Computer-Based Instruments

NI 5911 User Manual

Digital Oscilloscope for PCI

NATIONAL INSTRUMENTS™

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The following conventions are used in this manual:

» — The **»** symbol leads you through nested menu items and dialog box options to a final action. The sequence **File»Page Setup»Options»Substitute Fonts** directs you to pull down the **File** menu, select the **Page Setup** item, select **Options**, and finally select the **Substitute Fonts** options from the last dialog box.

☞ — This icon to the left of bold italicized text denotes a note, which alerts you to important information.

This icon to the left of bold italicized text denotes a caution, which advises you of precautions to take to avoid injury, data loss, or a system crash.

This icon to the left of bold italicized text denotes a warning, which advises you of precautions to take to avoid being electrically shocked.

bold — Bold text denotes the names of menus, menu items, parameters, dialog boxes, dialog box buttons or options, icons, windows, Windows 95 tabs, or LEDs.

bold italic — Bold italic text denotes a note, caution, or warning.

italic — Italic text denotes variables, emphasis, a cross reference, or an introduction to a key concept. This font also denotes text from which you supply the appropriate word or value, as in Windows 3.*x*.

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1

Taking Measurements with the NI 5911

Thank you for buying a National Instruments 5911 digital oscilloscope with flexible resolution. The NI 5911 offers unsurpassed flexibility for performing measurements from DC to 100 MHz. Using the NI 5911 flexible resolution feature, you can choose the sampling rate and resolution best suited to your application.

Detailed specifications for the NI 5911 are in Appendix A, *Specifications*.

Connecting Signals

Figure 1-1 shows the front panel for the NI 5911. The front panel contains three connectors—a BNC connector, an SMB connector, and a 9-pin mini circular DIN connector.

The BNC connector is for attaching the analog input signal you wish to measure. The BNC connector is analog input channel 0. The SMB connector is for external triggers and for generating a probe compensation signal. The SMB connector is PFI1. The DIN connector gives you access to an additional external trigger line. The DIN connector can be used to access PFI2.

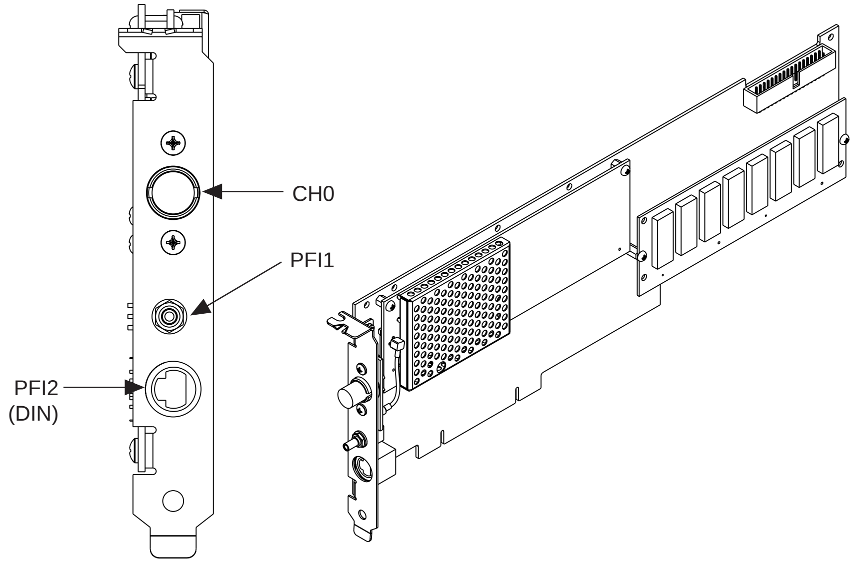
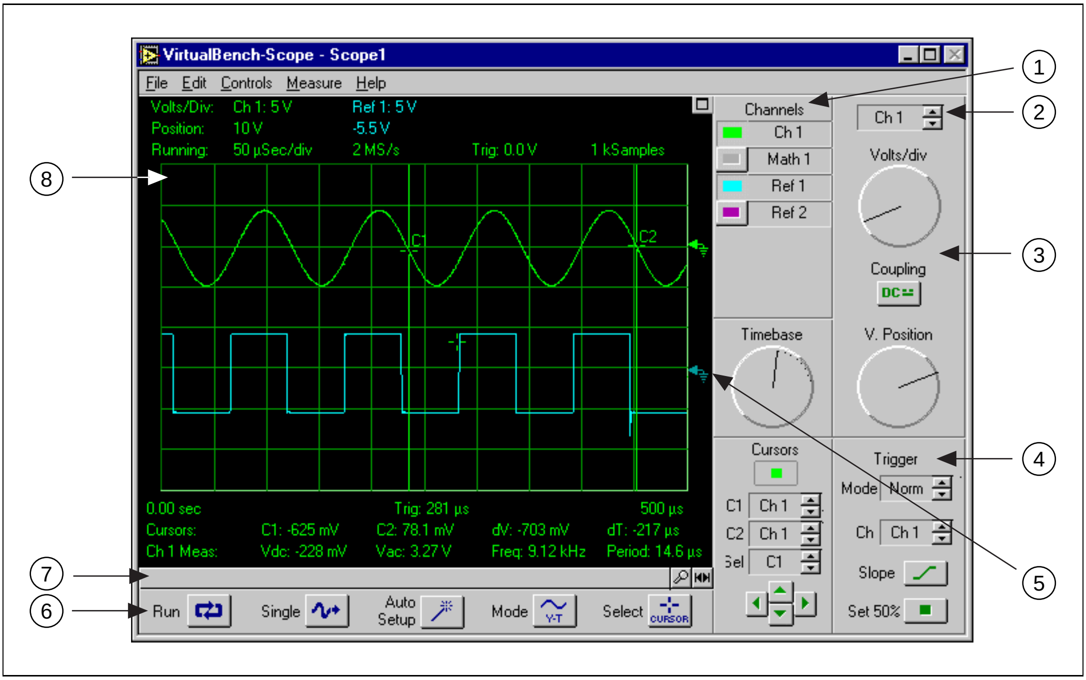


Figure 1-1. NI 5911 Connectors

Introduction to the VirtualBench-Scope Soft Front Panel

The VirtualBench-Scope soft front panel allows you to interactively control your NI 5911 as you would a desktop oscilloscope.

The following sections explain how to make connections to your NI 5911 and take simple measurements using the VirtualBench-Scope soft front panel, as shown in Figure 1-2. To launch the soft front panel, select **Start»Programs» National Instruments Scope»VirtualBench-Scope**.



1	Channel Display Selector	4	Trigger Setting Group	7	Zoom Controls
2	Channel Settings Selector	5	Vertical Slider	8	Graphics Display
3	Channel Settings	6	Main Control Bar		

Figure 1-2. VirtualBench-Scope Soft Front Panel

Soft Front Panel Features

The VirtualBench-Scope soft front panel has the following features:

- **Channel Display Selector**—selects a waveform for display on the graphics display.
- **Channel Settings**
  - **Channel Settings Selector**—selects the channel whose settings will be modified.
  - **Volts/div**—adjusts the vertical sensitivity of the channel you select.
  - **V. Position**—controls the DC offset of the displayed waveform.
- **Timebase**—controls the timebase setting. Turning the knob clockwise reduces the time period that appears in the graphics display. Each horizontal division represents one time period.
- **Graphics Display**—displays waveforms.

- **Vertical Slider**—adjusts the voltage offset for each channel. Use this slider when you want to adjust multiple waveforms in the graphics display.
- **Trigger Settings Group**—controls the conditions required for signal acquisition; for example, whether to wait for a digital trigger before acquiring data or whether to acquire data in free-run mode (no triggering).
- **Main Control Bar Buttons**
  - **Run**—acquires data continuously. Deselecting this button places the VirtualBench-Scope in idle mode.
  - **Single**—instructs VirtualBench-Scope to perform a single-sweep acquisition.
  - **Auto Setup**—configures the scope for the best timebase, volts per division, and trigger setting for each channel currently selected with the channel selector.
  - **Mode**—sets the mode of the scope to either volts versus time or X versus Y mode.
- **Zoom Controls**—adjusts the view of your display data.
  - **Scroll Bar**—adjusts the zoom view.
  - **Zoom In**—zooms in on displayed data. Each zoom increases the view by a factor of two.
  - **Zoom Out**—zooms out to full X scale.

Note: ***Refer to the*** *VirtualBench-Scope Online Help* ***for additional help on the front panel items.***

Using the VirtualBench-SCOPE Soft Front Panel

The following sections describe how to perform simple analog input measurements using the VirtualBench-SCOPE soft front panel.

Acquiring Data

When you launch VirtualBench-Scope, it operates in continuous run mode. You can start acquiring signals with VirtualBench-Scope by completing the following steps:

1. Connect a signal to Channel 0 of your NI 5911.
2. Configure VirtualBench-Scope.
   a. Select **General Settings** from the **Edit** menu on the front panel.
   b. Your NI 5911 is an IVI compliant device. To configure VirtualBench-SCOPE to use your NI 5911, click on the **IVI Device Type Selector** icon located in the **Settings** dialog box, shown in Figure 1-3.
   c. Select NI 5911 as the device you want to use from the **Device List** located in the **Settings** dialog box, shown in Figure 1-3. If the NI 5911 does not appear in the **Device list**, make sure you have properly configured the device using the Measurement & Automation Explorer.
   d. Click on **OK** to use these settings.

