

NI RF Signal Generators Help

September 2007, 371025E-01

This help file contains hardware and software information for NI RF signal generators. This help file contains an introduction to using NI RF signal generators hardware and software programming reference information.

For more information about this help file, refer to the following topics:

Using Help

Important Information

Related Documentation

Technical Support and Professional Services

To comment on National Instruments documentation, refer to the <u>National</u> <u>Instruments Web site</u>.

© 2004–2007 National Instruments Corporation. All rights reserved.

Related Documentation

Most NI-RFSG manuals also are available as PDFs. You must have Adobe Reader with Search and Accessibility 5.0.5 or later installed to view the PDFs. Refer to the Adobe Systems Incorporated Web site at www.adobe.com to download Adobe Reader. Refer to the National Instruments Product Manuals Library at ni.com/manuals for updated documentation resources.

The following documents contain information that you may find helpful as you use this help file:

- NI RF Signal Generators Getting Started Guide, printed and available in your RF signal generator kit. This document is also available in PDF format at Start»All Programs»National Instruments»NI-RFSG»Documentation.
- NI-RFSG Instrument Driver Readme, available at Start»All Programs»National Instruments»NI-RFSG»Documentation.
- NI Signal Generators Help, available at Start»All Programs»National Instruments»NI-FGEN»Documentation.
- For the latest NI-RFSG development information and NI-RFSG examples, visit the NI Developer Zone Web site at ni.com/zone.
- The specifications document for your device is printed and shipped with your RF signal generator. More information about this document is available in PDF format at Start»All Programs»National Instruments»NI-RFSG»Documentation»Specifications. Refer to the National Instruments Product Manuals Library at ni.com/manuals for the most recent specifications for your device.
- The user manual for your device is available in PDF format at Start»All Programs»National Instruments»NI-**RFSG**»Documentation
- The specifications document for your NI arbitrary waveform generator module, if applicable, is printed and shipped with your RF signal generator and available in PDF format at Start»All Programs»National Instruments»NI-

FGEN»Documentation»Hardware Specifications.

Using Help

<u>Conventions</u> <u>Navigating Help</u> <u>Searching Help</u> <u>Printing Help File Topics</u>

Conventions

This help file uses the following formatting and typographical conventions:

- The » symbol leads you through nested menu items and » dialog box options to a final action. The sequence **File**»**Page** Setup»Options directs you to pull down the File menu, select the Page Setup item, and select Options from the last dialog box. P This icon denotes a tip, which alerts you to advisory information. This icon denotes a note, which alerts you to important M information. This icon denotes a caution, which advises you of precautions to take to avoid injury, data loss, or a system crash. Bold text denotes items that you must select or click on in the bold software, such as menu items and dialog box options. Bold text also denotes parameter names, emphasis, or an introduction to a key concept. Underlined text in this color denotes a link to a help topic, green help file, or Web address. Italic text denotes variables, emphasis, cross-references, or italic an introduction to a key concept. Italic text also denotes text that is a placeholder for a word or value that you must supply.
- monospace Text in this font denotes text or characters that you should enter from the keyboard, sections of code, programming examples, and syntax examples. This font is also used for the proper names of disk drives, paths, directories, programs, subprograms, subroutines, device names, functions, operations, variables, filenames, and extensions.

Navigating Help (Windows Only)

To navigate this help file, use the **Contents**, **Index**, and **Search** tabs to the left of this window or use the following toolbar buttons located above the tabs:

- Hide—Hides the navigation pane from view.
- Locate—Locates the currently displayed topic in the Contents tab, allowing you to view related topics.
- **Back**—Displays the previously viewed topic.
- **Forward**—Displays the topic you viewed before clicking the **Back** button.
- **Options**—Displays a list of commands and viewing options for the help file.

Searching Help (Windows Only)

Use the **Search** tab to the left of this window to locate content in this help file. To search for words in a certain order, such as "related documentation," add quotation marks around the search words as shown in the example. Searching for terms on the **Search** tab allows you to quickly locate specific information and information in topics that are not included on the **Contents** tab.

Wildcards

You also can search using asterisk (*) or question mark (?) wildcards. Use the asterisk wildcard to return topics that contain a certain string. For example, a search for "prog*" lists topics that contain the words "program," "programmatically," "progress," and so on.

Use the question mark wildcard as a substitute for a single character in a search term. For example, "?ext" lists topics that contain the words "next," "text," and so on.



Note Wildcard searching will not work on Simplified Chinese, Traditional Chinese, Japanese, and Korean systems.

Nested Expressions

Use nested expressions to combine searches to further refine a search. You can use Boolean expressions and wildcards in a nested expression. For example, "example AND (program OR VI)" lists topics that contain "example program" or "example VI." You cannot nest expressions more than five levels.

Boolean Expressions

Click the **•** button to add Boolean expressions to a search. The following Boolean operators are available:

- **AND** (default)—Returns topics that contain both search terms. You do not need to specify this operator unless you are using nested expressions.
- **OR**—Returns topics that contain either the first or second term.
- **NOT**—Returns topics that contain the first term without the second term.
- **NEAR**—Returns topics that contain both terms within eight words of each other.

Search Options

Use the following checkboxes on the **Search** tab to customize a search:

- Search previous results—Narrows the results from a search that returned too many topics. You must remove the checkmark from this checkbox to search all topics.
- Match similar words—Broadens a search to return topics that contain words similar to the search terms. For example, a search for "program" lists topics that include the words "programs," "programming," and so on.
- Search titles only—Searches only in the titles of topics.

Printing Help File Topics (Windows Only)

Complete the following steps to print an entire book from the **Contents** tab:

- 1. Right-click the book.
- 2. Select **Print** from the shortcut menu to display the **Print Topics** dialog box.
- 3. Select the **Print the selected heading and all subtopics** option.
 - Note Select Print the selected topic if you want to print the single topic you have selected in the **Contents** tab.
- 4. Click the **OK** button.

Printing PDF Documents

This help file may contain links to PDF documents. To print PDF documents, click the print button located on the Adobe Acrobat Viewer toolbar.

Devices

Expand this book to view the topics that describe your RF signal generator hardware and functionality in more detail.

This section includes information about the following devices:

- <u>NI 5650/5651/5652 RF signal generator</u>
- NI 5670 RF vector signal generator
- <u>NI 5671 RF vector signal generator</u>
- NI 5672 RF vector signal generator

NI 5670 Overview

The NI PXI-5670 is an NI RF vector signal generator consisting of the following two PXI hardware modules:

- NI 5421 16 bit, 100 megasample-per-second (MS/s) arbitrary waveform generator (AWG) module (400 MS/s interpolated).
- □ NI 5610 2.7 GHz RF superheterodyne upconverter module.

Note There is no physical device labeled "NI 5670." The NI 5670 is the instrument comprised of the NI 5610 upconverter module and the NI 5421 AWG module. The NI 5670 is operated by NI-RFSG.

The hardware modules interconnect using SMA-SMB coaxial cables, included in your hardware kit, as illustrated in the following figure. Refer to section *6. Interconnecting the NI 5670/5671/5672 Modules* in the <u>NI RF Signal Generators Getting Started Guide</u> for more information about interconnecting hardware modules.



The NI 5670 follows industry-standard Plug and Play specifications for the PXI bus and can be seamlessly integrated with compliant systems. For NI 5670 specifications, refer to the <u>specifications document</u> that shipped with your RF signal generator.

NI RF Vector Signal Generator Hardware Operation

The NI RF vector signal generator hardware consists of two parts: the NI 5421/5441/5442 arbitrary waveform generator (AWG) module and the NI 5610 RF upconverter module. The NI 5421/5441/5442 generates a signal centered at an intermediate frequency (IF) between 15 and 35 MHz. The IF signal is sent to the NI 5610, which frequency-translates it to center between 250 kHz and 2.7 GHz.

The NI-RFSG driver software operates both hardware modules as a single instrument by handling all module programming and interaction. When you specify a carrier frequency and power for the RF output signal, NI-RFSG selects the appropriate IF frequency and power level settings for the NI 5421/5441/5442 AWG module, and the frequency shift, gain, and attenuation settings for the NI 5610 upconverter module. The following figure illustrates the NI RF signal generator driver architecture.



The power and carrier frequency of the IF signal generated by the NI 5421/5441/5442 are determined by the NI-RFSG software. To optimize dynamic range, NI-RFSG attempts to use the full scale of the NI 5421/5441/5442 digital-to-analog converter (DAC) and adjusts output signal power by means of the NI 5610 attenuators.

The NI 5610 contains a stable and accurate 10 MHz frequency reference. A coaxial cable feeds the frequency reference from the NI 5610 10 MHz

OUT (TO AWG CLK IN) front panel connectors to the NI 5421/5441/5442 CLK IN front panel connectors. The NI 5421/5441/5442 locks its internal reference clock to this reference.



Note NI RF signal generator operation requires that the NI 5610 module front panel connector labeled 10 MHz OUT (TO AWG CLK IN) be connected to the NI 5421/5441/5442 module front panel connector labeled CLK IN. Most timing configurations generate an error if this interconnection is not in place.

The NI 5610 reference can also be locked to an external 10 MHz frequency reference. The source of this external reference can be either the REF IN connector on the NI 5610 module front panel or the PXI_CLK10 backplane signal.

The NI 5610 accomplishes frequency shifting by mixing the IF signal with local oscillators in the NI 5610 signal chain circuit. One of these local oscillator (LO) signals can be tuned from 3.2 GHz to 5.9 GHz. A separate output connector on the NI 5610 module front panel, LOCAL OSC OUT 0, allows you to export this LO signal if you have enabled the oscillator output using the Local Oscillator Out 0 Enabled property or the NIRFSG_ATTR_LOCAL_OSCILLATOR_OUT_0_ENABLED attribute.

Power Up and Reset Conditions

The NI RF signal generator hardware is in the following state after powering on or restarting the system and allowing the PC operating system and the NI-RFSG driver to fully load. These conditions are also true after a device reset (performed directly from MAX or by calling the <u>niRFSG Reset Device</u> VI or the <u>niRFSG_ResetDevice</u> function).

- Thermal shutdown monitoring is activated.
- NI 5610 upconverter module RF enclosure is powered on.
- Both module front panel ACCESS LEDs are green.
- LOCAL OSC OUT 0 module front panel output connector is disabled.
- Reverse power protection relay is open.
- All attenuators are asserted.
- Generation Mode is set to CW (continuous wave).
- Both module front panel ACTIVE LEDs are OFF.
- RF output power is set to < -140 dBm.
- NI 5610 onboard 10 MHz reference clock is selected as the NI RF signal generator reference clock.
- Warmup begins (if applicable).

Hardware Front Panel Connectors and Indicators

These sections describe the connectors and LED indicators on the front panels of both PXI/PXIe hardware modules comprising the NI 5670/5671/5672 RF signal generators. All input connectors and output connectors are AC-coupled.

NI 5421/5441 AWG Module Front Panel

The following figure shows the NI 5421/5441 AWG module front panel, which contains five connectors and two multicolor LEDs.

The following table provides connector and use information for the NI 5421/5441 AWG module front panel connectors:

	Connector	Use
NATIONAL INSTRUMENTS NI PXI-54XX	CH0	Returns an IF waveform for upconversion to the desired RF frequency.
ACCESS ACTIVE CH 0		Connect to the IF INPUT connector on the NI 5610 front panel.
	CLK IN	Receives the NI 5421/5441 internal clock reference signal.
PEL1		Connect to the REF OUT connector on the NI 5610 front panel.
DIGITAL DATA & CONTROL	PFI 0 PFI 1	Bidirectional SMB connectors. When used as an output connector, the PFI terminals can route out signals such as waveform markers or the start trigger. When used as an input connector, the PFI terminals accept a trigger from an external source to start or step through signal generation.
	DIGITAL DATA & CONTROL (DDC)	Routes the 16-bit digital pattern outputs, digital pattern clock output, trigger outputs, trigger inputs, and a clock input.

The following table provides LED and indications information for the NI 5421/5441 AWG module front panel LEDs:

T

LED	Indications
ACCESS	Indicates the basic hardware status of the

	NI 5421/5441 module. This LED functions identically to the ACCESS LED on the upconverter module front panel:
	OFF—The module is not yet functional or has detected a problem with a power rail.
	AMBER—The module is being accessed by the PXI bus.
	GREEN—The module is ready to be programmed by a driver.
ACTIVE	Indicates the state of the NI 5421/5441 hardware module:
	OFF—The module is not armed or triggered.
	AMBER—The module is armed and waiting for a Start trigger.
	GREEN—The module has received a <u>Start</u> <u>trigger</u> and is generating a waveform.
	RED—The module has detected an error state; this may indicate PLL unlocking, self-test failure or calibration failure.

NI 5610 Upconverter Module Front Panel

The following figure shows the NI 5610 RF upconverter front panel, which contains six connectors and two multicolor LEDs:

The following table provides connector and use information for the NI 5610 RF upconverter module front panel connectors:

	Connector	Use
TO AWG CLK IN CLK IN	10 MHz OUT (TO AWG CLK IN)	Returns replications of the upconv frequency reference signal, useful
	10 MHz OUT	devices. Each replication is 180° (the other. Signal generation at the always enabled.
10 MHz OUT 50 Ω 1Vp-p 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0		Connect the upper of these two cc CLK IN connector on the AWG mc
REF IN +16 dBm MAX ± 5V DC MAX OO ACCESS ACTIVE ACCESS ACTIVE RF OUTPUT 50 Ω 250 kHz - 2.7 GHz	REF IN	Passes an external frequency refe can be propagated to the PXI bac NI 5610 can lock to this signal.
	IF INPUT	Passes the IF signal from the AW(frequency translation.
		Connect to the CH 0 output on the panel.
	LOCAL OSC OUT 0	Passes the local oscillator (LO) sig generation at this connector is ena Local Oscillator Out 0 Enabled pro NIRFSG_ATTR_OSCILLATOR_OU attribute. The frequency of this LC
		approximately 3.2 GHz greater that
		frequency.

The following table provides information about the NI 56 module front panel LEDs and the device states they ind

LED	Indications
ACCESS	Indicates the basic hardware status of the NI LED functions identically to the ACCESS LEI module front panel:
	OFF–The module is not yet functional.
	AMBER–The module is being accessed by the terms of ter
	GREEN–The module is ready to be program
ACTIVE	Indicates the state of the NI 5610 hardware:
	OFF–The module is in an uninitialized state;
	AMBER–The module <u>PLLs</u> are attempting to
	GREEN–The module is in a ready state; app
	locked and the reverse power protection circi
	RED–The module has detected an error state an overload (reverse power protection circuit failure in an applicable PLL, a self-test or cali thermal shutdown condition.

NI 5421 AWG Module

The NI 5421 is a single-channel 16-bit 100 MS/s arbitrary waveform generator module.

This section contains information about the NI 5421 AWG module when used with the NI 5610 upconverter. For more information about the NI 5421 AWG module and its use as a stand-alone device, refer to the <u>NI Signal Generators Help</u>.

NI 5421/5441 Memory Options

NI 5421/5441 modules are available with four onboard waveform memory size options: 8 MB (NI 5421 only), 32 MB, 256 MB, and 512 MB.

Onboard waveform memory size dictates the maximum time duration for which arbitrary waveforms can be generated without repeating the same waveform data. If your application requires arbitrary waveform playback over long time durations without looping, choose a larger AWG module onboard waveform memory option. For example, 256 MB of onboard memory can store approximately 1.28 s of waveform data at the default IQ rate of 100 MS/s.

If <u>phase continuity</u> is desired, large AWG onboard memory sizes allow finer frequency tolerances in repetitive playback. Frequency tolerance for arbitrary waveforms is limited by available memory size when phase continuity is enabled. When phase continuity is disabled, this limitation on frequency tolerance does not apply.

The following table lists maximum playback times for each memory option using the default IQ rate of 100 MS/s.

Memory Size (MB)	Playback Time Without Looping (ms)
8	40
32	160
256	1,280
≥ 512	≤ 2,560

Note Not all onboard memory can be used for waveform storage. A portion of Onboard memory stores instructions that specify how the waveforms are generated. These instructions typically require less than 1 KB of onboard memory.

NI 5610 RF Upconverter Module

The NI 5610 is a 250 kHz to 2.7 GHz superheterodyne upconverter hardware module that frequency-translates IF input signals between 15 and 35 MHz to a desired RF frequency between 250 kHz and 2.7 GHz.

Note The NI 5610 upconverter module (two slots wide) is connected to the PXI backplane through the leftmost of its two occupied PXI or PXI Express slots. For example, installing the NI 5610 module in Slot 2 occupies Slots 2 and 3. Slot numbers are printed on the PXI or PXI Express chassis.

The NI 5610 offers 20 MHz real-time bandwidth and an on-board 10 MHz highly stable, low phase-noise oven-controlled crystal oscillator (OCXO) reference clock that can be software-configured to drive the PXI 10 MHz backplane clock only when the NI 5610 is installed in Slot 2 of a PXI chassis.

Two replications of the NI 5610 onboard 10 MHz reference clock signal are generated from the NI 5610 module front panel <u>connectors</u> labeled REF 1 and REF 2. Each replication is 180° out-of-phase from the other. Signal generation at these connectors is always enabled. The following figure illustrates the NI 5610 upconverter module block diagram.



Frequency Translation

The NI 5610 has 121 dB of available attenuation range, adjustable in steps of 1 dB (nominal). The attenuators are dispersed throughout the NI 5610 signal chain circuit to optimize the system performance. The NI 5610 is designed to be used with an NI AWG module, which provides fine <u>power level adjustment</u> for the NI RF signal generator.

