG is recommended for single-qubit control pulses and parametric 2-qubit gates, whereas the HDAWG is recommended for flux-bias 2-qubit gates.

# Specifications

## General

Output channels	4 or 8
Dimensions	449 × 460 × 145 mm 17.6 × 18.1 × 5.7 inch
Weight	15 kg (33 lb)
Power supply	AC: 100 – 240 V; 50/60 Hz
Supported clock frequencies	10 MHz or 100 MHz (external or internal)
Connectors	SMA, 32-bit DIO, ZSync LAN, USB 3.0

## Waveform Generation

AWG cores	1 per channel
Waveform resolution	14-bit analog + 2 bit marker
Waveform memory	98 kSa per channel
Instruction memory	32k instructions per core
Marker outputs	1 per channel
Trigger inputs	1 per channel
AWG sampling rate	2 GSa/s
Minimum waveform length	32 Sa

## Signal Outputs

Frequency range	DC - 8.5 GHz
Signal bandwidth	1.0 GHz
Output range	-30 dBm to +10 dBm
Output impedance	50 Ω
Number of synthesizers	4 (both models)
D/A conversion	14-bit, 6 GSa/s
Phase noise (@ 6 GHz)	-90 dBc/Hz @ 1 kHz offset -98 dBc/Hz @ 10 kHz offset -100 dBc/Hz @ 100 kHz offset
Output level accuracy	±(1 dBm of setting)
Spurious-free dynamic range (excl. harmonics) (0 dBm)	74 dBc @ 1 GHz 66 dBm @ 4 GHz 65 dBm @ 8 GHz
Output worst harmonic component (10 dBm)	-40 dBc @ 1 GHz -40 dBc @ 4 GHz -36 dBc @ 8 GHz