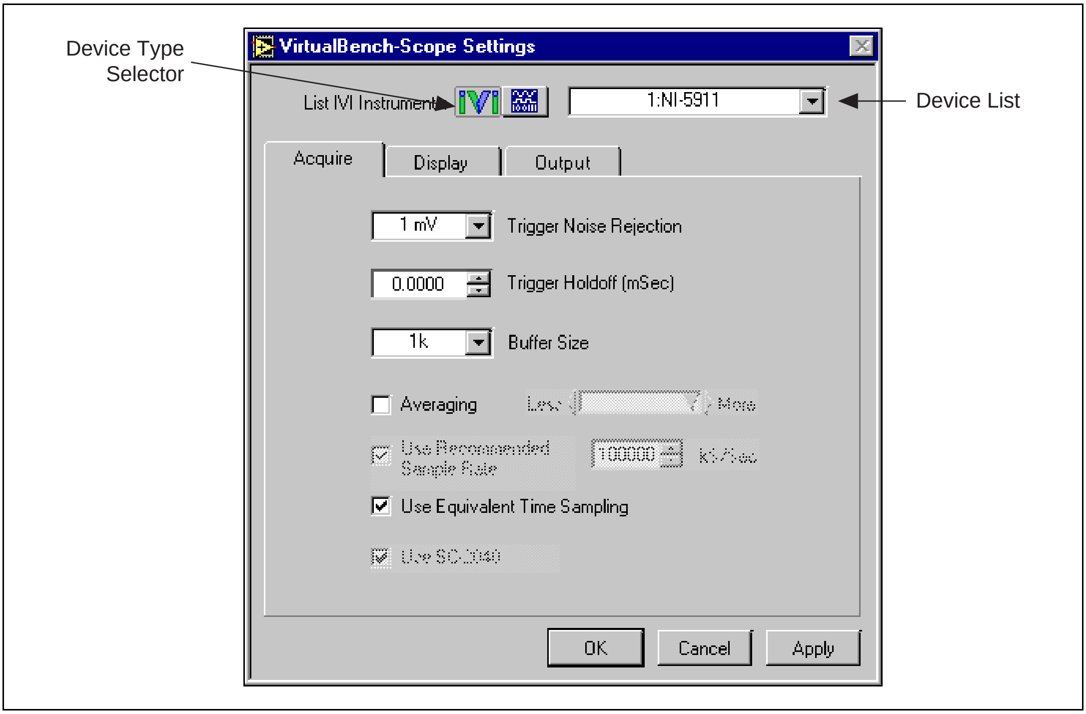


Figure 1-3. Acquire Tab of VirtualBench-Scope Settings Dialog Box

Note: ***When you launch VirtualBench-Scope, it automatically uses the settings of your previous VirtualBench-Scope session.***

3. Enable the **Ch 0** button in the Channel Selector group. Disable all other channels.
4. Click on **AutoSetup** on the main control bar.
5. Click on **Run** to start the acquisition.

Note: ***Refer to the*** *VirtualBench-Scope Online Help* ***for additional help on configuring VirtualBench-Scope for your specific application.***

2

Hardware Overview

This chapter includes an overview of the NI 5911, explains the operation of each functional unit making up your NI 5911, and describes the signal connections. Figure 2-1 shows a block diagram of the NI 5911.

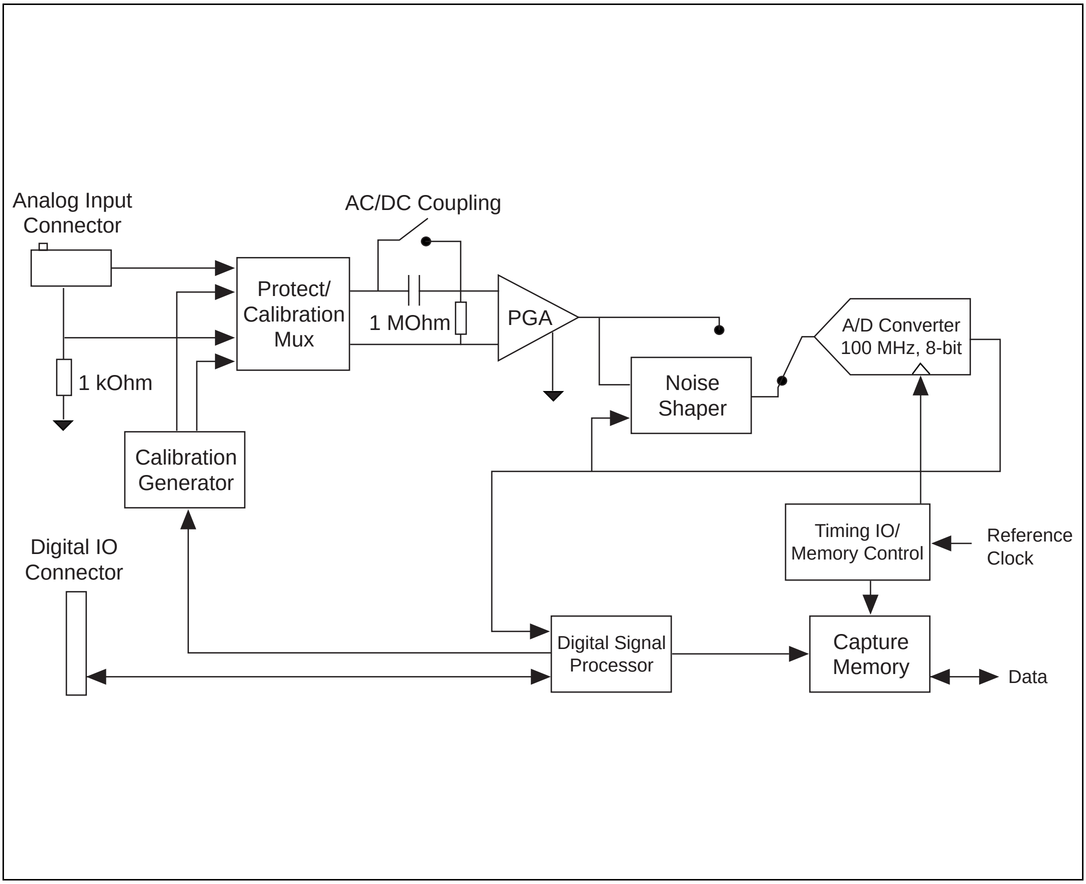


Figure 2-1. NI 5911 Block Diagram

Measurement Fundamentals

The NI 5911 has a differential programmable gain input amplifier (PGIA) at the analog input. The purpose of the PGIA is to accurately interface to and scale the signal presented at the connector to the analog-to-digital converter (ADC) regardless of source impedance, source amplitude, DC biasing or common-mode noise voltages.

Differential Input

When measuring high dynamic range signals, ground noise is often a problem. The PGIA of the NI 5911 allows you to make noise-free measurements of the signal. The NI 5911 PGIA is a differential amplifier. The PGIA differential amplifier efficiently rejects any noise which may be present on the ground signal. Internal to the PGIA, the signal presented at the negative input is subtracted from the signal presented at the positive input. As shown in Figure 2-2, this subtraction removes ground noise from the signal. The inner conductor of the BNC is V+, the outer shell is V–.

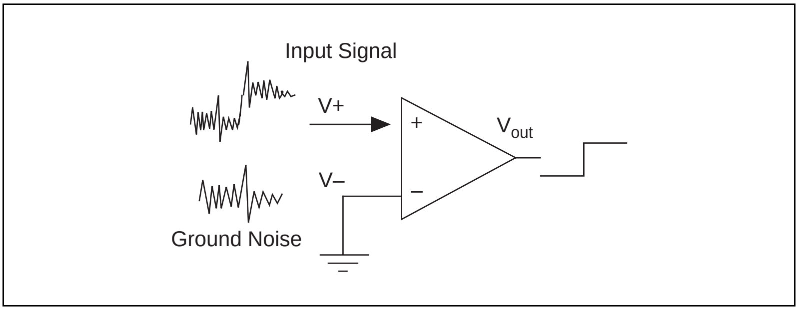


Figure 2-2. Noise-Free Measurements of Signal

Grounding Considerations

The path for the positive signal has been optimized for speed and linearity. You should always apply signals to the positive input and ground to the negative input. Reversing the inputs will result in higher distortion and lower bandwidth.

The negative input of the amplifier is grounded to PC ground through a 10 kΩ resistor. The PGIA is therefore referenced to ground, so it is not necessary to make any external ground connections. If the device you connect to the NI 5911 is already connected to ground, ground-loop noise voltages may be induced into your system. Note that in most of these situations, the 10 kΩ resistance to PC ground is normally much higher than the cable impedances you use. As a result, most of the noise voltage occurs at the negative input of the PGIA where it is rejected, rather than in the positive input, where it would be amplified.

Input Ranges

To optimize the ADC resolution, you can select different gains for the PGIA. In this way, you can scale your input signal to match the full input range of the converter. The NI 5911 PGIA offers seven different input ranges, from ±0.1 V inputs to ±10 V inputs as shown in Table 2-1.

Table 2-1. Input Ranges for the NI 5911

Range	Input Protection Threshold
± 10 V	±10 V
± 5 V	±5 V
± 2 V	±5 V
± 1 V	±5 V
± 0.5 V	±5 V
± 0.2 V	±5 V
± 0.1 V	±5 V

Input Impedance

The input impedance of the NI 5911 PGIA is 1 MΩ between the positive and negative input. The output impedance of the device connected to the NI 5911 and the input impedance of the NI 5911 form an impedance divider, which attenuates the input signal according to the following formula:

$$V_m = \frac{V_s R_{in}}{R_s + R_{in}}$$

where V_m is the measured voltage, V_s is the source voltage, R_s is the external source, and R_{in} is the input impedance.

If the device you are measuring has a very large output impedance, your measurements will be affected by this impedance divider. For example, if the device has 1MΩ output impedance, your measured signal will be 1/2 the actual signal value.

Input Bias

The inputs of the PGIA typically draw an input bias current of 1 nA at 25° C. Attaching a device with a very high source impedance can cause an offset voltage to be added to the signal you measure, according to the formula $R_s \times 1$ nA, where R_s is the external source impedance. For example, if the device you have attached to the NI 5911 has an output impedance of 10 kΩ, typically the offset voltage is 10 µV (10 kΩ x 1 nA).

Input Protection

The NI 5911 features input-protection circuits that protect both the positive and negative analog input from damage from AC and DC signals up to ± 42 V.

If the voltage at one of these inputs exceeds a threshold voltage, V_{tr}, the input clamps to V_{tr} and a resistance of 100 kΩ is inserted in the path to minimize input currents to a nonharmful level.

The protection voltage, V_{tr}, is input range dependent, as shown in Table 2-1.

