

NI 5670 RF Vector Signal Generator User Manual

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NI-5670 RF Vector Signal Generator User Manual

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This document contains hardware and software information for the NI-5670 RF Vector Signal Generator hardware and software.

To comment on the documentation, email techpubs@ni.com

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Conventions

This help file uses the following conventions:

< >	Angle brackets that contain numbers separated by an ellipsis represent a range of values associated with a bit or signal name—for example, dBIO<3..0>.
[]	Square brackets enclose optional items—for example, [response].
»	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.
	This icon denotes a tip, which alerts you to advisory information.
	This icon denotes a note, which alerts you to important information.
	This icon denotes a caution, which advises you of precautions to take to avoid injury, data loss, or a system crash.
bold	Bold text denotes items that you must select or click on in the software, such as menu items and dialog box options. Bold text also denotes parameter names, emphasis, or an introduction to a key concept.
dark red	Text in this color denotes a caution.
<u>green</u>	Underlined text in this color denotes a link to a help topic, help file, or Web address.
<i>italic</i>	Italic text denotes variables or cross references. This font 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, and code excerpts.
<i>monospace italic</i>	Italic text in this font denotes text that is a placeholder for a word or value that you must supply.

Key Terms

You may find the following definitions helpful as you use this document:

AWG

Arbitrary Waveform Generator — refers to the NI 5421 arbitrary waveform generator hardware module.

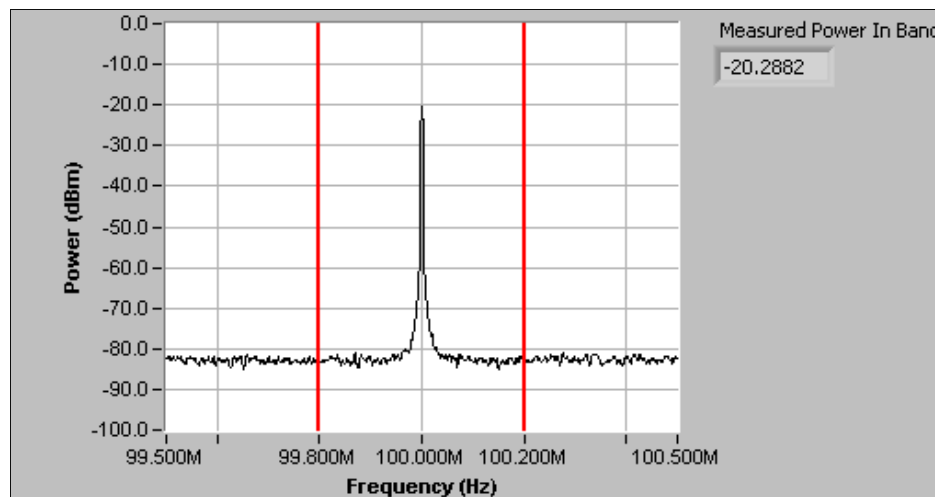
Average Power

The NI-RFSG software allows you to specify the power level of the RF output signal. NI-RFSG interprets this power level to mean average power level.

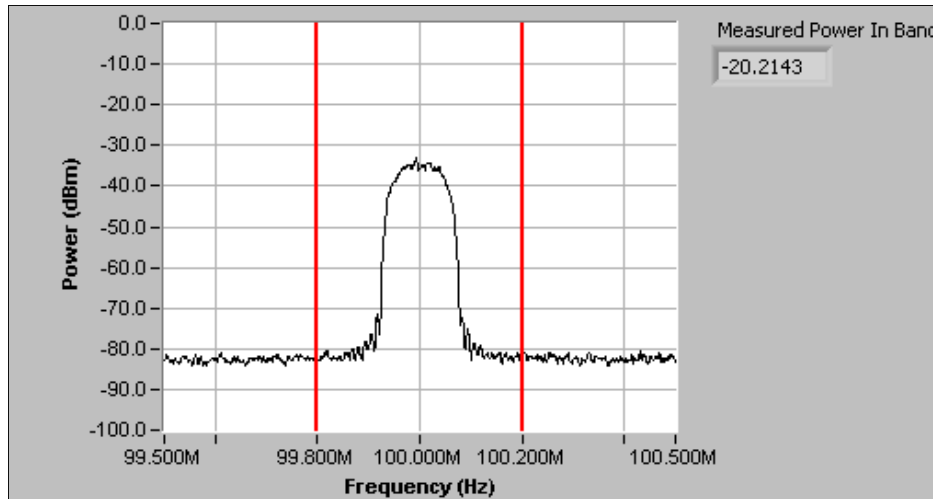
The average power level of a signal can be measured at least two ways:

1. Using a power meter, or
2. Performing a power in band measurement across the entire signal bandwidth on a spectrum analyzer.

The following graphs depict the average power of two signals created by a NI 5670 with an NI-RFSG power level setting of -20 dBm:



Narrowband Signal: Average Power -20 dBm



QAM Wideband Signal: Average Power -20 dBm

Specify the average power using the niRFSG Configure RF VI or the niRFSG_Configure RF function.

Baseband

Refers to the range in the frequency spectrum occupied by the unmodulated information signal. Both the information signal and the complex I-Q signal are referred to as baseband signals.

IF

Intermediate Frequency — refers to the signal passed from the NI 5421 AWG module front panel CH 0 SMA connector to the NI 5610 upconverter module front panel INPUT SMA connector. This signal is upconverted to the requested RF output signal.

Module

Refers to one of the hardware components of the NI 5670: the NI 5421 arbitrary waveform generator or the NI 5610 wideband RF upconverter.

PLL

Phase-Locked Loop — refers to an electronic circuit that controls an oscillator so that the circuit maintains a constant phase angle relative to a reference signal. The main function of a PLL is to adjust the frequency of the onboard oscillator so that it matches that of an externally provided reference clock.

RF

Radio Frequency — refers to the signal output from the RF OUTPUT connector on the NI 5610 upconverter module front panel.

Upconverter

A device that frequency–translates IF signals to center around a specified RF frequency — refers to an NI 5610 2–slot RF upconverter hardware module.

Software Fundamentals

NI–RFSG Instrument Driver

The NI–RFSG instrument driver software controls all NI 5670 configuration and operation using LabVIEW VIs or LabWindows/CVI functions. The modules are associated in MAX, allowing the NI–RFSG instrument driver to transparently operate the NI 5610 upconverter module and the NI 5421 AWG module as a single instrument (the NI 5670).

The NI–RFSG driver configures and operates the NI 5670 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 5670 to include additional frequency–domain and modulation–domain tasks.

This section provides reference information regarding the NI–RFSG programming flow, state model, when to call NI–RFSG VIs/functions, information on installed examples, and basic NI–RFSG application building.

Refer to the *NI–RFSG LabVIEW reference* or the *LabWindows/CVI reference* sections for more information about using specific LabVIEW VIs, CVI functions, and properties.

The Spectral Measurements Toolkit

The Spectral Measurements Toolkit (SMT) contains 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 Spectral Measurements Toolkit Online Help, available at *Start»Programs»National Instruments»Spectral Measurements*, for detailed information on using the SMT.







NI–RFSG Instrument Driver Programming Flow

NI–RFSG VIs are located on the LabVIEW functions palette at *Instrument I/O»Instrument Drivers»NI–RFSG*. The top–level NI–RFSG functions palette is shown in the figure below:



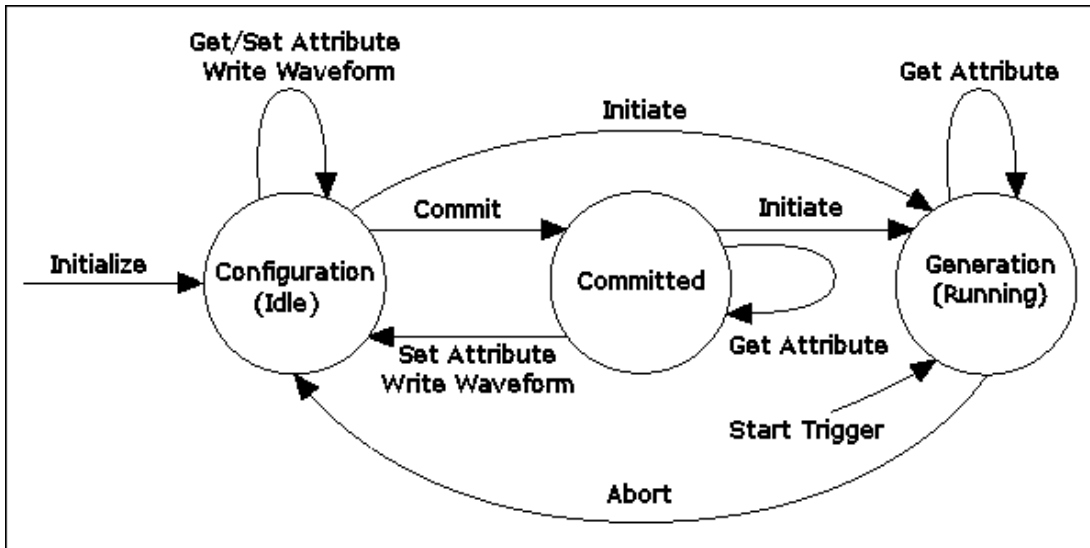
NI-RFSG LabVIEW Palette. Core VIs are Highlighted

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

- 
 1. niRFSG Initialize — Opens a session to the NI-RFSG device and initializes both the AWG and the upconverter hardware.
- 
 2. niRFSG Configure RF — Configures the frequency and power level of the RF output signal.
- 
 3. niRFSG Initiate — Initiates signal generation.
- 
 4. niRFSG Check Generation Status — Monitors signal generation status and checks for any errors which may occur during signal generation.
- 
 4. niRFSG Configure Output Enabled — Disables signal output at the NI 5610 upconverter module front panel RF OUT connector.
- 
 5. niRFSG Close — 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 5670 Programming State Model

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



NI-RFSG Programming State Model

Configuration— You can program all session properties in the Configuration state. However, when in the Configuration state, the properties have not yet been applied to the hardware module. Therefore the module configuration may not match the session property values. The NI-RFSG device does not generate a signal in the Configuration state.

Calling niRFSG Commit from the Configuration 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

Committed—

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.

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.

Generation—



Note NI-RFSG cannot set any attributes or write data during the Generation State.



Note niRFSG Close may be called from any state. Calling Close stops signal generation.

When to Use a VI

VI Name	Call During Configuration State?	Call During Committed/Generation State?
Check Generation Status	No	Yes
Clear All Arb Waveforms	Yes	No
Configure IQ Enabled	Yes	No
niRFSG Configure Output Enabled	Yes	Yes
Configure PXI Chassis Clk 10	Yes	No
Configure Reference Clock	Yes	No
Configure RF	Yes	No
Configure Trigger	Yes	No
Error Message	Yes	No
Query Arb Waveform Capabilities	Yes	No
Reset	Yes	No
Reset Device	Yes	Yes
Revision Query	Yes	No
Self Cal	Yes	No
Self Test	Yes	No
Send Software Edge Trigger	No	Yes
Wait Until Settled	No	Yes
Write Arb Waveform	Yes	No

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.

With LabVIEW running, select **Help»Find Examples** to launch the LabVIEW Example Finder. The Example Finder offers two ways to access all installed LabVIEW example VIs and their descriptions:

- 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 FM, for instance, to locate an example demonstrating FM signal generation using the NI 5670

and the NI Modulation Toolkit (if installed).

LabVIEW and LabWindows/CVI users can also access all installed NI-RFSG examples at **Start»Programs»National Instruments»NI-RFSG»Examples**. View LabVIEW examples by navigating to the <LabVIEW home>examples\instr\niRFSG folder. View examples for CVI by navigating to the <Program Files>\IVI\Drivers\niRFSG\Examples directory.

Examples are also available online at ni.com/examples that demonstrate integrating the NI 5670 RF Vector Signal Generator hardware and software with the NI 5660 RF Signal Analyzer and NI toolkit software including the Modulation Toolkit. Refer to the NI Developer Zone on the Web at ni.com/examples for these examples and more information.

Building a Basic NI-RFSG Application

Use the following procedure to begin using NI-RFSG to generate a signal:

1. Select **Start»Programs»National Instruments»LabVIEW 7»LabVIEW** to launch LabVIEW. The LabVIEW dialog appears.
2. Click **New**, choose **Blank VI**, and click **OK** to create a blank VI.
3. Display the block diagram by clicking it or selecting **Window»Show Block Diagram**.
4. Navigate to the NI-RFSG VIs on the **Functions»Instrument I/O»Instrument Drivers»NI-RFSG** palette. With LabVIEW running, click here to find the **NI-RFSG** LabVIEW palette.
5. Create the block diagram shown in Figure 1 by placing the five core VIs on the block diagram in the order they appear in the top row of the NI-RFSG functions palette.

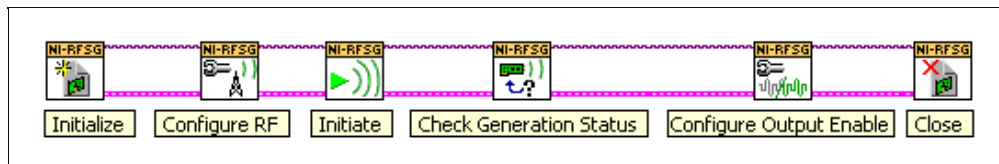


Figure 1: Basic NI-RFSG Block Diagram

6. Hover the cursor over the **resource name** terminal on the niRFSG Initialize VI and right-click. Select **Create»Control** to create a front panel field where you specify the NI 5670 device name. The **resource name** terminal is highlighted in Figure 2 below.

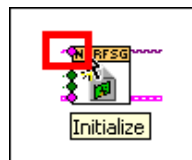


Figure 2: Resource Name Terminal on niRFSG Initialize VI

7. Hover the mouse tool over the **frequency** and **power level** terminals of the niRFSG Configure RF VI. The terminals are highlighted in Figure 3:

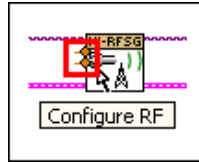


Figure 3. Frequency and Power Level Terminals on the niRFSG Configure RF VI

8. Right-click each terminal and select **Create»Control** from the shortcut menu to create frequency and power controls as shown in Figure 4.

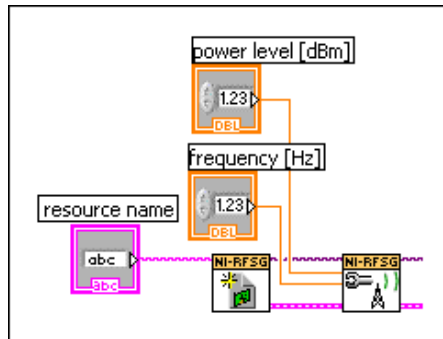


Figure 4. Frequency and Power Level Controls on the Block Diagram

9. Display the front panel by clicking it or selecting **Window»Show Front Panel**. Fields are displayed in which you can specify a frequency and power level.
10. In the VI front panel **power level (dBm)** field, type 0. In the **frequency (Hz)** field, type 100M (100 MHz).
11. In the VI front panel **resource name** field, type the NI 5610 upconverter module name that you specified in MAX. The NI 5610 upconverter module must be associated with a NI 5421 AWG module. Refer to the *NI 5670 Getting Started Guide*, installed at **Start»Programs»National Instruments»NI-RFSG»Documentation**, for more information.

Continuous waveform generation is controlled by means of a STOP button. A STOP button is typically used within a While Loop. This example places a While Loop around the Check Generation Status VI so that signal generation continues and waveform status is continuously checked until you click STOP.

Build a While Loop and STOP button by completing the following steps.

1. Display the block diagram by clicking it or selecting **Window»Show Block Diagram**.
2. Select the While Loop on the **All Functions»Structures** palette. With LabVIEW running, click here to find the While Loop on the **Structures** palette.
3. Enclose the niRFSG Check Generation Status VI in the While Loop, as shown in Figure 5 below.

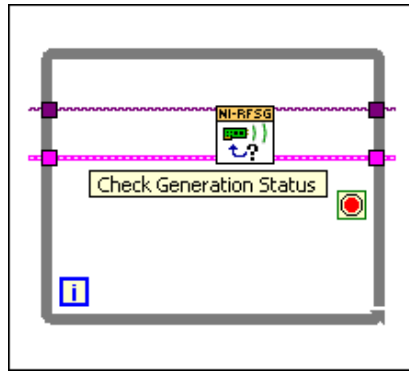


Figure 5. Enclose niRFSG Check Generation Status VI in the While Loop

4. Hover the mouse tool over the **Loop Condition** terminal of the While Loop. The terminal is highlighted in Figure 6 below.

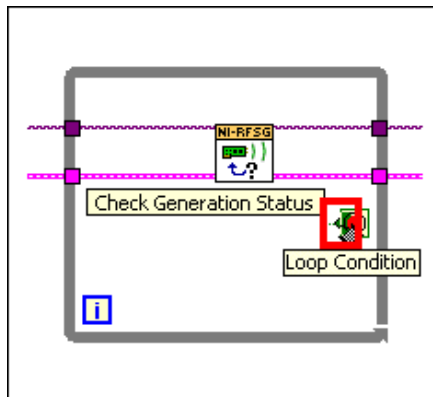


Figure 6. Loop Condition Terminal on While Loop

5. Right-click the **Loop Condition** terminal and select **Create Control** from the shortcut menu to create a **STOP** button on the VI front panel. The resulting portion of the block diagram is shown in Figure 7.

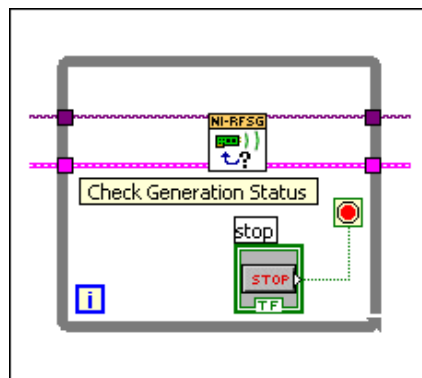


Figure 7. While Loop with Stop Button

6. Create an error indicator by right-clicking on the *error out* terminal of the niRFSG Close VI and selecting *Create»Indicator*. The *error out* terminal is highlighted in Figure 8 below:

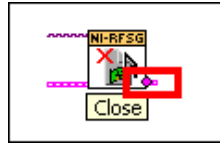


Figure 8. Error Out Terminal on niRFSG Close VI

7. Verify that your VI block diagram now looks like the example in Figure 9 below.

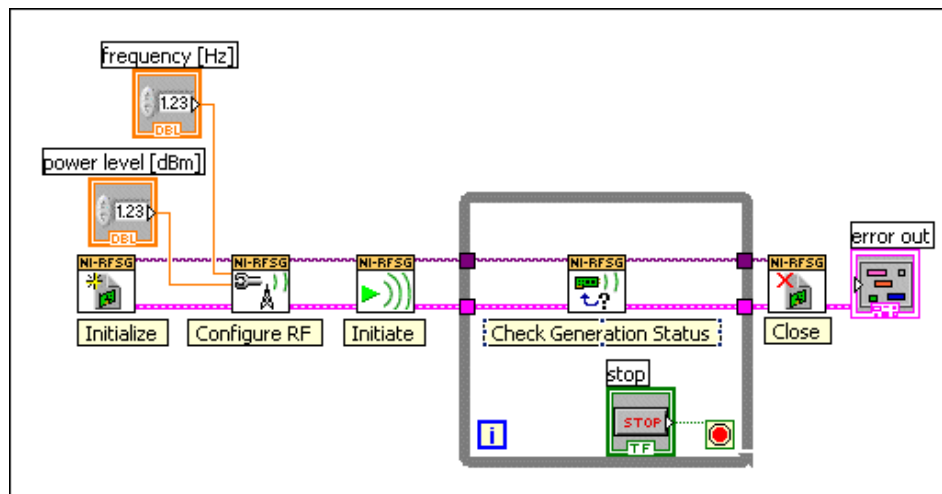


Figure 9. Basic Sine Wave Generation VI Block Diagram

8. Display the VI front panel by clicking it or by selecting *Window»Show Front Panel*. Verify that your VI front panel looks like the example in Figure 10 below.

