ADCPro™

User's Guide

TEXAS INSTRUMENTS

Contents

List of Figures

ADCPro™ User Guide

This user's guide describes ADCPro™, a software tool for evaluating analog-to-digital converters (ADCs). This tool is provided along with many evaluation modules (EVMs) from Texas Instruments to assist customers in evaluating a broad range of ADCs for various applications.

1 Introduction and Requirements

ADCPro is a modular software system from Texas Instruments for evaluating ADCs without the need for expensive logic analyzers and complex analysis routines. As a stand-alone tool, it is suitable for analyzing data sets captured during ADC testing. When paired with a Texas Instruments ADC EVM and suitable data capture card, it becomes part of a powerful evaluation package.

1.1 Features

- Ability to save and recall data sets
- Modular design allows additional EVMs and tests to be supported
- Time, histogram, and frequency domain testing

This manual is designed to help easily set up an evaluation system that closely replicates a manufacturer's system, and allows the user to arrive at meaningful results that can be compared to system requirements. Tests that are performed and the equipment required to perform these tests will be discussed; detailed test methodologies are also examined.

In this document, we identify the appropriate test equipment for use with an EVM and review basic ADC evaluation test methods. Essential performance parameters of an ADC are described, as well as how these parameters are characterized by following the IEEE Standard 1241-2000, the IEEE Standard for Terminology and Test Methods for ADCs. ADCPro implements some of the tests described in IEEE1241-2000. As a result of the modular ADCPro design, additional tests can be added to any installation of ADCPro as needed.

When running the ADCPro, the user is actually using three programs: a shell program that loads plug-ins; a plug-in program that communicates with the EVM hardware; and a test plug-in that analyzes data coming from the EVM plug-in. This modular design allows ADCPro to be used with a number of different data capture cards or motherboards that may ship in an EVM product development kit (PDK). Data files saved from ADCPro can be recalled for further analysis using an EVM plug-in that reads files.

1.2 Minimum System Requirements for ADCPro

- PC with:
  - Pentium III®/ Celeron® 866MHz or equivalent processor
  - Minimum 256MB of RAM (1GB or greater recommended)
  - Hard disk drive with at least 200MB free space
- Microsoft Windows® XP SP2/SP3 and Windows® 7 operating systems
- Mouse
- Optimized for 1024 × 768 resolution

> **NOTE:** Microsoft Windows® 7 includes an option in the Control Panel to scale overall display magnification, see Control Panel > Appearance and Personalization > Display. It is recommended that ADCPro be run on systems with the display magnification set to "Smaller - 100% (Default)" to avoid overlapping text/controls.

1.3 Additional Requirements for Use with Hardware

- TI ADC EVM-PDK: evaluation kit that includes data capture card and device EVM (optional)
- USB 1.1-compatible input (check requirements of individual EVMs)

Other configurations may work, but have not been tested. Users should be advised that when capturing larger data sets, PCs equipped with faster processors and larger RAM tend to perform better.

1.4 ADCPro Installation

For installation instructions please refer to the ADCPro Hardware and Software Installation Manual.

2 ADCPro Launcher

The ADCPro Launcher is a utility provided to ease installation and maintenance of ADCPro. From the Launcher the user may install ADCPro and ADCPro plug-ins, apply updates to ADCPro, visit the TI E2E community, and search for devices at www.ti.com.
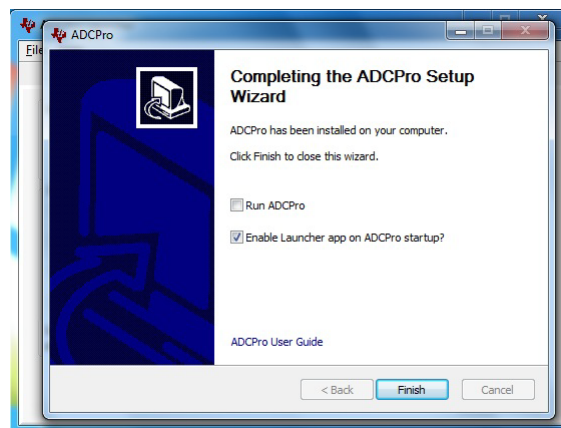
Figure 1. ADCPro Launcher Enable/Disable Switch

The ADCPro Launcher can be enabled or disabled on start-up once ADCPro is installed on the PC. At completion of the ADCPro installation, the prompt shown in Figure 1 will be displayed. The Launcher can also be enabled or disabled from the ADCPro toolbar under Settings > Configuration Settings - as discussed in Section 3.3.