AC Coupling

When you need to measure a small AC signal on top of a large DC component, you can use AC coupling. AC coupling rejects any DC component in your signal before it enters into the PGIA. Activating AC coupling inserts a capacitor in series with the input impedance. Input coupling can be selected via software. See Appendix B, *Digitizer Basics*, for more information on input coupling.

Measurement Modes

The ADC samples at a constant rate of 100 MS/s with a vertical resolution of 8 bits. Using random interleaved sampling (RIS), the sample rate can be increased to 1 GS/s. In this conventional mode of operation called *oscilloscope mode*, the analog bandwidth is 100 MHz.

For sampling signals with lower bandwidth, the ADC can be sourced through a noise shaping circuit that moves quantization noise on the output of the ADC from lower frequencies to higher frequencies. A digital lowpass filter applied to the data removes all but a fraction of the original shaped quantization noise. The signal is then resampled to a lower sampling frequency and a higher resolution. This mode, called *flexible resolution mode*, provides antialiasing protection due to the digital lowpass filter.

Oscilloscope Mode

In the oscilloscope mode, the NI 5911 works as a conventional desktop oscilloscope. This mode is useful for displaying waveforms and for deriving waveform parameters such as slew rate, rise time, and settling time. The sample resolution in oscilloscope mode is 8 bits.

The ADC converts at a constant rate of 100 MS/s, but you can choose to store only a fraction of these samples into memory at a lower rate. This allows you to store waveforms using fewer data points and decreases the burden of storing, analyzing, and displaying the waveforms. If you need faster sampling rates, you can use RIS to effectively increase the sampling rate to 1 GS/s for repetitive waveforms.

In oscilloscope mode, all signals up to 100 MHz are passed to the ADC. You need to ensure that your signal is band-limited to prevent aliasing. Aliasing and other sampling terms are described more thoroughly in Appendix B, *Digitizer Basics*.

Flexible Resolution Mode

Flexible resolution mode differs from oscilloscope mode in two ways: it has higher resolution (sampling rate dependent) and the signal bandwidth is limited to provide antialiasing protection. This mode is useful for spectral analysis, distortion analysis and other measurements where high resolution is crucial. Table 2-2 shows the relationship between the available sampling rates and the corresponding bandwidth for flexible resolution mode.

Table 2-2. Available Sampling Rates and Corresponding Bandwidth in Flexible Resolution Mode

Sampling Rate	Resolution	Bandwidth
12.5 MS/s	12 bits	4 MHz
5 MS/s	14 bits	2 MHz
2.5 MS/s	16 bits	800 kHz
1 MS/s	18 bits	400 kHz
500 MS/s	18 bits	200 kHz
200 MS/s	19 bits	80 kHz
100 MS/s	19 bits	40 kHz
50 MS/s	20 bits	20 kHz
20 MS/s	20 bits	8 kHz
10 MS/s	21 bits	4 kHz

Like any other type of converter that uses noise shaping to enhance resolution, the frequency response of the converter is only flat to its maximum useful bandwidth. The NI 5911 has a bandwidth of 4 MHz. Beyond this frequency, there is a span where the converter acts resonant and where a signal is amplified before being converted. These signals are attenuated in the subsequent digital filter to prevent aliasing. However, if the applied signal contains major signal components in this frequency range, such as harmonics or noise, the converter may overload and signal data will be invalid. In this case, you will receive an error signaling overload. You then need to either select a higher input range or attenuate the signal.

Acquisition System

The NI 5911 acquisition system controls the way samples are acquired and stored. It is possible for the NI 5911 to acquire data at different rates and resolutions. There are two sampling methods available in oscilloscope mode, *Real Time* and *Repetitive* (RIS). Using Real Time sampling, you can acquire data at a rate of 100 MS/n where n is a number from 1 to 4.3 million. RIS sampling can be used on repetitive signals to effectively extend the sampling rate above 100 MS/s. In RIS mode, you can sample at rates of 100 MS/s * n where n is a number from 2 to 10. The available sampling rates, resolutions, and bandwidth for flexible resolution mode are shown in Table 2-2.

During the acquisition, samples are stored in a circular buffer that is continually rewritten until a trigger is received. After the trigger is received, the NI 5911 continues to acquire posttrigger samples if you have specified a posttrigger sample count. The acquired samples are placed into onboard memory. The number of posttrigger or pretrigger samples is only limited by the amount of onboard memory.

Calibration

The NI 5911 can be calibrated for very high accuracy and resolution due to an advanced calibration scheme. There are two different calibration schemes depending on the type of calibration to be performed. *Internal calibration*, the more common of the two schemes, is performed via a software command that compensates for drifts caused by environmental temperature changes. Internal calibration can be executed without any external equipment connected. *External calibration*, which is performed much less frequently, is used to recalibrate the board when the specified calibration interval has expired. External calibration requires you to connect an external precision voltage reference to the board.

Internal Calibration

To provide the maximum accuracy independent of temperature changes, the NI 5911 contains a heater that stabilizes the temperature of the most sensitive circuitries on the board. However, the heater can accommodate for temperature changes over a fixed range of ±5 °C. When temperatures exceed this range, the heater will no longer be able to stabilize the temperature and signal data will no longer be accurate. When the temperature range has been exceeded, you will receive a warning and you will need to perform an internal calibration.

By executing a software command, you can internally calibrate the NI 5911without connecting any external equipment.

Internal calibration performs the following operations:

1. The heater is set to regulate over a range of temperatures centered at the current environmental temperature. The circuit components require a certain amount of time to stabilize at the new temperature. This temperature stabilization accounts for the majority of the calibration time.
2. Gain and offset are calibrated for each individual input range.

3. The linearity of the ADC is calibrated using an internal sinewave generator as reference.
4. The time-to-digital converter used for RIS measurements is calibrated.

Note ***Do not apply high-amplitude or high-frequency signals to the NI 5911 during internal calibration. For optimal calibration performance, disconnect the input signal from the NI 5911.***

External Calibration

External calibration is used to calibrate the internal reference on the NI 5911. The NI 5911 is already calibrated when it is shipped from the factory. Periodically, the NI 5911 will need external calibration to remain within the specified accuracy. For more information on calibration, contact National Instruments using the support information in Appendix C, *Customer Communication*. For actual intervals and accuracy, refer to Appendix A, *Specifications*.

Triggering and Arming

There are several triggering methods for the NI 5911. The trigger can be an analog level that is compared to the input or any of several digital inputs. You can also call a software function to trigger the board. Figure 2-3 shows the different trigger sources. When a digital signal is used, that signal must be at a high TTL level for at least 40 ns before any triggers will be accepted.

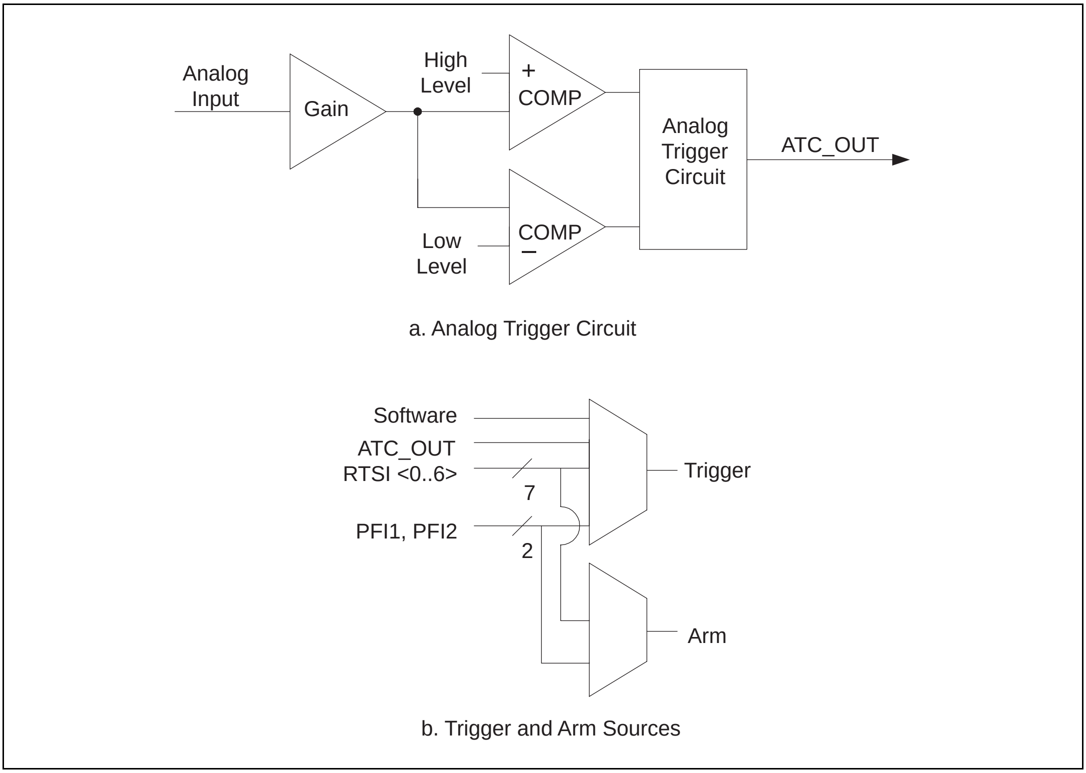


Figure 2-3. Trigger Sources

Analog Trigger Circuit

The analog trigger on the NI 5911 operates by comparing the current analog input to an onboard threshold voltage. This threshold voltage, **triggerValue**, can be set within the current input range in 170 steps. This means that for a ±10 V input range, the trigger can be set in increments of 20 V/170 = 118 mV. There may also be a **hysteresisValue** associated with the trigger that can be set in the same size increments. The **hysteresisValue** is used to create a trigger window the signal must pass through before the trigger is accepted. Triggers can be generated on a rising or falling edge condition as illustrated in the following figures. The four different modes of operation for the analog trigger are shown in Figures 2-4 to 2-7.