Local Oscillators

The local oscillators (LO) provide the signals required for mixing in the upconversion process. The LOs are phase-locked to the onboard reference OCXO at all times. The LOs cannot lock to external reference directly; only the OCXO locks directly to external references. Access the final LO signal from the front panel SMA connector labeled LOCAL OSC OUT 0 by enabling signal export using the Local Oscillator Out 0 Enabled property or the

NIRFSG_ATTR_LOCAL_OSCILLATOR_OUT_0_ENABLED attribute. The frequency of this LO can vary between 3.2 and 5.9 GHz, depending upon the specified output frequency and intermediate frequency automatically chosen by NI-RFSG.

NI 5610 Onboard Reference Clock

The NI 5610 onboard 10 MHz OCXO reference clock offers superior accuracy and phase noise specifications to the 10 MHz reference built into most PXI chassis. When the NI 5610 is installed in Slot 2 of a PXI chassis, this reference can be used to drive the 10 MHz PXI backplane clock and serve as the master reference for the PXI system. Refer to the <u>Timing Configurations</u> topic for information about configuring this option. The following figure illustrates the timing circuit block diagram.



The preceding figure shows the routing of the 10 MHz frequency references. Notice that when the NI 5610 is programmed to lock to an external reference, the LOs still lock to the onboard OCXO, which is locked to the external reference.

 $\overline{\mathbb{N}}$

Note The NI PXI-5610 OCXO cannot lock to all 10 MHz references. The reference must meet the specifications provided in the specifications document for your module so that the OCXO can lock to the reference.

Tip NI recommends that you do not lock the OCXO to a reference that is lower quality. In this situation, use the NI 5610 as the master reference clock instead.

Refer to the <u>specifications document</u> that shipped with your NI RF signal generator for NI 5610 onboard OCXO frequency reference specifications.

Timing Configurations

The timebases of both RF signal generator hardware modules (the AWG module and the upconverter module) must be frequency-locked to a common 10 MHz reference clock. The following clock sources are available:

- <u>10 MHz NI 5610 upconverter module Onboard Reference Clock</u>
- <u>10 MHz External Reference Clock</u> (connected to NI 5610 front panel REF IN connector)
- PXI 10 MHz backplane clock

The NI 5610 onboard frequency reference (a very accurate and stable OCXO) can drive the 10 MHz PXI backplane clock *only* if the upconverter module is installed in Slot 2 of a PXI chassis. The NI 5610 *cannot* drive the 10 MHz PXI backplane clock in a PXI Express chassis. When the NI 5610 is installed in PXI Slot 2 of a PXI chassis, you can configure it to drive the 10 MHz PXI backplane clock with the NI 5610 onboard frequency reference or with an external frequency source connected to the REF IN front panel connector on the NI 5610 module.

Timing Configuration	NI 5610 PXI Slot Location	Compatible Chassis	Module Front Panel Connections		С
AWG module locked to upconverter module onboard OCXO, 10 MHz PXI backplane clock independent (default configuration)	Any PXI slot	PXI/PXIe	Connect the TO AWG CLK IN front panel connector on the upconverter module to the CLK IN front panel connector on the AWG module.	1. 2.	Set the F OnBoar NIRFSG to NIRFS Set the F None or NIRFSG attribute
AWG module locked to	PXI Slot 2 only	PXI	Connect the TO AWG CLK IN	1.	Set the F OnBoar

Available timing configurations are shown in the following table.

upconverter module onboard OCXO, 10 MHz PXI backplane clock locked to upconverter module onboard OCXO			front panel connector on the upconverter module to the CLK IN front panel connector on the AWG module.	2.	NIRFSG to NIRFS Set the F OnBoar NIRFSG attribute NIRFSG
Upconverter module and AWG module locked to external reference, 10 MHz PXI backplane clock independent	Any PXI slot	PXI/PXIe	Connect the TO AWG CLK IN front panel connector on the upconverter module to the CLK IN front panel connector on the AWG module; connect the external reference signal to the upconverter module REF IN front panel connector	1. 2.	Set the F RefIn or <u>NIRFSG</u> to NIRFS Set the F None or <u>NIRFSG</u> attribute
Upconverter module and AWG module locked to external reference, 10 MHz PXI backplane clock locked to external	PXI Slot 2 only	PXI	Connect the TO AWG CLK IN front panel connector on the upconverter to the CLK IN front panel connector on the AWG module; connect the external	1. 2.	Set the F RefIn or <u>NIRFSG</u> to NIRFS Set the F RefIn or <u>NIRFSG</u> attribute

reference			reference signal to the upconverter module REF IN connector front panel.		
RF signal generator locked to 10 MHz PXI backplane clock*	Any PXI slot	PXI/PXIe	No front panel connections are required	1. 2.	Set the F PXI_CLF NIRFSG to NIRFS Set the F None or NIRFSG attribute
AWG module sampled externally using the external sample clock	Any PXI slot	PXI/PXIe	Connect the TO AWG CLK IN front panel connector on the upconverter module to the external clock source on the NI 5650/5651/5652 module; connect the external reference clock source to the CLK IN front panel connector on the AWG module.	1.	Set the <i>A</i> ClkIn or <u>NIRFSG</u> attribute

*The <u>onboard reference</u> of the NI 5610 upconverter module offers frequer superior to the frequency reference built into most PXI chassis. Do not loc unless the backplane clock is driven by a high-accuracy reference (built-ir

Using an External Reference Clock Through the Front Panel

the NI RF signal generator can be programmed to phase lock to a 10 MHz external reference clock signal connected to the NI 5610 upconverter module front panel SMA connector labeled REF IN.

The pulling range of the upconverter module onboard OCXO is specified at ± 10 Hz. This implies that the external reference signal must be accurate to within ± 10 Hz for the upconverter module onboard OCXO to phase lock to it. Reference signal accuracy is the frequency offset observed from a rubidium source at 25 °C room temperature. Most references available on the market do not meet the upconverter module OCXO pulling range requirement due to variability with temperature.

The phase noise of the system is also affected by external phase locking. Although the NI RF signal generator tries to minimize the effect of noisy references by using a very small <u>phase-locked loop bandwidth</u>, a considerable remnant may exist if the reference phase noise is 20 to 30 dB poorer than the upconverter module onboard OCXO. Some rubidium sources on the market have more phase noise than the upconverter module onboard reference but exhibit high long-term stability.

The external reference signal power level must be greater than –10 dBm or 0.2 $V_{p\text{-}p}$ into 50 $\Omega.$

Exporting a Frequency Reference

You can export onboard reference of the NI 5610 upconverter module to other benchtop instruments or PXI modules.

The 10 MHz reference signal from the upconverter module <u>onboard</u> <u>OCXO</u> is always available on the <u>10 MHz OUT front panel connectors</u>. Both connectors transmit replicas of the upconverter module 10 MHz frequency reference signal, 180° out-of-phase with each other. If the upconverter module has been <u>configured</u> to lock to an external reference signal, then the signal generated at the 10 MHz OUT upconverter module front panel connector is also locked to the specified reference.

The upconverter module can also be configured to drive the 10 MHz PXI backplane clock with its highly accurate onboard reference clock. This option is only available when the upconverter module is installed in PXI Slot 2 on a PXI chassis. The upconverter module and the NI RF signal generator can also be configured to lock to an external reference clock signal attached to the REF IN connector on the upconverter module front panel.

Note The onboard reference of the upconverter module offers frequency stability and phase noise far superior to the frequency reference built into most PXI chassis. Do not lock to the 10 MHz PXI backplane clock unless the backplane clock is driven by a high-accuracy reference (built-in or installed in PXI Slot 2).

NI 5670 IQ Rates

In Arb waveform and Script modes, the NI 5670 supports two IQ rates:

- 100 megasamples per second (MS/s)— default. This setting provides the best possible antialiasing performance, up to 20 MHz of real-time bandwidth, and the best time-domain resolution of the signal. This setting is recommended for most applications.
- 50 MS/s This setting has several specific situations in which it is useful. These situations are discussed in more detail in the following section.

CW generation mode ignores the <u>IQ Rate (S/s)</u> property or the <u>NIRFSG_ATTR_IQ_RATE</u> attribute setting and always uses an IQ rate of 100 MS/s.
When to Use a 50 MS/s Rate

Two main cases exist in which the IQ Rate property or the <u>NIRFSG_ATTR_IQ_RATE</u> attribute setting of 50 MS/s may be useful:

 Very large waveforms — setting the IQ rate to 50 MS/s halves the memory required to store the same time duration of a given waveform (compared to an IQ rate of 100 MS/s). For example, using an AWG module equipped with the 256 MB memory option, 1.28 s of data sampled at 100 MS/s (equivalent to 2²⁷ samples) can be stored in the AWG module onboard memory. By contrast, approximately 2.56 s of data sampled at 50 MS/s (equivalent to 2²⁸ samples) can be stored in the same amount of memory.



Note Not all available onboard memory can be used for waveform storage. The onboard memory is shared between waveforms and instructions that indicate how the waveform is to be generated.

2. Speed optimization — setting the IQ rate to 50 MS/s can improve speed performance if you need to resample the signal. The resampling process can consume significant CPU time, and larger resampling ratios (final IQ rate / initial IQ rate) require more resampling time. Therefore, resampling to 50 MS/s is less time-consuming than resampling to 100 MS/s.

Implications of Using a 50 MS/s Rate

Setting the IQ Rate property or the NIRFSG_ATTR_IQ_RATE attribute to 50 MS/s has the following implications:

- The NI-RFSG driver must place the IF carrier frequency at 18 MHz ± 1 MHz to avoid aliasing. Forcing the IF carrier frequency to that point implies that the NI-RFSG driver does not have the freedom to pick an IF carrier frequency that could optimize the waveform size if phase continuity is enabled.
- Output signal bandwidth must be < 5 MHz to avoid aliasing.
- Close-in phase noise is higher.

NI 5670/5671 Generation Modes

The NI 5670/5671 has three available generation modes, which are specified using the <u>Generation Mode</u> property or <u>NIRFSG_ATTR_GENERATION_MODE</u> attribute:

- **CW mode**—NI-RFSG software internally generates a continuouswave signal (a sine tone). Frequency and power settings relate to the frequency and power of the sine tone.
- Arb waveform mode—User-provided complex IQ baseband signals are upconverted to RF. Phase continuity, signal bandwidth, frequency tolerance, IQ rate, and digital IF equalization settings are configurable. Output frequency relates to the center frequency. Power settings relate to the power of the specified arbitrary waveform, depending on the setting of the <u>Power Level Type</u> property or the <u>NIRFSG_ATTR_POWER_LEVEL_TYPE</u> attribute.
- **Script mode**—Scripts specify dynamic waveform generation operations. For example, a script could configure the device to generate waveform A, then wait for the Script trigger, then generate waveform B. Refer to <u>scripting instructions</u> for more information.

Phase Continuity

Note This section always applies to the NI 5670. This section only applies to the NI 5671 when the <u>DUC</u> is disabled.

An array containing a sine wave is phase-continuous if the phase of its last point is equal to the phase of its first point, minus the phase difference between any two adjacent samples. In other words, a sinusoidal waveform array is phase-continuous if it contains an integer number of cycles of the sinusoid.

An arbitrary array is phase-continuous if the phase of its last point is equal to the phase of its first point, minus the phase difference between any two adjacent samples for every frequency component of the array.

The user-specified baseband IQ waveform written to the AWG module must be phase-continuous, or a phase glitch appears in the RF output signal when the generation loops back to the beginning of the waveform in AWG onboard memory. NI-RFSG upconverts the user-provided baseband IQ signal to IF by multiplying it with a carrier. The IF waveform array is phase-continuous only if the array contains an integer number of cycles of the IF carrier frequency. The following figure represents a sine wave sampled at two different sample rates. Circles represent phasecontinuous sampling of the sine wave. Squares represent non-phasecontinuous sampling of the sine wave.



Phase glitches in the RF output signal that are due to phase discontinuities in the IF waveform can be addressed by repeating the original IF waveform. For example, you can double an array containing 1.5 cycles of the IF waveform to form a new phase-continuous IF waveform array containing 3 cycles.

For some combinations of waveform size and IF frequency, you may need to repeat the original waveform multiple times to attain phase continuity. In fact, if the original array contains an irrational number of cycles, it is impossible to arrive at an exact integer number of cycles in the repeated array. However, you can get close and then coerce the IF frequency to the nearest quantum to get an exact integer number of cycles. NI-RFSG software coerces the IF waveform by as much as the specified frequency tolerance to minimize array size. This ensures phase continuity at the expense of introducing a frequency quantization error¹. The maximum possible frequency error introduced is inversely proportional to the size of the IF waveform array; therefore, it is possible to make the frequency quantization error arbitrarily small as long as the array size can be arbitrarily large.

In practice, you can ensure phase continuity and keep the frequency error of the IF carrier within a given tolerance (determined by your memory size). A large memory size allows a small frequency tolerance, while a small memory size can give rise to a larger frequency tolerance error.

Note You may continue to encounter "out of memory" errors (or "memory full" errors) when the original waveform is smaller than the specified maximum waveform size. To overcome this problem, increase the frequency tolerance setting. This change allows NI-RFSG to coerce to an RF frequency that requires fewer buffer repetitions.

By default, NI-RFSG assumes that the user-specified input IQ array is phase-continuous. NI-RFSG repeats the input IQ array as necessary to ensure phase continuity in the IF waveform after IQ-to-IF upconversion.

If phase continuity is irrelevant to your application (for example, your array represents a burst signal with a significant portion of the envelope equal to zero power), disable array repetition by using the <u>Phase</u> <u>Continuity Enabled</u> property or the

NIRFSG_ATTR_PHASE_CONTINUITY_ENABLED attribute. This step can often save processing time and AWG onboard memory, but it does not ensure phase coherence in the IF waveform between bursts.



Note Disabling phase continuity does not force the output waveform to be non phase-continuous; rather, it stops NI-RFSG from repeating the waveform to ensure phase continuity.

¹ The term *frequency error* refers to the difference between the userrequested RF output frequency and the actual RF output frequency of the NI RF signal generator. The NI-RFSG driver coerces the output frequency as close to the requested value as allowed by the <u>Frequency Tolerance (Hz)</u> property or the

NIRFSG_ATTR_FREQUENCY_TOLERANCE attribute. The absolute frequency error in the output value of the NI RF signal generator is determined by the 10 MHz reference used during generation. When using the upconverter module onboard reference, this error is less than 50 ppb.

Power Level Adjustment

the NI RF signal generator output signal power level results from both the upconverter module gain settings and the AWG module IF power. NI-RFSG transparently adjusts both hardware modules to achieve the requested RF output power level. Hardware settings are selected by NI-RFSG to optimize linearity and noise floor performance.



Note Refer to the <u>specifications document</u> that shipped with your RF signal generator for guaranteed output power ranges.

Adjustment Components

- The NI 5610 upconverter module adjusts the NI RF signal generator output signal power level in increments of 1 dB by asserting up to 121 dB of onboard IF and RF attenuation. The NI 5610 upconverter module has a maximum output power level specified at 10 dBm (at room temperature). (Absolute maximum power is a function of frequency and is unit-dependant. Refer to the Allow Out of Specification User Settings property or the <u>NIRFSG ATTR ALLOW OUT OF SPECIFICATION USER SETTIF</u> attribute for more information about absolute maximum power). Attenuation settings for given frequencies and temperatures are determined during <u>calibration</u>.
- The AWG module provides fine signal power adjustment by tuning the main digital-to-analog converter (DAC) attenuation and by scaling the digital waveform. NI-RFSG automatically selects a DAC attenuation setting based on signal power requirements. As more attenuation is required, the following components are adjusted:
 - Main DAC 3 dB of analog signal attenuation is available (in increments of less than 0.02 dB) by adjusting the NI 5421/5441 module main DAC attenuation. Attenuating the DAC output signal allows very fine resolution control over signal power while maintaining optimal DAC dynamic range, ensuring no bits are lost from the digital representation of the waveform. Adjusting the main DAC does not apply to the NI 5672.
 - Digital Waveform Scaling If more attenuation is needed, NI-RFSG modifies the digital waveform such that it does not occupy the full-scale output voltage of the DAC. Scaling the digital waveform this way potentially decreases the dynamic range and thus the signal-to-noise ratio, but offers more than 30 dB of attenuation. However, scaling has no effect on observable RF signal generator signal-to-noise ratios because NI-RFSG scales the digital waveform only at power levels , where other components dominate the signal-to-noise ratio (< -85 dBm typical). NI-RFSG performs scaling on both sine waves and arbitrary waveforms as

required.

If the frequency output is varied while keeping power output levels constant, NI-RFSG may automatically adjust the attenuator settings and the IF power levels to maintain constant power output.

Attenuator Hold

The attenuator hold feature allows you to adjust the output level in fine decrements without switching the internal attenuators on the NI RF signal generator. To achieve this, NI-RFSG sets the NI 5610 to the attenuation corresponding to the highest desired power level in a sweep (refer to the Power Sweep example) and then adjusts output signal amplitude by scaling the IF digital waveform such that it does not use the full scale of the DAC onboard the AWG module. Scaling the digital waveform potentially decreases the dynamic range and thus the signal-to-noise ratio.

Use attenuator hold when you need to keep the power monotonically changing while preserving the same power error at the specific frequency setting.

Complete the following steps to configure attenuator hold:

- 1. Open a session to the instrument.
- 2. Configure the <u>Attenuator Hold Max Power (dBm)</u> property or the <u>NIRFSG_ATTR_ATTENUATOR_HOLD_MAX_POWER</u> attribute. This setting specifies the highest power level on your sweep.
- 3. Specify the power level of the output signal (*P*).
- 4. Enable attenuator hold mode using the <u>Attenuator Hold Enabled</u> property or the <u>NIRFSG_ATTR_ATTENUATOR_HOLD_ENABLED</u> attribute. The attenuators are set at commit time.
- 5. Initiate signal generation.