> **NOTE:** No user data outside of the ADCPro and ADCPro plug-in installation is inspected by the ADCPro Launcher. No data on the PC is monitored or reported back to Texas Instruments.

2.1 Welcome Tab

The *Welcome* tab is displayed for users who do not have ADCPro installed or for users who are migrating from ADCPro v1.2.2 to ADCPro v2.0.0 and beyond. Installed ADCPro plug-ins will be shown on this tab and may be selected for update to be compatible with the new version of ADCPro. Click the *Get ADCPro* button once all desired components to convert are selected and the Launcher will begin downloading and installing the requested features.
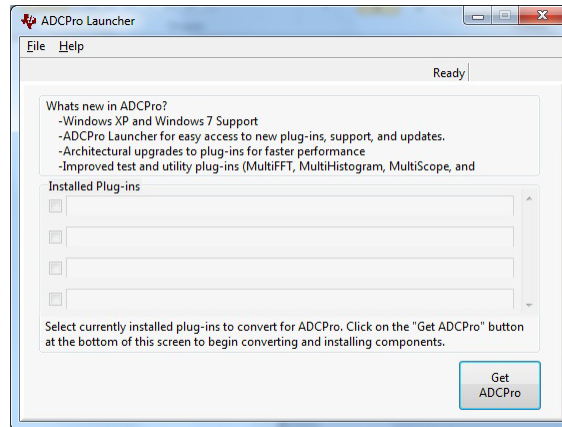
Figure 2. ADCPro Launcher Welcome Tab

2.2 General Tab

The *General* tab is the default window for the ADCPro Launcher. This window will always be the first page visible unless ADCPro is not installed on the PC, in this case the *Welcome* tab is made visible and the user will be prompted to install ADCPro.

From the *General* tab the user may check for ADCPro updates, search for new ADCPro plug-ins, visit the Precision Data Converters E2E Community, search for Precision Data Converter products at www.it.com, and launch ADCPro. Additionally, a message of the day is displayed on this tab to present Precision Data Converter and ADCPro announcements.

> **NOTE:** To Launch ADCPro return to the *General* tab.

Figure 3. ADCPro Launcher General Tab

2.3 Updates Tab

The *Updates* tab is accessed by clicking the *Check for Updates* button on the *General* tab. The ADCPro Launcher will scan the PC for installed components and component versions. If updates are available for the ADCPro shell or individual plug-ins they will be populated in the *Update* tab, as shown in Figure 4.
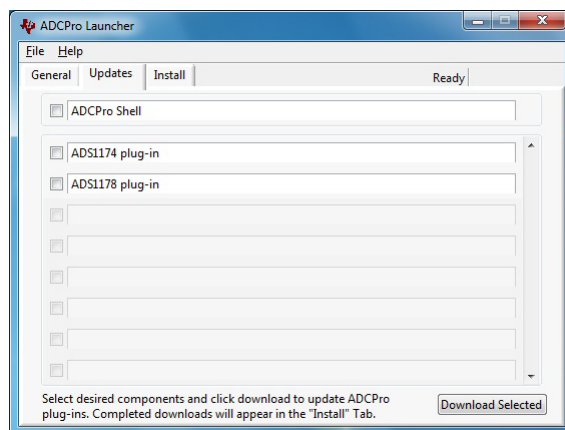
Figure 4. ADCPro Launcher Updates Tab

To select an item for update click the check-box next to the item. Once all desired updates have been selected, click the *Download Selected* button and follow the prompt to either confirm or cancel the requested downloads. As the downloads complete the items will be removed from the *Updates* tab and placed in the *Install* tab.