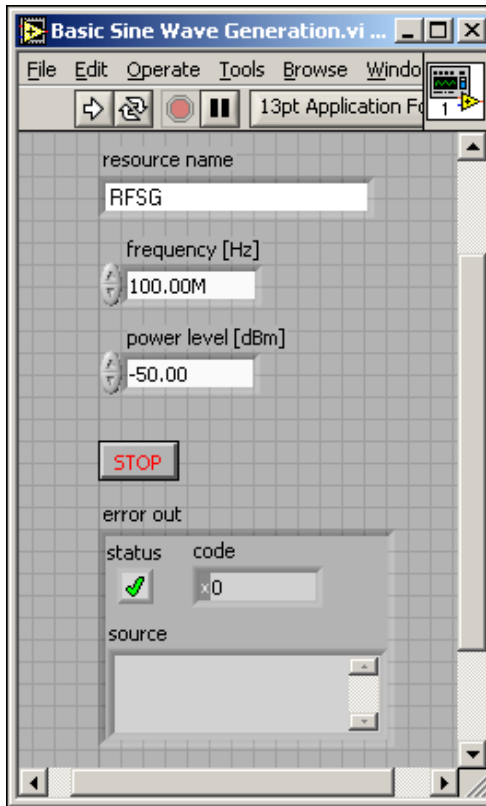




Figure 10. Basic Sine Wave Generation VI Front Panel

 **Note** The *resource name* control is populated with the NI 5610 upconverter module name specified in MAX; refer to the *NI 5670 Getting Started Guide*, installed at *Start»Programs»National Instruments»NI–RFSG»Documentation*, for more information.

9. Click the **Run** icon on the VI taskbar  to initiate sine wave generation.
10. Click the front panel **Stop** button  to stop sine wave generation.

 **Note** Always stop VI operation using the front panel STOP button you created. Never stop a VI with the ABORT button on the taskbar. The ABORT button does not free memory resources and leaves hardware and software in an unknown state.

You have successfully generated a continuous sine wave signal using the NI–RFSG driver software and the NI 5670 hardware.

NI 5670 RF Vector Signal Generator


Hardware Reference

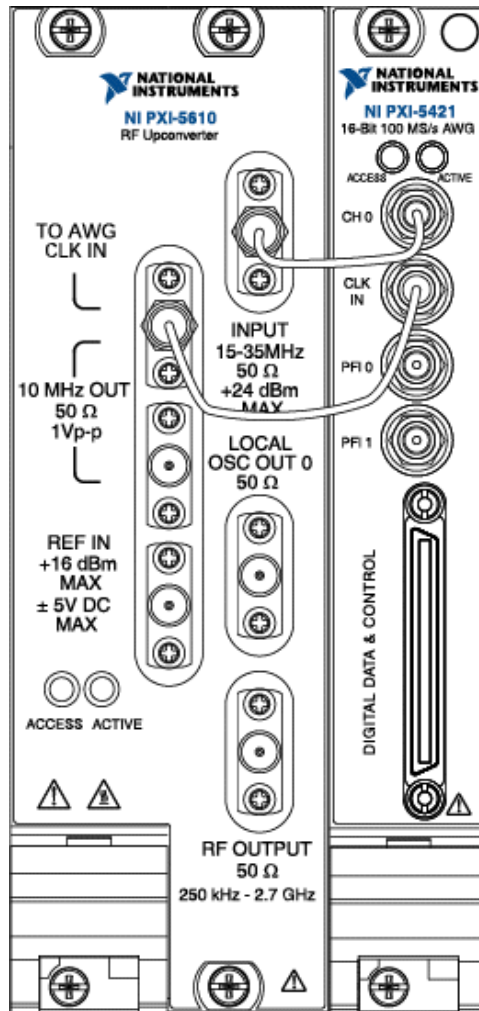
This section includes information relevant to the use the NI 5670 hardware modules. NI–RFSG hardware specifications are available at *Start»Programs»National Instruments»NI–RFSG»Documentation»Specifications*.

NI 5670 Overview

The NI 5670 is a modular RF signal source consisting of 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 the "NI 5670." The NI 5670 is the instrument comprised of the two hardware modules (NI 5610 and NI 5421) operated by the NI–RFSG instrument driver. The hardware modules interconnect using the included SMA–SMB coaxial cables as illustrated below.



Interconnected NI 5670 Front Panels

The NI 5670 has the following characteristics and features:

- 250 kHz to 2.7 GHz frequency range
- +13 dBm to –145 dBm amplitude range
- 22 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
- < -119 dBc/Hz typical noise density
- Up to 256 MB of AWG module onboard waveform memory (see *Memory Options* for details)
- NI-RFSG instrument driver software transparently operates both modules as a single unit.
- Three slots wide PXI/3U Compact PCI form factor

The NI 5670 follows industry-standard Plug and Play specifications for the PXI bus, and can be seamlessly integrated with compliant systems.


NI 5670 Theory of Operation

The NI 5670 RF Vector Signal Generator hardware consists of two parts: the NI 5421 arbitrary waveform generator (AWG) module and the NI 5610 RF upconverter module. The NI 5421 generates a signal centering at an intermediate frequency (IF) between 15 and 35 MHz. The IF signal is fed into the NI 5610, which frequency-translates its center frequency to anywhere up to 2.7 GHz.

The NI-RFSG driver software operates both hardware modules as a single instrument by handling all module programming and interaction. When the user specifies 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 AWG module, and the frequency shift and gain or attenuation settings for the NI 5610 upconverter module.

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

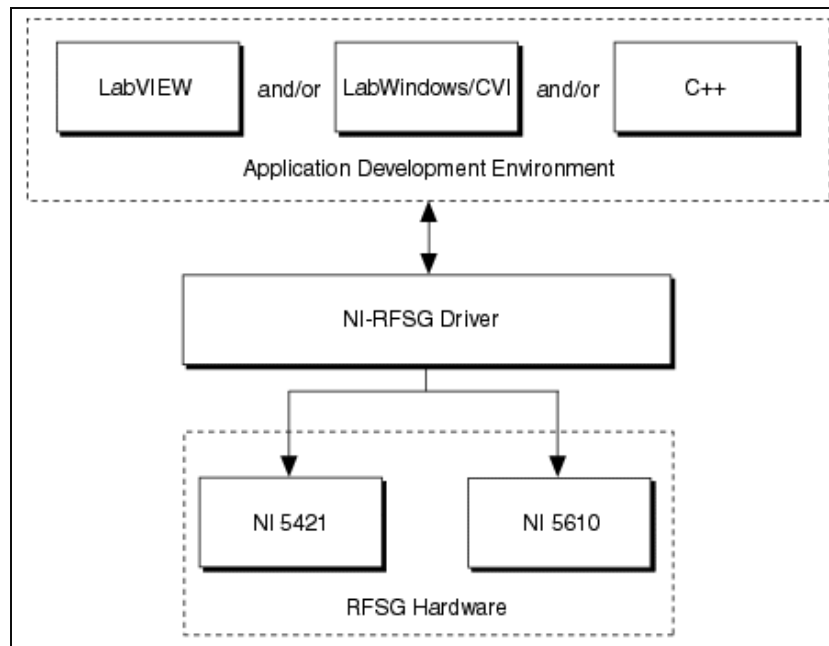
The NI 5610 contains a stable and accurate 10 MHz frequency reference. A coaxial cable feeds the reference out of the front panel of the NI 5610 and into the NI 5421. The NI 5421 locks its internal reference clock to this reference.

 **Note** NI 5670 operation requires that the NI 5610 module front panel connector labeled 10 MHz OUT (TO AWG CLK IN) be connected to the NI 5421 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 CLK 10 backplane signal.

The NI 5610 accomplishes its 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. There is a separate output on the NI 5610 module front panel (LOCAL OSC OUT 0) from which you may export this LO signal if it has been enabled using the Local Oscillator Out 0 Enabled property.

NI-RFSG software automatically compensates for temperature-induced changes in the output power levels of the NI 5670 modules. Power variation versus temperature is calibrated during factory calibration and stored in nonvolatile memory on each module. NI-RFSG reads this information from both modules. It also reads the temperature of each module from onboard temperature sensors, and uses this information to adjust the final power level accordingly.



NI 5670 Flow Diagram

Power Up and Reset Conditions

The NI 5670 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 niRFSG Reset Device VI or function).

- Thermal shutdown monitoring is activated.
- NI 5610 RF enclosure is powered on
- Both module front panel ACCESS LEDs are green.
- The LOCAL OSC OUT 0 module front panel output connector is disabled.
- Reverse power protection relay is open.
- All attenuators are asserted
- Both module front panel ACTIVE LEDs are OFF.
- RF output power is set to < -140 dBm.
- Realtime bandwidth is set to 100 Hz.

- NI 5610 onboard 10 MHz reference clock is set as the NI 5670 reference clock.
- Warmup begins (if applicable)

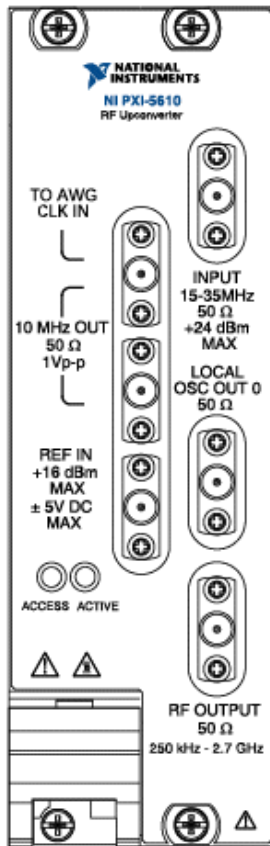
Hardware Front Panel Connectors and Indicators

These sections describe the connectors and LED indicators on the front panels of both NI 5670 hardware modules. All inputs and outputs are AC-coupled.

NI 5610 Upconverter Module

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:



NI 5610 Front Panel

Connector	Use
10 MHz OUT (TO AWG CLK IN)	Connect the upper of these two connectors to the CLK IN connector on the NI 5421 front panel. Both connectors output replications of the upconverter 10 MHz frequency reference signal, useful for driving other devices. Each replication is 180° out-of-phase with the other. Output at these connectors is always on.
10 MHz OUT	
REF IN	Inputs an external frequency reference signal which can be propagated to the PXI backplane. The NI 5610 can lock to this signal.
IF INPUT	Inputs the IF signal from the NI 5421 AWG module for frequency translation. Connect to the CH 0 output on the NI 5421 front panel.
LOCAL OSC OUT 0	Outputs the local oscillator signal. Output at this connector is enabled using the

	Local Oscillator Out 0 Enabled property. The frequency of this LO signal is always about 3.2 GHz greater than the output signal.
RF OUTPUT	Outputs the upconverted signal at the requested RF frequency.


The following table provides LED and indications information for the NI 5610 RF upconverter module front panel LEDs:

LED	Indications
ACCESS	<p>Indicates the basic hardware status of the NI 5610 module. This LED functions identically to the ACCESS LED on the AWG module front panel:</p> <p>OFF—The module is not yet functional.</p> <p>AMBER—The module is being accessed by the PXI bus.</p> <p>GREEN—The module is ready to be programmed by a driver.</p>
ACTIVE	<p>Indicates the state of the NI 5610 hardware:</p> <p>OFF—The module is in an uninitialized state; there is no error.</p> <p>AMBER—The module PLLs are attempting to lock.</p> <p>GREEN—The module is in a ready state; applicable PLLs are locked and the reverse power protection circuit is closed.</p> <p>RED—The module has detected an error state; this may indicate an overload (reverse power protection circuit is open), lock failure in an applicable PLL, a self-test or calibration failure, or a thermal shutdown condition.</p>

NI 5421 AWG Module

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

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



The diagram shows the front panel of the NI 5421 AWG module. At the top left, there is a logo for National Instruments and the text 'NI PXI-5421 16-Bit 100 MS/s AWG'. Below this are two LEDs labeled 'ACCESS' and 'ACTIVE'. The main section of the panel features five connectors: 'CH 0', 'CLK IN', 'PFI 0', and 'PFI 1'. At the bottom, there is a vertical slot labeled 'DIGITAL DATA & CONTROL'.

Connector	Use
CH0	Outputs an IF waveform for upconversion to the desired RF frequency. Connect to the IF INPUT connector on the NI 5610 front panel.
CLK IN	Inputs the NI 5421 internal clock reference signal. Connect to the REF OUT connector on the NI 5610 front panel.
PFI 0	Bidirectional SMB connectors. As an input, the PFI terminals can accept a trigger from an external source to start or step through signal generation.
PFI 1	

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

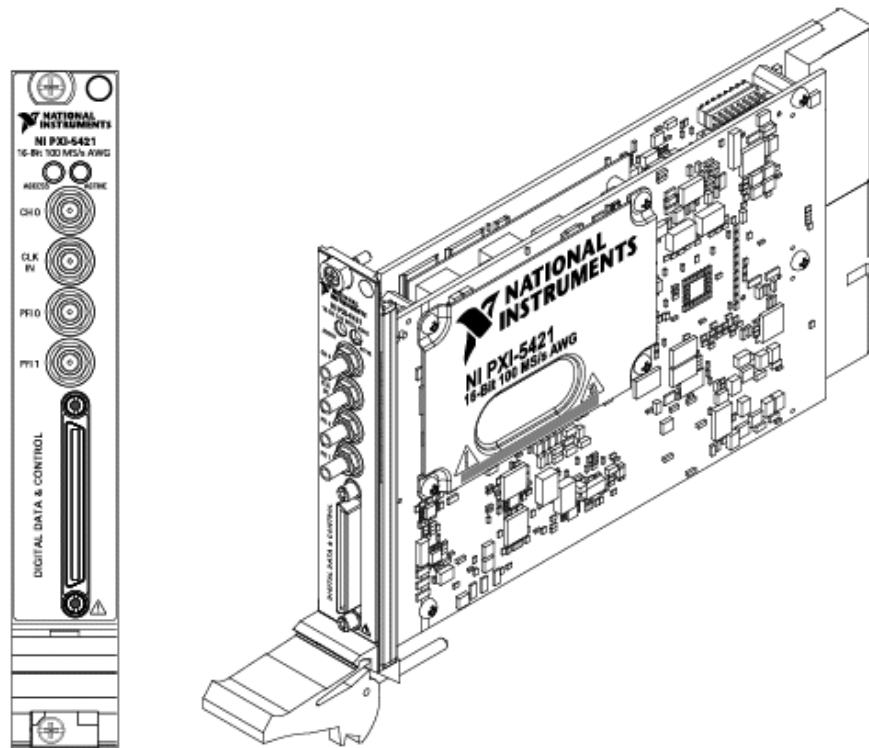
LED	Indications
ACCESS	Indicates the basic hardware status of the NI 5421 module. This LED functions identically to the ACCESS LED on the upconverter module front panel: OFF—The module is not yet functional, or has detected a problem with a power rail. AMBER—The module is being accessed by the PXI bus. GREEN—The module is ready to be programmed by a driver.
ACTIVE	Indicates the state of the NI 5421 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 start trigger and is generating a waveform.

NI 5421
Front Panel

RED—The module has detected an error state; this may indicate PLL unlocking, self-test failure or calibration failure.

NI 5421 AWG Module

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



NI 5421 AWG Module

For complete, in-depth information specific to the NI 5421 AWG module and its use as a standalone device, refer to the *NI Signal Sources Help*, located at **Start»Programs»National Instruments»NI-FGEN»Documentation**.

Memory Options

The NI 5421 can be purchased with three onboard waveform memory size options: 8 MB, 32 MB, and 256 MB. The memory size chosen affects both NI 5670 playback time and tuning resolution for repetitive waveforms.

Onboard waveform memory size dictates playback time, or the maximum time duration for which arbitrary waveforms can be generated without repeating the same waveform data. If your application requires complex IQ waveform playback for long time durations without looping, choose a larger NI 5421 onboard waveform memory option. For example, 256 MB of onboard memory can store


approximately 1.28 seconds of waveform data at the default sample clock rate of 100 MS/s. 32 MB of onboard memory can store about 0.16 seconds of 100 MS/s waveform data, and 8 MB can store approximately 0.04 seconds.

Another benefit of large AWG onboard memory sizes, however, is finer frequency resolution in repetitive playback of the generated waveform. As discussed in the *Phase Continuity* section, frequency resolution for arbitrary waveforms is limited by available memory size when phase continuity is enabled. When the Phase Continuity Enabled property is set to FALSE, this limitation on frequency resolution does not apply.

The table below lists the playback time and the maximum frequency resolution that can be obtained for each memory option using the default sample clock rate of 100 MS/s and phase continuity enabled.