Note Generation starts at the specified power level *P*, but the attenuators are set in such a way that the requested maximum power can be achieved by incrementing the digital waveform.

Output Enabled

You can disable signal output at the upconverter module RF OUTPUT front panel connector using the <u>Output Enabled</u> property or the <u>NIRFSG_ATTR_OUTPUT_ENABLED</u> attribute. You can change the output enable state at any time during waveform generation, and the generation continues on internally.

Refer to the Output Enabled property or the

NIRFSG_ATTR_OUTPUT_ENABLED attribute for more information about enabling signal output.



Note The output enabling circuitry uses mechanical relays and attenuators to switch between the enabled and disabled states. When you change a setting that results in asserting new relay or attenuator settings, the output signal may be interrupted for up to 10 ms as electromechanical components debounce.

Triggers

Triggers are signals that cause the NI RF signal generator to perform an action. the NI RF signal generator supports a <u>Start trigger</u> and several <u>Script triggers</u>.

Start Trigger

A Start trigger initiates signal generation. When a Start trigger is received, the RF output signal begins to generate as shown in the following figure. Received triggers are ignored until the <u>niRFSG Initiate</u> VI or the <u>niRFSG Initiate</u> function is called. A Start trigger received after signal generation has started is ignored. The following figure illustrates an NI-RFSG Start trigger model.



the NI RF signal generator Start trigger is controlled by the AWG module. Configure the Start trigger using the <u>Start Trigger Type</u> property or the <u>NIRFSG_ATTR_START_TRIGGER_TYPE</u> attribute.

Note The NI 5610 upconverter module adds an additional delay, typically 1200 ns, to the delay from the Start trigger to waveform generation that is specified for stand-alone use of the AWG module.

Start Trigger Types

The following three types are available for the NI RF signal generator Start trigger:

- **None**—Signal generation starts immediately upon execution of the <u>niRFSG Initiate</u> VI or the <u>niRFSG_Initiate</u> function. No Start trigger is necessary. This configuration is the default in NI-RFSG.
- **Software**—After initiation, signal generation does not begin until a software Start trigger is received. Call the <u>niRFSG Send Software</u> <u>Edge Trigger</u> VI or the <u>niRFSG_SendSoftwareEdgeTrigger</u> function to send the software Start trigger.
- **Digital Edge**—After initiation, signal generation does not begin until a digital edge is received. Specify the digital edge source by using the <u>Digital Edge Start Trigger Source</u> property or the <u>NIRFSG_ATTR_DIGITAL_EDGE_START_TRIGGER_SOURCE</u> attribute.
- **Tip** Sending a software trigger when the <u>Start Trigger Type</u> property or the <u>NIRFSG_ATTR_START_TRIGGER_TYPE</u> attribute is set to Digital Edge or NIRFSG_VAL_DIGITAL_EDGE, respectively, also starts signal generation. You can use this to create a software timeout to avoid leaving the instrument in a waiting state if the digital edge is never received.

The following figure depicts the possible software trigger sources for the AWG module.



Note Refer to the <u>NI RF Signal Generators Getting Started Guide</u> for more information about AWG modules and triggering.

Script Trigger

A Script trigger is a general-purpose trigger with a role that is entirely determined by the context of the dynamic generation script. A script allows you to create sophisticated dynamic generation operations. For example, the script can configure the device to generate waveform A, then wait for a Script trigger, then generate waveform B. You can configure up to four Script triggers for use in your application.

Refer to <u>Scripting Instructions</u> for information about using scripts.

Clocking

There are three modes of clocking to consider to acheived desired IQ rates on NI RF signal generators.

Divide-Down Clocking

Divide-down clocking divides an RF signal generator timebase to derive a unique frequency.

The divide-down clocking mechanism is preferred when possible because it offers the lowest jitter of the sample clock. However, IQ rates will be coerced to what rates the hardware can achieve. Read the value of the IQ rate back after setting it to see what the actual IQ rate is when using divide-down clocking.

High-Resolution Clocking

High-resolution clocking enables the most precise frequency resolution. This clocking mode is useful for applications that require a precise clock frequency, which is not possible using the divide-down clocking scheme.

High-resolution clocking is the preferred clocking mode to acheive precise IQ rates. However, high-resolution clocking has more jitter than divide-down clocking. Jitter produces increased IQ signal phase noise. Use divide-down clocking for the best possible phase-noise performance.

External Clocking

External clocking allows you to connect an external clock to the NI RF signal generator. This external clock can then be used as the Sample clock for the device.

Marker Events

A marker is an event that the NI 5670/5671/5672 device generates in relation to a waveform that is generated. The event is configured to occur at the time that a specific location or sample *n* in the waveform generates on the AWG CH 0 connector. If the waveform loops multiple times in a segment, the marker generates each time the waveform loops. The following figure shows a waveform being generated on the AWG CH 0 connector. The waveform contains a pulse that represents a waveform sample *n* that is one sample clock in width. The second pulse, the marker event, represents the pulse that generates when the corresponding waveform sample *n* outputs at the AWG CH 0 connector.



 t_{m1} represents the delay in time of the marker event generated relative to the configured waveform sample *n* being generated.

 t_{m2} represents the marker event pulse width in time.

Advanced Topics

This section contains information for the advanced user who wants to optimize performance by better understanding the internals of the NI RF signal generator.

Thermal Management

The NI 5610 upconverter module operates at an internal temperature of approximately 45 °C (113 °F) under conditions of proper airflow and 25 °C (77 °F) ambient temperatures. The upconverter module front panel may reach approximately 39 °C (99 °F) during normal operation.



Caution Allow time for the NI 5610 upconverter module to cool before removing it from the PXI/PXIe chassis. Use caution when handling a recently used upconverter module.

After the warm-up period, the temperature of the NI RF signal generator hardware is typically stable. However, if the temperature varies during signal generation due to changes in external factors, such as ambient temperature or cooling airflow, call the niRFSG Perform Thermal Correction VI or the niRFSG PerformThermalCorrection function to maintain output signal power within specified tolerances. Temperature compensation factors apply when signal generation begins. Thermal management updates the temperature compensation factor if the temperature changes over time.

Warming Up

NI recommends warming up the NI RF signal generator hardware for 30 minutes before operation. The unit is fully functional prior to this time, but frequency and amplitude accuracy and other specifications are not guaranteed until the NI RF signal generator has fully completed warming up.



Note Warming up begins when the operating system and NI-RFSG have completely loaded and the PXI or PXI Express chassis has been powered on. Driver loading can be verified by running a self-test in MAX or calling the <u>niRFSG Self Test</u> VI or the <u>niRFSG self_test</u> function.

NI 5610 Temperature Monitoring

Query the internal temperature of the NI 5610 upconverter module by calling the <u>niRFSG Perform Thermal Correction</u> VI or the <u>niRFSG_PerformThermalCorrection</u> function. The internal temperature and is also monitored by the hardware modules.

When the niRFSG Perform Thermal Correction VI or the niRFSG_PerformThermalCorrection function is called, NI-RFSG checks the temperature to adjust the output level to correct for changes in temperature. Separately, a state machine built into the hardware monitors the temperature of the RF enclosure for thermal shutdown conditions that could damage the equipment.

User Querying

Querying the value of the <u>Device Temperature (°C)</u> property or the <u>NIRFSG_ATTR_DEVICE_TEMPERATURE</u> attribute returns the internal temperature of the NI 5610.



Note The temperature sensor queried by the Device Temperature (°C) property or the NIRFSG_ATTR_DEVICE_TEMPERATURE attribute is within the NI 5610 RF enclosure and contains an internal clock that is activated when the sensor is enabled. This clock can cause low-level close-in phase noise spurs, usually below -70 dBc that vary from unit to unit. For this reason, NI highly recommends that the temperature sensor not be continuously queried to maintain a cleaner spectrum.

Automatic Thermal Shutdown Monitoring

Once NI-RFSG has completely loaded, the RF enclosure is powered on. After that time, circuitry on the NI 5610 upconverter module continuously monitors device temperature. The RF enclosure is powered off before the temperature raises high enough to damage the NI 5610.

If safe temperature limits are exceeded, the NI RF signal generator hardware is shut down and the NI-RFSG software returns an error. You must perform a device reset to restore power to the RF enclosure. Reset the NI RF signal generator hardware by right-clicking both hardware modules in MAX and selecting **Reset Device** or by calling the <u>niRFSG_ResetDevice</u> function.



Note The NI 5610 is warm to the touch during normal operation. It should never reach a temperature high enough to cause thermal shutdown unless the fan or vents on the PXI or PXI Express chassis are blocked or the filters on the fans are excessively dusty. If you get a thermal shutdown error, make sure that the filters are clean and that you have a clear path for airflow through your PXI or PXI Express chassis. Review the guidelines in the *Maintain Forced-Air Cooling Note to Users* document that shipped with the product and make any necessary adjustments to ensure that the device is cooled effectively.

IF Response and Software Equalization

Digital IF equalization is the process of adjusting the frequency content of the signal so that the effective gain is independent of the frequency. In terms of frequency response, a flat response or constant gain versus frequency is desirable for highest modulation quality in the generated signal.

The NI 5610 upconverter module introduces small variations in the IF gain/phase response of the NI RF signal generator. These variations are introduced by the anti-imaging filters used in performing image-free upconversion.

Plots of the typical magnitude response of the NI 5610 upconverter module with the digital IF equalization enabled (upper graph) and disabled (lower graph) are shown in the following figures. Use the <u>Digital</u> IF Equalization Enabled property or the

NIRFSG_ATTR_DIGITAL_IF_EQUALIZATION_ENABLED attribute to enable software equalization.



As can be seen from the typical response, there is ± 2 dB max gain variation between the center of the IF band and the outer edges of the passband. This variation results in degradation of the modulation quality

for wide-bandwidth signals generated using high symbol rates (greater than approximately 500 kS/s).

The variation in the frequency response can be reduced by equalizing the digital data stream to compensate for the passband response of the NI 5610 upconverter. This equalization is controlled using the Digital IF Equalization Enabled property or the

NIRFSG_ATTR_DIGITAL_IF_EQUALIZATION_ENABLED attribute. Use this property or attribute to enable or disable software equalization and to query the enabled or disabled state of the software equalizer.

When digital IF equalization is enabled, software equalization improves the modulation quality for wider real-time bandwidth (greater than 500 kHz) signal generation.



Note The equalizer performs both gain and phase compensation to get a better response. For simplicity, only the gain response is discussed in this section.

• NI 5670/5671 Software equalization is not recommended for narrow-bandwidth signal generation. Software equalization realizes little to no improvement in narrow-bandwidth signals but still requires additional computation time for digital filtering.

Symbol Rate	Recommended Equalization	Comments
≤500 kS/s, Filter Alpha < 0.25	disabled (default for NI 5670/5671)	There is little performance gain from turning on equalization because the occupied bandwidth is 500 kHz or less. Disabling equalization is recommended for faster throughput.
>500 kS/s	enabled (default for NI 5672)	The modulation quality (error vector magnitude) is improved by enabling equalization for wide bandwidth (greater than approx. 500 kHz) signals.

• NI 5670/5671 For faster test times with equalization enabled, save a digital waveform that has been pre-equalized. This step allows the digital filtering operation and the associated computation time to be done once, as opposed to every time the same waveform pattern is generated. NI provides low level tools to extract the

equalization filter coefficients stored in the onboard nonvolatile memory. Refer to <u>NI Technical Support</u> if you need to access these tools.

Other considerations:

The factory-determined equalizer filter coefficients are valid for 25 ± 10 °C. For operation outside this temperature range, NI recommends that the equalizer filter be determined under the operating environment. Refer to the <u>NI Developer Zone</u> for example code that demonstrates how to determine the filter coefficients using a digitizer.

It is helpful to calibrate and compensate the entire signal chain on a system basis for some advanced applications, such as the following:

- Custom equalizer filtering operations that take into account not only the passband response of the NI 5610 upconverter but an external signal conditioning device such as a filter or amplifier
- Determining equalizer coefficients in the field for ambient temperature outside the 25 $^{\circ}C \pm 10 ^{\circ}C$ range

In cases like these, NI recommends disabling the software equalization (by using the Digital IF Equalization Enabled property or the NIRFSG_ATTR_DIGITAL_IF_EQUALIZATION_ENABLED attribute) and applying the equalization filter in your application program before passing the data to NI-RFSG. NI application development environments, including LabVIEW and LabWindows™/CVI™, have built-in tools for digital filtering operations to assist with this task.

Noise Floor

Noise floor is the measure of the noise density (dBm/Hz), or the noise power, in a signal of 1 Hz bandwidth. Noise can be classified into several types: shot noise, thermal noise, flicker noise, burst noise, quantization noise, and avalanche noise. In the NI 5610 upconverter module, thermal noise is the dominant noise source. Thermal noise is caused by random fluctuations produced by thermal agitation of bound charges.

The noise due to a matched resistive load can be expressed as the following relationship:

 $N_{i} = kTB$ watts

where

k is Boltzmann's Constant ($k = 1.38 \times 10^{-23} J/K$)

T is the resistor temperature in Kelvin

B is the bandwidth in Hz.

If *B* is set to 1 Hz, then N_i is equal to the output noise density in watts/Hz. For the system shown in the following figure, the output noise floor is the combination of the input noise multiplied by the gain or loss of the system plus the internal noise of the system, N_n .



The internal noise of a system is therefore:

$$N_n = N_iG - N_o$$

The noise factor (F) of a system is a measure of how noisy a component or system is. The noise factor is defined as the following relation:

$$F = \frac{SNR_{in}}{SNR_{out}} = \frac{\frac{S_i / N_i}{N_i}}{\frac{S_o / N_o}{N_o}}$$

 $S_0 = GS_i$

$$\Rightarrow F = \frac{N_o}{GN_i}$$

$$\Rightarrow N_o = FGN_i$$

$$\therefore N_n = (F-1)GkTB$$

and $N_o = N_iG + (F-1)GkTB$ (Watts)

$$N_o = FGkTB$$
 (Watts)

$$N_o(B=1) = 10log(1000(FGkT)) (dBm/Hz)$$

If N_i is equal to kTB, then

 $N_0 = FGkTB$ (watts)

 $N_0(B = 1) = 10\log(1000(FGkT))$ (dBm/Hz)

Therefore, the output noise floor of the NI 5610 is not only dependent on the noise generated by the internal components, but it is also dependent on the noise generated by the source and by system settings. The noise floor of the NI RF signal generator is dominated by the NI 5610 upconverter module. This behavior is because the NI 5610 upconverter utilizes a superheterodyne architecture that locates a significant amount of gain in the broadband output section. As a result, care should be taken in nonfrequency-selective applications (such as testing broadband devices with broadband detectors), as noise power is integrated. Integrated noise power can be calculated using the following formula:

 $N_o = N_o(dBm/Hz) + 10logB$

where

B is equal to 2.7 GHz (if no external filter is used)

 $N_{\rm o}$ is the noise floor spectral density

With the NI RF signal generator set to minimum power output, the noise power density at the output is -158 dBm/Hz. The following table shows

typical output noise power density for several RF signal generator output power level settings:

Power Level (dBm)	Typical Noise Floor (dBm/Hz)
-57	-158
-50	-157
-40	-154
-30	-147
-20	-140
-10	-130
0	-120
10	-110

Third-Order Intercept

Third-order intercept (TOI) point is a measurement of the degree of linearity of a system. TOI point is a calculated number derived from a two-tone intermodulation test. Typically, two tones of the same power level and of different frequencies are applied to the input of a device. When the signal is generated, the two desired tones appear with distortion products. These distortion products are a result of nonlinearities within the device. The following equation represents the input signals:

$$\mathbf{x}(t) = \mathbf{A}_1 \mathbf{Cos}(\omega_1 t) + \mathbf{A}_2 \mathbf{Cos}(\omega_2 t)$$

A nonlinear device has an output response that is expressed by the following equation:

$$y(t) = a_1 x(t) + a_2 x^2(t) + a_3 x^3(t) + \dots$$

where

 $\mathbf{v}_{\mathbf{X}}$ coefficients represent the gain and the degree of nonlinearity within the device

 x^2 terms represent the second-order distortion terms

x³ represents the third-order distortion terms

 $a_1 x(t)$ represents the desired output

Plugging x(t) into yt results in distortion factors shown in the following table:

Frequency	Distortion Order	Typical Output Power Level
0 (DC offset)	Second	$0.5_{\alpha_2}(A_1^2 + A_2^2)$
2 _{w1}	Second	$0.5_{a_2}A_1^2$
2 _{ω2}	Second	$0.5_{a_2}A_2^2$
^ω 2 ^ω 1	Second	$0.5_{a_2}A_1A_2$
^{ω2+ω} 1	Second	$0.5_{a_2}A_1A_2$
3 _{w1}	Third	$0.25_{a_3}A_1^{3}$
3ω ₂	Third	0.25 ₉₃ A ₂ ³
ω <u>1</u>	Third	$0.75_{a_3}A_1^3 + 1.5A_1A_2^2$

ω2	Third	$0.75_{\alpha_3}A_2^3 + 1.5A_2A_1^2$
$2_{\omega_2-\omega_1}, 2_{\omega_2}+_{\omega_1}$	Third	$0.75_{a_3}A_1A_2^2$
$2\omega_1 - \omega_2, 2\omega_1 + \omega_2$	Third	$0.75_{a_3}A_2A_1^2$

The terms of most interest are $2_{w_2-w_1}$ and $2_{w_1-w_2}$ because these terms are closer into the carrier and are more difficult to filter out. For broadband systems such as CATV, it is important to consider all the terms that fall within this bandwidth. A plot of the desired output signal frequency versus input power is shown in the following figure. Also shown in this plot are the second-order distortion level and the third-order distortion level power levels versus input power.