> **NOTE:** While the ADCPro Launcher is downloading components the GUI is locked from all user interaction. Status messages and status bar in the upper right corner will reflect progress.

2.4 Search Tab

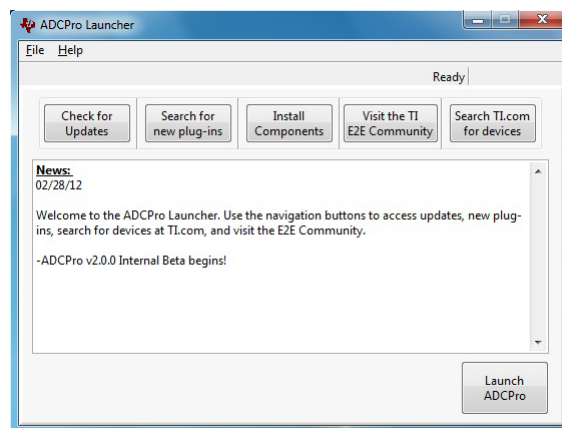The *New Plug-ins* tab is accessed by clicking on the *Search for New Plug-ins* button on the *General* tab. The ADCPro Launcher will scan the local system for installed ADCPro components and display components that are not yet installed on the PC. Plug-ins that are already installed on the PC but may have available updates will not be displayed on this tab. Updates are only displayed on the *Updates* tab.

To select an item for download click the check-box next to the item. Once all desired components have been selected click the *Download Selected* button and follow the prompts to either confirm or cancel the requested downloads. As the downloads complete the items will be removed form the *New Plug-ins* tab and placed in the *Install* tab.

The *New Plug-ins* tab also features a search bar that may be used to search for specific plug-ins to install. Items selected for download will remain at the top of the displayed list of plug-ins as the search string changes. The search bar is prepared to accept regular expressions, or special characters, for advanced searches. For more information concerning special search characters, please refer to the ADCPro Launcher Help.
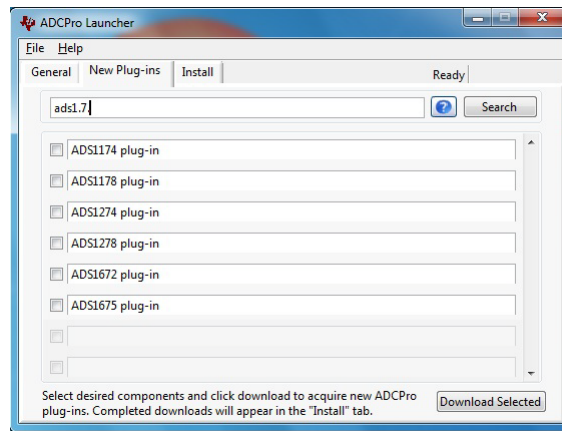
Figure 5. ADCPro Launcher New Plug-ins Tab

2.5   Install Tab

The *Install* tab is made visible either by clicking the *Install Components* button on the *General* tab or by clicking the *Check for Updates* or *Search for New Plug-ins* buttons on the *General* tab. When downloads are complete from either the *Updates* tab or *New Plug-ins* tab the *Install* tab will be made visible. The *Install* tab presents all of the components that have been downloaded on the PC. Items can be installed individually by double-clicking on the item name or all items can be installed automatically by clicking the *Install All* button.

NOTE: If an update has been downloaded for the ADCPro shell and components are installed manually, it is important to run the ADCPro shell installer first, followed by each desired component. Alternatively, the *Install All* button will automatically run the shell installer first if it is present.
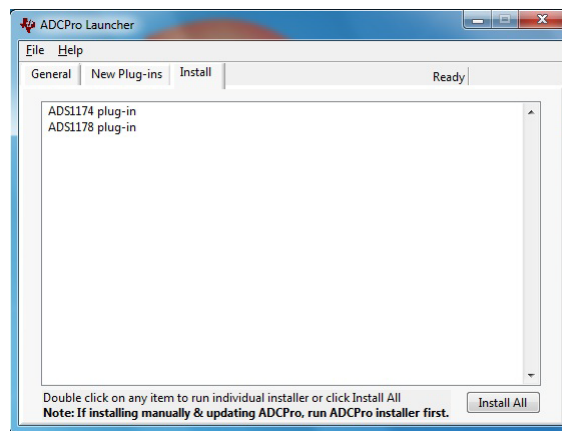
Figure 6. ADCPro Launcher Install Tab