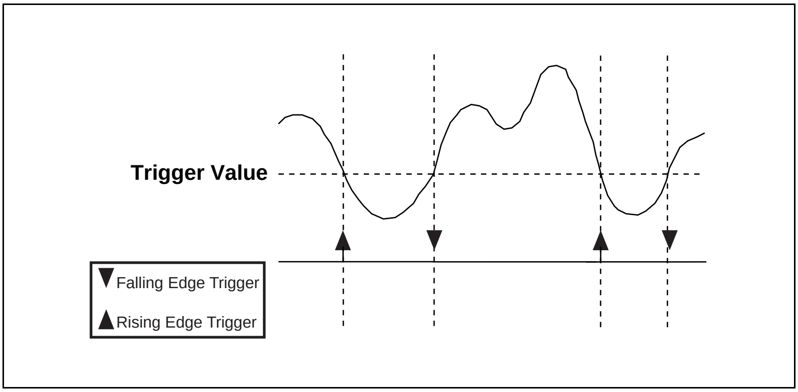


Figure 2-4. Below-Level Analog Triggering Mode

In below-level analog triggering mode, the trigger is generated when the signal value is less than **triggerValue. hysteresisValue** is unused.

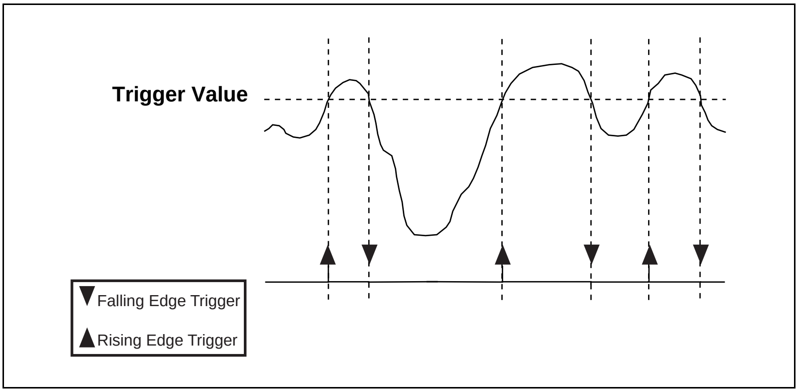


Figure 2-5. Above-Level Analog Triggering Mode

In above-level analog triggering mode, the trigger is generated when the signal value is greater than **triggerValue. hysteresisValue** is unused.

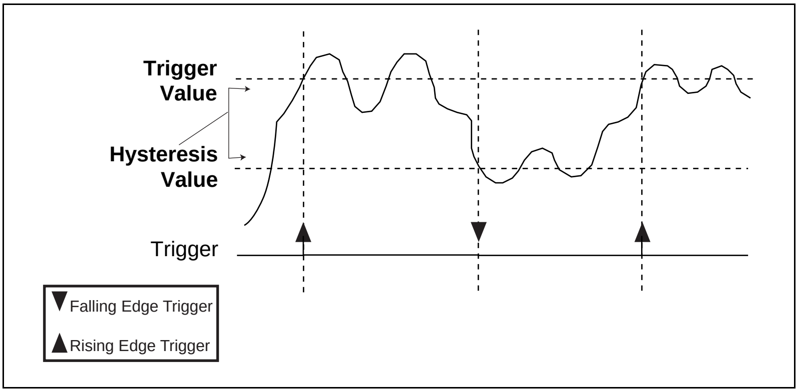


Figure 2-6. High-Hysteresis Analog Triggering Mode

In high-hysteresis analog triggering mode, the trigger is generated when the signal value is greater than **triggerValue**, with the hysteresis specified by **hysteresisValue**. The signal must cross back below the **hysteresisValue** before another trigger is generated.

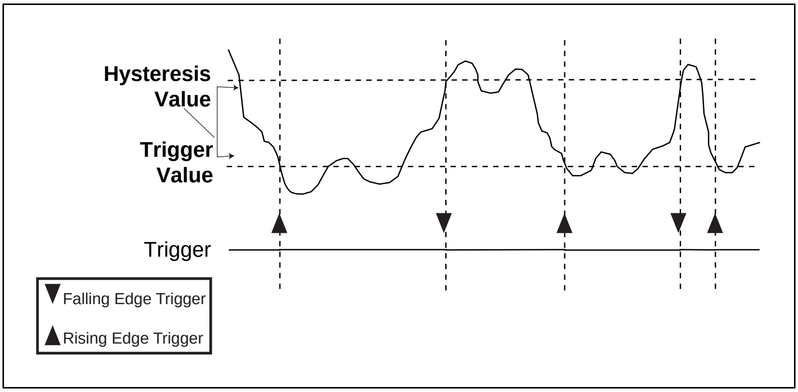


Figure 2-7. Low-Hysteresis Analog Triggering Mode

In low-hysteresis analog triggering mode, the trigger is generated when the signal value is less than **triggerValue**, with the hysteresis specified by **hysteresisValue**. The signal must cross back above the **hysteresisValue** before another trigger is generated.

Trigger Hold-Off

Trigger hold-off is provided in hardware using a 32-bit counter clocked by a 25 MHz internal timebase. With this configuration, you can select a hardware hold-off value of 40 ns to 171.8 s in increments of 40 ns.

When a trigger is received during acquisition, the trigger counter is loaded with the desired hold-off time. Hardware then rejects all triggers until the counter has expired or the current acquisition completes, whichever is longer. The time the acquisition takes to complete from the time a trigger occurs is (posttrigger samples) / (sample rate(MHz)). If this time is larger than the trigger hold-off time, the trigger hold-off has no effect because triggers are always rejected during acquisition. Figure 2-8 shows a timing diagram of signals when hold-off is enabled and the hold-off time is longer than posttriggered acquisition.

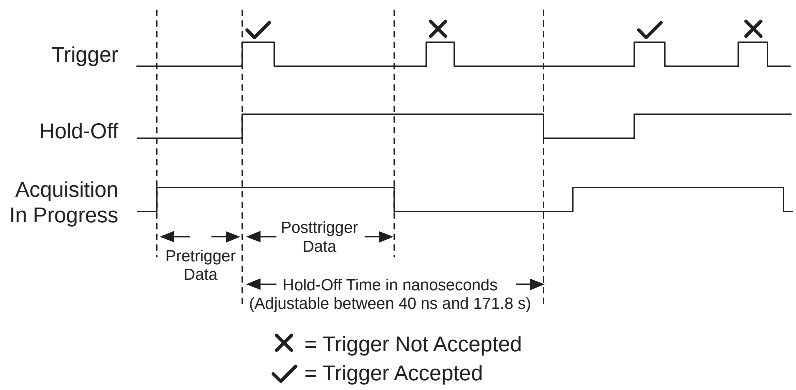


Figure 2-8. Timing with Hold-Off Enabled

Memory

Samples are acquired into onboard memory on the NI 5911 before being transferred to the host computer. The minimum size for a buffer is approximately 4,000 8-bit oscilloscope mode samples or 1,000 32-bit decimation mode samples. Software allows you to specify buffers of less than these minimum sizes. When specifying a smaller buffer size, the minimum number of points are still acquired into onboard memory, but only the specified number of points are retrieved into the host computer's memory.

The total number of samples that can be stored depends on the size of the Acquisition Memory Module installed on the NI 5911 and on the size of each acquired sample.

Multiple Record

After the trigger has been received and the posttrigger samples have been stored, the NI 5911 can be configured to begin another acquisition that is stored in another memory record on the board. This is a *multiple record acquisition.* To perform multiple record acquisitions, the NI 5911 is configured to the number of records to be acquired before starting the acquisition. The NI 5911 acquires an additional record each time a trigger is accepted until all the requested records have been stored in memory. This process does not require software intervention after the initial setup has been completed.

Between each record, there is a *dead time* of approximately 5 µs during which the trigger is not accepted. During this time, the memory controller is setting up for the next record. There may also be additional dead time while the minimum number of pretrigger samples are being acquired. Figure 2-9 shows a timing diagram of a multiple record acquisition.

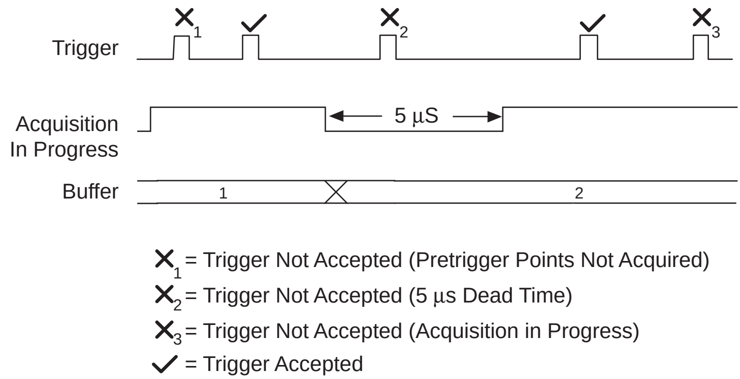


Figure 2-9. Multiple Buffer Acquisition

Errors During Acquisition

The NI 5911 has circuitry to detect error conditions that may affect the acquired data. The NI 5911 uses a heater circuit to maintain constant temperature on the critical circuitry used in flexible resolution mode. If this circuit is unable to maintain the temperature within specification, an error is generated. This error indicates that the temperature of the ADC is out of range and should be recalibrated by performing an internal calibration. During acquisition in flexible resolution mode, an error will be generated if the input to the ADC goes out of range for the converter. The fact that this condition has occurred may not be obvious by inspecting the acquired data due to the digital filtering that takes place on the acquired data. Therefore an error will occur to let you know that the data includes some samples that were out of the range of the converter and may be inaccurate.

RTSI Bus Trigger and Clock Lines

The RTSI bus allows National Instruments boards to synchronize timing and triggering on multiple devices. The RTSI bus has seven bidirectional trigger lines and one bidirectional clock signal.

You can program any of the seven trigger lines to provide or accept a synchronous trigger signal. You can also use any of the RTSI trigger lines to provide a synchronization pulse from a master board if you are synchronizing multiple NI 5911 boards.

You can use the RTSI bus clock line to provide or accept a 10 MHz reference clock to synchronize multiple NI 5911 boards.