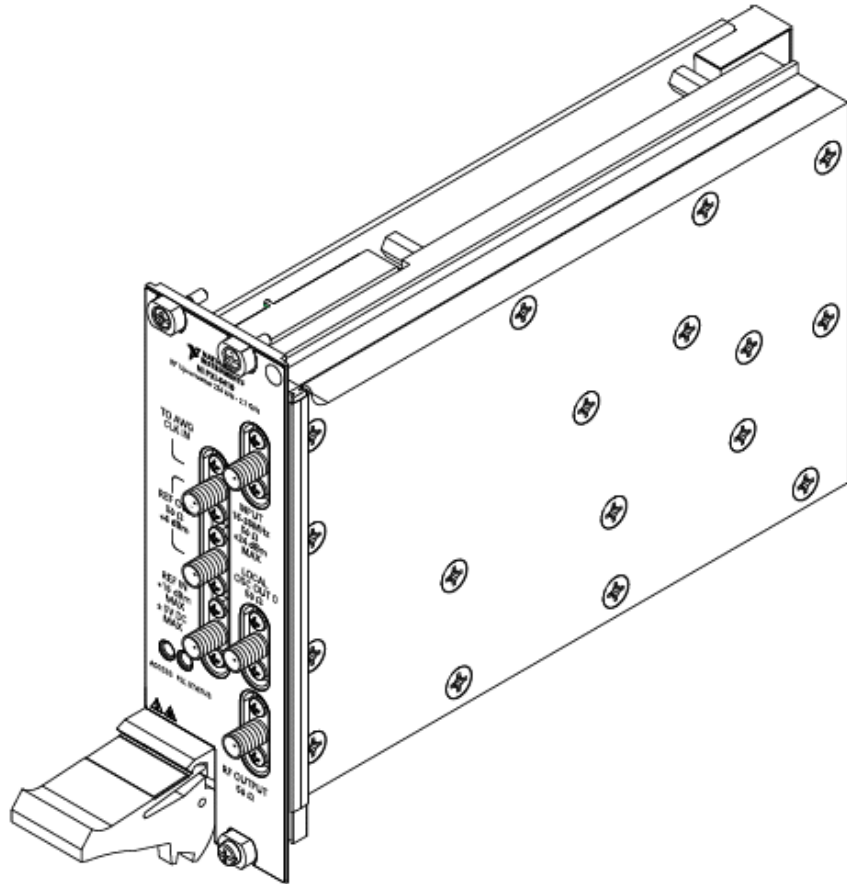
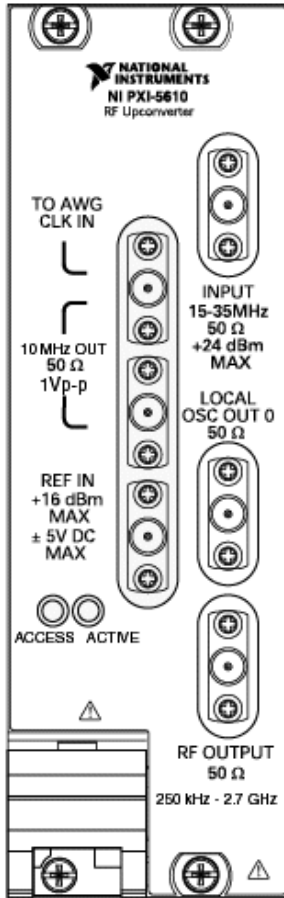
Memory Size (MB)	Playback Time Without Looping (msec)
8	40
32	160
256	1280

Memory Sizes versus Playback Time and Frequency Resolution

 **Note** Not all 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.

NI 5610 Upconverter Module

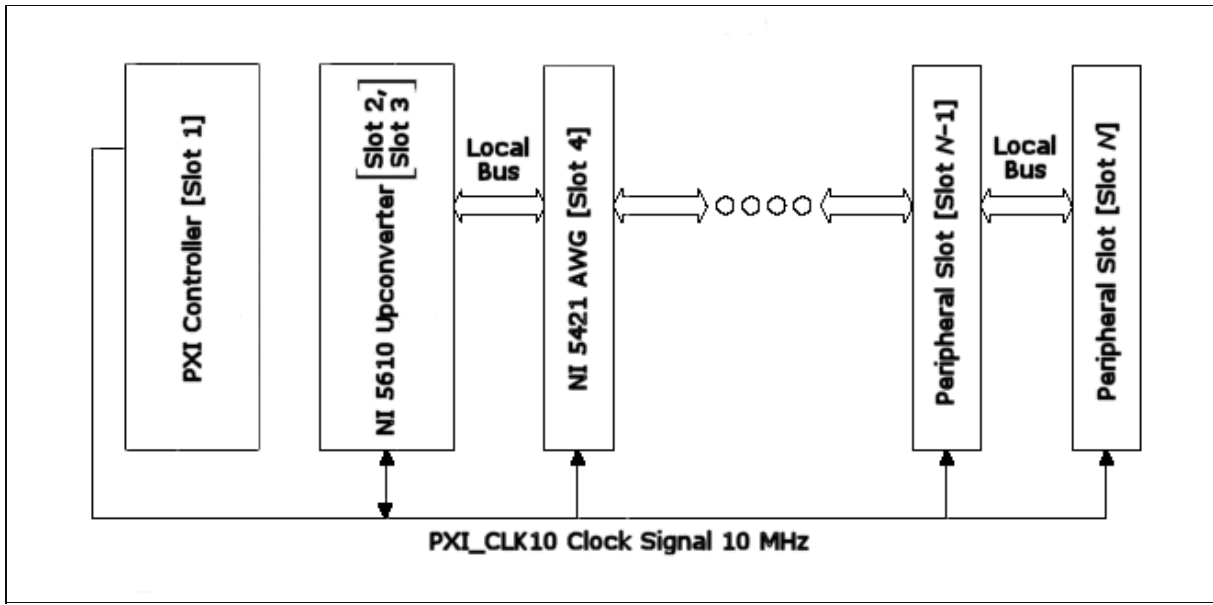
The NI 5610, shown below, is a 250 kHz to 2.7 GHz superheterodyne upconverter hardware module that frequency–translates IF input signals between 15 MHz and 35 MHz to a desired RF frequency between 250 kHz and 2.7 GHz.



The NI 5610 Upconverter Module

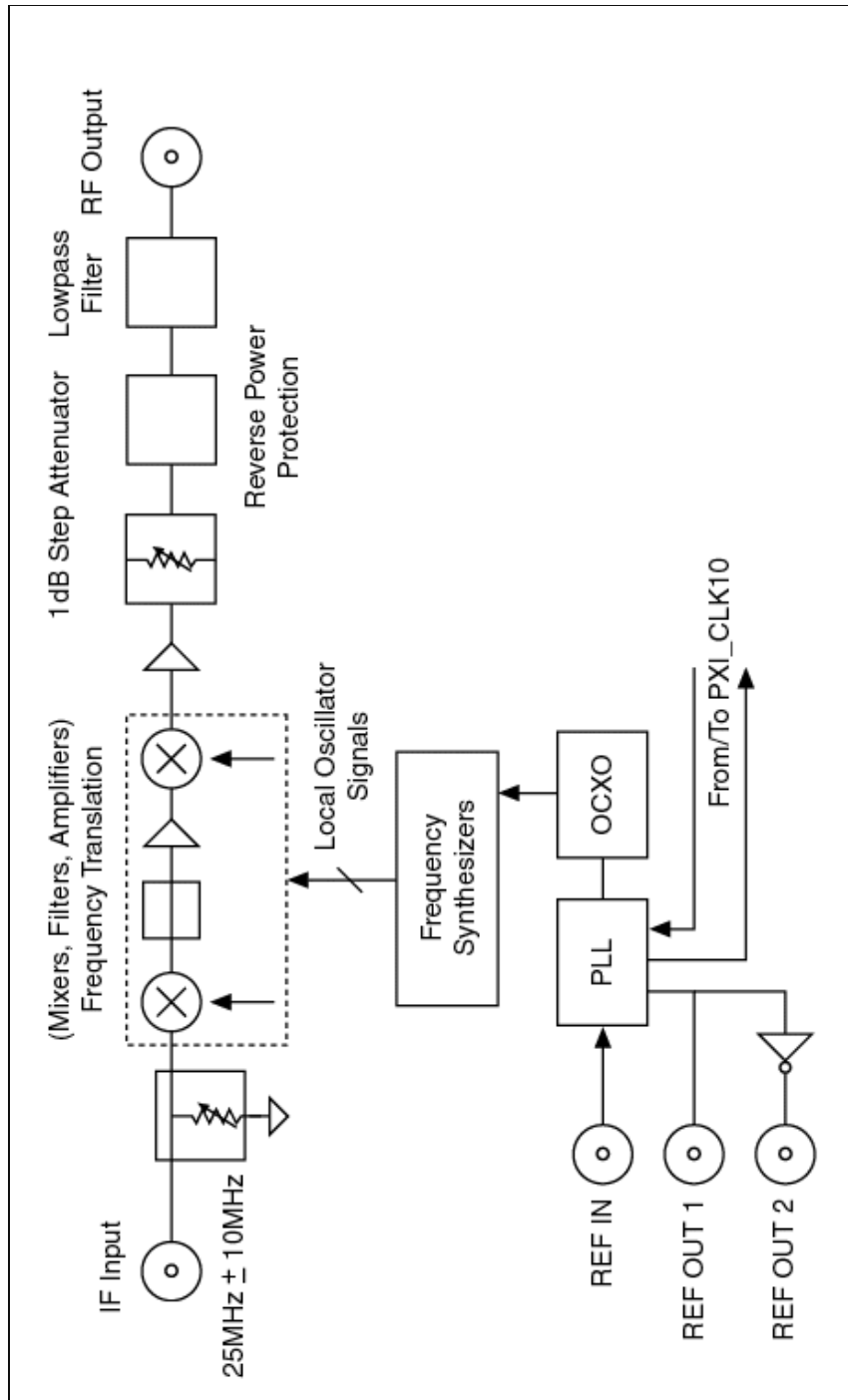
Note The NI 5610 upconverter module (two slots wide) is connected to the PXI backplane through the leftmost of its two occupied PXI slots. Thus installing the NI 5610 module in PXI Slot 2, for instance, occupies PXI Slots 2 and 3. Slot numbers are printed on the PXI chassis.

The NI 5610 offers 22 MHz real-time bandwidth and an on-board 10 MHz highly stable, low phase noise ovenized 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 PXI Slot 2.



The NI 5610 can Drive the PXI backplane Clock from PXI Slot 2

Two replications of the NI 5610 onboard 10 MHz reference clock signal are output from the NI 5610 module front panel connectors labeled REF 1 and REF 2. Each replication is 180° out-of-phase from the other. Output at these connectors is always on. Refer to *Timing Configurations* for more information.



NI 5610 High-Level Block Diagram

Frequency Translation

The NI 5610 frequency translation process occurs through several different conversion stages. Each stage consists of amplifiers, filters, attenuators, and mixers.

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 the NI 5421 AWG module, which provides the fine power control adjustment of the NI 5670 Vector Signal Generator. Refer to *Power Level Adjustment* for more information.

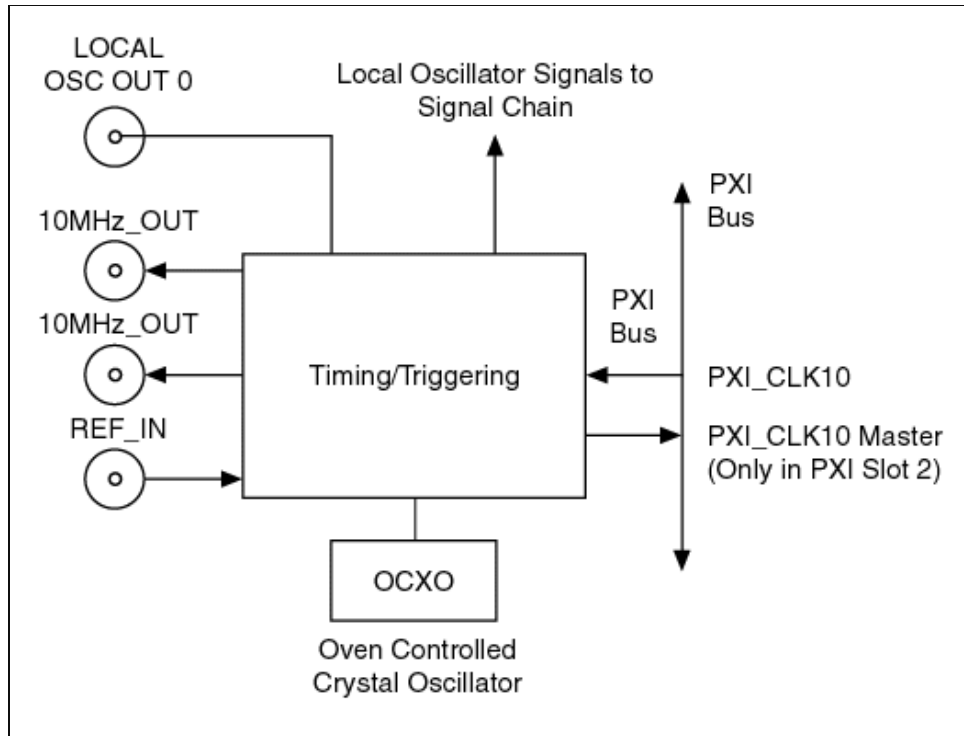
If the output frequency is varied while keeping output power levels constant, the attenuator settings and the IF power may vary automatically to maintain constant output power.

Local Oscillators

The local oscillators (LO) provide the signals required for mixing in the upconversion process. The local oscillators are phase-locked to the onboard reference OCXO at all times. They cannot lock to external reference directly; only the OCXO can lock directly to external references. The user can access the final LO signal via the front panel SMA connector labeled LOCAL OSC OUT 0 by setting the `NIRFSG_ATTR_LOCAL_OSCILLATOR_OUT_0_ENABLED` property to ENABLE. The frequency of this LO varies between 3.2 GHz and 5.9 GHz, depending upon the specified output frequency and intermediate frequencies 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 PXI Slot 2, this reference can be used to drive the 10 MHz PXI backplane clock and serve as the master reference for the PXI system. See *Timing Configurations* for information on how to configure this option.



timing circuit block diagram

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

Refer to the *NI 5670 Specifications* document, located at **Start»Programs»National Instruments»NI-RFSG»Documentation**, for NI 5610 onboard OCXO frequency reference specifications.

Timing Configurations

The timebases of both NI 5670 hardware modules (NI 5421 AWG module and the NI 5610 upconverter module) must be frequency-locked to a common 10 MHz reference clock. The following clock sources are available:

- 10 MHz NI 5610 Onboard Reference Clock
- 10 MHz External Reference Clock (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 PXI Slot 2. When the NI 5610 is installed in PXI Slot 2, 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 connector on the NI 5610 module front panel.

Available timing configurations are shown in the table below.

Timing Configuration	NI 5610 PXI Slot Location	Module Front Panel Connections	How to Configure
NI 5421 locked to NI 5610 onboard OCXO, 10 MHz PXI backplane clock independent	Any PXI slot	Connect the TO AWG CLK IN connector on the NI 5610 module front panel to the CLK IN connector on the NI 5421 front panel	Set the Ref Clock Source property to OnBoardClock; Set the PXI Chassis Clk 10 Source property to None. This is the default configuration in the NI-RFSG driver software
NI 5421 locked to NI 5610 onboard OCXO, 10 MHz PXI backplane clock locked to NI 5610 onboard OCXO	PXI Slot 2 <i>only</i>	Connect the TO AWG CLK IN connector on the NI 5610 module front panel to the CLK IN connector on the NI 5421 front panel	Set the Ref Clock Source property to OnBoardClock; Set the PXI Chassis Clk 10 Source property to OnBoardClock.
NI 5610 and NI 5421 locked to external reference, 10 MHz PXI backplane clock independent	Any PXI slot	Connect the TO AWG CLK IN connector on the NI 5610 module front panel to the CLK IN connector on the NI 5421 front panel; external reference signal attached to the NI 5610 REF IN connector	Set the Ref Clock Source property to RefIn; Set the PXI Chassis Clk 10 Source property to None.
NI 5610 and NI 5421 locked to external reference, 10 MHz PXI backplane clock locked to external reference	PXI Slot 2 <i>only</i>	Connect the TO AWG CLK IN connector on the NI 5610 module front panel to the CLK IN connector on the NI 5421 front panel; external reference signal attached to the NI 5610 REF IN connector	Ref Clock Source property to RefIn; Set the PXI Chassis Clk 10 Source property to RefIn.
NI 5670 locked to 10 MHz PXI backplane clock*	Any PXI slot	No front panel connections are required	Set the Ref Clock Source property to PXI_CLK_10; Set the PXI Chassis Clk 10 Source property to None.

*The onboard reference of the NI 5610 offers far superior frequency stability and phase noise than the

frequency reference built into most PXI chassis. Do not lock to the 10 MHz PXI backplane clock unless it is driven by a high-accuracy reference (built-in or installed in PXI Slot 2).

Using an External Reference Clock Via the Front Panel

The NI 5670 can be programmed to phase lock to a 10 MHz external reference clock signal connected to the NI 5610 module front panel SMA connector labeled REF IN.

The pulling range of the NI 5610 onboard OCXO is specified at ± 10 Hz, but may be as large as ± 15 Hz. Pulling range is the amount of frequency variation tolerable in an external reference clock signal to which the NI 5610 onboard OCXO can be electronically locked. This implies that the external reference signal must be accurate to within ± 10 Hz in order for the NI 5610 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 NI 5610 pulling range requirement due to variability with temperature.

The phase noise of the system is also affected by external phase locking. Although the NI 5670 tries to minimize the effect of noisy references by using a very small phase-locked loop bandwidth, a considerable remnant may exist if the reference phase noise is 20 dB to 30 dB poorer than the NI 5610 onboard OCXO. Some rubidium sources on the market have more phase noise than the NI 5610 onboard reference, but exhibit very high long-term stability.

The external reference signal power level must be > -10 dBm or $0.2 V_{p-p}$ into 50 Ohm.

Exporting a Frequency Reference

The onboard reference of the NI 5610 may be exported to other benchtop instruments or PXI modules.

The 10 MHz reference signal from the NI 5610 onboard OCXO is always available on the module front panel connectors labeled 10 MHz OUT. Both connectors output replications of the upconverter 10 MHz frequency reference signal, 180° out-of-phase with each other. If the NI 5610 has been configured to lock to an external reference signal, then the signal output from the 10 MHz OUT NI 5610 module front panel connector is also locked to the specified reference.

The NI 5610 can also be configured to drive the 10 MHz PXI backplane clock with its highly accurate onboard reference clock. To do this, the NI 5670 must be installed in PXI Slot 2. The NI 5610 can also be configured to lock to an external reference clock signal attached the REF IN connector on the module front panel.



Note The onboard reference of the NI 5610 offers far superior frequency stability and phase noise than the frequency reference built into most PXI chassis. Do not lock to the 10 MHz PXI backplane clock unless it is driven by a high-accuracy reference (built-in or installed in PXI Slot 2).

Sine Waveform Mode versus Arbitrary Waveform Mode

In sine waveform generation mode, NI-RFSG software internally calculates a phase-continuous sine wave signal at commit time. Very narrow output signal bandwidth settings and a sample clock rate of 100 MS/s are always used for sine signal generation. Frequency and power settings relate to the frequency and power of the sine tone.

In arbitrary waveform generation mode, a user-provided complex IQ baseband signal is upconverted to IF at commit time. Phase continuity, signal bandwidth and sample clock rate settings are configurable. Output frequency and power settings relate to the center frequency and average power of the specified arbitrary waveform.



Note The maximum allowed peak envelope power (PEP), also called maximum instantaneous power, is 17 dBm. In sine waveform mode, all envelope power is contained in the single tone, so tone power levels of up to 17 dBm can be achieved, depending on the frequency. However, in arbitrary waveform mode the envelope power depends on the arbitrary waveform, and may exceed allowable PEP without peaks at similar power levels.

The following table details the differences between sine and arbitrary waveform generation modes:

	Sine Waveform Generation Mode	Arbitrary Waveform Generation Mode
Output Waveform Type	sine wave	arbitrary waveform
Phase-Continuous	always	optional, depending on input waveform
Waveform Source	driver software-generated	user-specified complex baseband IQ data
Sample Clock Rate	always 100 MS/s	100 or 50 MS/s
Bandwidth	always narrow	specified in the Signal Bandwidth property
Frequency	specifies the frequency of the output sine tone	specifies the center frequency of the output arbitrary waveform
Power Level	specifies the sine tone power level	specifies the average power level of the arbitrary waveform
Digital IF Equalization	disabled	optional

Sample Clock Rate

NI-RFSG provides for two sample clock rates in arbitrary waveform generation mode:

- 100 megasamples per second (MS/s) — default
- 50 MS/s


Sine generation mode always uses a sample clock rate of 100 MS/s.

The default sample clock rate for arbitrary waveform generation is 100 MS/s. This setting provides the best possible anti-aliasing performance, up to 20 MHz of real-time bandwidth, and the best time-domain resolution of the signal. It is therefore the recommended setting for most applications.

When to Use a 50 MS/s Rate

Two main cases exist in which a sample rate setting of 50 MS/s may be useful:

1. Very large waveforms – setting the sample clock rate to 50 MS/s halves the memory required to store the same time duration of a given waveform. For example, if the NI 5421 AWG module is equipped with the 256 MB memory option, 1.28 seconds of data sampled at 100MS/s (equivalent to 2^{27} samples) can be stored in the NI 5421 onboard memory. By contrast, approximately 2.56 seconds of data sampled at 50 MS/s (equivalent to 2^{28} 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 sample clock to 50 MS/s can improve speed performance if resampling of the signal is required. The resampling process can consume significant CPU time, and the larger the resampling ratio (final sample rate / initial sample rate) the more time resampling takes. Therefore, resampling to 50 MS/s will be less time-consuming than resampling to 100 MS/s.