The output second-order intercept point (OIP₂) and the output third-order intercept point (OIP₃) occur where the second-order line and third-order line, respectively, intersect the desired output signal. If A_1 is set equal to A_2 , and each value is increased by 1 dB, then the third-order distortion products increases 3 dB for every 1 dB increase in output power. The second-order distortion products increases 2 dB for every 1 dB increase in output power. Therefore, based on a two-tone intermodulation test, the output IP₃ can be calculated using the following formula:

 $OIP_3 = P_{out} (dBm) + .5IMD_{3rd} (dBc)$

 $OIP_2 = P_{out} (dBm) + IMD_{2nd} (dBc)$

The TOI is dependent upon power levels. The following table summarizes typical RF signal generator performance.

Frequency (MHz)	-20 dBm/tone	-6 dBm/tone	5 dBm/tone
100	86 dBc	78 dBc	54 dBc
1000	86 dBc	86 dBc	54 dBc

2000	86 dBc	86 dBc	50 dBc
2700	86 dBc	82 dBc	46 dBc

As the power output level increases, the TOI point increases, except for power levels above -3dBm/tone. Beyond -3dBm/tone, there is a step reduction in the TOI point, as shown in the preceding table. The second-order intercept point behaves in a similar manner. This step change above -3 dBm/tone is caused by the architecture and attenuator locations of the NI 5610 upconverter module.
Dynamic Range

Dynamic range is the range between the minimum detectable signal (in this case the noise floor) and the -1 dB compression point, as shown in the following figure.



Dynamic range is expressed with the following equation:

DR (dB) = P_{1dB} (dBm) – *Noise Floor* (dBm/Hz)

Another term often used to describe the dynamic range is the spurious free dynamic range (SFDR). In the traditional sense of an amplifier or transmitter, SFDR is the level at which the intermodulation distortion (IMD) products are equal to the noise floor. Therefore, the input signals are adjusted such that the difference between the desired signals and the noise floor is equal to the difference between the desired signals and the spurs. The following figure is a graphical representation of the SFDR.



The SFDR can be calculated from the third order intercept (TOI) point and the second order intercept (SOI) point using the following equations:

 $SFDR_{TOI} = 2/3(OIP_3 - Noise Floor)$ $SFDR_{SOI} = .5(OIP_2 - Noise Floor)$

Using the NI 5610 upconverter module as a stand-alone unit, maximize the SFDR using the same <u>procedure</u> used to maximize the TOI. This procedure minimizes RF attenuation.

When using the NI 5610 upconverter module in conjunction with an AWG module as a calibrated RF signal generator, the SFDR for a two-tone signal is the difference between the desired tones and the intermodulation levels. This value can be calculated from the TOI and SOI using the following equations:

 $IMD_{TOI} = 2(OIP_3 - P_{out})$ $IMD_{SOI} = OIP_2 - P_{out}$

Output Power (dBm)	Noise Floor (dBm/Hz)	TOI Products (dBc)
-20	-140	-86
-6	-126	-86
5	-115	-54

Frequency Tuning Times

Many factors contribute to NI RF signal generator frequency tuning times. One factor is the amount of time required for the NI 5610 upconverter phase-locked loop (PLL) to lock to a new frequency. Because the NI RF signal generator is an AWG-based vector signal generator, tuning times must also account for the time to configure the AWG module. This configuration time may include recalculating and writing a new waveform to the AWG module onboard memory.

If a new waveform is not written to the AWG module, the AWG module frequency settling time is 0 ms. Writing a new waveform is not required when the NI RF signal generator is tuned in steps of 1 MHz (when using signal bandwidths greater than 10 MHz) or steps of 5 MHz (when using signal bandwidths less than or equal to 10 MHz).

Upconverter Module Frequency Tuning Time

When the frequency is changed in a PLL system, the signal loses its lock on the initial frequency and achieves a lock on the new final frequency. The signal takes time to settle to within the frequency tolerance of the final frequency. Furthermore, the tolerance may be set to a ratio of the step frequency size. For example, in GSM, the signal must settle to less than 2 ppm of the frequency step size in about 860 ms. *Tuning speed* is defined as the time required by the signal to lose its lock on one specific frequency and jump to another specific frequency within a specified frequency tolerance.

The upconverter module front panel ACTIVE LED indicates hardware PLL lock status. The ACTIVE LED indicator turns green when five consecutive pairs of comparison clock cycles are within 15 ns of each other, so it is possible that the signal has not yet settled to within the specified tolerance when the hardware lock ACTIVE LED indicator is lit. To provide a clearer understanding of the hardware lock times, a table of upconverter module PLL lock times for different tuning step sizes is provided in the following table.

Fraguanay Talaranaa	Step Size		
Frequency iderance	10 MHz	100 MHz	1000 MHz
10 kHz	2 ms	6 ms	12.5 ms
1 kHz	4 ms	12 ms	17.5 ms
100 Hz	12 ms	18 ms	25 ms

The upconverter module tunes in steps of 1 MHz (when using signal bandwidths greater than 10 MHz), or steps of 5 MHz (when using signal bandwidths less than or equal to 10 MHz). Upconverter-only (for example, CW generation mode) tuning times are specified in the preceding table.



Note The frequency tuning step size is equal to 5 MHz when the PLL bandwidth is set to LOW using the <u>Signal Bandwidth (Hz)</u> property or the <u>NIRFSG_ATTR_SIGNAL_BANDWIDTH</u> attribute.

NI 5670 CW Generation Mode Tuning Speed Factors

In CW generation mode, the NI-RFSG driver automatically creates the phase-continuous sine waveform needed for the specified frequency.

In CW generation mode, the following factors contribute to the tuning time:

- Frequency step size (desired frequency previous frequency)— The upconverter module has different tuning times for various frequency step sizes.
- **Requested RF output frequency**—The IF waveform size varies, depending on the requested RF output frequency. As the size increases, more time is needed to compute and upload the waveform to the AWG module onboard memory. Refer to the <u>Phase Continuity</u> section for more information about waveform size.
- Frequency tolerance setting—Increasing the frequency tolerance allows the NI-RFSG driver to approximate the desired frequency using a smaller number of waveform cycles, decreasing tuning time. Refer to the *Phase Continuity* section for more information about waveform cycles.

Typically, the largest delay in tuning to a new frequency is the time it takes the upconverter module to lose its lock on the current frequency and acquire a lock on the new frequency. Depending on the step size, the upconverter module takes different amounts of time to lock to new frequencies.

Tips The following measures can decrease CW generation mode tuning times:

P

- Increase the value of the frequency tolerance by using the <u>frequency tolerance</u> property or <u>NIRFSG_ATTR_FREQUENCY_TOLERANCE</u> attribute as much as allowed by your application.
- Change your RF frequency in 5 MHz step sizes so that recalculation of the sine waveform is not required.

NI 5670 Arb Waveform Mode Tuning Speed Factors

A user-specified complex IQ baseband signal is passed to NI-RFSG in arb waveform mode. Then, depending on different parameters, NI-RFSG upconverts the signal to IF and uploads it to the AWG module onboard memory.

In arb waveform mode, the following main factors affect RF signal generator tuning time:

- Waveform size—The bigger the waveform the longer it takes to be recalculated and uploaded to AWG module onboard memory. Increasing the waveform size increases the required tuning time in a linear fashion.
- **Digital IF equalization**—The process of <u>digitally equalizing</u> the waveform is computationally demanding and adds to tuning times.
- Phase continuity—If the Phase Continuity Enabled property or the NIRFSG_ATTR_PHASE_CONTINUITY_ENABLED attribute is enabled, NI-RFSG may repeat the IQ waveform before upconverting it to IF to ensure phase continuity. Repeating the IQ waveform changes the size of the IF waveform and, as noted, increases the NI RF signal generator tuning time. The final IF waveform size depends on the frequency tolerance, desired frequency, and input size.
- Desired frequency—A change in the RF output frequency may require calculation of a new IF waveform centered at a different IF frequency. This situation occurs when the RF frequency change desired is not a multiple of 5 MHz (for signal bandwidths ≤ 10 MHz and <u>CW mode</u>) or 1 MHz (for signal bandwidths > 10 MHz).
- Available RAM—Large waveforms require a large amount of RAM. If sufficient RAM is unavailable, the system uses virtual memory, which dramatically increases execution times.
- Note Refer to the <u>specifications document</u> that shipped with your RF signal generator device for specific tuning times.
- **Tips** The following measures can decrease arbitrary waveform tuning times:
 - Disable digital IF equalization for signal bandwidths less

than 500 kHz.

- Disable <u>phase continuity</u> if your application does not require a phase-continuous signal.
- Write large waveforms in blocks to avoid exceeding RAM capacity and using virtual memory. NI-RFSG <u>examples</u> demonstrate how to write waveforms in blocks.

Phase-Locked Loop Bandwidth

The phase-locked loop (PLL) bandwidth characterizes loop dynamics such as tuning speed, stability, and phase noise shaping. When the PLL bandwidth is designed for *x* Hz, it is measured at *x* Hz from the center of the carrier signal, as shown in the following figure. The region of frequency between the carrier and the PLL bandwidth is "inside the loop," and the region higher then the PLL bandwidth is "outside the loop."



Tuning speed increases with bandwidth and vice versa. PLL theory states that the phase noise of the local oscillator (LO) signal may be broken into the two following components:

- phase noise of the tuning oscillator
- noise from the loop components with the reference signal, inclusive

The tuning oscillator phase noise dominates the region outside the loop, while the region inside the loop is dominated by the loop components.

There are three possible loop bandwidth settings: LOW, MEDIUM, and HIGH. At the HIGH loop bandwidth setting, phase noise less than or equal to 10 kHz offset from the carrier is minimized. The HIGH setting is also used for instantaneous bandwidths less than 10 MHz. At lower settings (MEDIUM or LOW), the phase noise close to the carrier increases while phase noise outside the loop bandwidth frequency decreases. When signal bandwidth is set greater than 10 MHz, the only available loop bandwidth option is LOW. Use the Signal Bandwidth (Hz) property or the NIRFSG_ATTR_SIGNAL_BANDWIDTH to change loop bandwidth settings.

Spurs

Several different categories define the spurious behavior of the NI 5610 upconverter module. The first category includes spurs that are independent of the input signal and occurring at frequencies less than 2.7 GHz. All spurs fitting this criteria are less than or equal to – 80 dBm in amplitude.

Spurs due to intermodulation distortion (IMD) are dependent on the drive and change as the drive level changes. The following equation predicts how the IMD products will change with output power:

$$IMD_{TOI} = 2(OIP_3 - P_{out})$$
$$IMD_{SOI} = OIP_2 - P_{out}$$

Third-order intermodulation distortion (IMD_{TOI}) is the difference in dB or dBc between P_{out} and the distortion signals.



Note IMD_{TOI} degrades by 2 dB for every 1 dB increase in P_{out} for the third order distortion terms, and degrades by 1 dB for every 1 dB increase in P_{out} for the second order terms.

The second category of spurs are dependent on the input signal and occur at frequencies less than 2.7 GHz, but not within ± 10 MHz of the desired output signal. All spurs in this category are less than -80 dBc in amplitude, with the exception of one spur at approximately -60 dBc. The output frequency for this spur can be determined using the following equation:

$$f_{\rm spur} = 3225 - f_{\rm out} - f_{\rm in}$$

where

 f_{spur} , f_{out} , and f_{in} are in MHz.



The third category of spurs includes those within ± 10 MHz of the carrier frequency. These spurs are the result of signals modulating one of the local oscillator (LO) signals. These spurs are below -50 dBc for frequencies less than 1 kHz and below -60 dBc for frequencies from 1 to 2 kHz. Beyond 2 kHz, spurious levels are below -70 dBc.

The final category of spurs are greater than 2.7 GHz. An LO spur occurs at 2.88 GHz and at multiples of 2.88 GHz; these spurs are less than – 80 dBm in amplitude. As part of the architecture of the NI 5610 upconverter module, a broad tuning LO tunes over the range of 3.2 to 5.9 GHz. The frequency of this LO is always approximately 3.2 GHz greater than the output signal.

When the LOCAL OSC OUT 0 connector on the NI 5610 front panel is disabled by using the Local Oscillator Out 0 Enabled property or NIRFSG_ATTR_LOCAL_OSCILLATOR_OUT_0_ENABLED attribute, the LO leakage at the RF OUT connector is typically less than –80 dBm for output frequencies greater than 100 MHz. For output frequencies <100 MHz, the LO leakage at the RF OUT connector is dependent on the filters in the output section and can be as great as –35 dBm.

Note At frequencies greater than 100 MHz, the LO level is affected by the attenuators in the RF signal chain.

When the LOCAL OSC OUT 0 connector on the NI 5610 upconverter module front panel is enabled, LO leakage is about –45 dBm for output frequencies greater than 100 MHz. For frequencies less than 100 MHz, LO leakage is dependent on the filters in the output section and on the output power setting. However, even with the NI 5670 output power set to the minimum level, the LO leakage at the RF OUT front panel connector

(with the LOCAL OSC OUT O connector enabled) could be as great as - 40 dBm.

This section does not address harmonic-related spurs.

Understanding Calibration Correction

Each RF signal generator hardware module (the AWG module and the upconverter module) is calibrated individually, and the uncertainty due to matching two devices is taken into consideration when specifying power level accuracy of the NI RF signal generator.



Note Refer to the printed <u>specifications document</u> that shipped with your device for detailed RF signal generator specifications.

This section discusses the three areas of upconverter module calibration: IF passband calibration, RF flatness calibration, and temperature coefficient determination.



Caution Factory calibration is invalidated if the RF enclosure is opened. To preserve guaranteed calibration, do not disassemble the NI 5610 RF enclosure.

IF Passband Calibration

IF passband flatness refers to the flatness, or variation, in power level over frequency in the 20 MHz input band of the NI 5610. IF flatness is not a function of the output frequency of the NI 5610, but rather of the internal filtering of the NI 5610.

RF Flatness Calibration

RF flatness refers to the variation in NI 5610 gain versus frequency over the specified output bandwidth of the NI 5610. RF flatness is a function of the frequency to which the local oscillator is tuned. The overall gain of the NI 5610 thus depends on both the input IF frequency and the output RF frequency.

Temperature Calibration

The NI 5610 thermally compensates to account for changes in gain with hardware temperature. The uncompensated gain of the NI 5610 upconverter module drifts at a rate of approximately 0.05 dB per degree Celsius.

To compensate for this drift, calibration coefficients are saved into the onboard nonvolatile memory of the module during calibration. These coefficients are used by NI-RFSG to compensate for variations in gain and frequency-dependent effects resulting from temperature changes.

Power Requirements

Each RF signal generator hardware module (upconverter module and AWG module) interfaces to the PXI or PXI Express backplane through a separate PXI or PXI Express bus connector. The upconverter module occupies two PXI or PXI Express slots and interfaces to the PXI or PXI Express backplane via its leftmost occupied slot, while the AWG module interfaces via its occupied PXI or PXI Express slot. Each of the devices is constrained in power consumption to the maximum power specified by the PXI or PXI Express standard. While the AWG module is limited in power consumption to what is available to a single PXI or PXI Express slots available to it, unless otherwise limited by the connector pin-rating per PXI standard.



Note Refer to the printed <u>specifications document</u> that shipped with your RF signal generator for detailed information about RF signal generator power requirements.

NI 5671 Overview

The NI 5671 is a RF vector signal generator consisting of the following two PXI hardware modules:

- NI 5441— 16 bit, 100 MS/s arbitrary waveform generator (AWG)
 PXI module (400 MS/s interpolated) with <u>digital upconverter</u> (DUC).
- □ NI 5610— 2.7 GHz RF superheterodyne upconverter PXI module.
- Note There is no physical device labeled "NI 5671." The NI 5671 is the instrument comprised of the NI 5610 upconverter module and the NI 5441 AWG module. The NI 5671 is operated by NI-RFSG.

The hardware modules interconnect using SMA-SMB coaxial cables, included in your hardware kit, as illustrated in the following figure. Refer to section *6. Interconnecting the NI 5670/5671/5672 Modules* in the <u>NI RF Signal Generators Getting Started Guide</u> for more information about interconnecting hardware modules.



The NI 5671 has the following characteristics and features:

• 250 kHz to 2.7 GHz frequency range

- -145 to +10 dBm amplitude range
- 20 MHz real-time bandwidth with <u>DUC</u> disabled, 6.6 MHz with DUC enabled
- 10 MHz oven-controlled crystal oscillator (OCXO) timebase
 - ±20 ppb frequency stability
 - ±50 ppb frequency accuracy
- 132 dB compression-to-noise dynamic range
- –120 dBm/Hz typical noise density (0 dBm output level, 15 to 35 °C)
- ≥512 MB of AWG module <u>onboard waveform memory</u>
- NI-RFSG transparently operates both modules as a single unit
- Three-slot wide PXI/3U Compact PCI form factor

The NI 5671 follows industry-standard Plug and Play specifications for the PXI bus and can be seamlessly integrated with compliant systems.

NI 5441 AWG Module

The NI PXI-5441 is a single-channel 16-bit 100 MS/s arbitrary waveform generator (AWG) PXI module equipped with a <u>digital upconverter (DUC)</u>.

This section contains information about the NI 5441 AWG module when used with the NI 5610 upconverter. For more information specific to the NI 5441 AWG module and its use as a stand-alone device, refer to the <u>NI Signal Generators Help</u>.