PFI Lines

The NI 5911 has two digital lines that can be used to accept a trigger, accept or generate a reference clock, or output a square wave of programmable frequency. The function of each PFI line is independent, however, only one trigger source can be accepted during acquisition.

PFI Lines as Inputs

You can select PFI1 or PFI2 as inputs for a trigger or a reference clock. Please see the section, *Synchronization*, for more information about the use of reference clocks in the NI 5911.

PFI Lines as Outputs

You can select PFI1 or PFI2 to output several digital signals.

Reference Clock is a 10 MHz clock that is synchronous to the 100 MHz sample clock on the NI 5911. You can use the reference clock to synchronize to another NI 5911 configured as a slave device or to other equipment that can accept a 10 MHz reference.

Frequency Output is a 1 kHz digital pulse train signal with a 50% duty cycle. The most common application of Frequency Output for the NI 5911 is to provide a signal for compensating a passive probe.

Synchronization

The NI 5911 uses a digital phase lock loop to synchronize the 100 MHz sample clock to a 10 MHz reference. This reference frequency can be supplied by a crystal oscillator on the board or through an external frequency input through the RTSI bus clock line or a PFI input.

The NI 5911 may also output its 10 MHz reference on the RTSI bus clock line or a PFI line so that other NI 5911 boards or other equipment can be synchronized to the same reference.

While the reference clock input is sufficient to synchronize the 100 MHz sample clocks, it is also necessary to synchronize clock dividers on each NI 5911 board so that internal clock divisors are also synchronized on the different boards. These lower frequencies are important because they are used to determine trigger times and sample position.

To synchronize the NI 5911 clock dividers, you must connect the boards with a National Instruments RTSI bus cable. One of the RTSI bus triggers must be designated as a synchronization line. This line will be an output from the master board and an input on the slave boards. To synchronize the boards, a single pulse is sent from the master to the slaves, which gives them a reference time to clear the clock dividers on the boards. Hardware arming cannot be used during a multiple board acquisition.

A

Specifications

This appendix lists the specifications of the NI-5911. These specifications are typical at 25° C unless otherwise specified.

NI 5911

Acquisition System

Bandwidth .... 100 MHz maximum, at all input ranges

Number of channels .... 1 for PCI, 2 for VXI

Number of flexible resolution ADC....... 1 for PCI, 2 for VXI

Max sample rate .... 1 GS/s repetitive, 100 MS/s single shot

Sample onboard memory .... 4 MB or 16 MB

Memory sample depth

Sampling Frequency	**Mode**	**Sample depth (4 MB option)**	**Sample depth (16 MB option)**
100 MHz/n*	Oscilloscope	4 MS	16 MS
12.5 MHz	Flexible Resolution	1 MS	4 MS
5 MHz	Flexible Resolution	1 MS	4 MS
2.5 MHz	Flexible Resolution	1 MS	4 MS
1 MHz	Flexible Resolution	1 MS	4 MS
500 kHz	Flexible Resolution	1 MS	4 MS

Sampling Frequency	Mode	Sample depth (4 MB option)	Sample depth (16 MB option)
200 kHz	Flexible Resolution	1 MS	4 MS
100 kHz	Flexible Resolution	1 MS	4 MS
50 kHz	Flexible Resolution	1 MS	4 MS
20 kHz	Flexible Resolution	1 MS	4 MS
10 kHz	Flexible Resolution	1 MS	4 MS
* $1<n<2^{32}$ in oscilloscope mode			

Memory record sizes ....2,000 samples, to maximum sample depth determined by sample frequency

Vertical sensitivity (input ranges)

Input Range	Noise Referred to Input
±10 V	174 dBfs/sqrt(Hz)
±5 V	168 dBfs/sqrt(Hz)
±2 V	160 dBfs/sqrt(Hz)
±1 V	154 dBfs/sqrt(Hz)
±0.5 V	148 dBfs/sqrt(Hz)
±0.2 V	140 dBfs/sqrt(Hz)
±0.1 V	134 dBfs/sqrt(Hz)

Acquisition Characteristics

Accuracy

Amplitude accuracy	± 0.05% signal ± 0.0001% fs (5 to 40° C) for all input ranges at 1 kHz (excluding ripple from digital filters)
DC offset	0.1 mV + 0.01% fs (5° C to 40° C) for all input ranges
Input coupling	DC and AC, software selectable
AC coupling cut-off frequency (–3 dB)	15 Hz ±2%
Input impedance	1 MΩ ±2%
Max measurable input voltage	±10 V (DC + peak AC)
Input protection	±42 VDC (DC + peak AC)
Input bias current	±1 nA, typical at 25° C

Common-Mode Characteristics

Impedance to chassis ground	10 kΩ
Common-mode rejection ratio	CMRR > –70 dB, (Fin < 1 kHz)

Filtering

Sampling Frequency	Filter Mode	Bandwidth	Ripple	Alias Attenuation
100 MHz/*n*	Oscilloscope	100 MHz	±3 dB	N/A
12.5 MHz	Flexible Resolution	3.75 MHz	±0.2 dB	–60 dB
5 MHz	Flexible Resolution	2 MHz	±0.1 dB	–70 dB
2.5 MHz	Flexible Resolution	1 MHz	±0.05 dB	–80 dB
1 MHz	Flexible Resolution	400 kHz	±0.005 dB	–80 dB
500 kHz	Flexible Resolution	200 kHz	±0.005 dB	–80 dB
200 kHz	Flexible Resolution	80 kHz	±0.005 dB	–80 dB
100 kHz	Flexible Resolution	40 kHz	±0.005 dB	–80 dB
50 kHz	Flexible Resolution	20 kHz	±0.005 dB	–80 dB
20 kHz	Flexible Resolution	8 kHz	±0.005 dB	–80 dB
10 kHz	Flexible Resolution	4 kHz	±0.005 dB	–80 dB

*$1<n<2^{32}$ in oscilloscope mode

Dynamic Range

Noise (excluding input-referred noise)

Sampling Frequency	Bandwidth	Noise Density	Total Noise
100 MHz/*n*	100 MHz	–120 dBfs/sqrt(Hz)	–43 dBfs
12.5 MHz	3.75 MHz	–135 dBfs/sqrt(Hz)	–64 dBfs
5 MHz	2 MHz	–150 dBfs/sqrt(Hz)	–83 dBfs
2.5 MHz	1 MHz	–155 dBfs/sqrt(Hz)	–91 dBfs
1 MHz	400 kHz	–160 dBfs/sqrt(Hz)	–104 dBfs
500 kHz	200 kHz	–160 dBfs/sqrt(Hz)	–107 dBfs
200 kHz	80 kHz	–160 dBfs/sqrt(Hz)	–111 dBfs
100 kHz	40 kHz	–160 dBfs/sqrt(Hz)	–114 dBfs
50 kHz	20 kHz	–160 dBfs/sqrt(Hz)	–117 dBfs
20 kHz	8 kHz	–160 dBfs/sqrt(Hz)	–121 dBfs
10 kHz	4 kHz	–160 dBfs/sqrt(Hz)	–124 dBfs
*$1<n<2^{32}$ in oscilloscope mode			

Distortion

Sampling Frequency	SFDR for input 0 dBfs	SFDR for input –20 dBfs	SFDR for input –60 dBfs (typical)
100 MHz/*n*	50 dB	50 dB	N/A
12.5 MHz	65 dB	85 dB	125 dB
5 MHz	70 dB	90 dB	130 dB
2 MHz	75 dB	95 dB	135 dB
1 MHz	85 dB	105 dB	145 dB
500 kHz	90 dB	110 dB	150 dB
200 kHz	100 dB	110 dB	160 dB
100 kHz	100 dB	110 dB	160 dB
50 kHz	100 dB	110 dB	160 dB
20 kHz	100 dB	110 dB	160 dB
10 kHz	100 dB	110 dB	160 dB

Timebase System

Number of timebases ....2, RTSI clock configured as a 10 MHz clock output (Master), or RTSI clock configured as a 10 MHz reference clock input (Slave).

Clock accuracy (as Master) ....10 MHz ± 50 ppm

Clock input tolerance (as Slave)............10 MHz ± 100 ppm

Clock jitter ....<75 pS_{rms}, independent of reference clock source

Clock compatibility ....TTL for both input and output

Interpolator resolution
(repetitive only) ....1 ns

Sampling clock frequencies

- Oscilloscope mode...........................100 MHz/n, where $1<n<2^{32}$
- Flexible Resolution mode................100 MHz/n, where n = 8, 20, 50, 100, 200, 500, 1000, 2000, 5000, 10000

Synchronization ....Via RTSI trigger lines

Phase difference......................................Between multiple instruments <5 ns, at any input frequency <100 MHz from input connector to input connector

Triggering Systems

Modes ....Above threshold, below threshold, between thresholds, outside thresholds

Source ....CH0, RTSI<0..6>, PFI 1,2

Slope ....Rising/falling

Hysteresis	Full-scale voltage/*n*, where *n* is between 1 and 170; full-scale voltage on TRIG is fixed to ±5 V (without external attenuation)
Coupling	AC/DC on CH0, TRIG
Pretrigger depth	1 to 16 million samples
Posttrigger depth	1 to 16 million samples
Holdoff by time	40 ns - 171.85 in increments of 40 ns
Sensitivity	170 steps in full-scale voltage range
TRIG input range	± 5 V (without external attenuation)
TRIG input impedance	1 MΩ ± 1% in parallel with 30 pF ± 15 pF
TRIG input protection	±42 V [(DC + peak AC) < 10 kHz, without external attenuation]

Acquisition Modes

RIS	1 GS/s down to 200 MS/s effective sample rate, repetitive signals only. Data is interleaved in software.
RIS accuracy	<0.5 nS
Single-shot	100 MS/s down to 10 kS/s sample rate for transient and repetitive signals

Power Requirements

+5 VDC	4 A
+12 VDC	100 mA
–12 VDC	100 mA

Physical

Dimensions ....33.8 x 9.9 cm (13.3 x 3.9 in)

I/O connectors
- Analog input CH0............................BNC female
- Digital triggers.................................SMB female, 9-pin DIN

Operating Environment

Ambient temperature ....5 to 40° C

Relative humidity ....10% to 90%, noncondensing

Storage Environment

Ambient temperature ....–20 to 65° C

EMC Compliance

CE97, FCC

Calibration

Internal...Internal calibration is done upon software command. The calibration involves gain, offset and linearity correction for all input ranges and input modes.
- Interval .... week, or any time temperature changes beyond ±5° C. Hardware detects temperature variations beyond calibration limits, which can also be queried by software.