Implications of Using a 50 MS/s Rate

Setting the sample clock rate to 50 MS/s has the following implications:

- The NI-RFSG driver will place the IF carrier frequency at 20MHz \pm 2.5MHz to avoid aliasing. However, forcing the IF carrier frequency at that point implies that the NI-RFSG driver will 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. This constraint is due to the Nyquist frequency (25 MHz) and to the upconverter input IF range (15 MHz to 35 MHz).

Phase Continuity

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 (modulo 2π). 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 (modulo 2π) for every frequency component of the array.

The user-specified baseband IQ waveform downloaded input to the NI 5421 is upconverted to an IF waveform which is input to the NI 5610 upconverter module. The IF waveform must be phase-continuous or a phase glitch appears in the RF output signal when the waveform loops back to the beginning of the array. The IF waveform array will only be phase-continuous if the array contains an integer number of cycles of the IF frequency.

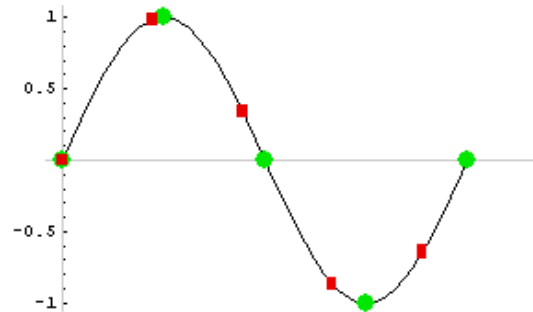



Figure 1. A sine wave sampled at two different sample rates. Circles represent phase-continuous sampling of the sine wave. Squares represent non-continuous sampling of the sine wave.

Phase glitches in the RF output signal that are due to a non-integer number of samples in the IF waveform can be addressed by repeating the original IF waveform. For example, an array containing 100.5 cycles of the IF waveform can be copied and concatenated to form a new phase-continuous IF waveform array which contains 201 cycles.

For some combinations of array size and IF frequency, it may be necessary to repeat the original IF array 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. 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, it is possible both to ensure phase continuity and keep the frequency error of the IF carrier within a tolerance (which depends on your memory size). A large memory size allows a small frequency error, while a small memory size can give rise to a larger frequency tolerance error.

Note You may encounter "out of memory" errors (or "memory full" errors) even when the original waveform is smaller than the specified maximum waveform size. To overcome this problem,  increase the frequency tolerance setting. This allows the driver 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), then you can disable array repetition by setting the Phase Continuity Enabled property to FALSE. This will often save processing time and AWG onboard memory, but 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 the NI-RFSG driver from repeating the waveform to ensure phase continuity.

¹ The term "frequency error" refers to the difference between the user-requested RF output frequency and the actual RF output frequency of the NI 5670. The NI-RFSG driver coerces the output frequency as close to the requested value as allowed by the "Frequency Tolerance" attribute. The absolute frequency error in the output value of the NI 5670 is determined by the 10 MHz reference used during generation. When using the NI 5610 onboard reference, this error is less than 50 ppb.

Resampling and Phase Continuity

Resampling can disturb phase continuity. For example, if a sine wave sampled at 4 samples per cycle, in a 4-sample long phase-continuous array, is resampled to a rate of 4.5 samples per cycle, the 4 original samples (the rate change produces 4.5 samples, but only an integer number of samples can be returned by the resampler) are no longer phase-continuous. Phase continuity is only preserved if an integer number of samples in the original array becomes an integer number of samples in the resampled array.

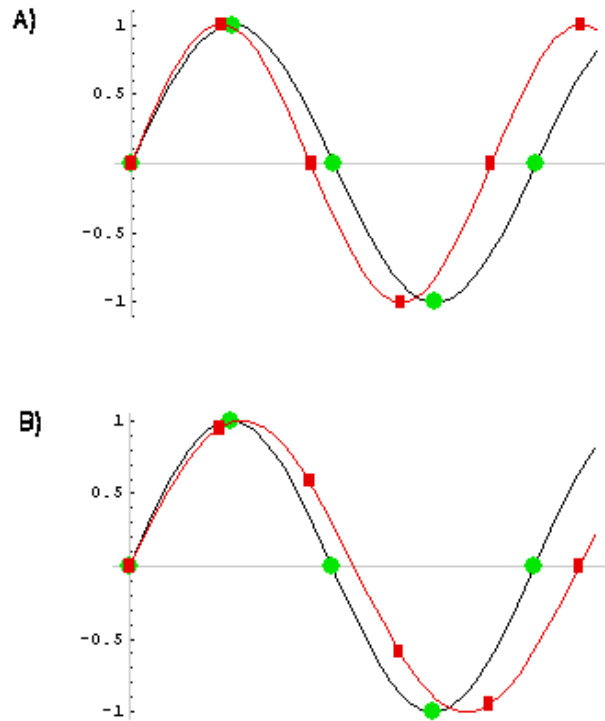


Figure 2. A sine wave with its frequency coerced to be phase–continuous at an integer sample rate. In graph A, no resampling is needed. In graph B, a single cycle has been resampled from 4 (circles) to 5 (squares) samples per cycle.

Address this using a similar approach to that mentioned above: repeat the original array. If the original array is copied and concatenated, there are now 8 samples in the new phase–continuous array. The frequency content of the new array is exactly the same as the frequency content of the original array. If resampling is performed from 4 to 4.5 samples per cycle, the 8 samples becomes 9 samples. Since 9 is an exact integer, phase continuity will be preserved. This strategy is shown in some NI–RFSG examples.

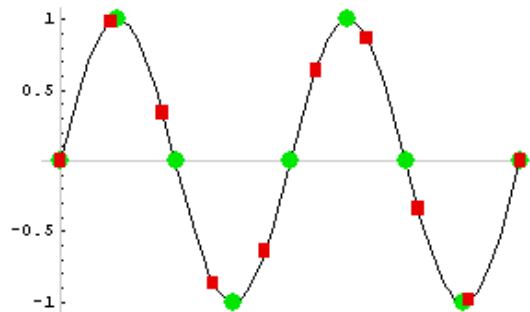


Figure 3: Both sample rates are phase–continuous on two cycles.

Power Level Adjustment

NI 5670 output signal power level is a result of both the NI 5610 upconverter module gain settings and the the NI 5421 AWG module IF waveform power. The NI–RFSG driver transparently adjusts both devices to achieve an actual RF output power level that is within specified tolerances of the power level requested using the Power Level property. Hardware settings are selected by NI–RFSG to optimize linearity and noise floor performance.

This section describes the components adjusted to reach the specified amplitude, and scenarios describing how these adjustments are combined.



Note See the *NI 5670 Specifications*, installed at **Start»Programs»National Instruments»NI–RFSG»Documentation** for guaranteed output power ranges.

Adjustment Components

- The NI 5610 upconverter module adjusts NI 5670 output signal power in increments of 1 dB by asserting up to 121 dB of onboard IF and RF attenuation. The NI 5610 has a nominal gain of 20 dB and a maximum output power level specified at 13 dBm linear power minimum (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.) Attenuation settings versus frequency and temperature are determined during calibration.
- The NI 5421 AWG module provides fine resolution signal power adjustment by tuning the main digital–to–analog converter (DAC) attenuation. This fine–tuning of the main DAC attenuation is performed by the gain DAC. The NI 5421 has two signal paths, the Direct Path and the Low–Gain/High–Gain Amplifier path. NI–RFSG automatically selects a path and DAC attenuation setting based on signal power requirements. As progressively more attenuation is required, these components are adjusted as follows:

1. **5421 Direct Path**

The NI 5421 Direct Path optimizes NI 5670 linearity for high power level signals. The Direct Path removes the NI 5421 analog filter, attenuation sections, and amplifiers from the signal path, yielding an output signal with the lowest possible distortion and flat frequency response. The NI 5421 AWG Direct path provides a 1 V_{pk–pk} full–scale output into a 50 Ohm load with no offset (approximately +4 dBm output power into a 50 Ohm load). 3 dB of analog signal attenuation is available (in increments of less than 0.02 dB) by adjusting the NI 5421 main DAC attenuation. Attenuating the DAC output signal allows very fine resolution control over signal power while always maintaining the dynamic range of the DAC, ensuring no bits are lost from the digital representation of the waveform. This path is used when attenuation levels of 3 dB or less are required from the NI 5421.

2. **High–Gain/Low–Gain Path**

The Low–Gain/High–Gain Amplifier Path offers much greater attenuation than the Direct Path, and allows NI–RFSG to set the and amplifiers onboard the NI 5421 AWG module. The Low Gain/High Gain amplifier path offers up to approximately 35 dB of attenuation.




Tip Main DAC attenuation adjustment is still used for fine power level control

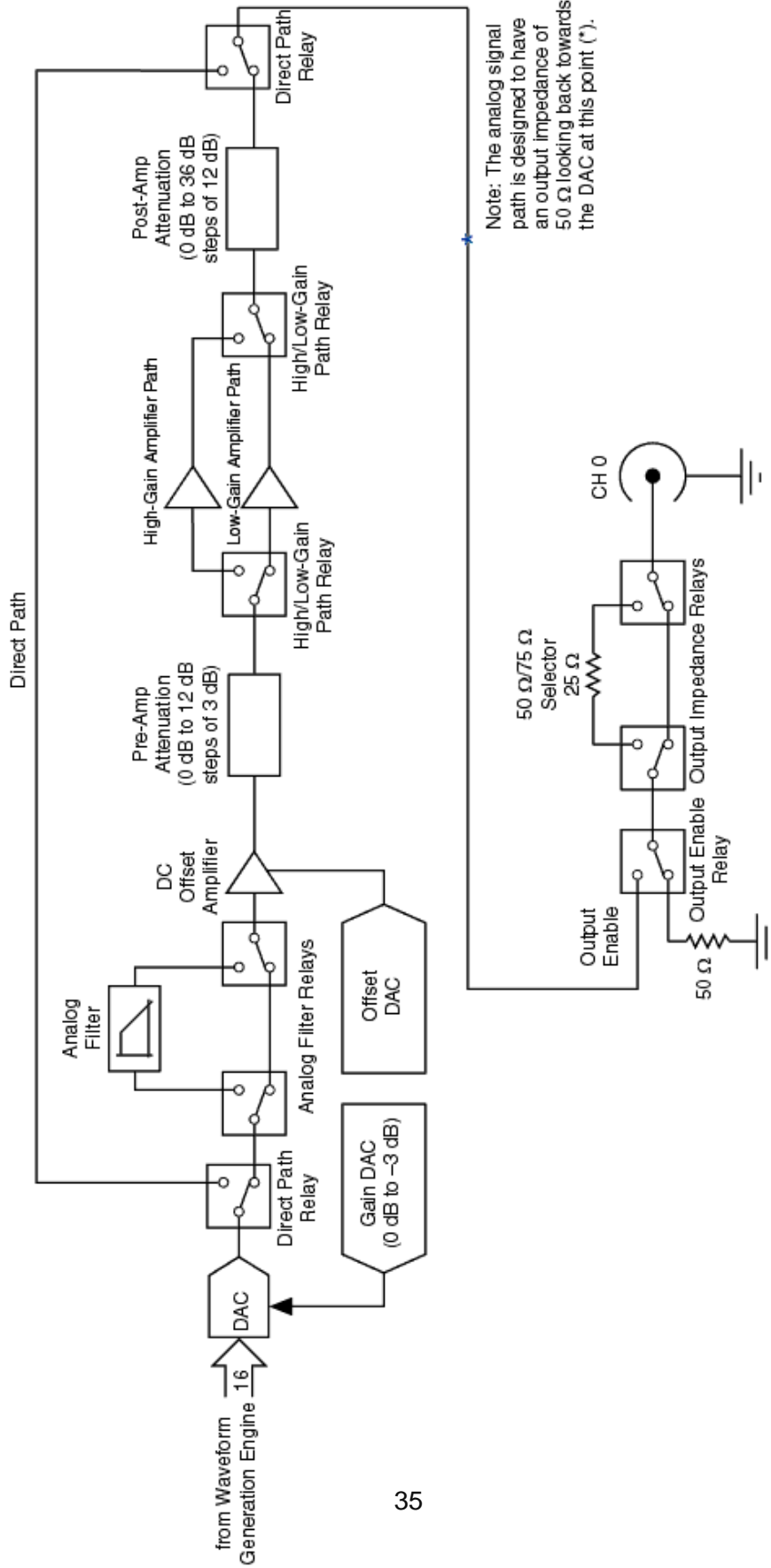
(within 0.02 dB) and offers up to additional 3 dB of output attenuation.

3. *Digital Waveform Scaling*

If more than approximately 38 dB of attenuation is required from the NI 5421, the NI-RFSG driver uses the Low-Gain/High-Gain Amplifier Path with maximum attenuation, and additionally modifies the digital waveform such that it does not use 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 in addition to that asserted by the Low-Gain/High-Gain Amplifier path. Scaling has no observable effect on NI 5670 signal-to-noise ratios, however, because NI-RFSG only scales the digital waveform at power levels (< -135 dBm typical) where other components dominate the signal-to-noise ratio. The NI-RFSG driver performs scaling on both sine waves and arbitrary waveforms as required.


 **Tip** Attenuator hold mode avoids using the NI 5421 Main Path. This improves accuracy at low power levels (< -80 dBm, depending on frequency) but decreases frequency tuning speeds. Refer to the *Attenuator Hold* property help for details.

Refer to the *NI Signal Sources Help*, located at **Start»Programs»National Instruments»NI-FGEN»Documentation**, for complete information about NI 5421 output paths.



NI 5421 Analog Paths Block Diagram

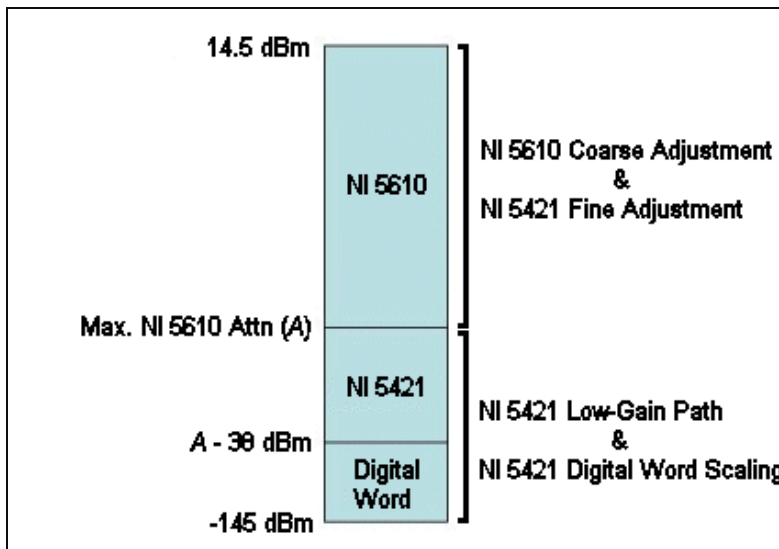
NI 5421 Analog Paths Block Diagram

 **Note** Refer to the *NI Signal Sources Help*, located at *Start»Programs»National Instruments»NI-FGEN»Documentation*, for complete information about NI 5421 output paths.

Adjustment Scenarios

There are three ways the NI-RFSG driver may achieve the output power level specified in the Power Level property. NI-RFSG automatically selects the scenario which optimizes linearity and noise floor performance while achieving the requested power level.


Refer to the figure below and the table on the following page for descriptions of NI 5670 power level adjustment scenarios. A represents the maximum attenuation of the NI 5610 upconverter.



NI 5670 Power Level Adjustment

Approximate Signal Power	Adjustment Scenario
> -85 dBm	The NI 5610 upconverter attenuators are asserted in 1 dB steps to approximate output power. The NI 5421 is configured to use the Direct Path and the main DAC attenuation is adjusted to fine-tune signal power to the specified level. The full dynamic range of the NI 5421 DAC is used, and noise and intermodulation distortion are minimized.
-90 dBm to -130 dBm	The NI 5610 upconverter attenuators are fully asserted and the NI 5421 is configured to use the Low-Gain/High-Gain Amplifier Path with appropriate attenuation. The attenuation of the main AWG DAC is still adjusted to fine-tune signal power to the specified level. Intermodulation distortion is negligible because distortion products are below the noise floor.

< -130 dBm	The NI 5610 upconverter attenuators are fully asserted and the NI 5421 is configured to use the Low-Gain/High-Gain Amplifier Path with maximum attenuation. In addition, the digital waveform is scaled such that it does not use the full-scale output voltage of the DAC. Scaling the digital waveform has no observable effect on dynamic range, which at these power levels is dictated by the thermal noise floor.
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 **Note** All ranges are approximations. See the *NI 5670 Specifications*, installed at **Start»Programs»National Instruments»NI-RFSG»Documentation** for guaranteed output power ranges.

Attenuator Hold Mode


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

The attenuator hold feature allows the user to adjust the output level in fine decrements without switching the internal attenuators on the NI 5670. To achieve this, the NI-RFSG driver 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 NI 5421 AWG. Scaling the digital waveform potentially decreases the dynamic range and thus the signal-to-noise ratio. Tuning speed may also increase slightly.

When attenuator hold mode is enabled, the NI-RFSG driver only allows signal power settings such that the DAC always uses at least 4 bits. This allows at least 55 dB attenuation below max power if the temperature is kept within +/- 20 degrees Celcius.

To configure attenuator hold complete the following steps:


1. Open a session to the instrument.
2. Configure the Attenuator Hold Max Power property. 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 Attenuator Hold Enabled property. 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 only by incrementing the digital waveform.

Output Enable

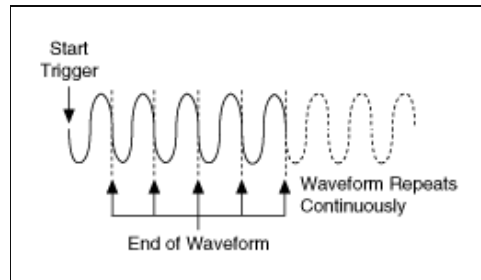
You can disable signal output at the NI 5610 upconverter module front panel SMA connector labeled RF OUTPUT using the Output Enable function. You can change the output enable state at any time during waveform generation and the generation continues on internally.

Refer to the Configure Output Enabled property for more information on using output enable.

 **Note** Output enable 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, bouncing of the electromechanical components may interrupt the output signal for up to 10 ms.


Start Triggers

Start triggers initiate signal generation. When a start trigger is received, the RF output signal begins to generate continuously as shown in the figure below. Received triggers are ignored until niRFSG Initiate is called. Triggers received after signal generation has started are ignored.



NI 5670 Start Trigger Model

NI 5670 start triggering is controlled by the NI 5421 AWG module. NI 5670 start triggers are configured using the niRFSG Start Trigger Type property.

 **Note** The NI 5610 upconverter module adds an additional delay, typically 1200 ns, to the delay from the start trigger to waveform out that is specified for standalone use of the NI 5421. Refer to the *NI-FGEN Online Help* for more information about NI 5421 triggering.