3 ADCPro

3.1 Launching ADCPro

From the Windows **Start** menu, select *ADCPro....*

When ADCPro begins, it displays a splash screen (Figure 7). This screen shows the version number of the software. the user can also find the version number under the **Help** menu.
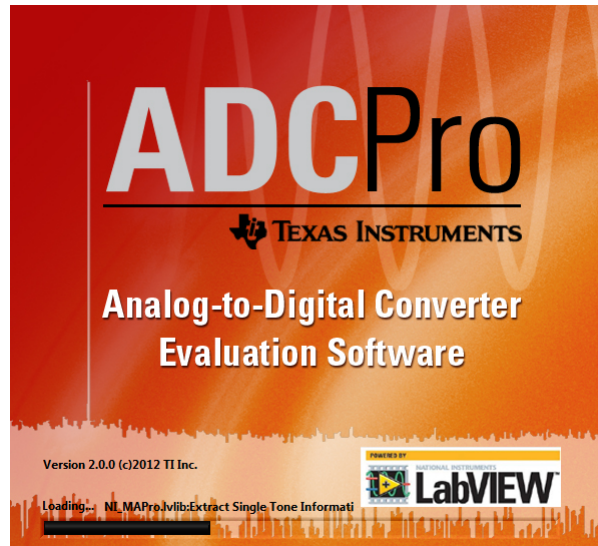
Figure 7. Start-Up Splash Screen

After a few moments, the software initializes and the splash screen disappears. The screen shown in Figure 8 then displays.
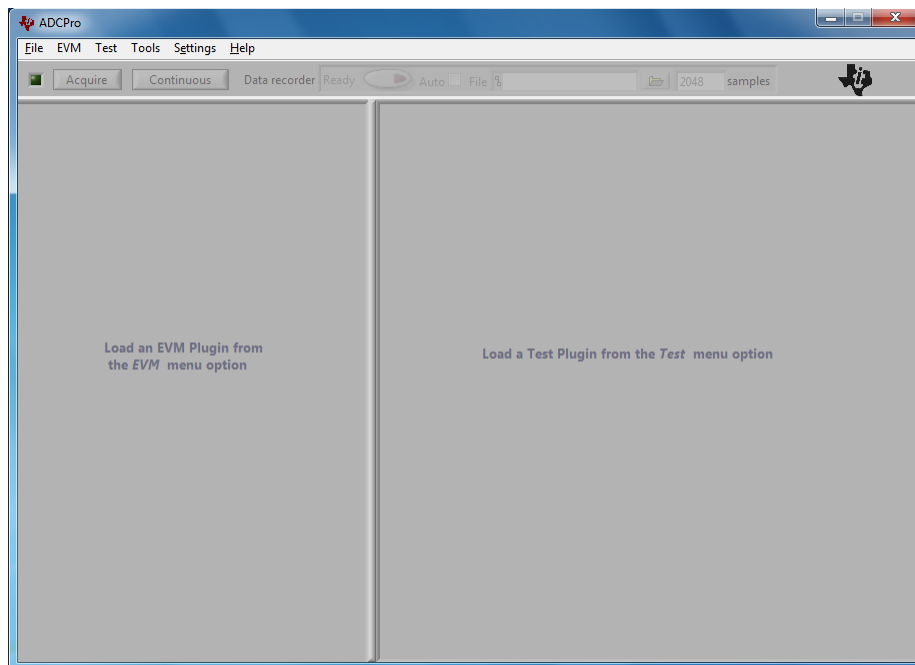
Figure 8. Initial ADCPro Screen

3.2 ADCPro Architectural Overview

ADCPro is built upon a plug-in architecture using LabVIEW software. The main program, shown in Figure 8, is called the *shell*. The shell loads *plug-ins* to collect and analyze data.