Digital Upconverter

A digital upconverter (DUC) accepts a complex IQ waveform as its input. The DUC then converts this complex waveform to a real waveform with the same frequency content but centered at a higher IF center frequency. In other words, the baseband signal is "upconverted" to IF. This upconversion is done digitally in DUC firmware.

The DUC is a set of algorithms implemented in an FPGA. Two main operations are performed by these algorithms: resampling and upconversion. The FPGA resamples the baseband IQ waveform from the given IQ rate to the digital-to-analog converter (DAC) sample rate (100 MS/s). The DUC then multiplies the resampled IQ waveform by an internally-generated complex IF carrier. This multiplication produces a waveform with a center frequency that matches the IF carrier frequency and frequency content that matches the baseband IQ waveform. This upconverted waveform is then fed into the DAC.



The NI PXI-5671 uses the DUC in the NI 5441 AWG module when the IQ rate is set to 8.33 MS/s or less. The DUC on the NI PXI-5672 is always enabled. The DUC offers the following benefits:

- Lower IQ rates configurable in smaller intervals:
 - Reduces the onboard memory required for a given waveform. For example, for a 1 MHz wide signal, you can set the IQ rate using the IQ Rate (S/s) property or the <u>NIRFSG_ATTR_IQ_RATE</u> attribute to 1.25 MS/s, meaning that each second of the waveform duration uses 1.25 million samples of onboard memory. If you set the IQ rate to 100 MS/s, each second of the waveform duration uses 100 million samples of onboard memory.
 - Increases the maximum duration of a waveform; the smaller

the IQ rate, the longer a waveform can be generated without repetition. For example, using an NI PXIe-5672 with 256 MB of memory running at an IQ rate of 6.1 kS/s, the maximum waveform duration is over three hours. In contrast, the maximum waveform duration for a signal at an IQ rate of 100 MS/s is approximately 1.34 seconds.

- Guarantees that a <u>phase-continuous</u> input waveform remains phase continuous upon generation, regardless of the setting of the <u>Phase Continuity Enabled</u> property or the <u>NIRFSG ATTR PHASE CONTINUITY ENABLED</u> attribute.
- Frequency accuracy is not constrained by the Frequency Tolerance (Hz) property or the NIRFSG_ATTR_FREQUENCY_TOLERANCE attribute. The Frequency Tolerance (Hz) property or the NIRFSG_ATTR_FREQUENCY_TOLERANCE attribute is ignored, and NI-RFSG sets the frequency as accurately as possible for the hardware.
- Changing the RF frequency does not cause the arbitrary waveform to be rewritten to the AWG module. This capability can dramatically speed up applications that generate the same signal at multiple RF frequencies.

NI 5671 IQ Rates

In Arb waveform and Script generation modes the NI 5671 supports several IQ rates:

- 100 MS/s—default. Waveforms sampled at this IQ rate can use the full 20 MHz bandwidth of the NI RF signal generator. No other IQ rate can use the full bandwidth of the NI RF signal generator.
- 50 MS/s This setting has several specific situations in which it is useful. These situations are discussed in more detail in the following section.
- (100 MS/s)/n, where n = 12,14,16,...,512,516,520,...,1024 (for example, n is divisible by 2 between 12—512, and divisible by 4 between 512—1024). Using one of these IQ rates enables the <u>DUC</u>.

Refer to the <u>IQ Rate (S/s)</u> property or the <u>NIRFSG_ATTR_IQ_RATE</u> attribute for more information about IQ rates.

When to Use a 50 MS/s Rate

The NI 5671 supports 50 MS/s only for compatibility with applications written for the NI 5670. The highest DUC IQ rate is 8.33 MS/s, which supports signal bandwidths up to 6.66 MHz. Sampling at 50 MS/s only supports signal bandwidths up to 5 MHz. Using the NI 5671 with an IQ rate of 50 MS/s will work, but using one of the DUC rates instead requires less AWG memory and generally requires less processing time.

Implications of Using a 50 MS/s Rate

Setting the IQ Rate property or NIRFSG_ATTR_IQ_RATE attribute to 50 MS/s has the following implications:

- NI-RFSG is forced to place the IF carrier frequency at 18 MHz ± 0.5 MHz to avoid aliasing. Forcing the IF carrier frequency to that point implies that NI-RFSG does not have the freedom to pick an IF carrier frequency that could optimize the waveform size if phase continuity is enabled.
- Output signal bandwidth must be less than 5 MHz to avoid aliasing.
- Close-in phase noise is higher.

NI 5671/5672 CW Generation Mode Tuning Speed Factors

In CW generation mode, NI-RFSG automatically creates the phasecontinuous sine waveform needed for the specified frequency.

In CW mode, the frequency step size (*desired frequency* minus *previous frequency*) contributes to the tuning time. The upconverter module has different tuning times for various frequency step sizes.

Typically, the largest delay in tuning to a new frequency is the time it takes the upconverter module to lose lock on the current frequency and acquire lock on the new frequency. Depending on the step size, the upconverter module takes different amounts of time to lock to new frequencies.

NI 5671 Arb Waveform Mode Tuning Speed Factors

In arb waveform generation mode, a user-specified complex IQ baseband signal is written to the AWG module.



Note These considerations only apply when the IQ rate specified with the <u>IQ Rate (S/s)</u> property or <u>NIRFSG_ATTR_IQ_RATE</u> attribute is less than or equal to 8.33 MS/s. Refer to <u>NI 5670 Arb</u> <u>Waveform Mode Tuning Speed Factors</u> for other valid IQ rates.

In arb waveform mode, the following main factors affect RF signal generator tuning time:

- **Digital IF equalization**—The process of <u>digitally equalizing</u> the waveform is computationally demanding and adds to tuning times.
- Available RAM—Large waveforms require a large amount of RAM. If sufficient RAM is unavailable, the system uses virtual memory, which dramatically increases execution times.
- Note Refer to the <u>specifications document</u> that shipped with your RF signal generator device for specific tuning times.
- **Tips** The following measures can decrease arbitrary waveform tuning times:
 - 1. For signal bandwidths less than 500 kHz, disable digital IF equalization.
 - 2. Disable <u>phase continuity</u> if your application does not require a phase-continuous signal.
 - 3. Write large waveforms in blocks to avoid exceeding RAM capacity and using virtual memory. NI-RFSG <u>examples</u> demonstrate how to write waveforms in blocks.

NI 5672 Overview

The NI 5672 is a RF vector signal generator consisting of the following PXI hardware module and PXI Express hardware module:

- In NI 5442— 16 bit, 100 megasample-per-second (MS/s) arbitrary wave form generator (AWG) PXI Express module (400 MS/s interpolated) with <u>digital upconverter (DUC)</u>.
- □ NI 5610— 2.7 GHz RF superheterodyne upconverter PXI module
- Note There is no physical device labeled "NI 5672." The NI 5672 is the instrument comprised of the NI 5610 upconverter module and the NI 5442 AWG module. The NI 5672 is operated by NI-RFSG.

The hardware modules interconnect using SMA-SMB coaxial cables, included in your hardware kit, as illustrated in the following figure. Refer to section *6. Interconnecting the NI 5670/5671/5672 Modules* in the NI RF Signal Generators Getting Started Guide for more information about interconnecting hardware modules.



The NI 5672 has the following characteristics and features:

- 250 kHz to 2.7 GHz frequency range
- -145 to +10 dBm amplitude range
- 20 MHz real-time bandwidth
- 10 MHz oven-controlled crystal oscillator (OCXO) timebase
 - ±20 ppb frequency stability
 - + ±50 ppb frequency accuracy
- 132 dB compression-to-noise dynamic range
- -120 dBm/Hz typical noise density (0 dBm output level, 15 to 35°C)
- ≥ 512 MB of AWG module <u>onboard waveform memory</u>
- NI-RFSG instrument driver software transparently operates both modules as a single unit

• Three-slot wide PXI/3U Compact PCI form factor

The NI 5672 follows industry-standard Plug and Play specifications for the PXI/PXIe bus, and can be seamlessly integrated with compliant systems.

NI 5442 AWG Module Front Panel

The following figure shows the NI 5442 AWG module front panel, which contains four connectors and two multicolor LEDs:

The following table provides connector and use information for the NI 5442 AWG module front panel connectors.

())	Connector	Use
NATIONAL INSTRUMENTS	CH0	Generates an <u>IF</u> waveform for upconversion to the desired RF frequency.
сно		Connect to the IF INPUT front panel connector on the NI 5610.
	CLK IN	Passes the NI 5442 internal clock reference signal.
PFI 1		Connect to the REF OUT front panel connector on the NI 5610.
	PFI 0	Bidirectional SMB connectors. When used as an
	PFI 1	output connector, the PFI terminals can route out signals such as waveform markers or the start trigger. When used as an input connector, the PFI terminals accept a trigger from an external source to start or step through signal generation.



The following table provides LED and indications information for the NI 5442 AWG module front panel LEDs.

LED	Indications
ACCESS	Indicates the basic hardware status of the NI 5442 module. This LED functions identically to the ACCESS LED on the upconverter module front panel:
	OFF—The module is not yet functional or has

	detected a problem with a power rail.
	AMBER—The module is being accessed by the PXIe bus.
	GREEN—The module is ready to be programmed by a driver.
ACTIVE	Indicates the state of the NI 5442 hardware module:
	OFF—The module is not armed or triggered.
	AMBER—The module is armed and waiting for a <u>Start trigger</u> .
	GREEN—The module has received a <u>Start trigger</u> and is generating a waveform.
	RED—The module has detected an error state; this may indicate PLL unlocking, self-test failure or calibration failure.

NI 5442 AWG Module

The NI PXIe-5442 is a single-channel 16-bit 100 MS/s arbitrary waveform generator (AWG) PXI Express module equipped with a <u>digital</u> <u>upconverter (DUC)</u>.

This section contains information about the NI 5442 AWG module when used with the NI 5610 RF upconverter. For more information specific to the NI 5442 AWG module and its use as a stand-alone device, refer to the <u>NI Signal Generators Help</u>.

NI 5442 Memory Options

NI 5442 modules can be purchased with three onboard waveform memory size options: 32 MB, 256 MB, and 512 MB.

Onboard waveform memory size dictates the maximum time duration for which arbitrary waveforms can be generated without repeating the same waveform data. If your application requires arbitrary waveform playback over long time durations without looping, choose a larger AWG module onboard waveform memory option. For example, 256 MB of onboard memory can store approximately 1.28 s of waveform data at the default IQ rate of 100 MS/s.

Phase continuity enables large AWG onboard memory sizes to allow finer frequency tolerances in repetitive playback. Frequency tolerance for arbitrary waveforms is limited by available memory size when phase continuity is enabled. Phase continuity is always enabled on the NI 5672.

Memory Size (MB)	Playback Time Without Looping (msec)
32	160
256	1,280
≥512	≤2,560

The following table lists maximum playback times for each memory option using the default IQ rate of 100 MS/s.

Note Not all onboard memory can be used for waveform storage. Onboard memory is shared between waveforms and instructions that specify how the waveforms are generated. These instructions typically require less than 1 KB of onboard memory.

NI 5672 IQ Rates

In Arb waveform and Script modes, the NI 5672 supports several IQ rates:

- 100 megasamples per second (MS/s) (default)
- 50 MS/s
- (100 MS/s)/*n*, where *n* can be of the values expressed in the following table:

n	In steps of
1	N/A
2	N/A
4-10	2
12-4,096	4
4,096-8,192	8
8,192-16,384	16

Refer to the <u>IQ Rate (S/s)</u> property or the <u>NIRFSG_ATTR_IQ_RATE</u> attribute for more information about IQ rates.



Note 100 and 50 MS/s IQ rates are only supported for backwards compatibility with applications written to use the NI 5670/5671. For all other applications, use an IQ rate less than or equal to 25 MS/s.

NI 5672 Generation Modes

The NI 5672 has three available generation modes, which are specified using the <u>Generation Mode</u> property or <u>NIRFSG ATTR GENERATION MODE</u> attribute:

- **CW mode** NI-RFSG software internally generates a continuouswave signal (a sine tone). In this mode, frequency and power settings relate to the frequency and power of the sine tone.
- Arb waveform mode user-provided complex IQ baseband signals are upconverted to RF. In this mode, signal bandwidth, IQ rate, and digital IF equalization settings are configurable. Output frequency relates to the center frequency. Power settings relate to the power of the specified arbitrary waveform, depending on the setting of the Power Level Type property or the NIRFSG_ATTR_POWER_LEVEL_TYPE attribute.
- Script mode scripts specify dynamic waveform generation operations. For example, a script could configure the device to generate waveform A, then wait for the Script trigger, then generate waveform B. Refer to <u>Scripting Instructions</u> for more information about scripts.

NI 5672 Arb Waveform Mode Tuning Speed Factors

A user-specified complex IQ baseband signal is passed to the NI-RFSG driver in arb waveform mode.

In this mode, the amount of available RAM affects RF signal generator tuning time because large waveforms require a large amount of RAM. If sufficient RAM is unavailable, the system uses virtual memory, which dramatically increases execution times.



Note Refer to the <u>specifications document</u> that shipped with your RF signal generator device for specific tuning times.



Tips The following measures can decrease arbitrary waveform tuning times:

- 1. Disable <u>phase continuity</u> if your application does not require a phase-continuous signal.
- 2. Write large waveforms in blocks to avoid exceeding RAM capacity and using virtual memory. NI-RFSG <u>examples</u> demonstrate how to write waveforms in blocks.
NI 5650/5651/5652 Module Front Panel

The following figure shows the NI 5650/5651/5652 module front panel, which contains two connectors and two multicolor LEDs.

The following table provides connector and use information for the NI 5650/5651/5652 module front panel connectors:

$(\textcircled{\bullet}) \bigcirc$	Connector	Use
RF Signal Generator	RF OUT	Generates the RF signal at the requested frequency and power level.
ACCESS 500 kHz-6.6 GHz RF OUT 50 Ω	REF IN/OUT	Routes a frequency reference signal to or from the NI 5650/5651/5652. This connector can be configured as an external frequency reference input or as an output for the onboard 10 MHz
Reverse Power 2 W MAX		
	The following table provides information about the NI 5650/5651/5652 module front panel LEDs and the device states they indicate:	
	LED	Indications
IN 5 Vp-p MAX OUT 1 Vp-p	ACCESS I	ndicates the basic hardware status of the NI 5650/5651/5652 module.
	C	DFF—The module is not yet functional or has letected a problem with a PXI power rail.
⊕ -	ŀ	AMBER—The module is being accessed.
	C	GREEN—The module is ready to be programmed.
	ACTIVE 	ndicates the state of the NI 5650/5651/5652 nardware module:
	t	DFF—The module is in an uninitialized state; here is no error.

AMBER—The module PLLs are attempting to lock.
GREEN—The module is generating a signal; applicable PLLs are locked.
RED—The module has detected an error state; this may indicate lock failure in an applicable PLL, self-test failure or calibration failure, or a thermal shutdown condition.

NI RF Signal Generator Hardware Operation

The following figure is the system block diagram of the NI 5650/5651/5652 hardware module. Control signals and data transferred between the circuit blocks are managed by the system control unit. The system control unit contains all the necessary registers for device control from the host computer. Additionally, it contains the temperature monitor and modulation components. Refer to later sections for more information about these and other functions of the system control unit.



In the upper left hand corner of the diagram is the clocking circuitry. Contained in this circuit are the system clock reference and the direct digital synthesizer (DDS). The system clock is a 200 MHz voltagecontrolled crystal oscillator (VCXO) that can be programmed to phaselock to an external 10 MHz clock signal, present at the REF IN/OUT connector.

The DDS clocked by the 200 MHz reference provides signals of up to 50 MHz, with very fine frequency steps. RF signals below 50 MHz come directly from the DDS. Refer to <u>Using the NI 5650/5651/5652 REF</u> <u>IN/OUT Connector</u> for more information about the onboard reference clock.

Above 50 MHz, signal generation takes place inside the main synthesizer circuit. The synthesizer is phase-locked to the DDS output signal as a reference. This DDS reference signal delivers the necessary fine tuning steps of the synthesizer; the synthesized RF frequency steps are typically 1 Hz or less.

Following the main synthesizer are dividers and multipliers to scale the frequency over the range of 50 MHz to the upper frequency limit of the NI 5650/5651/5652. The lowpass filters implemented allow for an entire octave band, and this impacts the harmonic levels of signals close to the lower end of the octave band. For example, for the NI PXI-5651, a division ratio of 16 results in the octave range of 100 to 200 MHz, and the lowpass filter starts rolloff at 200 MHz. The output of the divided signal contains harmonics: at 100 MHz RF output, the second harmonic is very strong, while at 199 MHz RF output, the second harmonic is suppressed by more than 20 dB. Similarly, during multiplication, the subharmonics are improved at certain frequencies. The worst-case harmonics are specified in the <u>specifications document</u> for your device.

Fine amplitude control is performed by the automatic leveling control (ALC) loop. The ALC has a very broad frequency response, typically from 100 kHz to over 6.6 GHz. The reference for the ALC is set by a temperature-stable voltage DAC. Additional temperature calibration performed during the manufacturing process makes the ALC very stable over the specified operating temperature.

The final block of the system includes the attenuators. These attenuators have a typical range of 100 dB. However, at higher frequencies, reduced isolation limits this range. Thus, the lowest achievable power level increases as the frequency increases.

The calibration data stored in the EEPROM is used by NI-RFSG to correctly set up the hardware for signal generation. Calibration data is used by the instrument driver to compensate for non-ideal components and temperature variation. Refer to <u>Understanding Factory Calibration</u> for more information about calibration data.