Start Trigger Options

The following three options are available for the NI 5670 start trigger:

1. **None**—Signal generation starts immediately upon execution of the niRFSG Initiate VI. No trigger is necessary. This is the default configuration in NI-RFSG.
2. **Software**—After initiation, signal generation does not begin until a software trigger is received. Call the niRFSG Send Software Edge Trigger VI to send the software start trigger.
3. **Digital Edge**—After initiation, signal generation does not begin until a digital edge is received. Specify the digital edge source by setting the Digital Edge Start Trigger Source property to one of the following options:

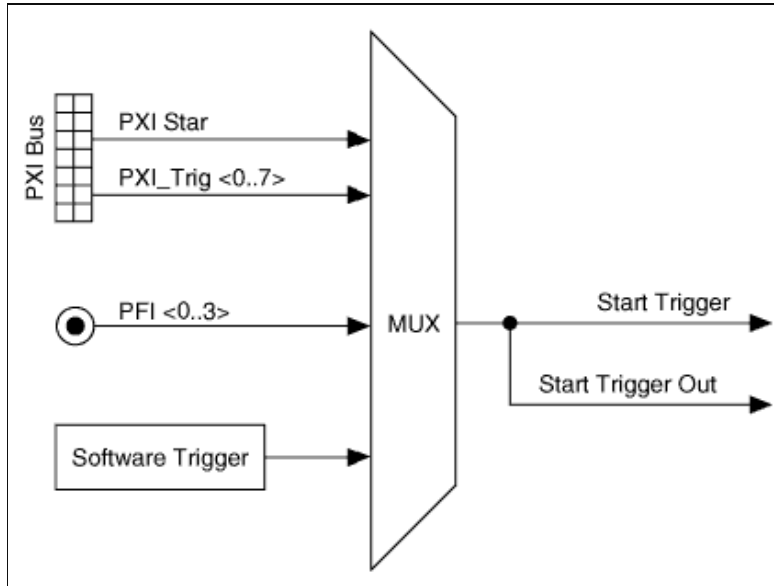
Digital Edge Sources

- ◆ PFI <0..3>
- ◆ PXI_TRIG <0..7>
- ◆ PXI_STAR



Tip Sending a software trigger when the Start Trigger Type property is set to Digital Edge also starts signal generation. This allows use of 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 NI 5421 AWG module:



NI 5421 Start Trigger Sources

Advanced Topics

This section contains information for the advanced user who wants to optimize performance by more deeply understanding the NI 5670.

NI 5670 Thermal Management

The NI 5610 operates at an internal temperature of approximately 45 °C (113 °F) under conditions of proper airflow and 25 °C (77 °F) ambient temperatures. The NI 5610 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 from the PXI chassis. Use caution when handling a recently used module.

After the warm up period, the temperature of the NI 5670 hardware is typically stable. However, if the temperature does vary due to external factors such as ambient temperature or cooling airflow changes, NI-RFSG automatically applies thermal correction to maintain output signal power within specified tolerances.

Warmup

NI recommends warming up the NI 5670 for 30 minutes before operation.


 **Note** Warmup begins when the operating system and the NI-RFSG driver have fully loaded. Driver loading can be verified by running a self-test in MAX or calling niRFSG Self Test.

NI 5610 Temperature Monitoring

The internal temperature of the NI 5610 can be queried by the user, and is additionally monitored by two separate automatic processes. The NI-RFSG software monitors the temperature for the purpose of adjusting 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 which could damage the equipment.

User Querying

Querying the value of the upconverter temperature property returns the internal temperature of the NI 5610.

 **Note** The temperature sensor queried by the upconverter temperature property is within the NI 5610 RF enclosure and contains an internal clock that is activated when it is enabled. This clock can cause low-level close-in phase noise spurs, usually below -70 dBc and varying from unit to unit. For this reason it is highly recommended that the temperature sensor not be continuously queried in order to maintain a cleaner spectrum.

Automatic Thermal Correction

The yaw, or uncorrected gain drift, of the NI 5610 upconverter module is approximately 0.05 dB per °C. The NI-RFSG software corrects for this temperature drift periodically. This thermal correction can be disabled using the Thermal Correction Enabled property.

Each time an output signal is requested the NI-RFSG software checks the upconverter temperature and adjusts the attenuation and the full-scale IF level as necessary to output the requested power level within specified accuracy. After signal generation has started, the NI-RFSG software periodically checks the temperature of the NI 5610. If the temperature has changed more than 0.5 °C from when the generation started, the NI-RFSG software readjusts the attenuation and/or the IF level to maintain a constant output level.

Assuming proper warmup, the temperature of the NI 5670 hardware should not change during operation. If the temperature does change significantly due to external factors such as ambient temperature or cooling airflow changes, it is possible that having thermal correction enabled may cause transient noise in the RF output signal when the correction is being applied.


For some applications this transient caused by the attenuator switching during level adjustment may not be acceptable. You can disable thermal correction for applications that are sensitive to this transient by

setting the niRFSG Thermal Correction Enabled property to DISABLE. When thermal correction is disabled, NI–RFSG only readjusts the output level when you stop and restart signal generation.

You can disable operating temperature monitoring using the Thermal Correction Enabled property. Enabling thermal correction (default) may cause noise on the output signal when the correction is being applied, but ensures constant output power despite temperature fluctuations.

Automatic Thermal Shutdown Monitoring

Once the NI–RFSG driver has loaded, the RF enclosure is powered on. From that time onward, circuitry on the NI 5610 continuously monitors the temperature. It will power off the RF enclosure before the temperature gets high enough to damage the NI 5610. If this happens the NI–RFSG software will return an error and you must reset the NI 5610 in order to restore power to the RF enclosure. You can reset the NI 5670 by right–clicking both hardware modules in MAX and selecting Reset Device, or by calling niRFSG Reset Device VI.

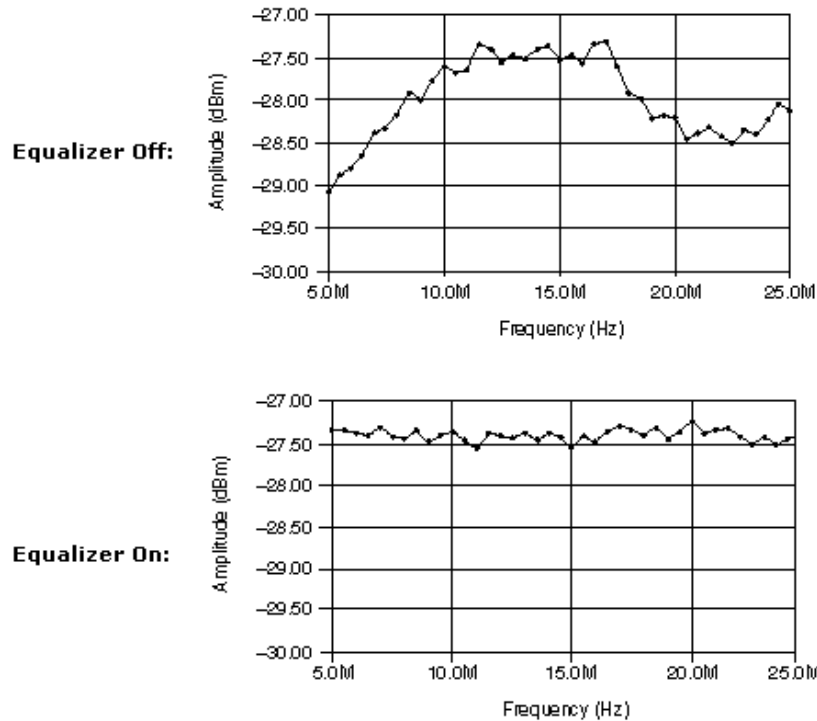
 **Note** The NI 5610 will be warm to the touch during normal operation. It should never reach a temperature high enough to cause thermal shutdown unless the fan or vents on the PXI chassis are blocked, or the filters on the fans are excessively dusty. If you get a thermal shutdown error, make sure the filters are clean and that you have a clear path for airflow through your PXI chassis.

Software Equalizer

Equalization is the process of adjusting the frequency content of the signal or the frequency response of the signal path 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 RF Vector Signal Generator. These variations are introduced by the anti–imaging filters that are used in performing an image–free upconversion.

Plots of the typical magnitude response of the NI 5610 upconverter with and without software equalization enabled are shown in the figures below.




Typical Passband Response of the NI 5610 Upconverter Module With and Without Equalization

As can be seen from the typical response, there is +/- 2 dB max gain variation between the center of the 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 (> approx. 500 Kilosymbols/Second (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 can be performed via a digital filtering operation by the NI-RFSG driver software.

The equalizer filtering uses coefficients that are determined and stored in the onboard nonvolatile memory during calibration.

 **Note** The equalizer performs both gain and phase compensation to get the best response. For simplicity, only the gain response is discussed here.

The property that controls the equalization is Digital IF Equalization Enabled. This property can be used to enable/disable software equalization or to query the enabled/disabled state of the software equalizer.

When enabled, software equalization improves the modulation quality for wider real-time bandwidth (> 500 kHz) signal generation.

Tip 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)	Because the occupied bandwidth is 500 kHz or less, there is little performance gain from turning on equalization. Disabling equalization (default) is recommended for faster throughput.
>500 kS/s	Enabled	The modulation quality (Error Vector Magnitude) is improved by enabling equalization for wide bandwidth (> approx. 600 kHz) signals.

For faster test times with equalization ON, you may consider saving a digital waveform that has been pre-equalized so that the digital filtering operation, and the associated computation time, is done once as opposed to every time the same waveform pattern has to be generated. There are low level tools available to extract the equalization filter coefficients stored in the onboard nonvolatile memory. Please refer NI technical support if you need to access these tools.

Other considerations:

The factory determined equalizer filter coefficients are valid for 25 °C +/- 10 °C. For operation outside this temperature range, it is recommended that the equalizer filter be determined under the operating environment. Please refer to ni.com/examples for example code that allows you to determine the filter coefficients using a digitizer.

You may want 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 °C +/- 10 °C range

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

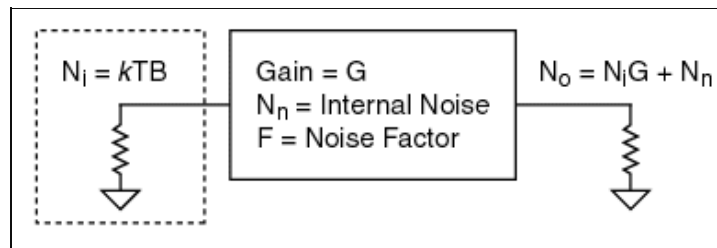
Noise Floor

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

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

$$N_i = kTB \text{ Watts}$$

where k is Boltzmann's Constant ($k = 1.38 \times 10^{-23} \text{J/K}$), T is the resistor temperature in degrees Kelvin, and B is the bandwidth in Hertz. If B is set to 1 Hz, then N_i is equal to the output noise density in W/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 :



NI 5670 Noise Floor

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:

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

$$S_o = GS_i$$

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

$$\Rightarrow N_o = FGN_i$$

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

$$\text{and } N_o = N_iG + (F-1)GkTB \text{ (Watts)}$$

$$N_o = FGkTB \text{ (Watts)}$$

$$N_o(B=1) = 10\log(1000(FGkT)) \text{ (dBm/Hz)}$$

If N_i is equal to kTB then,

$$N_o = FGkTB \text{ (Watts)}$$

$$N_o(B=1) = 10\log(1000(FGkT)) \text{ (dBm/Hz)}$$

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 PXI-5670 is dominated by the NI 5610. This is because the NI 5610 utilizes a superheterodyne architecture, and a significant amount of gain is located in the broadband output section (refer to the 5610 block diagram). As a result, care should be taken in non-frequency-selective applications such as testing a broadband device with a broadband detector, as noise power is integrated. Integrated noise power can be calculated using the following formula:

$$N_o = N_o(\text{dBm/Hz}) + 10\log B$$

where B is equal to 2.7 GHz (if no external filter is used) and N_o is the noise floor spectral density. With the NI 5670 set to minimum output power the noise power density at the output is -158 dBm/Hz. When the NI 5670 is set for power levels greater than 5 dBm the typical noise power density at the output is -152 dBm/Hz. The following table shows typical output noise power density for several NI 5670 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

Typical Noise Floor versus Power Levels at 2 GHz

Third-Order Intercept

Third-order intercept point is a figure of merit of the degree of linearity of a system. Third-order intercept 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. At the output of the device not only will there be the two desired tones, but there will also be distortion products. These distortion products are a result of nonlinearities within the device. Consider the following equation to represent the input signals:

$$x(t) = A_1 \cos(\omega_1 t) + A_2 \cos(\omega_2 t)$$

A nonlinear device will have an output response that can be expressed by:

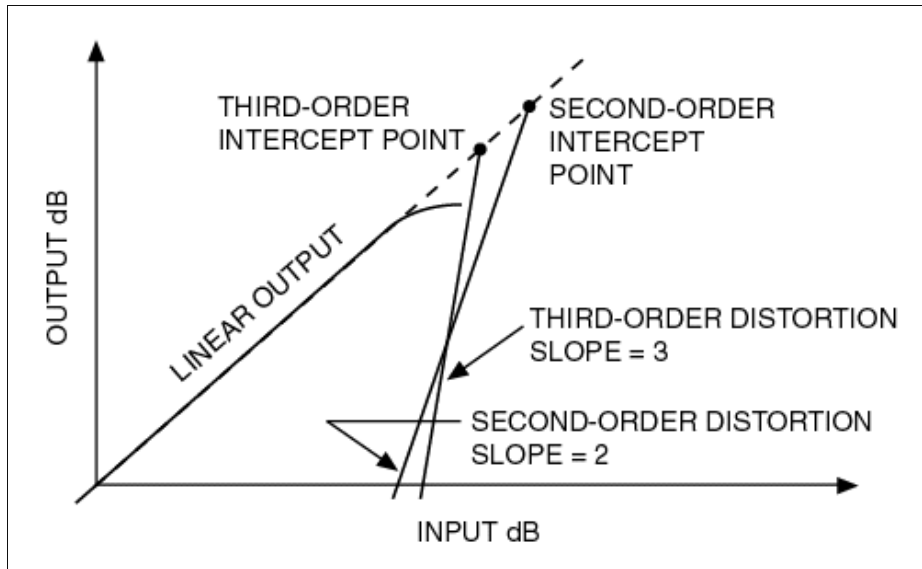
$$y(t) = a_1 x(t) + a_2 x^2(t) + a_3 x^3(t) + \dots$$

Where the a_n coefficients represent the gain and the degree of nonlinearity within the device. The x^2 terms represent the second-order distortion terms and the x^3 represents the third-order distortion terms, and $a_1 x(t)$ represents the desired output.

Plugging $x(t)$ into $y(t)$ results in the following distortion factors:

Frequency	Distortion Order	Typical Output Power Level
0 (DC offset)	Second	$0.5a_2(A_1^2 + A_2^2)$
$2\omega_1$	Second	$0.5a_2A_1^2$
$2\omega_2$	Second	$0.5a_2A_2^2$
$\omega_2 - \omega_1$	Second	$0.5a_2A_1A_2$
$\omega_2 + \omega_1$	Second	$0.5a_2A_1A_2$
$3\omega_1$	Third	$0.25a_3A_1^3$
$3\omega_2$	Third	$0.25a_3A_2^3$
ω_1	Third	$0.75a_3A_1^3 + 1.5A_1A_2^2$
ω_2	Third	$0.75a_3A_2^3 + 1.5A_2A_1^2$
$2\omega_2 - \omega_1, 2\omega_2 + \omega_1$	Third	$0.75a_3A_1A_2^2$
$2\omega_1 - \omega_2, 2\omega_1 + \omega_2$	Third	$0.75a_3A_2A_1^2$

The terms of most interest are $2\omega_2 - \omega_1$ and $2\omega_1 - \omega_2$, because these are closer into the carrier and difficult to filter off. For broadband systems such as CATV it is important to consider all the terms that fall within its 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.



Second- and Third-Order Intercepts

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 intersect the desired output signal respectively. If A₁ is set equal to A₂, and each one is increased 1 dB, then the third-order distortion products will increase 3 dB for every 1 dB increase in output power. The second-order distortion products will increase 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:

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

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

The third-order intercept is dependent upon power levels. The following table is a summary of the typical performance:

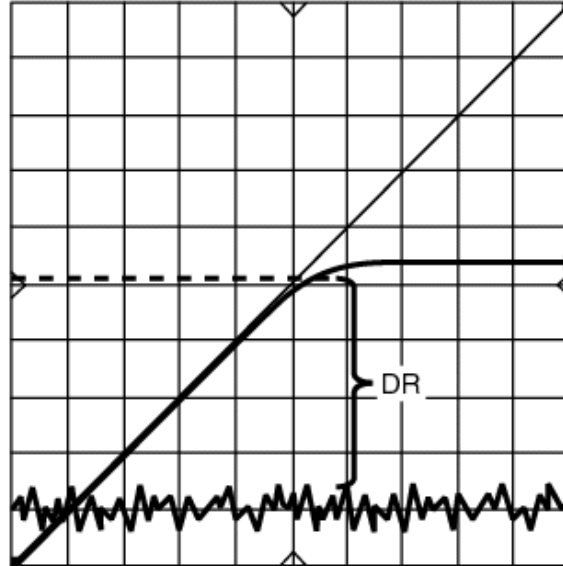
Frequency (MHz)	-20 dBm/tone	-6 dBm/tone	5 dBm/tone
100	86 dBc	78 dBc	54 dBc
1000	86 dBc	86 dBc	54 dBc
2000	86 dBc	86 dBc	50 dBc
2700	86 dBc	82 dBc	46 dBc

Typical Third-Order Distortion Products (dBc)

As the output power level is increased, the third-order intercept point increases, except for power levels above -3dBm/tone. Beyond this power level there is a step reduction in TOI as shown in the table above. 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.

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:

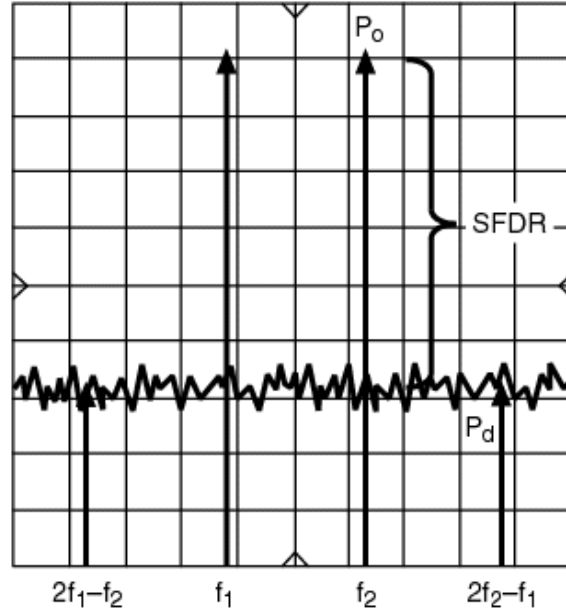


Dynamic Range

Dynamic range is expressed with the following equation:

$$DR \text{ (dB)} = P_{1dB} \text{ (dBm)} - \text{Noise Floor (dBm/Hz)}$$

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, this is the level at which the 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 would be equal to the difference between the desired signals and the spurs. The following figure is a graphical representation of the spurious free dynamic range:



Spurious-Free Dynamic Range

The spurious free dynamic range can be calculated from the third order intercept point and the second order intercept point using the following equations:

$$SFDR_{TOI} = 2/3(OIP_3 - Noise\ Floor)$$

$$SFDR_{SOI} = .5(OIP_2 - Noise\ Floor)$$

Using the NI 5610 as a stand alone unit, to maximize the SFDR follow the same procedure used to maximize the third order intercept point which is to minimize RF attenuation.