Data are collected for analysis using an *EVM Plug-In*, so named because in most cases the data are collected from a TI EVM via a hardware interface, usually over a universal serial bus (USB) connection.

When the shell initializes, it scans a directory named *evm* in the *plugins* ADCPro directory and populates two menus, **EVM** and **Test**, with any plug-ins it finds. Plug-ins that provide data to the ADCPro software are classified as *EVM plug-ins*, while those that take the collected data and analyze or manipulate it are classified as *Test plug-ins*.

To use ADCPro, the following steps are required:
- Load an EVM plug-in
- Load a Test plug-in

To load an EVM plug-in, select it from the **EVM** menu. To load a test plug-in, select it from the **Test** menu. To unload a plug-in, select the *Unload* option from the respective menu.

Only one of each type of plug-in can be loaded at a time. If selecting a different plug-in, the previous plug-in is automatically unloaded.

3.3 ADCPro Main Menus

The ADCPro shell screen has four drop-down menu options: **File**, **EVM**, **Test**,**Tools**, **Settings**, and **Help**.

- The **File** menu contains three items: *Minimize EVM Plugin*, *Screen Capture of ADCPro Screen*, and *Exit*.
  - The *Minimize EVM Plugin* item collapses the EVM plug-in panel to allow the Test Plug-in to expand to the entire ADCPro main panel. This action can also be performed using the **F8** function key. Selecting the menu item again or pressing the function key will restore the main panel to the default display.

    Figure 9 shows an enlarged view of the Multiscope plug-in panel.

Figure 9. ADCPro Main Panel with Test Plug-in Maximized

   – The *Screen Capture of ADCPro Screen* item allows the user to capture the main panel of ADCPro in one of three file formats: jpg, png, or bmp.
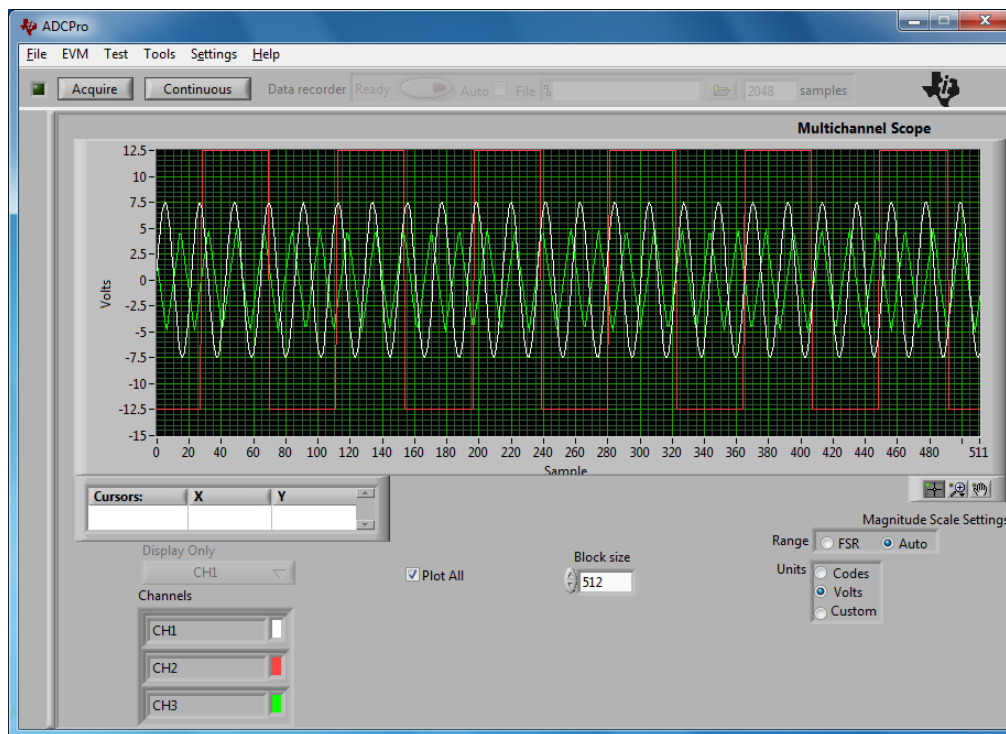
   – The *Exit* item closes the ADCPro software when selected. This action can also be performed by using the **Alt+Q** key combination.