NI 5650/5651/5652 Power Level Adjustment

Fine amplitude adjustment is performed by the automatic leveling control (ALC) loop, and coarse attenuation is performed by the attenuators. The ALC is calibrated for amplitude and temperature variation and is used to control the upper 10 dB. When possible, NI-RFSG uses only the ALC to get the specified power. However, if more than 10 dB of attenuation is

needed at the specified frequency¹, then the attenuators are used. For this reason, signal amplitude has best absolute and relative accuracy at the uppermost 10 dB, which is typically better than specified. Below the first 10 dB of power, the attenuators assert and error increases.



Note Refer to the <u>specifications document</u> that shipped with your RF signal generator for guaranteed output power ranges.

¹Power range varies depending on frequency.

NI 5650/5651/5652 Power Up and Reset Conditions

The NI 5650/5651/5652 signal generator hardware is in the following state after powering on or restarting the system.

- The REF IN/OUT connector is configured as an input.
- The VCXO reference clock is free running and its frequency is uncalibrated.
- The DDS is inactive.
- The main synthesizer is off.
- The DDS signal path is selected.
- The ALC is set for minimum amplitude.
- All attenuators are fully asserted.
- Thermal shutdown monitoring is activated.

The NI 5650/5651/5652 returns to the power-up state after a device reset is performed either directly from MAX or by calling the <u>niRFSG Reset</u> <u>Device</u> VI or the <u>niRFSG_ResetDevice</u> function.

Using the NI 5650/5651/5652 REF IN/OUT Connector

The NI 5650/5651/5652 REF IN/OUT connector can be programmed as an input connector or output connector. Phase-locking to an external source configures the connector as an input connector, and exporting the reference signal configures the connector as an output connector. The ability to export or import the reference signal makes it possible to frequency-lock NI RF devices together using one as the master.



Note Although the devices may be frequency-locked together, their generated RF signals are not phase-synchronized.

Coupling of the external reference signal into the reference circuit is possible, potentially producing offset phase spurs in the RF signal. For these reasons, disconnect or turn off any signals connected to the REF IN/OUT connector when REF IN/OUT is not being used.

Refer to the <u>specifications document</u> that shipped with your RF signal generator for NI 5650/5651/5652 onboard frequency reference specifications.

Modulation Modes

The NI 5650/5651/5652 RF signal generator can generate three types of modulated signals, including:

- Frequency shift keying (FSK) signals
- On-off keying (OOK) signals
- Frequency modulated (FM) signals

Refer to <u>NI 5650/5651/5652 Modulation Implementation</u> for more information about frequency modulation.

Frequency-Shift Keying

Frequency-shift keying (FSK) is a type of frequency modulation which assigns bit values to discrete frequency levels. The NI 5650/5651/5652 is capable of producing a 2-FSK signal. The user can control the following modulation parameters:

- Internal modulation waveform types: user-defined bit stream, or pseudorandom bit sequence (PRBS)
- Symbol rate
- FSK deviation

NI-RFSG calculates the exact symbol rate and FSK deviation, which can differ slightly from the input parameters.

For user-defined bit streams, the valid symbol rate range and bit stream length are determined by the following relations:

 $1 \le bit stream length \le 1022$

```
Symbol rate = 50 MHz / (n \times m)
```

where

 $5 \le n < 2^{16}$

 $1 \le m \le$ floor(1022/bit stream length)

For PRBS:

```
Symbol rate = 10 \text{ MHz}/n
```

where

 $1 \le n < 2^{16}$



Note The maximum recommended symbol rate is 100 kHz. Higher symbol rates are possible but produce degraded modulation accuracy.

On-Off Keying (OOK)

OOK is a modulation scheme that varies the power level of the carrier signal between two discrete power levels. The user can control the following modulation parameters:

- Internal modulation waveform type: 1,024-bit user-defined bitstream or PRBS
- Symbol rate



Note The maximum recommended symbol rate is 100 kHz. Higher symbol rates are possible but produce degraded modulation accuracy.

A bit value of 1 sets the carrier signal power to the value configured by the Power Level (dBm) property or the NIRFSG ATTR POWER LEVEL attribute. A bit value of 0 sets the carrier signal power to the lowest possible level for this frequency. Refer to the specifications document for your device for minimum and maximum power levels.

During a bit value of 1 (high power level), the NI 5650/5651/5652 bypasses the main attenuators. Therefore, the high power level range is limited by the power level range of the ALC. The supported OOK high power level range is from the maximum specified power level for this frequency to approximately 10 dB lower than the maximum specified power. Refer to the specifications document for your device for minimum and maximum power levels.

For user-defined bit streams, the valid symbol rate range and bit stream length are related in the following relations:

 $1 \leq bit stream length \leq 1024$

Symbol rate = 10 MHz / $(n \times m)$

where

 $5 \le n \le 2^{16}$

```
1 \le m \le floor(1,022/bit stream length)
```

For PRBS:

```
Symbol rate = 10 MHz/n
where
```

 $1 \leq n < 2^{16}$

The symbol rate is determined by a programmable 16-bit register, as indicated in the following equation:

PRBS symbol rate = 10 MHz/n

where

 $1 \leq n < 2^{16}$

Frequency Modulation

Frequency Modulation (FM) is a form of modulation in which changes in the frequency of the carrier wave correspond directly with changes in the baseband signal. You can control the following modulation parameters:

- Internal modulation waveform types: square, sine, triangle
- Modulation waveform frequency
- FM deviation

The valid modulation waveform frequency (modulation rate) range is expressed in the following equation:

Modulation Rate = 50 MHz / $n \times m$

where

 $1 \leq n < 2^{16}$

 $10 \le m \le 2038$ or $10 \le m \le 1020$ (for square modulation waveforms)

m is the number of samples per waveform, which is optimized by the driver to produce the most linear waveform for a desired rate. Also, m is always an even number for the FM rate calculation.

NI 5650/5651/5652 Modulation Implementation

The main synthesizer has two modes: low and high, corresponding to 20 and 200 kHz loop bandwidths, respectively. During single tone (sine) generation, the low loop bandwidth is selected for the best possible phase noise performance. The specified phase noise is based on low loop bandwidth.

The modulation implemented on the NI 5650/5651/5652 requires that the high loop bandwidth must be used. Choosing high loop bandwidth increases phase noise from 20 kHz and outward; the phase noise close to the carrier does not change. Loop bandwidths do not affect far out noise density; that is, the far out noise of the system remains unchanged.

All frequency modulation occurs within the phase-locked loop (PLL) of the main synthesizer circuitry. Changing the direct digital synthesis (DDS) reference frequency directly modulates the generated signal. In effect, controlling the frequency of the DDS controls the frequency of the generated RF signal. The PLL bandwidth of the main synthesizer is set to high loop bandwidth when modulation is turned on in order to accommodate high modulation rates. During normal operation, with modulation turned off, the loop bandwidth setting returns to low loop bandwidth.

Sinusoidal Tone Versus Modulation Operation

The main synthesizer has two modes: low and high, corresponding to 10 and 200 kHz loop bandwidths, respectively. During single tone (sine) generation, the low loop bandwidth is selected for the best possible phase noise performance. The specified phase noise is based on low loop bandwidth. Override the loop bandwidth defaults if your application requires it.

Ideally, low loop bandwidth should be used when modulation is turned on; however, the modulation implemented on the NI 5650/5651/5652 requires that the high loop bandwidth must be used. Choosing high loop bandwidth increases phase noise from 20 kHz and greater; the phase noise close to the carrier does not change. Loop bandwidths do not affect far out noise density; that is, the far out noise of the system remains unchanged.

NI 5650/5651/5652 Temperature Monitoring

The NI 5650/5651/5652 hardware module includes two temperature sensors. One sensor is located inside the metal enclosure and monitors the RF analog circuitry temperature. Query this temperature sensor through NI-RFSG. NI-RFSG polls the temperature sensor at defined intervals to correct for amplitude and frequency deviations as the temperature of the metal enclosure changes.

The second temperature sensor is located outside the RF enclosure and monitors the temperature of the digital interface circuitry. This sensor is polled by the NI 5650/5651/5652 system control unit (not the instrument driver) every minute by default. If this sensor reads temperatures above 75 °C, it shuts down the PXI power rails to power down the RF enclosure and protect the RF circuitry from damage. When this sensor reads 75 °C on the digital circuit board, the temperature inside the metal RF enclosure is close to 80 °C.

NI 5650/5651/5652 User Querying

Querying the value of the <u>Device Temperature (°C)</u> property or the <u>NIRFSG_ATTR_DEVICE_TEMPERATURE</u> attribute returns the temperature within the NI 5650/5651/5652 RF enclosure. This metal enclosure contains the RF circuitry.

Note Serial signals between the sensor and the system control unit could potentially modulate the signal being generated, causing phase spurs. After the device is thoroughly warmed up, its temperature varies only slightly and slowly, so it is not necessary to constantly poll this temperature sensor.

For these reasons, NI-RFSG reads the temperature sensor at most every minute. Queries to the the Device Temperature (°C) property or the NIRFSG_ATTR_DEVICE_TEMPERATURE attribute return the previous sensor reading until at least one minute has passed since the previous sensor reading occurred.

NI 5650/5651/5652 Thermal Shutdown Monitoring

If safe temperature limits are exceeded, the RF enclosure is powered off and NI-RFSG returns an error.

Re-enabling Device After Thermal Shutdown

You must perform a device reset in order to restore power to the RF enclosure. Reset the NI RF signal generator hardware by right-clicking the NI 5650/5651/5652 hardware module in MAX and selecting **Reset Device** or by calling the <u>niRFSG Reset Device</u> VI or the <u>niRFSG_ResetDevice</u> function.

Note The NI 5650/5651/5652 is warm to the touch during normal operation. It should never reach a temperature high enough to cause thermal shutdown unless the fan or vents on the PXI chassis are blocked, or the filters on the fans are excessively dusty. If you get a thermal shutdown error, ensure the filters are clean and that you have a clear path for airflow through your PXI chassis. Review the guidelines in the *Maintain Forced-Air Cooling Note to Users* document that shipped with the product and make any necessary adjustments to ensure that the device is cooled effectively.

Noise Floor and Signal-to-Noise Ratio

Noise floor changes as signal amplitude changes. For instance, the noise floor may be -150 dBm/Hz for a signal level of -5 dBm, and it may increase to -140 dBm/Hz for a signal level of 5 dBm. It may seem that the latter signal has less integrity, but this is not the case because (assuming all other factors are equal) the signal dynamic range is still 145 dBc/Hz. Consequently, the signal-to-noise ratio (SNR) is specified, but the noise floor of the product is not. While SNR is not the same for all signal levels, it remains relatively constant until the absolute noise density is at or below the theoretical limit of -173.8 dBm/Hz at room temperature. Beyond this limit, the SNR decreases one-to-one with signal level.

NI 5650/5651/5652 Frequency Tuning Times

The following plot shows typical NI 5650/5651/5652 frequency sweep tuning times (to within approximately 1 ppm of the requested frequency).



You may experience overshoot or undershoot when changing power level settings, as shown in the following plot. The plot shows a 1 GHz signal swept from -30 to -10 dBm in 40 steps.



NI 5650/5651/5652 Understanding Factory Calibration

National Instruments performs calibration of the NI 5650/5651/5652 that is relative to an NIST-traceable standard over the specified operating temperature range. Calibration consists of two major parts: frequency accuracy calibration and amplitude accuracy calibration.

For frequency accuracy, the 200 MHz system clock is calibrated against an NIST-traceable rubidium clock at room temperature and over the NI 5650/5651/5652 operating temperature range. It is important that the NI 5650/5651/5652 temperature stabilizes before critical frequency accuracy measurements are taken. Although the NI 5650/5651/5652 reference clock is sensitive to rapid changes in temperature, it has a slow response because its temperature varies with that of the metal RF enclosure, which has a high thermal inertia and therefore responds slowly to ambient temperature changes.

For amplitude accuracy, the ALC and attenuators are calibrated over the entire specified temperature range. The amplitude accuracy is calibrated against an NIST-traceable power meter for power levels greater than – 40 dBm. For power levels below –40 dBm, a signal analyzer is used to make measurements relative to 0 dBm absolute. The accuracy of the power measurement for signals less than -40 dBm is thus dependent upon the relative accuracy of the signal analyzer. The relative accuracy of the signal analyzer is a function of its ADC linearity.

N

Note Refer to the printed <u>specifications document</u> that shipped with your device for detailed RF signal generator specifications.



Caution Factory calibration is invalidated if the RF enclosure is opened. To preserve guaranteed calibration, do not disassemble the NI 5650/5651/5652 RF enclosure.

Integration and System Considerations

This section contains information about integrating NI RF signal generators into a PXI-based measurement system.

The PXI architecture has built-in timing and triggering features that can synchronize multiple devices over a backplane timing bus. Multiple devices in a modular instrumentation system can share a common reference clock and synchronize to triggers that are distributed over controlled signal paths that ensure matched propagation. PC plug-ins with RTSI also provide an internal bus that can be accessed by multiple devices. Internal routing of these timing signals in PXI and PC plug-ins with RTSI eliminate complicated external wiring. Standardized timing protocols eliminate incompatibilities, giving you the best performance when synchronizing any kind of analog, digital, or timing measurements.

Environment

Device performance and reliability may be limited at temperatures above the specified operating range. For best performance take the following precautions:

- Ensure that the ambient temperature is within the specifications for the device and is stable (±5 °C).
- Follow standard metrology practices.
- Use a PXI or PXI Express chassis with a well-designed cooling system.

Operating NI PXI and PXI Express RF signal generators outside the specified operating temperatures can increase bias currents in the electronic components, increase noise, accelerate drifts, and decrease product life. Beyond the maximum specified operating temperatures, the device may perform differently than during factory calibration, resulting in measurement errors. Also, operating the device outside of the humidity specification (>80%, >35 °C) may cause leakages between circuit components and introduce measurement error.

To optimize cooling and ensure best performance and reliability the use the following guidelines:

- Chassis that provide multiple fan speed settings should always be run with fans set on HIGH or AUTO, if applicable to your chassis. Never set the fans to LOW or turn them off.
- $\overline{\mathbb{N}}$
 - **Note** In newer NI chassis the settings are HIGH and AUTO, in some older NI chassis the fan settings may be HI and LO.
 - All empty slots in the chassis should be occupied with a slot blocker or covered with a filler panel.
 - Remove and clean the inlet filters often to prevent buildup of dust and other foreign material that may restrict airflow.
 - The chassis should be located such that the fan inlets and outlet vents are not obstructed. Other objects and equipment should be kept a minimum of 3 inches from the fan inlets.

For more information about forced-air cooling, refer to your chassis documentation.

PXI/PXI Express Chassis Cooling

Not all PXI or PXI Express chassis provide the same cooling. When selecting a PXI or PXI Express chassis, consideration should be given to providing adequate airflow for high power and sensitive devices such as NI RF signal generators.

NI RF signal generators are high-precision instruments and may be sensitive to interference from other electronic devices. To optimize the accuracy and performance of the device, you may need to locate the device in a slot away from devices with power supplies and other noisy circuitry. The device may also be sensitive to heat generated by highpower products in neighboring slots. When possible, consider locating the device away from high-power devices to optimize cooling.

PXI Modules

PCI eXtensions for Instrumentation (PXI) modular instrumentation delivers a PC-based, standardized, high-performance measurement and automation system. PXI combines the high-speed PCI bus with integrated timing and triggering designed specifically for measurement and automation applications to deliver significant performance improvements over older architectures. The following figure shows a typical PXI chassis installation.



NI RF Signal Generators Available as PXI Modules

The NI 5650/5651/5652/5670/5671 RF signal generators are available in the PXI form factor.

Chassis Guidelines

NI PXI RF signal generators can be installed in the following chassis and slots:

- **PXI chassis**—NI PXI RF signal generators can be installed in any peripheral slot of a PXI chassis.
- **PXI-Express chassis**—NI PXI RF signal generators can be installed in the following PXI Express chassis slots:
 - PXI-1 slots—Accepts PXI modules
 - PXI hybrid slots—Accepts either PXI modules that are hybrid slot-compatible or PXI Express modules

Using PXI-Compatible Products with Standard CompactPCI Products

The ability to use PXI-compatible products with standard CompactPCI products is an important feature provided by the *PXI Specification*, revision 2.1. If you use a PXI-compatible plug-in device in a standard CompactPCI chassis, you cannot use PXI-specific functions, but you can still use the basic plug-in device functions. For example, the PXI trigger bus on a NI signal generators is available in a PXI chassis but not in a CompactPCI chassis. The CompactPCI specification permits vendors to develop sub-buses that co-exist with the basic PCI interface on the CompactPCI bus. Compatible operation is not guaranteed between CompactPCI devices with different sub-buses nor between CompactPCI devices with sub-buses and PXI. The standard implementation for CompactPCI does not include these sub-buses. NI signal generators work in any standard CompactPCI chassis. PXI-specific features, such as PXI_Trig bus and PXI_CLK10 reference are implemented on the J2 connector of the CompactPCI bus.

Related Topics

PXI Star Trigger Line

Related Web Topics

Refer to <u>PXI Specification Tutorial</u> at ni.com/zone for an overview of the PXI Specification.

Refer to <u>How do National Instruments PXI Boards map to the PXI</u> <u>Backplane?</u> at ni.com/zone for an overview of PXI-specific functions.

PXI Express Modules

The PXI Express Specification integrates PCI Express signaling into the PXI standard, which increases backplane bandwidth and enhances PXI timing and synchronization features by incorporating a 100 MHz differential reference clock and differential triggers. The PXI Express specification adds these features to PXI while maintaining backward compatibility.