When using the NI 5610 in conjunction with the NI 5421 as a calibrated unit, the spurious free dynamic range for a two-tone signal is the difference between the desired tones and the intermodulation levels. This number 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

Typical NI 5670 Performance @ 2GHz

Frequency Tuning Times

Many factors contribute to NI 5670 frequency tuning times. One factor is the amount of time required for the upconverter PLLs to lock to a new frequency. Because the NI 5670 is an AWG-based vector signal generator, tuning times must also account for the times that it takes to configure the NI 5421 AWG module. This time potentially includes recalculating and uploading a new waveform to the NI 5421 AWG module onboard memory.

NI 5670 overall tuning time is the longer of the NI 5610 upconverter module and NI 5421 AWG module tuning times. If the NI 5670 is tuned in steps of 1 MHz (when using signal bandwidths >10 MHz), or steps of 5 MHz (when using signal bandwidths ≥ 10 MHz), a new waveform is not written to the AWG module and AWG module settling time is 0 ms.

NI 5610 Upconverter Frequency Tuning Time

When the frequency is changed in a phase-locked loop system, the signal loses lock on the initial frequency and achieves lock on the new final frequency. The signal takes time to settle to within some frequency tolerance of the final frequency. Furthermore, the tolerance may be set to as 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 μ s. Our discussion will define tuning speed as the time required by the signal to lose lock on one specific frequency and jump to another specific frequency within a specified frequency tolerance.

The NI 5610 front panel ACTIVE LED indicates hardware PLL lock status. The ACTIVE LED indicator turns green when 5 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 comes on. To provide a clearer understanding of the hardware lock times, a table of NI 5610 phase-locked loop lock times for various tuning step sizes is provided below.

Frequency Tolerance	Step Size		
	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

NI 5610 Upconverter-Only (Sine Wave Mode) Tuning Times

The NI 5610 upconverter module tunes in steps of 1 MHz (when using signal bandwidths >10 MHz), or steps of 5 MHz (when using signal bandwidths ≥ 10 MHz). NI 5610-only tuning times are specified in the table above.

Sine Waveform Mode

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

Tuning Speed Factors

In sine waveform mode, the factors that contribute to the tuning time are:

1. Frequency step size (*desired frequency – previous frequency*).

The 5610 has different tuning times for various frequency step sizes.

2. Requested RF output frequency.

Depending on the requested RF output frequency the waveform size varies (see the *phase continuity* section for details). As the size increases, more time is needed to compute and upload the waveform to the NI 5421 AWG module onboard memory.

3. 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 (see the *phase continuity* section for details).

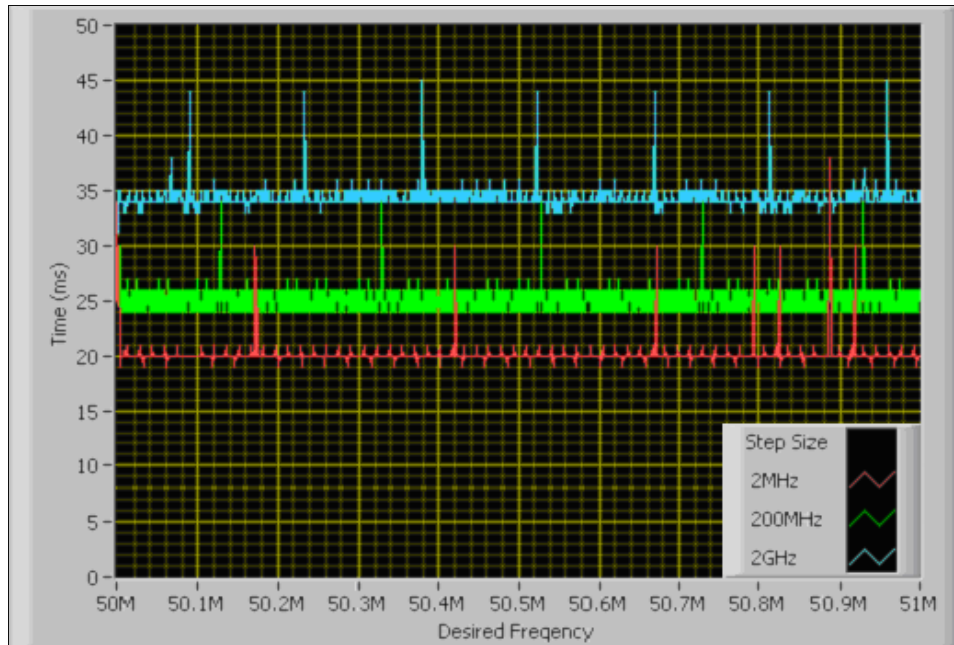
4. Automatic thermal correction.

Thermal monitoring begins with signal generation and continues until generation is stopped. The process of starting and stopping automatic thermal correction adds somewhat to the tuning time.

Typical tuning times

Typically, the largest delay in tuning to a new frequency is the time it takes the NI 5610 to lose lock on the current frequency and acquire lock on the new frequency. Depending on the step size, the NI 5610 takes different amounts of time to lock to new frequencies.

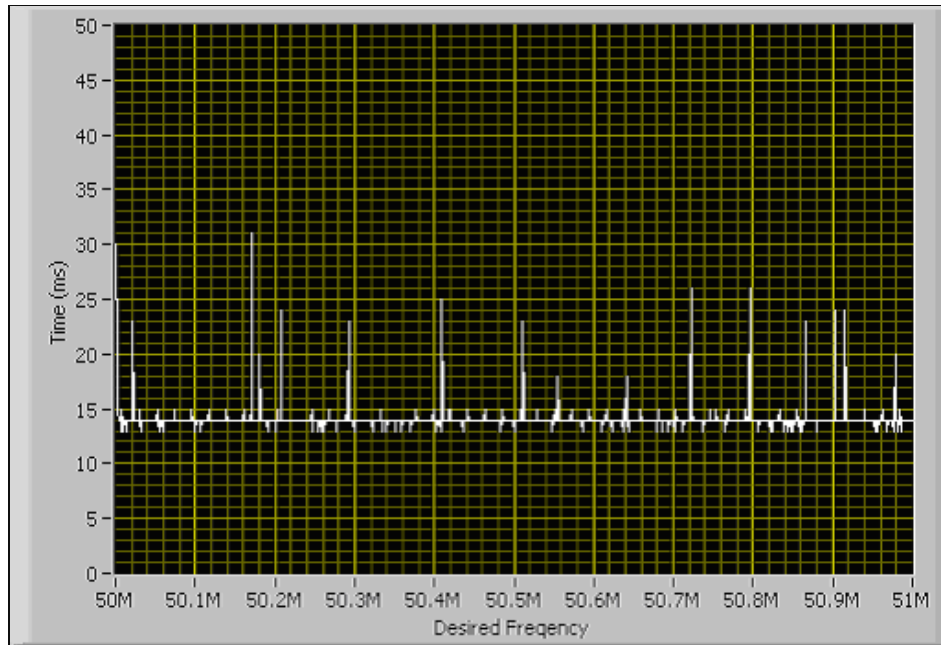
The following figure illustrates typical NI 5670 sinewave tuning times for different step sizes:



Typical NI 5670 Sinewave Tuning Times
 Thermal Correction Disabled
 Frequency Tolerance = 50 Hz
 Previous Frequency = *Desired Frequency* + *Step Size*

Upconverter tuning times are not a factor when the NI 5610 upconverter module does not have to be reconfigured, in which case the NI 5670 tuning time is dominated by the time it takes to compute and upload the sine waveform to the NI 5421 onboard memory.

The following graph depicts NI 5670 sinewave tuning times for small frequency step sizes:



Typical NI 5670 Sinewave Tuning Times -- Small Frequency Steps

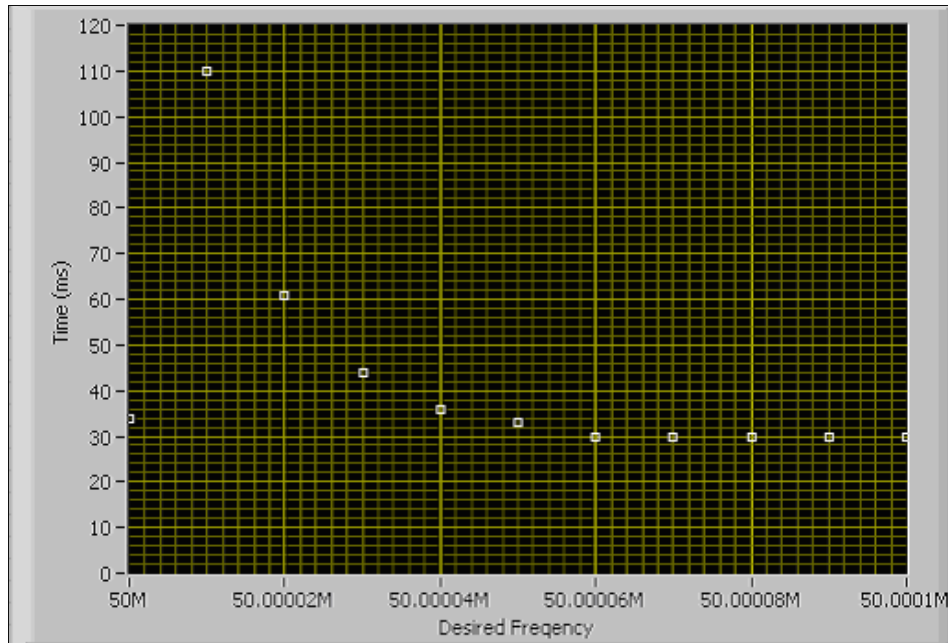
Thermal Correction Disabled
 Frequency Tolerance = 50 Hz
 Previous Frequency = 50 MHz

Maximum tuning time

The NI 5670 requires the maximum tuning time when ALL of the following conditions are true:

1. The frequency step size is > 2 GHz, AND
2. The frequency tolerance is at minimum setting (1 Hz), AND
3. The desired RF output frequency requires a large waveform.

The following graph depicts the NI 5670 sinewave tuning times under worst case conditions:



Worst Case NI 5670 Sinewave Tuning Times

NI 5610 step size: > 2 GHz
 Frequency Tolerance: 1 Hz
 Previous Frequency: 2.5 MHz

Tips The following measures can decrease sinewave tuning times:



1. Disable automatic thermal correction if your application does not require it.
2. Increase the frequency tolerance as much as allowed by your application.
3. Change your frequency in 5 MHz step sizes so that recalculation of the sine waveform is not required.

Arbitrary Waveform Mode

In arbitrary waveform mode a user-specified complex IQ baseband signal is written to the driver. Then, depending on different parameters, the NI-RFSG driver upconverts the signal to IF and uploads it to the NI 5421 AWG module onboard memory.

Tuning Speed Factors

In arbitrary waveform mode, the following main factors affect NI 5670 tuning time:

1. Waveform size.

The bigger the waveform the longer it takes to be recalculated and uploaded to NI 5421 AWG module onboard memory. Increasing the size of the waveform increases required tuning time in a linear fashion.

2. Digital IF equalization.

The process of digitally equalizing the waveform is very computationally demanding and adds to tuning times.

3. Phase continuity. If this property is enabled, NI-RFSG may repeat the IQ waveform before upconverting it to IF in order to ensure phase continuity. Repeating the IQ waveform changes the size of the IF waveform and, as noted, increases the NI 5670 tuning time. The final IF waveform size depends on the frequency tolerance, desired frequency, and input size.

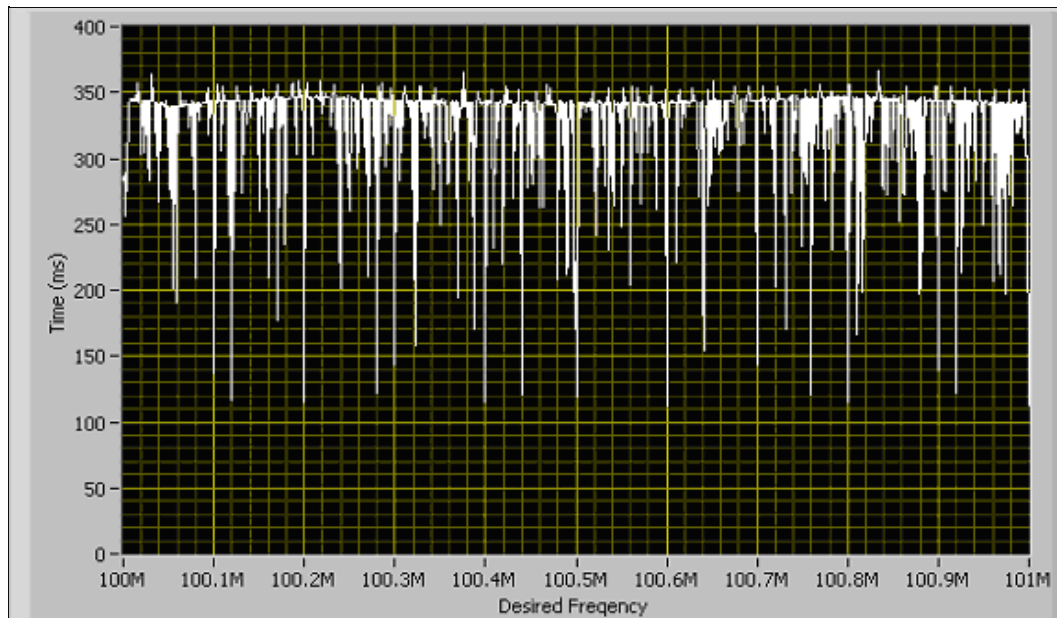
4. Desired frequency.

5. 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.

Typical Arbitrary Waveform Tuning Times

The following figures illustrate NI 5670 tuning times for an arbitrary waveform of 1 million samples with digital IF equalization disabled and enabled, respectively:



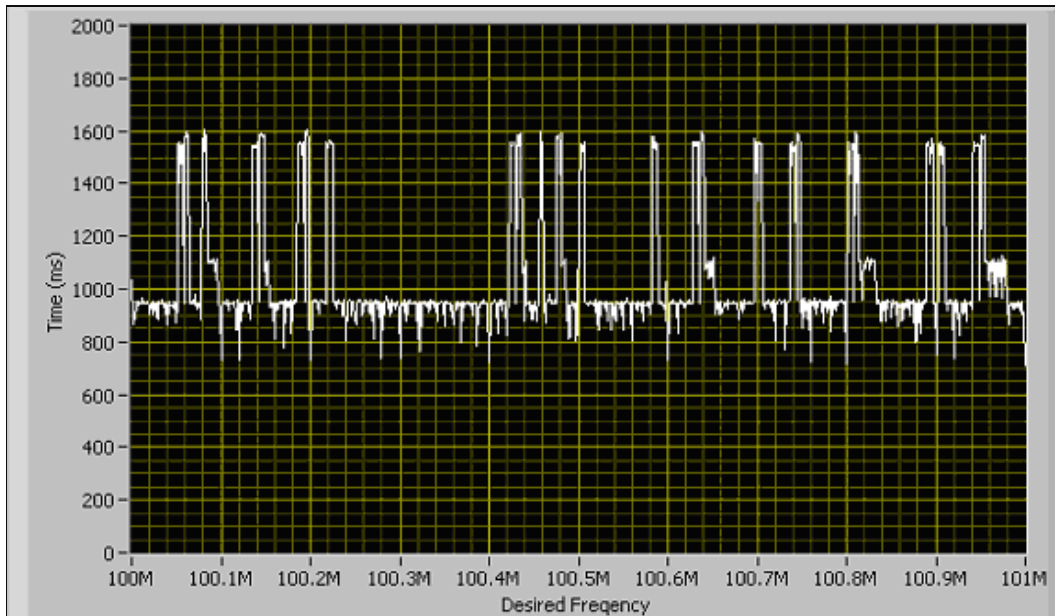
NI 5670 Arbitrary Waveform Tuning Times

Waveform Size: 1 Million Samples

NI 5610 step size: > 2 GHz

Phase Continuity: Disabled

Digital IF Equalization: Disabled



NI 5670 Arbitrary Waveform Tuning Times

Waveform Size: 1 Million Samples

NI 5610 step size: > 2 GHz

Phase Continuity: Disabled

Digital IF Equalization: Enabled

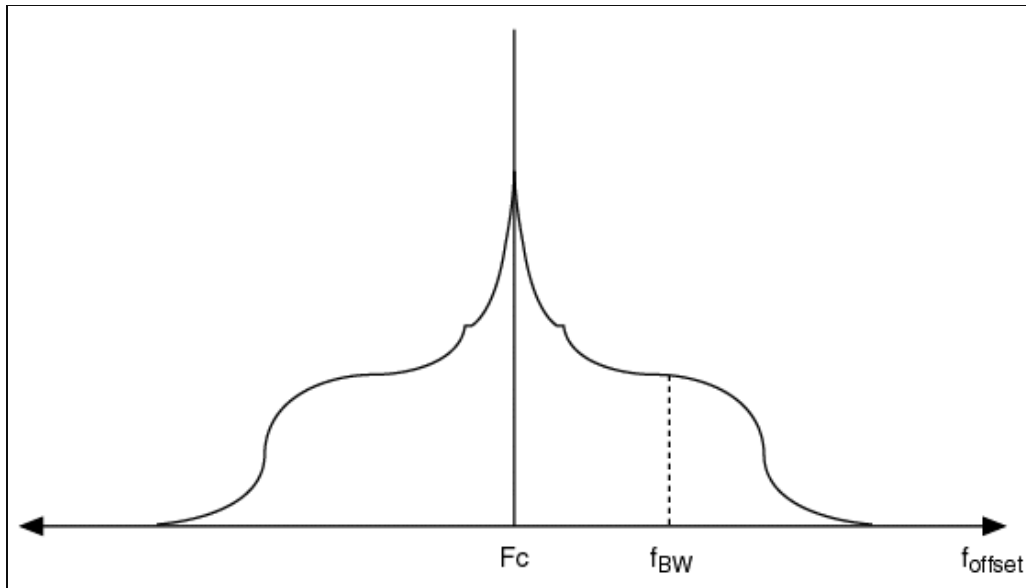
Tips The following measures can decrease arbitrary waveform tuning times:



1. For signal bandwidths < 600 kHz, disable digital IF equalization.
2. Disable phase continuity if your application does not require a phase-continuous signal.
3. Write large waveforms in chunks to avoid exceeding RAM capacity and using virtual memory. NI-RFSG examples demonstrate how to write waveforms in chunks.

Phase-Locked Loop Bandwidth

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



PLL Bandwidth

Tuning speed is increased as the bandwidth is increased, and vice versa. PLL theory states that the phase noise of the LO signal maybe broken into 2 components; the phase noise of the tuning oscillator and the noise from the loop components with the reference signal inclusive. The tuning oscillator phase noise dominates the region outside the loop, while the regiod inside the loop is dominated by the loop components.

There are 2 possible settings for loop bandwidth: LOW and HIGH, as shown in the following table. When signal bandwidth is set higher then 10 MHz, the only availabe loop bandwidth option is LOW. To change the loop bandwidth settings, change the signal bandwidth to greater then 10 MHz (for LOW loop bandwidth), and less then or equal to 10 MHz (for HIGH loop bandwidth).

Loop Bandwidth Setting	Use
High	Optimizes phase noise <=10 kHz offset from the carrier
Low	For real-time bandwidths >10 MHz, this is the only available setting

Spurs

There are several different categories defining the spurious behavior of the NI 5610. The first category are spurs occuring below 2.7 GHz that are independent of the input signal. All spurs that fit this criteria are less than -80 dBm.