- The **EVM** menu contains a list of all the EVM plug-ins currently installed. Further information regarding EVM plug-ins is given in Section 3.4.

- The **Test** menu contains a list of all the Test plug-ins currently installed. See Section 3.5 for more information regarding Test plug-ins.

- The **Tools** menu contains a list of all the basic tools for ADCPro. Additional information regarding tools is provided in Section 3.6.

- The **Settings** menu allows access to the ADCPro *Configuration Settings* menu, shown in Figure 10, where the user may enable or disable the ADCPro Launcher and view error logs.
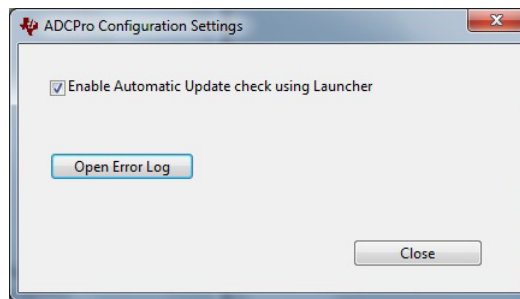
Figure 10. ADCPro Configuration Settings Menu

- The **Help** menu contains three selections: *About ADCPro...* and *Contact Us*.

   – The *About ADCPro...* item displays information regarding the current version of the ADCPro software and the names and versions of the active plug-ins.

   – The *Contact Us* item allows for comments and questions to be sent via email to adcpro_help@list.ti.com. Questions and comments assist us in program development and designing further software enhancements.

3.4 *EVM Plug-Ins—Getting Data Into ADCPro*

As a stand-alone program, with no hardware connected, ADCPro can be used to analyze data sets. This feature is an easy way to evaluate the tool. Data can come from two different plug-ins included in the distribution:

- **TripleGen:** a 3-channel function generator EVM plug-in;

- **FileReader:** an EVM plug-in that reads data files stored in the ADCPro format (tab-delimited text).

Since both of these plug-ins provide data to the analysis engine, they are considered EVM plug-ins, and appear under the **EVM** menu in the ADCPro shell. Selecting an EVM plug-in to use with ADCPro is done by simply selecting one of the menu items in the **EVM** menu; see Figure 11.
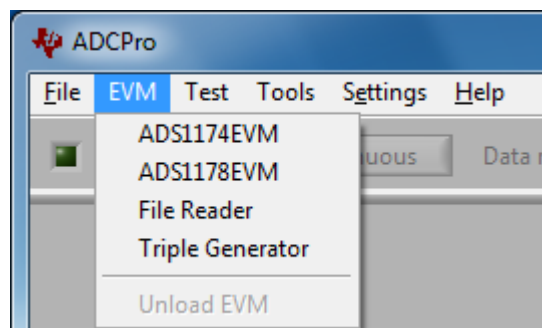
Figure 11. Selecting an EVM Plug-In

3.4.1   TripleGen

The TripleGen plug-in is a software function generator, and is included with the main ADCPro distribution. This EVM plug-in can create and feed data blocks to tests for analysis. It is a tool for verifying that tests function properly. See Figure 12.

The signals are generated using controls for each channel. The available controls are:

- **Resolution:** the number of data bits for the waveform data.
- **Max code:** the maximum code value (signed integer) of the data.
- **Min code:** the minimum code value (signed integer) of the data.
- **Fs:** the sampling frequency of the channel data (in Hz).

   NOTE: The sampling frequency (f_s) of Channel 2 and 3 is *always* the same as that of Channel 1.