External..Internal reference requires recalibration
- Interval...3 years

Warm-up time..1 minute

B

Digitizer Basics

This appendix explains basic information you need to understand about making measurements with digitizers, including important terminology.

Understanding Digitizers

To understand how digitizers work, you should be familiar with the Nyquist theorem and how it affects analog bandwidth and sample rate. You should also understand terms including vertical sensitivity, analog-to-digital converter (ADC) resolution, record length, and triggering options.

Nyquist Theorem

The Nyquist theorem states that a signal must be sampled at least twice as fast as the bandwidth of the signal to accurately reconstruct the waveform; otherwise, the high-frequency content will *alias* at a frequency inside the spectrum of interest (passband). An alias is a false lower frequency component that appears in sampled data acquired at too low a sampling rate. Figure B-1 shows a 5 MHz sine wave digitized by a 6 MS/s ADC. The dotted line indicates the aliased signal recorded by the ADC at that sample rate.

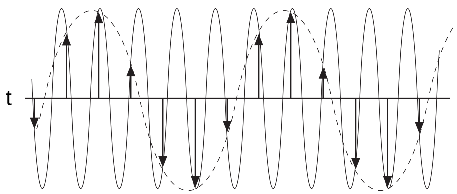


Figure B-1. Sine Wave Demonstrating the Nyquist Frequency

The 5 MHz frequency aliases back in the passband, falsely appearing as if it were a 1 MHz sine wave. To prevent aliasing in the passband, a lowpass filter limits the frequency content of the input signal above the Nyquist rate.

Analog Bandwidth

Analog bandwidth describes the frequency range (in Hertz) in which a signal can be digitized accurately. This limitation is determined by the inherent frequency response of the input path which causes loss of amplitude and phase information. *Analog bandwidth* is the frequency at which the measured amplitude is 3 dB below the actual amplitude of the signal. This amplitude loss occurs at very low frequencies if the signal is AC coupled and at very high frequencies regardless of coupling. When the signal is DC coupled, the bandwidth of the amplifier will extend all the way to the DC voltage. Figure B-2 illustrates the effect of analog bandwidth on a high-frequency signal. The result is a loss of high-frequency components and amplitude in the original signal as the signal passes through the instrument.

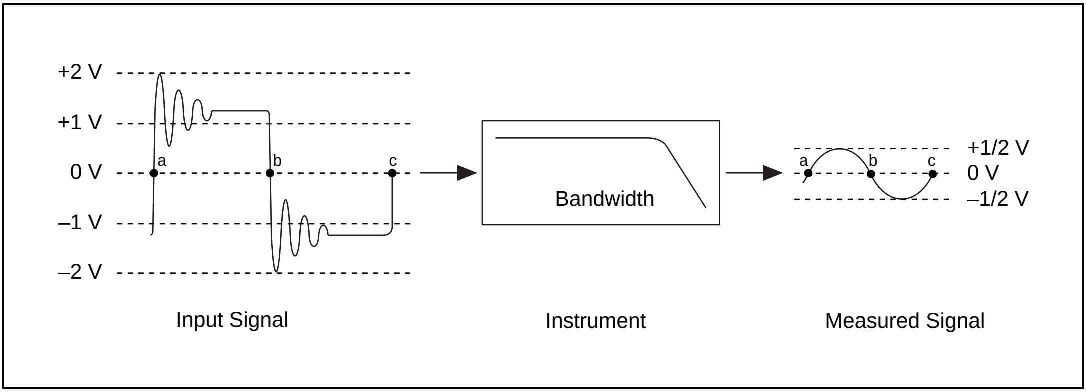


Figure B-2. Analog Bandwidth

Sample Rate

Sample rate is the rate at which a signal is sampled and digitized by an ADC. According to the Nyquist theorem, a higher sample rate produces accurate measurement of higher frequency signals if the analog bandwidth is wide enough to let the signal to pass through without attenuation. A higher sample rate also captures more waveform details. Figure B-3 illustrates a 1 MHz sine wave sampled by a 2 MS/s ADC and a 20 MS/s ADC. The faster ADC digitizes 20 points per cycle of the input signal compared with 2 points per cycle with the slower ADC. In this example, the higher sample rate more accurately captures the waveform shape as well as frequency.

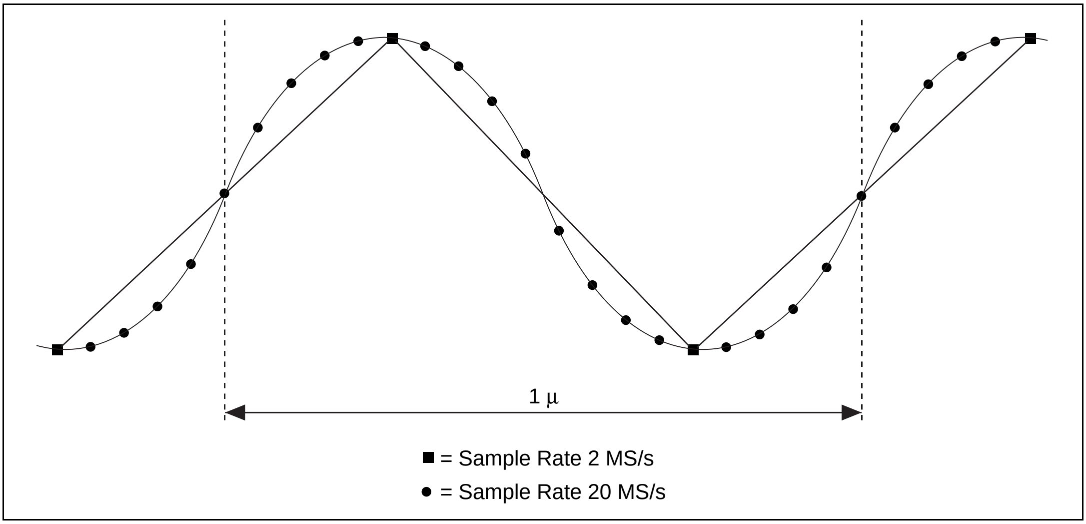


Figure B-3. 1 MHz Sine Wave Sample

Vertical Sensitivity

Vertical sensitivity describes the smallest input voltage change the digitizer can capture. This limitation is because one distinct digital voltage encompasses a range of analog voltages. Therefore, it is possible that a minute change in voltage at the input is not noticeable at the output of the ADC. This parameter depends on the input range, gain of the input amplifier, and ADC resolution. It is specified in volts per LSB. Figure B-4 shows the transfer function of a 3-bit ADC with a vertical range of 5 V having a vertical sensitivity of 5/8 V/LSB.

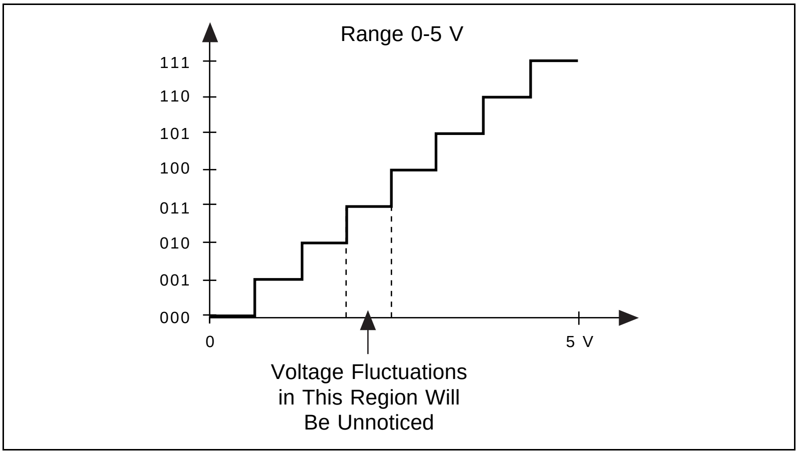


Figure B-4. Transfer Function of a 3-Bit ADC

ADC Resolution

ADC resolution limits the accuracy of a measurement. The higher the resolution (number of bits), the more accurate the measurement. An 8-bit ADC divides the vertical range of the input amplifier into 256 discrete levels. With a vertical range of 10 V, the 8-bit ADC cannot resolve voltage differences smaller than 39 mV. In comparison, a 12-bit ADC with 4,096 discrete levels can resolve voltage differences as small as 2.4 mV.

Record Length

Record length refers to the amount of memory dedicated to storing digitized samples for postprocessing or display. In a digitizer, record length limits the maximum duration of a single-shot acquisition. For example, with a 1,000-sample buffer and a sample rate of 20 MHz, the duration of acquisition is 50 µs (the number of points multiplied by the acquisition time/point or 1,000 x 50 ns). With a 100,000-sample buffer and a sample rate of 20 MHz, the duration of acquisition is 5 ms (100,000 x 50 ns).

Triggering Options

One of the biggest challenges of making a measurement is to successfully trigger the signal acquisition at the point of interest. Since most high-speed digitizers actually record the signal for a fraction of the total time, they can easily miss a signal anomaly if the trigger point is set incorrectly. The NI 5911 is equipped with sophisticated triggering options, such as trigger thresholds, programmable hysteresis values, and trigger hold-off. The NI 5911 also has two digital triggers that give you more flexibility in triggering by allowing you to connect a TTL/CMOS digital signal to trigger the acquisition.