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

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

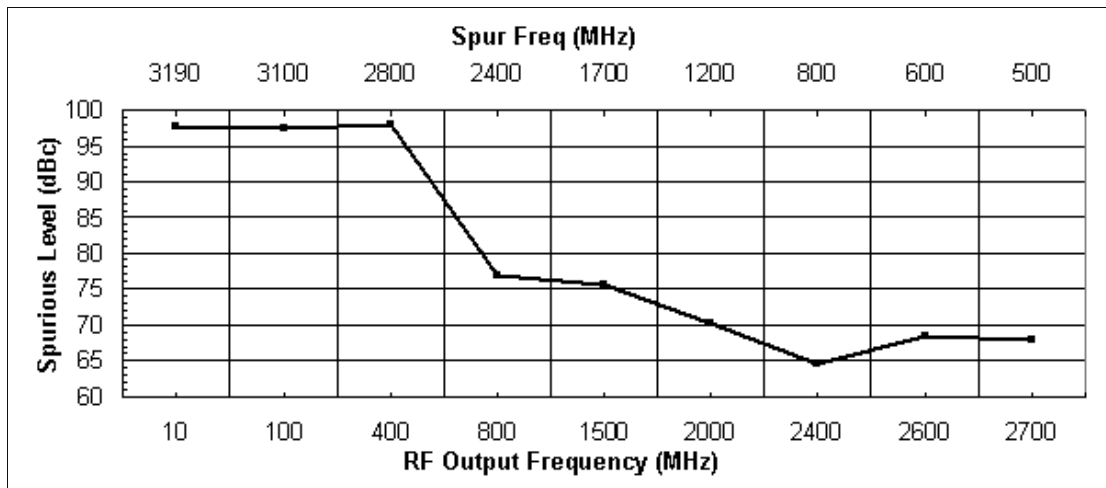
$$\text{IMD}_{\text{SOI}} = \text{OIP}_2 - P_{\text{out}}$$

It is important to note that the third order intermodulation distortion, which is the difference between P_{out} and the distortion signals in dB or dBc, 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 those that are less than 2.7 GHz and are dependent on the input signal, but not within ± 10 MHz of the desired output signal. All spurs falling in this category are less than -80 dBc, except for one, which is about -60 dBc. The output frequency for this spur can be determined by using the following equation:

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

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




NI 5610 Output Frequency Dependent Spur

Next are the spurs that are within ± 10 MHz of the carrier. These spurs are the result of signals modulating one of the LOs. These spurs should be below -50 dBc for frequencies less than 1 kHz and better than -60 dBc for frequencies between 1 kHz and 2 kHz. Beyond 2 kHz spurious levels are less than -70 dBc.

The last category of spurs are those greater than 2.7 GHz. There is a LO spur that occurs at 2.88 GHz and at multiples of 2.88 GHz. These spurs are less than -80 dBm. As part of the architecture of the NI 5610 there is a broad tuning local oscillator (LO) that tunes over the range of 3.2 GHz to 5.9 GHz. The frequency of this LO is always about 3.2 GHz greater than the output signal.

When the LOCAL OSC OUT 0 connector on the NI 5610 front panel is disabled, the LO leakage at the RF OUT connector is typically less than -80 dBm for output frequencies greater than 100 MHz. For output frequencies greater than 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 above 100 MHz. For frequencies below this, 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 0 connector enabled)could be as great as -40 dBm.

This section does not address harmonic-related spurs.

Understanding Calibration Correction

The NI 5421 and the NI 5610 are calibrated individually, and the uncertainty due to matching the two devices is taken into consideration when specifying power level accuracy of the NI 5670.

 **Note** Refer to the *NI 5670 Specifications* document, installed at **Start»Programs»National Instruments»NI-RFSG»Documentation**, for complete specifications.

This section discusses the three areas of NI 5610 calibration: IF passband calibration, RF flatness calibration, and temperature coefficient determination.

IF Passband Calibration

Intermediate Frequency (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.

There are six available IF attenuation levels on the NI 5610, including the 0 dB or no-IF-attenuation level. These six IF attenuation levels are characterized at calibration for each individual NI 5610 module. The calibration coefficients are saved into the onboard nonvolatile memory of the module. These calibration coefficients are used in determining the IF gain at a specific attenuation setting and specific IF frequency offset.

RF Flatness Calibration

Radio Frequency (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.

There are 71 calibrated RF attenuation levels available on the NI 5610, including the no-RF-attenuation level. Each level is characterized at calibration for each individual NI 5610 module over the entire frequency range. The calibration coefficients are saved into the onboard nonvolatile memory of the module. These calibration coefficients are used (along with temperature calibration and IF calibration

coefficients) in determining the RF gain of the NI 5610 for a specific IF and RF frequency setting and a specific module temperature.


Temperature Calibration

The NI 5610 is thermally compensated 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 Celcius.

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.

NI 5670 Power Requirements

Each module of the NI 5670 (NI 5610 upconverter and NI 5421 AWG) interfaces to the PXI backplane via a separate PXI bus connector. The NI 5610 upconverter module occupies two PXI Slots but interfaces to the PXI backplane via its leftmost occupied slot, while the NI 5421 interfaces via its occupied PXI Slot. Each of the devices is constrained in power consumption to the maximum power specified by the PXI standard. While the NI 5421 is limited in power consumption to what is available to one PXI Slot, the NI 5610 has the total power of two slots available to it, unless otherwise limited by the connector pin-rating per PXI standard.

 **Note** Refer to the *NI 5670 Specifications* document, accessible at **Start»Programs»National Instruments»NI-RFSG»Documentation**, for detailed information about NI 5670 power consumption.

Troubleshooting

This section contains troubleshooting information for common NI 5670 measurement and setup problems.

Troubleshooting Modulation Quality

When using modulation quality measurements such as Error Vector Magnitude (EVM) and Modulation Error Ratio (MER), a number of parameters can influence the measurements significantly. Two errors that can affect the signal quality are:

1. Failure to achieve carrier lock no recognizable constellation diagram or very poor, erratic EVM and MER measurements
2. Carrier lock achieved, but poor EVM, MER measurements

To ensure acceptable modulation quality, complete the following steps:

1. Verify the carrier frequency settings on the signal generator (transmitter) and signal analyzer (receiver). If these settings are out of tolerance — either by incorrect settings or by correct settings but poor tolerance on one of the devices — carrier lock fails. Typically, the carrier frequency must have a large error to have any impact on the signal.

Carrier offsets have no effect until the offset is either outside the lock range, or the signal is outside of the receiver bandwidth. In figure 1 below, a 30 kHz carrier offset has moved part of the signal outside of the receiver bandwidth. In this case, you can either tune the carrier, or use a wider receiver bandwidth setting.

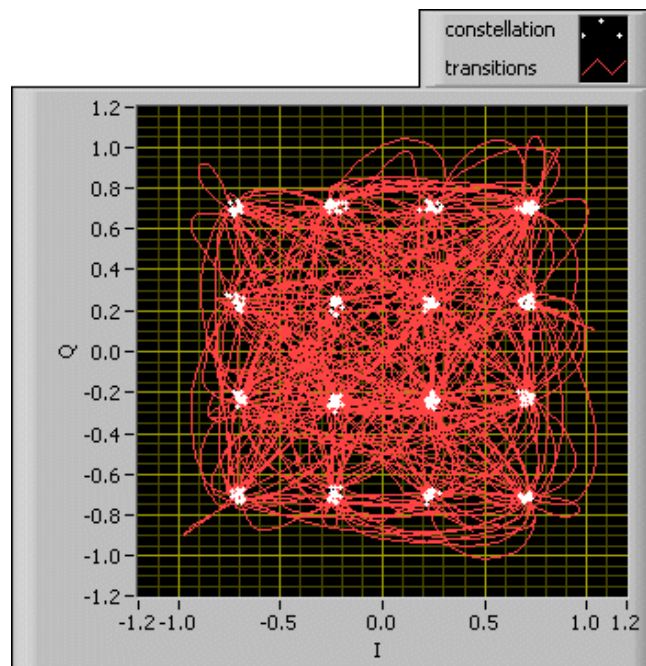


Figure 1. Incorrect Carrier Offset Settings

Figure 2 below shows a signal with a 100 kHz carrier offset and a bandwidth wide enough to encompass all signal information.

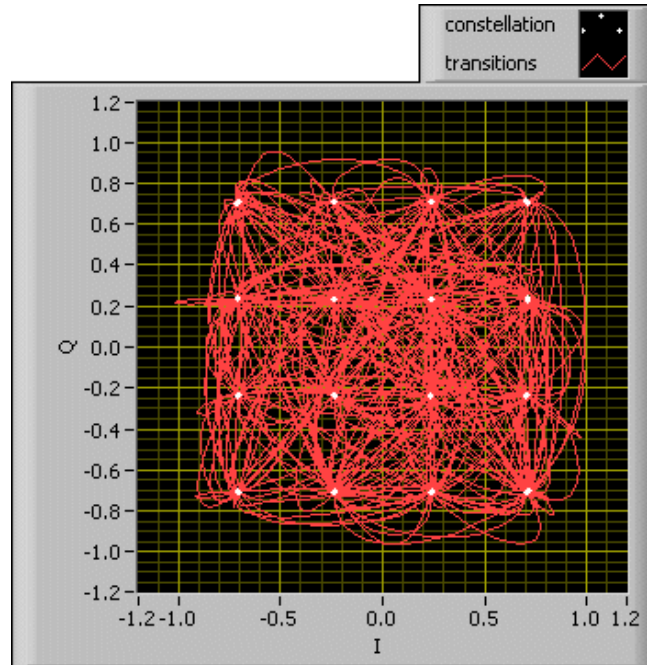


Figure 2. Correct Carrier Offset Settings

2. Verify that the modulation type settings match on both the transmitter and receiver.
3. Verify the symbol rates on the signal generator (transmitter) and signal analyzer (receiver). If these rates are out of tolerance—either by incorrect settings or by correct settings but poor tolerance on one of the devices—symbol recovery fails. Symbol rate error is more likely to have a gross impact on the signal than carrier frequency error because symbol rate error can look like a poor measurement.

Figures 3 and 4 below are examples of EVM plots with and without a symbol rate error.

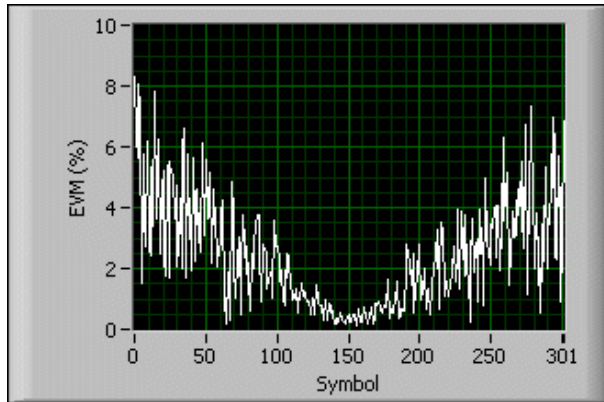


Figure 3. EVM with 50 Hz Symbol Rate Error

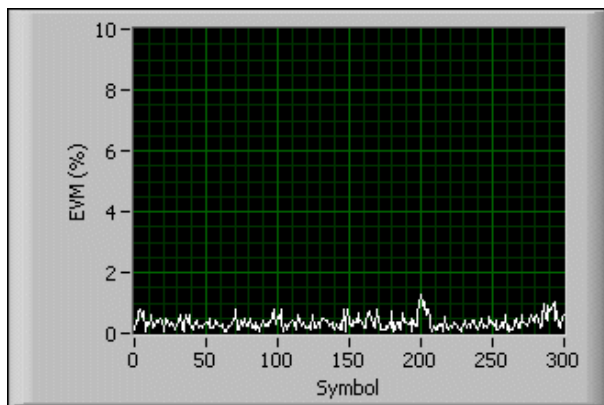


Figure 4. EVM with no Symbol Rate Error

Figures 5 and 6 below are examples of constellation plots with and without a symbol rate error.

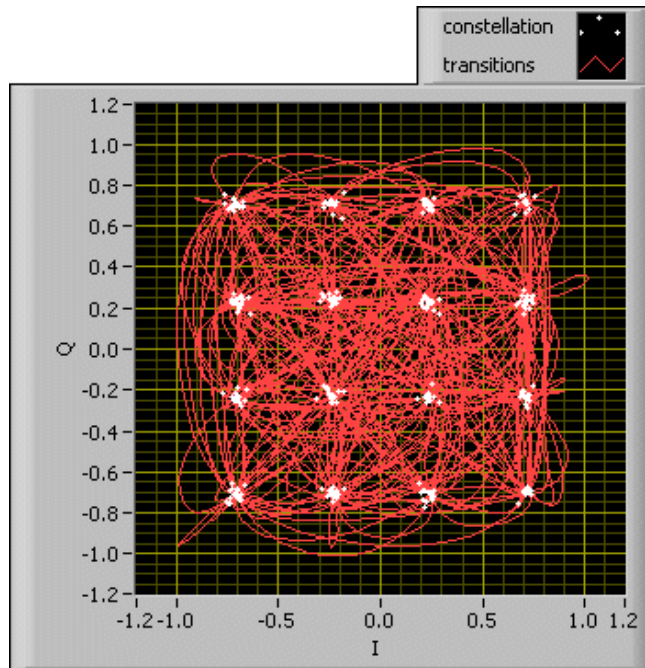


Figure 5. Constellation with 40 Hz Symbol Rate Error

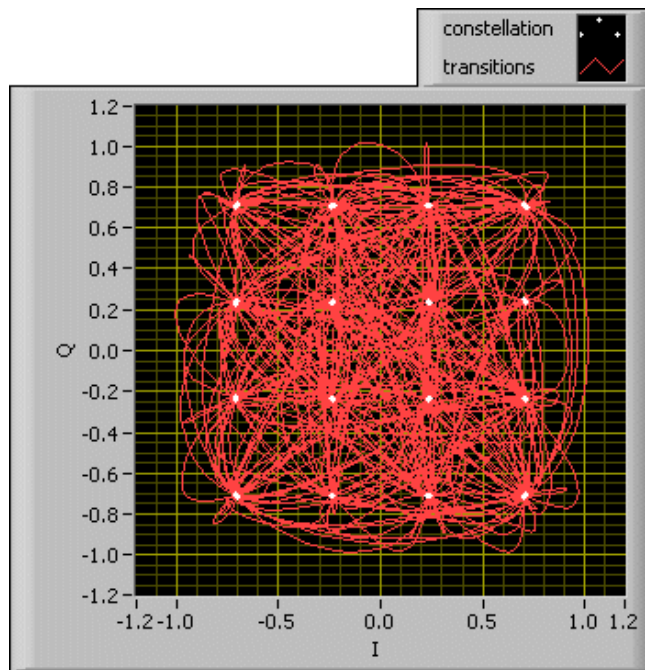


Figure 6. Constellation with All Parameters Correctly Tuned

4. Verify that the signal transmission power levels and the receiver input reference levels are consistent with each other. If the signal levels are not matched properly on the transmit and the receive side, MER and EVM degrades due to one of the following conditions:

1. The receiver (analyzer) is being over driven into nonlinear mode (saturation). To address this, increase the receiver reference level setting. If the measurements improve, the analyzer was being driven into saturation.

Alternately, you can reduce the generator (transmitter) power — if modulation quality improves, either the generator or the analyzer was driven into saturation.

Figure 7 below is a constellation plot from an overdriven receiver. To correct this error, you can either attenuate the power entering the receiver, or increase the receiver reference level setting.

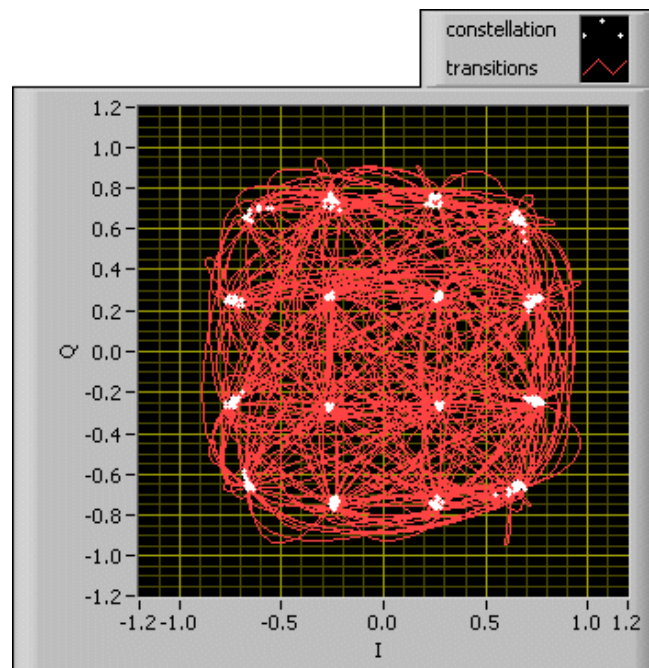


Figure 7. Overdriven Receiver

2. The input is being driven with a very low power signal, and a poor signal-to-noise ratio exists within the signal analyzer. Reduce the reference level on the analyzer. If the modulation quality measurements improve, the full dynamic range of the analyzer was not being utilized. Alternately, you can increase the power level of the transmitted signal from the signal source.

For example, Figure 8 shows an underdriven receiver. To correct this you can either amplify the power entering the receiver, or decrease the receiver reference level.

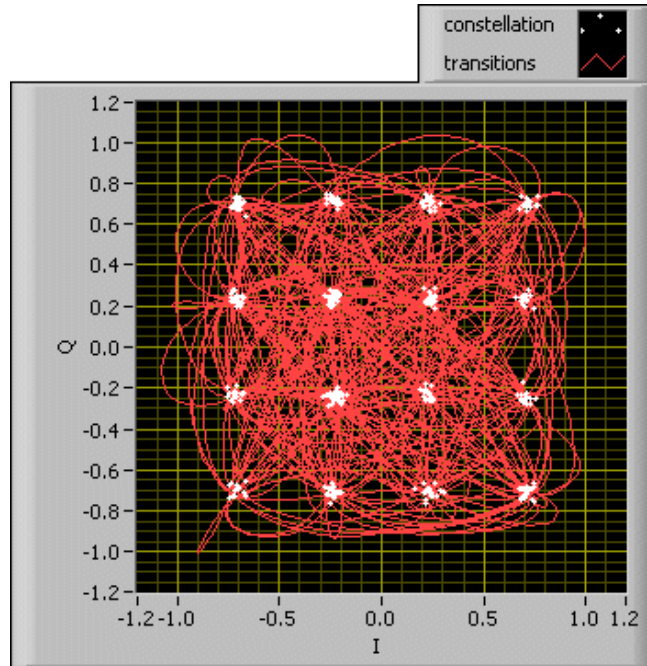



Figure 8. Underdriven Receiver

Notice that the constellation plots for almost all of these signals appear similar. Only the overdriven state is distinctively recognizable from the constellation. Symbol rate error can be recognized by the V-shaped envelope that appears on a plot of EVM per individual symbol.

 **Note** The QAM Demodulation LabVIEW example that ships with the Modulation Toolkit contains code for detection of over/underdriven signal power conditions.

5. Verify that the pulse shaping filter parameters— filter type and filter constant (alpha) — are matching on both the transmitter and receiver. Also make sure that the pulse shaping filter length is set appropriately.

 **Note** For small filter constants ($\alpha < 0.25$), verify that the pulse shaping filter length is set to 16 or larger.

For example, Figure 9 shows a wrong value entered for alpha (filter parameter). The transmitter uses an $\alpha = 0.3$, and the RFSA uses an $\alpha = 0.5$.