NI RF Signal Generators Available as PXI Express Modules

The NI 5672 RF vector signal generator is available in the PXI Express form factor.

Chassis Guidelines

NI PXI Express RF signal generators can be installed in the following PXI Express chassis slots:

- **PXI hybrid slots**—Accepts either PXI modules that are hybrid slotcompatible or PXI Express modules
- PXI Express slots—Accepts PXI Express modules



Note Refer to the documentation for your PXI Express device and chassis for more information about installing and configuring PXI Express modules.

Using PXI Express Products with CompactPCI Express Products

The CompactPCI/PXI Express backplane integrates PCI Express while still preserving compatibility with current PXI modules. PXI Express hybrid slots are capable of delivering signals for both PCI and PCI Express. Thus, the hybrid slot allows you to install a PXI module that uses PCI signaling or a PXI Express module that uses PCI Express signaling.

Related Web Topics

Refer to <u>PXI Express Specification Tutorial</u> at ni.com/zone for an overview of the PXI Express specification.

PXI Star Trigger Line (PXI Chassis Only)

The PXI star trigger is a feature implemented on National Instruments PXI chassis. PXI chassis have a PXI trigger bus that is linked to all slots in the chassis. In addition, PXI chassis have a PXI star trigger that is linked to Slot 2. The PXI star trigger is a high-performance trigger signal that you can use to synchronize all the devices in a chassis. You can also do this using the normal PXI trigger bus, but the PXI star trigger offers increased performance, specifically a propagation delay of no more than 5 ns and skew of no more than 1 ns.



The PXI star trigger lines allow a PXI star controller in Slot 2 to route signals to or from other peripheral slots with very low skew and at higher bandwidth than other PXI trigger lines.

When not using the PXI star line, you can use Slot 2 as a standard peripheral slot. However, when using PXI star, you must have a PXI star controller, (master) device in Slot 2, and one or more peripheral devices in the other slots.

If placed in a peripheral slot—Slot 3 or higher—all NI PXI RF signal generators can receive a signal from PXI star.

Additionally, an NI 5650/5651/5652/5670/5671 in a peripheral slot can be configured to drive a signal onto the PXI star line if the PXI star trigger controller is configured to receive it.

Related Topics

PXI Modules

PXI Trigger Lines

Eight PXI bus trigger lines are highly flexible and can be used in a variety of ways. For example, triggers can be used to synchronize the operation of several different PXI peripheral devices. In other applications, one device can control carefully timed sequences of operations performed on other devices in the system. Triggers may be passed from one device to another, allowing precisely timed responses to asynchronous external events that are being monitored or controlled. The number of triggers that a particular application requires varies with the complexity and number of events involved.



The PXI Specification is implemented with the RTSI bus through the PXI trigger lines. PXI Specification requires eight lines, PXI_Trig<0..7>, on the P2/J2 connector of the PXI chassis for the trigger lines. The RTSI features of NI signal generators is implemented on this sub-bus. The RTSI triggers <0..6> are implemented on PXI_Trig<0..6>, and the RTSI clock is routed on PXI_Trig7.

Refer to <u>How do National Instruments PXI Boards map to the PXI</u> <u>Backplane?</u> at ni.com/zone For an overview of PXI-specific functions.

Related Topics

PXI Star Trigger

System Reference Clock, PXI_CLK10

The PXI chassis supplies the PXI 10 MHz system reference clock signal (PXI_CLK10) independently to each peripheral slot. An independent buffer drives the clock signal to each peripheral slot. The buffer has a source impedance matched to the backplane and a skew ranging from less than 1 ns to better than 250 ps between slots. You can use this common reference clock signal to synchronize multiple devices in a measurement or control system. You can drive PXI_CLK10 from an external source through the PXI_CLK10_IN pin on the P2 connector of the PXI star trigger slot, which is Slot 2. Sourcing an external clock on this pin automatically disables the 10 MHz source on the backplane. You can synchronize multiple chassis that have connectors on the back panel for 10 MHz reference in and 10 MHz reference out. Refer to your PXI chassis documentation for more information.



Note PXI Express chassis have a PXI 10 MHz system clock signal, but NI-RFSG devices cannot drive it.

Integration and System Considerations **PFI** Lines

PFI lines are multipurpose programmable function input/output lines. These lines serve as connections to virtually all internal timing signals. NI RF signal generators have up to six digital lines that can accept or generate a trigger, generate a marker, accept or generate a reference clock. The function of each PFI line is independent.

To connect external signal generators to the PFI lines, use the <u>niRFSG</u> Configure Ref Clock VI or the niRFSG ConfigureRefClock function to route external signals to internal sources.

Use the <u>niRFSG Export Signal</u> VI or the <u>niRFSG_ExportSignal</u> function to route internal signals to the PFI lines on the front panel.



Caution If you enable a PFI line for output, do *not* connect any external signal source to it; doing so can damage the device, the computer, and the connected equipment.
NI-RFSG Programming Reference

This section provides reference information regarding the <u>NI-RFSG</u> <u>Programming State Model</u>.

Refer to the <u>Software Fundamentals</u> section for an introduction to NI-RFSG. For in-depth information about NI-RFSG programming, refer to the <u>NI-RFSG LabVIEW Reference</u>, <u>NI-RFSG Properties</u> or the <u>NI-RFSG</u> <u>C Function Reference</u> sections for more information about using specific LabVIEW VIs, properties, CVI functions, and attributes.

Software Fundamentals

NI-RFSG Instrument Driver

The NI-RFSG instrument driver software controls the configuration and operation of all NI RF signal generators using LabVIEW VIs or LabWindows/CVI functions. In the case of NI 5670/5671/5672 devices, the separate upconverter module and AWG module are associated in MAX, allowing NI-RFSG to transparently operate the upconverter module and the AWG module as a single NI PXI/PXIe-5670/5671/5672 RF signal generator.

NI-RFSG configures and operates NI RF signal generator hardware, performs waveform programming and generation, and is capable of basic IQ modulation tasks. Add-on software available from NI, such as the Modulation Toolkit (optional) and the Spectral Measurements Toolkit (included), extends the capability of the NI RF signal generators to include additional frequency-domain and modulation-domain tasks.

This section provides reference information regarding the NI-RFSG programming flow, state model, NI-RFSG VIs/functions, and information about installed examples.

Refer to the <u>NI-RFSG LabVIEW reference</u> or the <u>C Function Reference</u> sections for more information about using specific LabVIEW VIs, CVI functions, properties, and attributes.

Spectral Measurements Toolkit

The Spectral Measurements Toolkit (SMT) contains VIs functions for generating and analyzing analog modulated signals. Supported modulation formats include amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). SMT functions also perform frequency domain analysis tasks such as the zoom FFT and spectrum averaging, and measurements such as power in band and adjacent channel power.

Refer to the NI Spectral Measurements Toolkit User Guide, available at **Start**»**All Programs**»**National Instruments**»**Spectral Measurements**, for detailed information about using the SMT.

Modulation Toolkit

Modulation Toolkit The Modulation Toolkit integrates with SMT and NI RF Signal Analyzers for modulation/demodulation measurements and analysis. Modulation Toolkit VIs and functions generate and analyze analog and digital modulated IF signals in FSK, MSK, PSK, QAM, AM, FM, and PM formats. The Modulation Toolkit is capable of measuring several aspects of signals generated by a unit under test, including the following:

- Modulation quality and modulation index
- Signal impairments, bit error rate, and phase noise
- Carrier frequency drift and complementary cumulative distribution functions (CCDF) values

Refer to the Modulation Toolkit documentation, available at **Start»All Programs»National Instruments»Modulation**, for complete information about Modulation Toolkit VIs and functions.

NI-RFSG Instrument Driver Programming Flow

NI-RFSG VIs are located on the LabVIEW functions palette at **Measurement I/O**»**NI-RFSG**. The top-level NI-RFSG functions palette is shown, and the core VIs are highlighted in the following figure:



Every application using NI-RFSG must call the five VIs highlighted on the preceding palette image. These VIs are arranged from left to right in the order they must be called:



1. <u>niRFSG Initialize</u>Opens a session to the NI-RFSG device and initializes both the AWG and the upconverter hardware.



2. <u>niRFSG Configure RF</u>Configures the frequency and power level of the RF output signal.



3. <u>niRFSG Initiate</u>Initiates signal generation.



4. <u>niRFSG Check Generation Status</u> Monitors signal generation status and checks for any errors which may occur during signal generation.



5. <u>niRFSG Close</u>Closes the NI-RFSG session and deallocates memory resources used by NI-RFSG. You must call this VI once for every session opened with niRFSG Initialize.

NI-RFSG Programming State Model

The NI-RFSG programming model has three main states: Configuration (Idle), Committed, and Generation (Running). The following programming state model depicts the programming state model for the NI-RFSG hardware and software.



Configuration	You can program all session properties in the Configuration state. However, when the hardware module is in the Configuration state, the properties have not yet been applied. Therefore, the module configuration may not match the session property values. The NI-RFSG device does not generate a signal in the Configuration state.	
	Note When you read a property, NI-RFSG may analyze many properties in the current configuration in order to return the coerced value for that property. In general, avoid reading any properties until you have finished changing all the properties you would like to change. Otherwise, you may encounter errors if a property is read while the configuration is in an inconsistent state.	
Committed	 Calling the <u>niRFSG Commit</u> VI or the <u>niRFSG_Commit</u> function from the Committed state performs the following actions: Verifies all property settings Validates the specified configuration Writes all settings to the hardware modules 	

	 Writes the waveform to the AWG module onboard memory Transitions to the Committed state
	If any properties are changed while in the Committed state, the session implicitly transitions back to the Configuration state and the hardware configuration reflects the previously committed properties.
Generation	 In the Generation state, session properties always reflect the current state of the module, and the module is either waiting on a trigger or generating a signal. Note For the NI 5670/5671 devices, you cannot write any properties during the Generation state. However, the NI 5650/5651/5652 device family does allow some attributes to be changed during the Generation state.
Note The	piper Class VI or the piper class function may be

Note The <u>niRFSG Close</u> VI or the <u>niRFSG_close</u> function may be called from any state. Calling this VI or function stops signal generation.

Installed Examples

NI-RFSG includes several example applications for both LabVIEW and LabWindows/CVI. These examples are intended to serve as interactive tools, programming models, and as building blocks in your own applications.

LabVIEW users can use the NI Example Finder to search or browse examples. NI-RFSG examples are classified by keyword, so you can search for a particular device or measurements function. With LabVIEW running, select **Help**»**Find** Examples to launch the NI Example Finder. The NI Example Finder offers two ways to access all installed LabVIEW example VIs (including NI-RFSG and Modulation Toolkit examples) and their descriptions:

- Click the Browse tab to locate modulation examples by task at Hardware Input and Output»Modular Instruments»NI-RFSG or by directory structure at instr»niRFSG.
- Click the Search tab to search all installed examples by keyword. For example, searching for "RFSG" can be used to locate all RF signal generator examples.

The NI Example Finder is also available in LabWindows/CVI by selecting **Help**»**Find Examples**. LabVIEW and LabWindows/CVI users also can access all the installed NI-RFSG examples at **Start**»**All Programs**»**National Instruments**»**NI-RFSG**»**Examples**.

Examples also are available online that demonstrate integrating NI RF signal generators with the NI 5660 RF Signal Analyzer and NI toolkit software including the Modulation Toolkit. Refer to the <u>NI Developer Zone</u> at ni.com/zone for these examples and for more information.

- Click the Browse tab to locate an NI-RFSG example by task at Hardware Input and Output»Modular Instruments»NI-RFSG or by directory structure at instr\niRFSG.
- Click the Search tab to search all installed LabVIEW examples by keyword. Enter the keyword multitone, for instance, to locate an example demonstrating multitone signal generation using the NI RF signal generator and the Spectral Measurements Toolkit (if installed).

LabVIEW and LabWindows/CVI users can also access all installed NI-

RFSG examples at **Start**»**All Programs**»**National Instruments**»**NI-RFSG**»**Examples**. View LabVIEW examples by navigating to the <LabVIEW>\examples\instr\niRFSG folder. View examples for CVI by navigating to the Program Files\IVI\Drivers\niRFSG\Examples directory.

Examples are also available at the <u>NI Developer Zone</u> at ni.com/zone that demonstrate integrating the NI RF signal generator hardware and software with the NI RF signal analyzers and NI toolkit software, including the Modulation Toolkit.

Scripting Instructions

Scripts consist of five primary instructions: <u>generate</u>, <u>repeat/end repeat</u>, <u>wait</u>, <u>if/else/end if</u>, and <u>clear</u>. Additionally, all instructions in a script are surrounded by the keywords <u>script <script name>/end script</u>. Multiple scripts can exist on the device at one time—you can choose which script to execute by referencing the script name.

For examples of scripting applications, refer to <u>Common Scripting Use</u> <u>Cases</u>.

Note Some waveform names allowable in NI-RFSG cannot be used with the NI Script Editor. When working with scripts, ensure that your waveform name does NOT:

- contain spaces
- start with a number
- contain reserved words (such as generate or repeat)

Refer to the Script Editor Help for more information. To view the NI Script Editor Help, Launch the NI Script Editor and select **Help**»**Script Editor Help**.

Common Scripting Use Cases

Refer to <u>scripting instructions</u> for examples of using primary scripting instructions, including <u>generate</u>, <u>repeat/end repeat</u>, <u>wait</u>, and <u>clear</u>.

Single Waveform (one-shot/finite generation)

script singleWfmExample generate wfm01 end script

This script generates wfm01 and then stops. When generation stops, the last sample of wfm01 is held at the output.

Generating Waveforms with Markers

script wfm01MarkersExample generate wfm01 marker0 (0, 20) end script

This script generates the entire w fm01 waveform and generates a Marker event at samples 0 (the start of the waveform) and 20.

Sequence of Multiple Waveforms

script upWfm01DownExample generate countUp generate wfm01 generate countDown end script

Conditional Branching — If/Else

script branchingExample repeat forever generate wfm01 if scripttrigger0 then generate wfm02 else generate wfm03 end else end repeat end script

The following diagram illustrates the preceding script behavior:

scripttrigger0		<u> </u>				
output	wfm01	wfm03	wfm01	wfm02	wfm01	wfm03
265						time

Generating Waveform Subsets

```
script wfm01SubsetExample
  generate wfm01 subset (20, 60)
end script
```

This script generates 60 samples from w fm 01, starting at sample 20.



Note The subset beginning sample number must be an integer multiple of 4. The subset number of samples must also be an integer multiple of 4.

Finite Repetition (N Times)

script up3Wfm01DownExample generate countUp repeat 3 generate wfm01 end repeat generate countDown end script

Conditional Repetition — Repeat until Trigger

script upWfm01UntilTrigDownExample generate countUp repeat until scripttrigger0 generate wfm01 end repeat generate countDown end script

Continuous Generation — Repeat Forever

script upThenUpAndDownForeverExample generate countUp repeat forever generate countUpAndDown end repeat end script

Waiting for Triggers

script upWaitWfm01DownExample generate countUp wait until scripttrigger0 generate wfm01 generate countDown end script

The following diagrams illustrate the preceding script behavior:

countUp (last sample of countUp h	held) wfm01	countDown
countUp wfm01 countDown		time
	countUp (last sample of countUp)	countUp (last sample of countUp held) wfm01

```
script upWaitWfm01DownExample
generate countUp
clear scripttrigger0
wait until scripttrigger0
generate wfm01
generate countDown
end script
```



These two scripts are similar, but a script received during generation of countUp causes the first script to move to wfm01 after the smallest possible delay. By adding a clear instruction, you can ignore any triggers received before the wait instruction.

Finite Wait

script upWait32DownExample generate countUp wait 32 generate countDown end script

Stepping Through Multiple Waveforms

script stepThroughUpAllZerosDownExample repeat forever generate countUp clear scripttrigger0 wait until scripttrigger0

> generate allZeros clear scripttrigger0 wait until scripttrigger0

> generate countDown clear scripttrigger0 wait until scripttrigger0

end repeat end script

Bursting through Multiple Waveforms

script burstThroughUpDownThenZerosOnesExample repeat forever repeat until scripttrigger0 generate countUp generate countDown end repeat

repeat until scripttrigger0 generate allZeros generate allOnes end repeat end repeat end script

Operating System Support

For information about the supported operating system (OS) for your device, refer to the <u>NI-RFSG Instrument Driver Readme</u>.



Prefixes

Symbol	Prefix	Value
р	pico	10 -12
n	nano	10 ⁻⁹
μ	micro	10 -6
m	milli	10 ⁻³
k	kilo	10 ³
М	mega	10 6
G	giga	10 ⁹
Т	tera	10 12

Numbers and Symbols

- ° degrees
- negative of, or minus
- < less than
- > greater than
- \leq less than or equal to
- \geq greater than or equal to
- Ω ohms
- / per
- % percent
- ± plus or minus

Α

- ALC automatic level control
- analog A signal with an amplitude that can have a continuous range of values.
- AWG arbitrary waveform generator—A waveform generator capable of generating waveforms of arbitrary, user-defined shapes. The desired signal is designed by the user, loaded into the waveform generator memory, and output through a DAC.

В

bandwidth The measure of a circuit or transmission channel to pass a signal without significant attenuation over a range of frequencies. Bandwidth can also refer to the information rate (in bits per second) that can pass through a circuit or transmission channel.

baseband See <u>message signal</u>. signal

С

carrier The signal that carries the information encoded or modulated on it. Typically, the carrier is a fixed frequency sine wave, which may be amplitude-, phase-, or frequency- modulated.

carrier The frequency of the carrier signal that is a sinusoidal signal frequency upon which the desired signal to be transmitted is modulated. The sinusoidal signal "carries" the modulation.

center The frequency of the middle of the bandwidth of a channel. frequency

CW continuous wave—A continuous sine wave that is the carrier wave in a radio transmission.