Making Accurate Measurements

For accurate measurements, you should use the right settings when acquiring data with your NI 5911. Knowing the characteristics of the signal in consideration helps you to choose the correct settings. Such characteristics include:

- Peak-to-peak value—This parameter, in units of volts, reflects the maximum change in signal voltage. If V is the signal voltage at any given time, then $V_{pk\text{-}to\text{-}pk} = V_{max} - V_{min}$. The peak-to-peak value affects the vertical sensitivity or gain of the input amplifier. If you do not know the peak-to-peak value, start with the smallest gain (maximum input range) and increase it until the waveform is digitized using the maximum dynamic range without clipping the signal. Refer to Appendix A, *Specifications*, for the maximum input voltage for your NI 5911 device. Figure B-5 shows that a gain of 5 is the best setting to digitize a 300 mV, 1 MHz sine wave without clipping the signal.

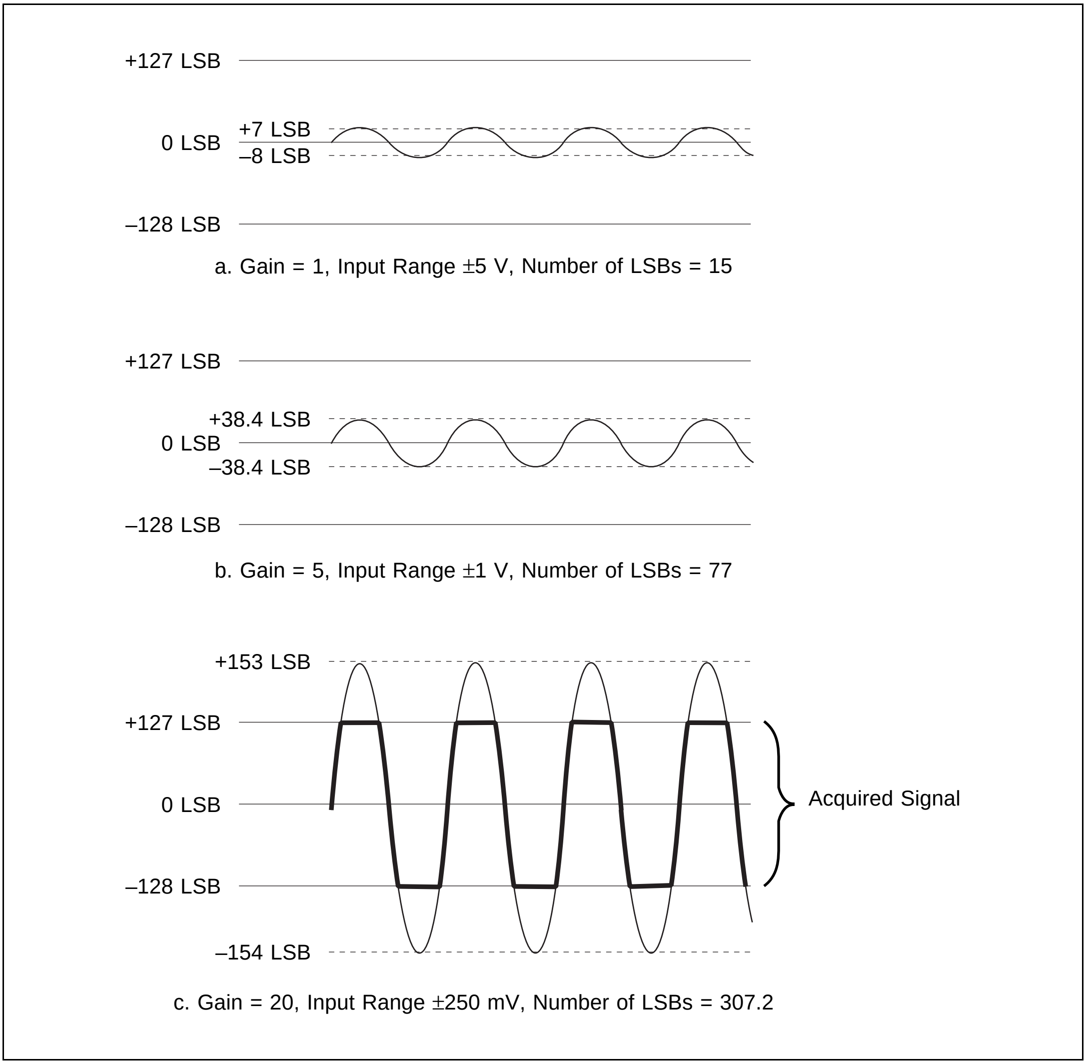


Figure B-5. Dynamic Range of an 8-Bit ADC with Three Different Gain Settings

- Source impedance—Most digitizers and digital storage oscilloscopes (DSOs) have a 1 MΩ input resistance in the passband. If the source impedance is large, the signal will be attenuated at the amplifier input and the measurement will be inaccurate. If the source impedance is unknown but suspected to be high, change the attenuation ratio on your probe and acquire data. In addition to the input resistance, all digitizers, DSOs, and probes present some input capacitance in parallel with the resistance. This capacitance can interfere with your measurement in much the same way as the resistance does.
- Input frequency—If your sample rate is less than twice the highest frequency component at the input, the frequency components above half your sample rate will alias in the passband at lower frequencies, indistinguishable from other frequencies in the passband. If the signal's highest frequency is unknown, you should start with the digitizer's maximum sample rate to prevent aliasing and reduce the digitizer's sample rate until the display shows either enough cycles of the waveform or the information you need.
- General signal shape—Some signals are easy to capture by ordinary triggering methods. A few iterations on the trigger level finally render a steady display. This method works for sinusoidal, triangular, square, and saw tooth waves. Some of the more elusive waveforms, such as irregular pulse trains, runt pulses, and transients, may be more difficult to capture. Figure B-6 shows an example of a difficult pulse-train trigger.

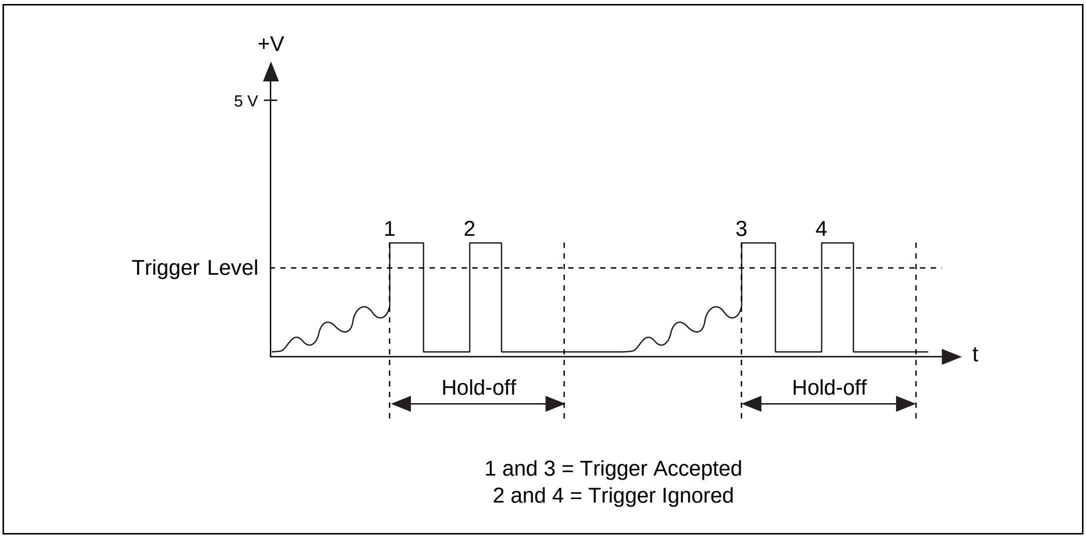


Figure B-6. Difficult Pulse Train Signal

Ideally, the trigger event should occur at condition one, but sometimes the instrument may trigger on condition two because the signal crosses the trigger level. You can solve this problem without using complicated signal processing techniques by using *trigger hold-off*, which lets you specify a time from the trigger event to ignore additional triggers that fall within that time. With an appropriate hold-off value, the waveform in Figure B-6 can be properly captured by discarding conditions two and four.

- Input coupling—You can configure the input channels on your NI 5911 to be DC coupled or AC coupled. DC coupling allows DC and low-frequency components of a signal to pass through without attenuation. In contrast, AC coupling removes DC offsets and attenuates low frequency components of a signal. This feature can be exploited to zoom in on AC signals with large DC offsets, such as switching noise on a 12 V power supply. Refer to Appendix A, *Specifications*, for input limits that must be observed regardless of coupling.

C

Customer Communication

For your convenience, this appendix contains forms to help you gather the information necessary to help us solve your technical problems and a form you can use to comment on the product documentation. When you contact us, we need the information on the Technical Support Form and the configuration form, if your manual contains one, about your system configuration to answer your questions as quickly as possible.

National Instruments has technical assistance through electronic, fax, and telephone systems to quickly provide the information you need. Our electronic services include a bulletin board service, an FTP site, a fax-on-demand system, and e-mail support. If you have a hardware or software problem, first try the electronic support systems. If the information available on these systems does not answer your questions, we offer fax and telephone support through our technical support centers, which are staffed by applications engineers.

Electronic Services

Bulletin Board Support

National Instruments has BBS and FTP sites dedicated for 24-hour support with a collection of files and documents to answer most common customer questions. From these sites, you can also download the latest instrument drivers, updates, and example programs. For recorded instructions on how to use the bulletin board and FTP services and for BBS automated information, call 512 795 6990. You can access these services at:

United States: 512 794 5422
Up to 14,400 baud, 8 data bits, 1 stop bit, no parity

United Kingdom: 01635 551422
Up to 9,600 baud, 8 data bits, 1 stop bit, no parity

France: 01 48 65 15 59
Up to 9,600 baud, 8 data bits, 1 stop bit, no parity

FTP Support

To access our FTP site, log on to our Internet host, `ftp.natinst.com`, as `anonymous` and use your Internet address, such as `joesmith@anywhere.com`, as your password. The support files and documents are located in the `/support` directories.

Fax-on-Demand Support

Fax-on-Demand is a 24-hour information retrieval system containing a library of documents on a wide range of technical information. You can access Fax-on-Demand from a touch-tone telephone at 512 418 1111.