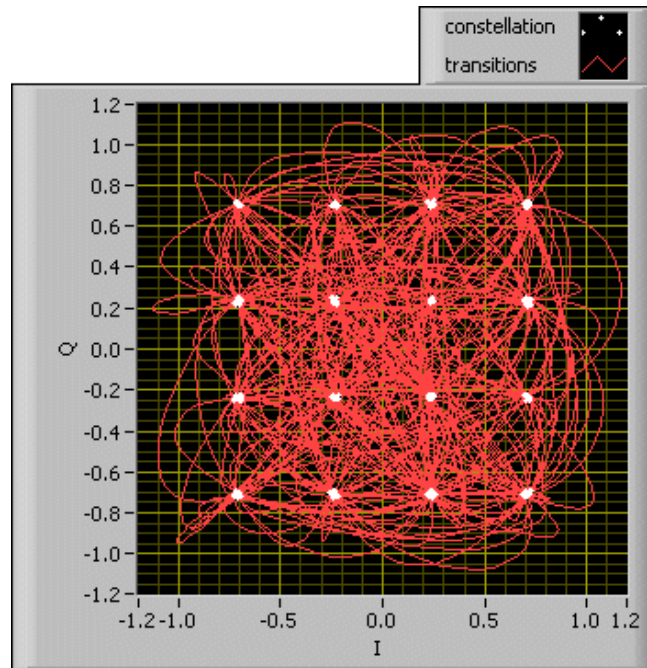


Figure 9. Filter Alpha Value Mismatch

In contrast, Figure 10, shows the wrong filter selection. The transmitter uses a root raised cosine filter, but the RFSA specifies a raised cosign filter.

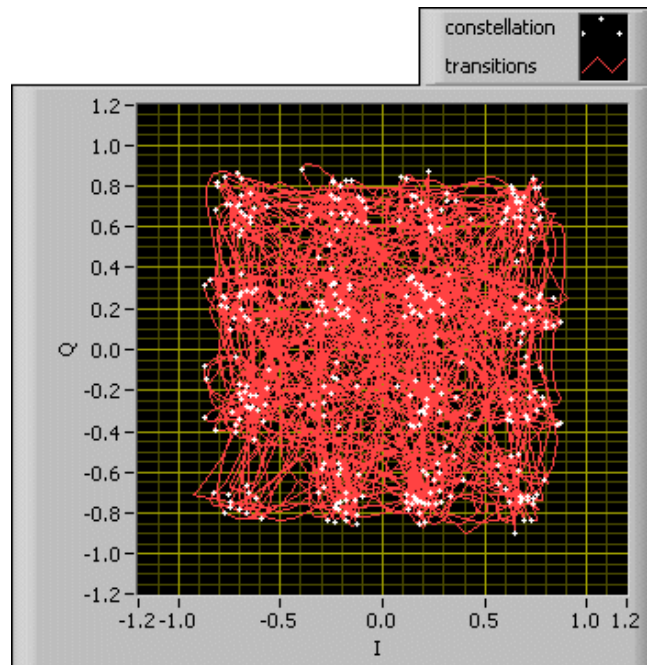


Figure 10. Filter Type Mismatch

6. For wide real-time bandwidth signal generation (span >500 kHz), enabling the Digital IF Equalization property improves modulation quality by compensating for the gain/phase response variations in the passband of the NI 5610 upconverter module.

For example, Figure 11 shows a wide bandwidth signal. The constellation shown below is for a signal with a symbol rate of 4 MS/s. All other figures have a symbol rate of 100 kHz.

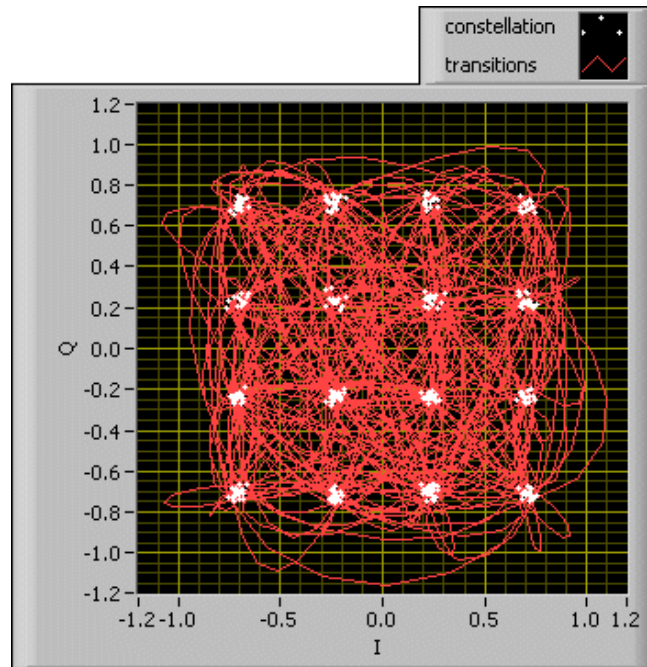



Figure 11. Wide Bandwidth (>500 kHz) Signal

 **Tip** With a wide bandwidth equalization may be required.

Front Panel ACCESS LED is Off When PXI Chassis is On

Failure to illuminate ACCESS LED may indicate a problem with the PXI power rail, a hardware module, or the LED. Troubleshoot this issue as follows:

1. Power off your PXI chassis
2. Remove any front panel connections between the NI 5670 modules.
3. Remove the NI 5670 hardware modules and inspect for damage. Do not reinstall a damaged device.
4. Reinstall both NI 5670 hardware modules in different PXI Slots. Use the procedure detailed in the Installing the Hardware section of the *NI 5670 RF Signal Generator Getting Started Guide*.
5. Power on your PXI chassis.
6. If either ACCESS LED still fails to light, contact NI technical support at ni.com/ask or call 866-275-6964 and ask to speak with a customer service representative.

Hardware Module Does Not Appear in MAX

Use the following procedure if either NI 5670 hardware module does not appear in Measurement & Automation Explorer (MAX):

1. In the MAX Configuration pane, click to highlight the NI-DAQmx Devices folder and press to refresh the list of installed devices.
2. If either module is still not listed, power down the system, ensure the NI 5670 hardware is correctly installed, and restart.
3. If either module still fails to appear in the MAX NI-DAQmx Devices folder, contact NI technical support at ni.com/ask or call 866-275-6964 and ask to speak with a customer service representative.

A Module Fails the Self-Test

The MAX self-test performs a brief test of device resources. If either module of the NI 5670 hardware does not pass the self-test, perform the following procedure:

1. Reboot your system.
2. Launch MAX and perform the self-test again. If the module still fails the self-test, proceed to step three.
3. Uninstall and reinstall the NI-RFSG driver software.
4. If either module still fails the self-test, contact NI technical support at ni.com/ask or call 866-275-6964 and ask to speak with a customer service representative.

The NI 5670 Test Panel Fails

The NI 5670 test panel tests both hardware modules as a single instrument. If the test panel fails or generates an error, perform the following procedure to the following steps to locate the problem:

1. Verify that both NI 5670 modules are interconnected through the front panels as shown in Figure 1 below.

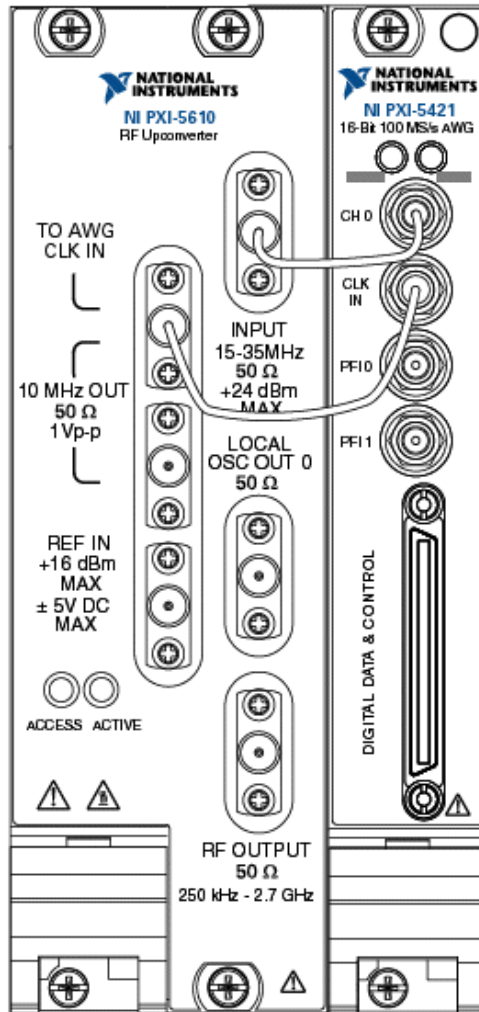


Figure 1: NI 5670 Front Panel Interconnection

2. Ensure that all front panel connections are secure. Loose connections can impair instrument operation.
3. Launch MAX by navigating to **Start»Programs»National Instruments»Measurement Automation** or by clicking the MAX desktop icon.
4. Navigate to the **Device and Interfaces»NI-DAQmx Devices** folder.
5. Right-click **NI 5610** and select **Properties** as shown in Figure 2 below.

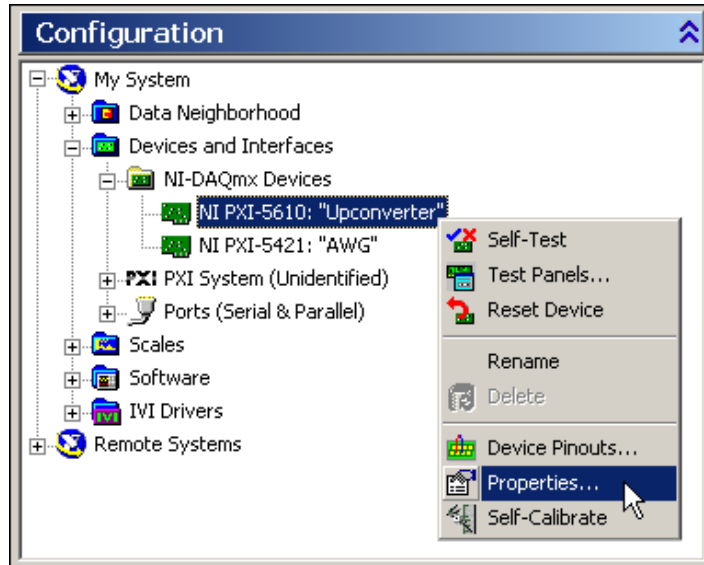


Figure 2. Select Properties From the NI 5610 MAX Right-Click Menu

6. In the *NI 5610 Device Properties* dialog, verify that the proper NI 5421 AWG module (that is, the one interconnected to the NI 5610 upconverter module) is associated as shown in Figure 3.



Figure 3. The NI 5610 Properties Dialog Displays the Associated AWG

7. If there is no AWG associated with the NI 5610, right-click the dropdown list to select an available NI 5421 AWG module to associate as shown in the *Configuring the Modules in MAX* section in the *NI 5670 Vector Signal Generator Getting Started Guide*.
8. When the correct NI 5421 AWG module is specified, click OK to return to MAX.
9. In the MAX Configuration pane, right-click NI 5610 and select **Test Panels** as shown in Figure 4.

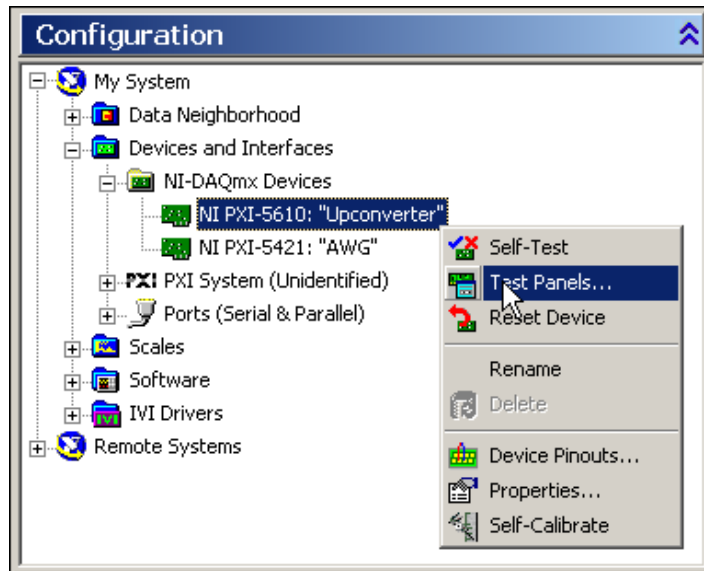


Figure 4. Open the NI 5670 Test Panel from the NI 5610 Right-Click Menu

10. In the *Test Panels* window, click the *NI 5610* tab to view the NI 5610 test panel shown in Figure 5 below.

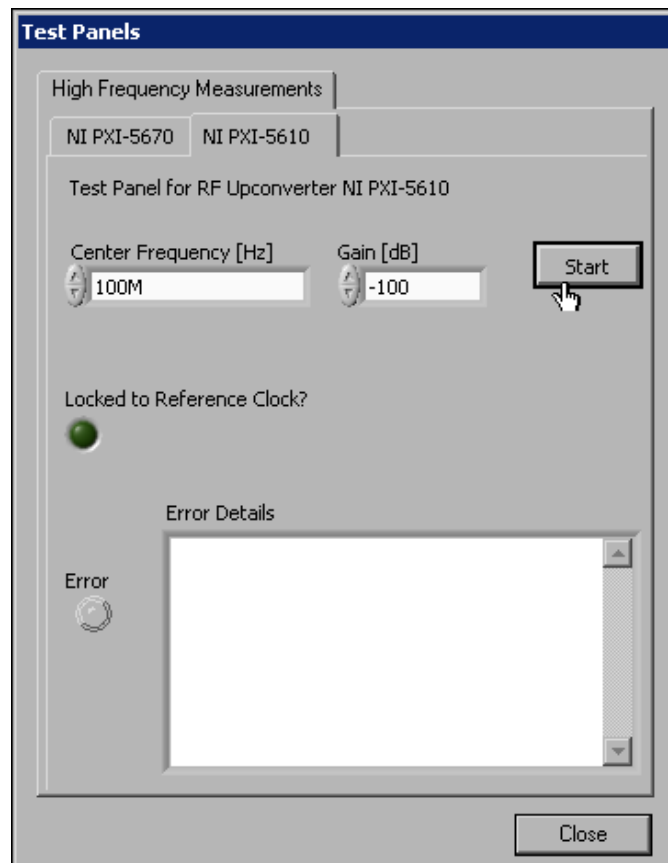


Figure 5. Click the NI 5610 Tab to View the Upconverter Module Test Panel

11. The NI 5610 tab verifies PLL locking and proper functioning of the upconverter hardware. Specify center frequency and gain settings.
12. Click the **Start** button to run the NI 5610 upconverter test panel.
13. During operation of the test panel, the ACTIVE LED on the NI 5610 upconverter module front panel is illuminated, and the test panel is displayed as shown in Figure 6.

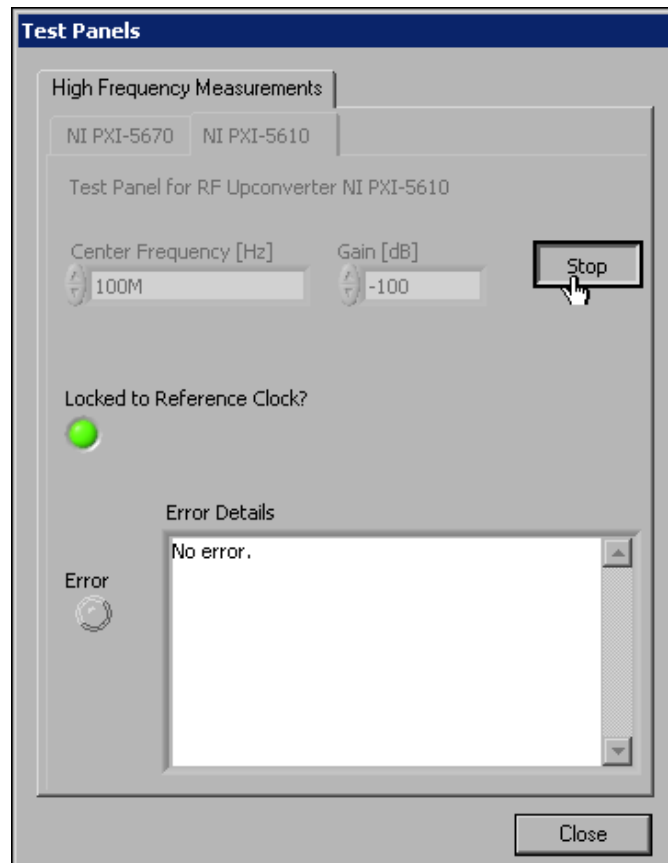


Figure 6. The NI 5670 Test Panel During Operation

14. Click **Stop** to halt upconverter operation.
15. If the NI 5610 test panel generates an error, shut down your system and reinstall the RF Vector Signal Generator software and hardware.

If the NI 5610 test panel does not generate an error, continue with the following steps:

16. Click the **NI PXI-5670** tab to return to the NI 5670 test panel.
17. Click **Start** in the NI 5670 test panel to begin waveform generation and verify proper operation.
18. Click **Stop** to halt signal generation and **Close** to return to the MAX main window.

If the NI 5670 test panel generates errors after successful operation of the NI 5610 test panel, complete the following steps:

1. Power down your PXI chassis
2. Disconnect the NI 5670 front panel coaxial cables.
3. Remove and reinstall your NI 5421 AWG hardware module.
4. Reconnect the NI 5670 front panel cables securely as shown in Figure 9.
5. Restart your system and run the *Self-Test Both Modules* and *Test Panels* procedures detailed in the *NI 5670 Getting Started Guide* document.

If failures continue, contact NI technical support at ni.com/ask or call 866-275-6964 and ask to speak with a customer service representative.

Important Information

Technical Support and Professional Services

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

- **Support**—Online technical support resources include the following:
 - ◆ **Self-Help Resources**—For immediate answers and solutions, visit our extensive library of technical support resources available in English, Japanese, and Spanish at ni.com/support. These resources are available for most products at no cost to registered users and include software drivers and updates, a KnowledgeBase, product manuals, step-by-step troubleshooting wizards, conformity documentation, example code, tutorials and application notes, instrument drivers, discussion forums, a measurement glossary, and so on.
 - ◆ **Assisted Support Options**—Contact NI engineers and other measurement and automation professionals by visiting ni.com/support. Our online system helps you define your question and connects you to the experts by phone, discussion forum, or email.
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Warranty

Both hardware modules of the NI 5670 RF Vector Signal Generator are 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.

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Related Documentation

These documents may contain information that you might find helpful as you use your NI-RFSG module.

- *NI 5670 RF Vector Signal Generator Getting Started Guide*, available in PDF format at **Start»Programs»National Instruments»NI-RFSG»Documentation**.
- For the latest NI-RFSG development information, visit the NI Developer Zone at ni.com/instruments. Search for the latest NI-RFSG examples at ni.com/examples. These links require an internet connection.
- *NI 5670 RF Vector Signal Generator User Manual*, available in PDF format at **Start»Programs»National Instruments»NI-RFSG»Documentation**.
- *NI Signal Sources Online Help*, available at **Start»Programs»National Instruments»NI-FGEN»Documentation**.
- *NI 5670 RF Vector Signal Generator Specifications*, available in PDF format at **Start»Programs»National Instruments»NI-RFSG»Documentation»Specifications**.
- *NI 5421 AWG Module Specifications*, available in PDF format at **Start»Programs»National**

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