D	
DAC	digital-to-analog converter—An electronic device, often an integrated circuit, that converts a digital number into a corresponding analog voltage or current.
DDS	direct digital synthesis—A signal generation technique that yields very high-frequency resolution.
DMA	direct memory access—Method by which data can be transferred to/from computer memory from/to a device or memory on the bus while the processor performs another task.
digital modulation	A technique for encoding digital data on a carrier frequency.
downconverter	A signal conditioning device that converts a specific band of high-frequency (RF) signals to lower, more manageable IF frequencies that can be digitized.
DUC	digital upconverter

Ε

EVM error vector magnitude—A measurement of demodulator performance in the presence of impairments. The soft symbol decisions obtained after decimating the recovered waveform at the demodulator output are compared against the ideal symbol locations. The root mean square (RMS) error vector magnitude and phase error are used to determine the EVM measurement over a window of N demodulated symbols.

F

- FIR finite-impulse response—Used to describe a filter with no feedback elements.
- FM frequency modulation
- FSK frequency-shift keying—A type of frequency modulation which assigns bit values to discrete frequency levels.

frequency Refers to the maximum absolute difference, during a deviation specified period, between the instantaneous frequency of the modulated wave and the carrier frequency.

- I
- IF intermediate frequency—Refers to the signal passed from the AWG module front panel CH 0 SMA connector to the upconverter module front panel INPUT SMA connector. This signal is upconverted to the requested RF output signal.

IQ A control signal for changing an RF carrier signal. signal

L

low- A circuit that attenuates the high-frequency components in an pass analog signal and only passes low frequencies. For imaging, a filter low-pass filter removes detail and blurs the image.
Μ

- message Contains the data for transmission. The message signal is used to modulate the carrier wave to create the modulated wave for transmission. The message signal data is recovered from the modulated wave by a process of demodulation. The message signal is often referred to as the baseband signal or the information signal.
- modulated The signal for transmission, which consists of the carrier wave modulated by the message signal. The message signal is recovered by the receiver through a process of demodulation.
- modulation A process, or the result of a process, by which characteristics of a carrier wave are altered according to information in the information signal to give rise to a modulated wave, which is transmitted.
- MER modulation error ratio—A measure of the signal-to-noise ratio (SNR) in a digitally modulated signal. Like SNR, MER is usually expressed in dB.
- module Refers to the NI 5650/5651/5652 hardware, or to one of the two hardware components of the NI 5670/5671/5672 RF signal generator: the AWG module or the upconverter module.
- MSK minimum shift keying—A subtype of FSK modulation. MSK uses a half-cycle sinusoidal pulse, making the phase change linear and keeping side lobes low to control adjacent-channel interference.
- MXI Multisystem Xtension Interface—A high-speed serial interface bus designed to connect computers to PXI, or to connect multiple PXI chassis. In this document, MXI refers to NI MXI-3 or MXI-4 systems.

Ν

NCO	numerically controlled oscillator—An oscillator that has a frequency that is controlled by a digital pattern.
NI 5421/5441/5442	NI 5421/5441/5442 refers to the AWG module included with the NI 5610 upconverter module to make up the NI 5670/5671/5672. Supported AWG modules include the NI PXI-5421 or NI PXI-5441.
NI 5650/5651/5652	NI 5650/5651/5652 refers to the NI PXI-5650, NI PXI- 5651, or NI PXI-5652 RF signal generators. These devices consist of a single PXI hardware module.
NI 5670/5671/5672	NI 5670/5671/5672 refers to the NI PXI-5670, NI PXI- 5671, or NI PXIe-5672 RF signal generators. The NI 5670/5671/5672 instruments are comprised of an upconverter hardware module, an AWG hardware module, and the NI-RFSG instrument driver. There is no single physical device labeled "NI PXI-5670," "NI PXI-5671," or "NI PXIe-5672."

0

- OCXO oven-controlled crystal oscillator
- OOK on-off keying—A modulation scheme which consists of keying a sinusoidal carrier signal on and off with a unipolar binary signal.
- OSP onboard signal processing

Ρ

phase noise	Noise in a carrier signal due to phase and frequency modulation in the signal. Phase noise is normally very close to the carrier, and is measured in decibels relative to the carrier frequency (dBc).
PLL	phase-locked loop—An electronic circuit which forces an output frequency to be locked to the same phase as a reference frequency.
PRBS	pseudorandom bit sequence
PSD	power spectral density—The power of a signal measured in the frequency domain and normalized to a 1 Hz bandwidth.
PCI Express	PCI Express eXtensions for Instrumentation—The PXI implentation of PCI Express, a scalable full-simplex serial bus standard that operates at 2.5 Gbps and offers both asynchronous and isochronous data transfers.
PXI Express- Compatible Module	A modified PXI module that is compatible with existing PXI chassis slots and PXY hybrid chassis slots. PXI Express-comptabile modules preserve hardware and software compatibility, with the exception of local bus features.

S

- SFDR spurious free dynamic range—The separation or distance, expressed in dB, from the amplitude of the fundamental frequency and the next highest spur.
- SINAD signal-to-noise distortion
- SMA A small type of threaded coaxial signal connector typically used in higher frequency applications.
- SMB sub-miniature type B—A small coaxial signal connector typically used in high-frequency applications. SMC uses a threaded connector, while the SMB "snaps" to the mating connector.
- SMC sub-miniature type C—A small coaxial signal connector typpically used in high-frequency applications. SMC uses a threaded connector, while the SMB "snaps" to the mating connector.
- SNR signal-to-noise ratio—The ratio of the desired signal amplitude to the noise signal amplitude at a given point in time. SNR is expressed as 20 times the logarithm of the amplitude ratio, or 10 times the logarithm of the power ratio. SNR is usually expressed in dB and in terms of peak values for impulse noise and rootmean-square values for random noise. In defining or specifying the SNR, specify the signal and noise characterizations, for example, peak-signal-to-peak-noise ratio to avoid ambiguity.

- Т
- TOI third order intercept—The theoretical level at which the third order harmonic distortion component has the same level as the fundamental tone.

tuning The time required by a signal to lose lock on one frequency and speed jump to another frequency within a given frequency tolerance.

V

- VCO voltage-controlled oscillator
- VCXO voltage-controlled crystal oscillator
- VSG vector signal generator

Important Information

Warranty Copyright Trademarks Patents Warning Regarding Use of NI Products

Warranty

NI RF signal generator hardware is warranted against defects in materials and workmanship for a period of one year from the date of shipment, as evidenced by receipts or other documentation. National Instruments will, at its option, repair or replace equipment that proves to be defective during the warranty period. This warranty includes parts and labor.

The media on which you receive National Instruments software are warranted not to fail to execute programming instructions, due to defects in materials and workmanship, for a period of 90 days from date of shipment, as evidenced by receipts or other documentation. National Instruments will, at its option, repair or replace software media that do not execute programming instructions if National Instruments receives notice of such defects during the warranty period. National Instruments does not warrant that the operation of the software shall be uninterrupted or error free.

A Return Material Authorization (RMA) number must be obtained from the factory and clearly marked on the outside of the package before any equipment will be accepted for warranty work. National Instruments will pay the shipping costs of returning to the owner parts which are covered by warranty.

National Instruments believes that the information in this document is accurate. The document has been carefully reviewed for technical accuracy. In the event that technical or typographical errors exist, National Instruments reserves the right to make changes to subsequent editions of this document without prior notice to holders of this edition. The reader should consult National Instruments if errors are suspected. In no event shall National Instruments be liable for any damages arising out of or related to this document or the information contained in it.

EXCEPT AS SPECIFIED HEREIN, NATIONAL INSTRUMENTS MAKES NO WARRANTIES, EXPRESS OR IMPLIED, AND SPECIFICALLY DISCLAIMS ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. CUSTOMER'S RIGHT TO RECOVER DAMAGES CAUSED BY FAULT OR NEGLIGENCE ON THE PART OF NATIONAL INSTRUMENTS SHALL BE LIMITED TO THE AMOUNT THERETOFORE PAID BY THE CUSTOMER. NATIONAL INSTRUMENTS WILL NOT BE LIABLE FOR DAMAGES RESULTING FROM LOSS OF DATA, PROFITS, USE OF PRODUCTS, OR INCIDENTAL OR CONSEQUENTIAL DAMAGES, EVEN IF ADVISED OF THE POSSIBILITY THEREOF. This limitation of the liability of National Instruments will apply regardless of the form of action, whether in contract or tort, including negligence. Any action against National Instruments must be brought within one year after the cause of action accrues. National Instruments shall not be liable for any delay in performance due to causes beyond its reasonable control. The warranty provided herein does not cover damages, defects, malfunctions, or service failures caused by owner's failure to follow the National Instruments installation, operation, or maintenance instructions; owner's modification of the product; owner's abuse, misuse, or negligent acts; and power failure or surges, fire, flood, accident, actions of third parties, or other events outside reasonable control.

Copyright

Under the copyright laws, this publication may not be reproduced or transmitted in any form, electronic or mechanical, including photocopying, recording, storing in an information retrieval system, or translating, in whole or in part, without the prior written consent of National Instruments Corporation.

National Instruments respects the intellectual property of others, and we ask our users to do the same. NI software is protected by copyright and other intellectual property laws. Where NI software may be used to reproduce software or other materials belonging to others, you may use NI software only to reproduce materials that you may reproduce in accordance with the terms of any applicable license or other legal restriction.

Trademarks

National Instruments, NI, ni.com, and LabVIEW are trademarks of National Instruments Corporation. Refer to the *Terms of Use* section on ni.com/legal for more information about <u>National Instruments trademarks</u>.

FireWire® is the registered trademark of Apple Computer, Inc.

Handle Graphics®, MATLAB®, Real-Time Workshop®, Simulink®, Stateflow®, and xPC TargetBox® are registered trademarks, and TargetBox™ and Target Language Compiler™ are trademarks of The MathWorks, Inc.

Tektronix® and Tek are registered trademarks of Tektronix, Inc.

Other product and company names mentioned herein are trademarks or trade names of their respective companies.

Members of the National Instruments Alliance Partner Program are business entities independent from National Instruments and have no agency, partnership, or joint-venture relationship with National Instruments.

Patents

For patents covering National Instruments products, refer to the appropriate location: **Help**»**Patents** in your software, the patents.txt file on your CD, or <u>ni.com/patents</u>.

WARNING REGARDING USE OF NATIONAL INSTRUMENTS PRODUCTS

(1) NATIONAL INSTRUMENTS PRODUCTS ARE NOT DESIGNED WITH COMPONENTS AND TESTING FOR A LEVEL OF RELIABILITY SUITABLE FOR USE IN OR IN CONNECTION WITH SURGICAL IMPLANTS OR AS CRITICAL COMPONENTS IN ANY LIFE SUPPORT SYSTEMS WHOSE FAILURE TO PERFORM CAN REASONABLY BE EXPECTED TO CAUSE SIGNIFICANT INJURY TO A HUMAN.

(2) IN ANY APPLICATION, INCLUDING THE ABOVE, RELIABILITY OF OPERATION OF THE SOFTWARE PRODUCTS CAN BE IMPAIRED BY ADVERSE FACTORS, INCLUDING BUT NOT LIMITED TO FLUCTUATIONS IN ELECTRICAL POWER SUPPLY, COMPUTER HARDWARE MALFUNCTIONS, COMPUTER OPERATING SYSTEM SOFTWARE FITNESS, FITNESS OF COMPILERS AND DEVELOPMENT SOFTWARE USED TO DEVELOP AN APPLICATION, INSTALLATION ERRORS. SOFTWARE AND HARDWARE COMPATIBILITY PROBLEMS, MALFUNCTIONS OR FAILURES OF ELECTRONIC MONITORING OR CONTROL DEVICES, TRANSIENT FAILURES OF ELECTRONIC SYSTEMS (HARDWARE AND/OR SOFTWARE), UNANTICIPATED USES OR MISUSES, OR ERRORS ON THE PART OF THE USER OR APPLICATIONS DESIGNER (ADVERSE FACTORS SUCH AS THESE ARE HEREAFTER COLLECTIVELY TERMED "SYSTEM FAILURES"). ANY APPLICATION WHERE A SYSTEM FAILURE WOULD CREATE A RISK OF HARM TO PROPERTY OR PERSONS (INCLUDING THE RISK OF BODILY INJURY AND DEATH) SHOULD NOT BE RELIANT SOLELY UPON ONE FORM OF ELECTRONIC SYSTEM DUE TO THE RISK OF SYSTEM FAILURE. TO AVOID DAMAGE. INJURY. OR DEATH. THE USER OR APPLICATION DESIGNER MUST TAKE REASONABLY PRUDENT STEPS TO PROTECT AGAINST SYSTEM FAILURES. INCLUDING BUT NOT LIMITED TO BACK-UP OR SHUT DOWN MECHANISMS. BECAUSE EACH END-USER SYSTEM IS CUSTOMIZED AND DIFFERS FROM NATIONAL INSTRUMENTS' TESTING PLATFORMS AND BECAUSE A USER OR APPLICATION DESIGNER MAY USE NATIONAL INSTRUMENTS PRODUCTS IN COMBINATION WITH OTHER PRODUCTS IN A MANNER NOT EVALUATED OR CONTEMPLATED BY NATIONAL INSTRUMENTS, THE USER OR

APPLICATION DESIGNER IS ULTIMATELY RESPONSIBLE FOR VERIFYING AND VALIDATING THE SUITABILITY OF NATIONAL INSTRUMENTS PRODUCTS WHENEVER NATIONAL INSTRUMENTS PRODUCTS ARE INCORPORATED IN A SYSTEM OR APPLICATION, INCLUDING, WITHOUT LIMITATION, THE APPROPRIATE DESIGN, PROCESS AND SAFETY LEVEL OF SUCH SYSTEM OR APPLICATION.

Technical Support and Professional Services

Visit the following sections of the National Instruments Web site at ni.com for technical support and professional services:

- <u>Support</u>—Online technical support resources at ni.com/support include the following:
 - Self-Help Resources—For answers and solutions, visit the award-winning National Instruments Web site for software drivers and updates, a searchable <u>KnowledgeBase</u>, product <u>manuals</u>, step-by-step troubleshooting wizards, thousands of example programs, tutorials, application notes, instrument drivers, and so on.
 - Free Technical Support—All registered users receive free Basic Service, which includes access to hundreds of Applications Engineers worldwide in the <u>NI Discussion</u> Forums at ni.com/forums. National Instruments Applications Engineers make sure every question receives an answer.

For information about other <u>technical support options</u> in your area, visit ni.com/services or <u>contact</u> your local office at ni.com/contact.

- <u>Training and Certification</u>—Visit ni.com/training for self-paced training, eLearning virtual classrooms, interactive CDs, and Certification program information. You also can register for instructor-led, hands-on courses at locations around the world.
- <u>System Integration</u>—If you have time constraints, limited in-house technical resources, or other project challenges, National Instruments Alliance Partner members can help. To learn more, call your local NI office or visit ni.com/alliance.
- Declaration of Conformity (DoC)—A DoC is our claim of compliance with the Council of the European Communities using the manufacturers declaration of conformity. This system affords the user protection for electronic compatibility (EMC) and product safety. You can obtain the DoC for your product by visiting ni.com/certification.
- <u>Calibration Certificate</u>—If your product supports calibration, you can obtain the calibration certificate for your product at ni.com/calibration.

If you searched ni.com and could not find the answers you need, contact your local office or NI corporate headquarters. You also can visit the <u>Worldwide Offices</u> section of ni.com/niglobal to access the branch office Web sites, which provide up-to-date contact information, support phone numbers, email addresses, and current events.

NI 5650/5651/5652 Overview

The NI PXI-5650/5651/5652 RF signal generator is a continuous-wave (CW) signal generator with internal modulation capability.

The NI 5650/5651/5652 is a one-slot PXI hardware module.

The NI 5650/5651/5652 RF signal generator module front panel contains two connectors and two multicolor LEDs, as shown in the following figure.



The NI 5650/5651/5652 follows industry-standard Plug and Play specifications for the PXI bus and can be seamlessly integrated with compliant systems.

For information about NI 5650/5651/5652 specifications, refer to the <u>specifications document</u> that shipped with your NI RF signal generator.

Branch Offices

Office	Telephone Number
Australia	1800 300 800
Austria	43 662 457990-0
Belgium	32 (0) 2 757 0020
Brazil	55 11 3262 3599
Canada	800 433 3488
China	86 21 5050 9800
Czech Republic	420 224 235 774
Denmark	45 45 76 26 00
Finland	358 (0) 9 725 72511
France	33 (0) 1 57 66 24 24
Germany	49 89 7413130
India	91 80 41190000
Israel	972 0 3 6393737
Italy	39 02 413091
Japan	81 3 5472 2970
Korea	82 02 3451 3400
Lebanon	961 (0) 1 33 28 28
Malaysia	1800 887710
Mexico	01 800 010 0793
Netherlands	31 (0) 348 433 466
New Zealand	0800 553 322
Norway	47 (0) 66 90 76 60
Poland	48 22 3390150
Portugal	351 210 311 210
Russia	7 495 783 6851
Singapore	1800 226 5886
Slovenia	386 3 425 42 00

South Africa	27 0 11 805 8197
Spain	34 91 640 0085
Sweden	46 (0) 8 587 895 00
Switzerland	41 56 2005151
Taiwan	886 02 2377 2222
Thailand	662 278 6777
Turkey	90 212 279 3031
United Kingdom	44 (0) 1635 523545
United States (Corporate)	512 683 0100