E-Mail Support (Currently USA Only)

You can submit technical support questions to the applications engineering team through e-mail at the Internet address listed below. Remember to include your name, address, and phone number so we can contact you with solutions and suggestions.

`support@natinst.com`

Telephone and Fax Support

National Instruments has branch offices all over the world. Use the list below to find the technical support number for your country. If there is no National Instruments office in your country, contact the source from which you purchased your software to obtain support.

Country	Telephone	Fax
Australia	03 9879 5166	03 9879 6277
Austria	0662 45 79 90 0	0662 45 79 90 19
Belgium	02 757 00 20	02 757 03 11
Brazil	011 288 3336	011 288 8528
Canada (Ontario)	905 785 0085	905 785 0086
Canada (Québec)	514 694 8521	514 694 4399
Denmark	45 76 26 00	45 76 26 02
Finland	09 725 725 11	09 725 725 55
France	01 48 14 24 24	01 48 14 24 14
Germany	089 741 31 30	089 714 60 35
Hong Kong	2645 3186	2686 8505
Israel	03 6120092	03 6120095
Italy	02 413091	02 41309215
Japan	03 5472 2970	03 5472 2977
Korea	02 596 7456	02 596 7455
Mexico	5 520 2635	5 520 3282
Netherlands	0348 433466	0348 430673
Norway	32 84 84 00	32 84 86 00
Singapore	2265886	2265887
Spain	91 640 0085	91 640 0533
Sweden	08 730 49 70	08 730 43 70
Switzerland	056 200 51 51	056 200 51 55
Taiwan	02 377 1200	02 737 4644
United Kingdom	01635 523545	01635 523154
United States	512 795 8248	512 794 5678

Technical Support Form

Photocopy this form and update it each time you make changes to your software or hardware, and use the completed copy of this form as a reference for your current configuration. Completing this form accurately before contacting National Instruments for technical support helps our applications engineers answer your questions more efficiently.

If you are using any National Instruments hardware or software products related to this problem, include the configuration forms from their user manuals. Include additional pages if necessary.

Name ____

Company ____

Address ____

____

Fax (___) _______________Phone (___) ______________________________________

Computer brand____________ Model __________________Processor___________________

Operating system (include version number) ____________________________________

Clock speed ______MHz RAM _____MB Display adapter __________________________

Mouse ___yes ___no Other adapters installed___________________________________

Hard disk capacity _____MB Brand____

Instruments used ____

____

National Instruments hardware product model _____________ Revision ____________________

Configuration ____

National Instruments software product ___________________ Version ____________________

Configuration ____

The problem is: ____

____

____

____

____

List any error messages: ____

____

____

The following steps reproduce the problem: _______________________________________

____

____

____

____

NI 5911 Hardware and Software Configuration Form

Record the settings and revisions of your hardware and software on the line to the right of each item. Complete a new copy of this form each time you revise your software or hardware configuration, and use this form as a reference for your current configuration. Completing this form accurately before contacting National Instruments for technical support helps our applications engineers answer your questions more efficiently.

National Instruments Products

Hardware revision ______________________________

Interrupt level of hardware ______________________________

Base I/O address of hardware ______________________________

Programming choice ______________________________

National Instruments software ______________________________

Other boards in system ______________________________

Base I/O address of other boards ______________________________

DMA channels of other boards ______________________________

Interrupt level of other boards ______________________________

Other Products

Computer make and model ______________________________

Microprocessor ______________________________

Clock frequency or speed ______________________________

Type of video board installed ______________________________

Operating system version ______________________________

Operating system mode ______________________________

Programming language ______________________________

Programming language version ______________________________

Other boards in system ______________________________

Base I/O address of other boards ______________________________

DMA channels of other boards ______________________________

Interrupt level of other boards ______________________________

Documentation Comment Form

National Instruments encourages you to comment on the documentation supplied with our products. This information helps us provide quality products to meet your needs.

Title: *NI 5911 User Manual*

Edition Date: October 1998

Part Number: 322150A-01

Please comment on the completeness, clarity, and organization of the manual.

If you find errors in the manual, please record the page numbers and describe the errors.

Thank you for your help.

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Title ______________________________

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Glossary

Prefix	Meanings	Value
p-	pico	10^{-12}
n-	nano-	10^{-9}
μ-	micro-	10^{-6}
m-	milli-	10^{-3}
k-	kilo-	10^{3}
M-	mega-	10^{6}
G-	giga-	10^{9}

Numbers/Symbols

%	percent
+	positive of, or plus
–	negative of, or minus
/	per
°	degree
±	plus or minus
Ω	ohm

A

A	amperes
AC	alternating current
AC coupled	the passing of a signal through a filter network that removes the DC component of the signal

A/D	analog-to-digital
ADC	analog-to-digital converter—an electronic device, often an integrated circuit, that converts an analog voltage to a digital number
ADC resolution	the resolution of the ADC, which is measured in bits. An ADC with16 bits has a higher resolution, and thus a higher degree of accuracy, than a 12-bit ADC.
amplification	a type of signal conditioning that improves accuracy in the resulting digitized signal and reduces noise
amplitude flatness	a measure of how close to constant the gain of a circuit remains over a range of frequencies
attenuate	to reduce in magnitude

B

b	bit—one binary digit, either 0 or 1
B	byte—eight related bits of data, an eight-bit binary number. Also used to denote the amount of memory required to store one byte of data.
bus	the group of conductors that interconnect individual circuitry in a computer. Typically, a bus is the expansion vehicle to which I/O or other devices are connected. Examples of PC buses are the PCI and ISA bus.

C

C	Celsius
CMRR	common-mode rejection ratio—a measure of an instrument's ability to reject interference from a common-mode signal, usually expressed in decibels (dB)
coupling	the manner in which a signal is connected from one location to another

D

dB	decibel—the unit for expressing a logarithmic measure of the ratio of two signal levels: dB=20log10 V1/V2, for signals in volts

DC	direct current
default setting	a default parameter value recorded in the driver. In many cases, the default input of a control is a certain value (often 0) that means *use the current default setting*.
differential input	an analog input consisting of two terminals, both of which are isolated from computer ground, whose difference is measured
double insulated	a device that contains the necessary insulating structures to provide electric shock protection without the requirement of a safety ground connection
drivers	software that controls a specific hardware instrument

E

EEPROM	electrically erasable programmable read-only memory—ROM that can be erased with an electrical signal and reprogrammed

F

filtering	a type of signal conditioning that allows you to filter unwanted signals from the signal you are trying to measure

G

gain	the factor by which a signal is amplified, sometimes expressed in decibels

H

hardware	the physical components of a computer system, such as the circuit boards, plug-in boards, chassis, enclosures, peripherals, cables, and so on
harmonics	multiples of the fundamental frequency of a signal
Hz	hertz—per second, as in cycles per second or samples per second

I

in.	inches
inductance	the relationship of induced voltage to current
input bias current	the current that flows into the inputs of a circuit
input impedance	the measured resistance and capacitance between the input terminals of a circuit
instrument driver	a set of high-level software functions that controls a specific plug-in DAQ board. Instrument drivers are available in several forms, ranging from a function callable language to a virtual instrument (VI) in LabVIEW.
interrupt	a computer signal indicating that the CPU should suspend its current task to service a designated activity
interrupt level	the relative priority at which a device can interrupt
I/O	input/output—the transfer of data to/from a computer system involving communications channels, operator interface devices, and/or data acquisition and control interfaces
ISA	industry standard architecture

M

m	meters.
MB	megabytes of memory.

N

noise	an undesirable electrical signal—Noise comes from external sources such as the AC power line, motors, generators, transformers, fluorescent lights, soldering irons, CRT displays, computers, electrical storms, welders, radio transmitters, and internal sources such as semiconductors, resistors, and capacitors. Noise corrupts signals you are trying to send or receive.

O

Ohm’s Law	(R=V/I)—the relationship of voltage to current in a resistance
overrange	a segment of the input range of an instrument outside of the normal measuring range. Measurements can still be made, usually with a degradation in specifications.

P

PCI	Peripheral Component Interconnect—a high-performance expansion bus architecture originally developed by Intel to replace ISA and EISA; it is achieving widespread acceptance as a standard for PCs and workstations and offers a theoretical maximum transfer rate of 132 Mbytes/s
peak value	the absolute maximum or minimum amplitude of a signal (AC + DC)
PXI	PCI eXtensions for Instrumentation. PXI is an open specification that builds off the CompactPCI specification by adding instrumentation-specific features.

R

R	resistor
RAM	random-access memory
resolution	the smallest signal increment that can be detected by a measurement system. Resolution can be expressed in bits or in digits. The number of bits in a system is roughly equal to 3.3 times the number of digits.
rms	root mean square—a measure of signal amplitude; the square root of the average value of the square of the instantaneous signal amplitude
ROM	read-only memory

S

s	seconds
S	samples
sense	in four-wire resistance the sense measures the voltage across the resistor being excited by the excitation current
settling time	the amount of time required for a voltage to reach its final value within specified limits
S/s	samples per second—used to express the rate at which an instrument samples an analog signal
system noise	a measure of the amount of noise seen by an analog circuit or an ADC when the analog inputs are grounded

T

temperature coefficient	the percentage that a measurement will vary according to temperature. *See also* thermal drift
thermal drift	measurements that change as the temperature varies
thermal EMFs	thermal electromotive forces—voltages generated at the junctions of dissimilar metals that are functions of temperature. Also called thermoelectric potentials.
thermoelecótric potentials	*See* thermal EMFs.
transfer rate	the rate, measured in bytes/s, at which data is moved from source to destination after software initialization and set up operations; the maximum rate at which the hardware can operate

V

V	volts
VAC	volts alternating current
VDC	volts direct current
V_{error}	voltage error
VI	virtual instrument—(1) a combination of hardware and/or software elements, typically used with a PC, that has the functionality of a classic stand-alone instrument (2) a LabVIEW software module (VI), which consists of a front panel user interface and a block diagram program
V_{rms}	volts, root mean square value

W

waveform shape	the shape the magnitude of a signal creates over time
working voltage	the highest voltage that should be applied to a product in normal use, normally well under the breakdown voltage for safety margin

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I

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P