- **Max V:** the maximum voltage value of the waveform.
- **Min V:** the minimum voltage value of the waveform.
- **Waveform:** the type of waveform to be generated. The types of waveforms available are:
  – *Sine*, *Square*, *Ramp Up*, *Ramp Down*, *Triangle*, *Pink Noise* and *White Noise*
- **Frequency:** the frequency of the generated signal (in Hz).
- **Amplitude:** the amplitude of the generated signal (referenced to 0dB).
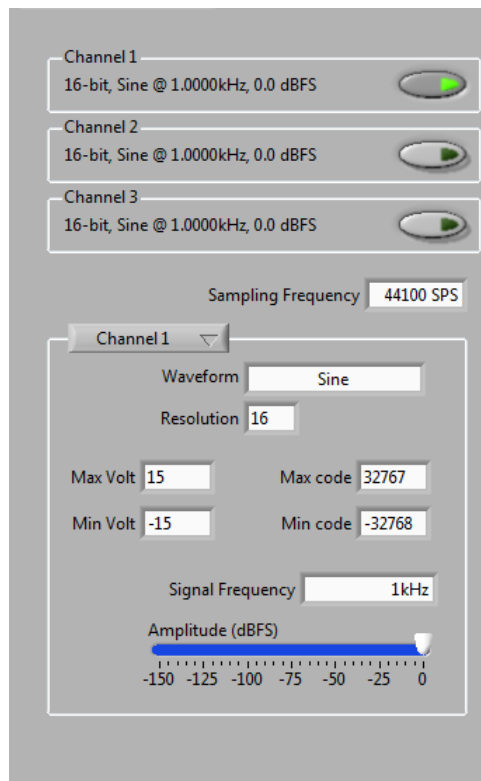
Figure 12. TripleGen EVM Plug-In Front Panel Display

3.4.2 FileReader

The FileReader plug-in allows a file that contains a data set to be loaded into the ADCPro shell so that the data can be analyzed using one of the test plug-ins. It is included with the main ADCPro distribution.

The format of data files that the FileReader can read is described in Section 3.5.5. These files are tab-delimited text files.

The FileReader main panel is shown in Figure 13. To load a file into the FileReader plug-in, select the folder button to the right of the **File Path and Name** control. Navigate to the active directory and select the text file to read. Alternatively, the file path and information can be manually entered into the window. If the file is a valid file, the LED to the right of the **File Path and Name** controls should turn green. The header data from the file should be displayed in the **File Information** area of the panel. The **CH_Attrib** selector can be changed to view the individual channel information read from the file.
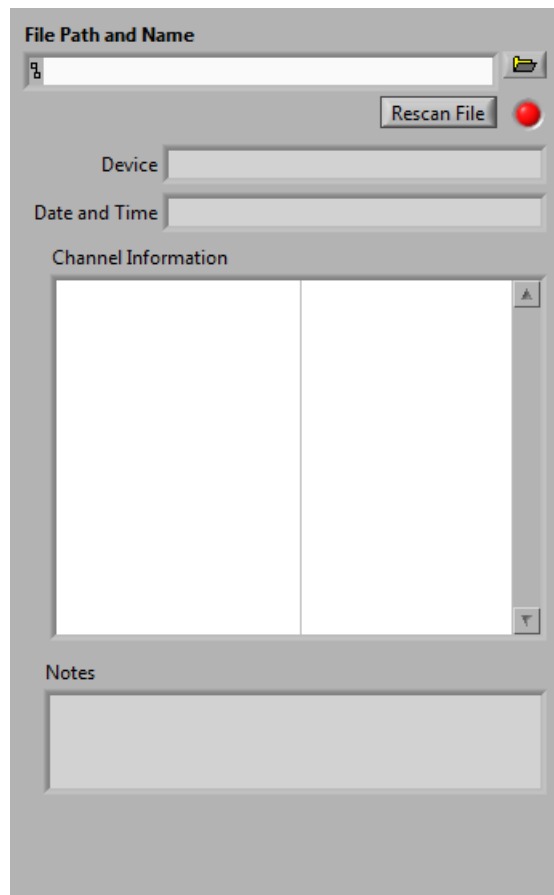
Figure 13. FileReader Plug-In Front Panel Display

The data in the specified file are read only once at the initial loading of the file. Subsequent acquisitions performed by the user do not re-scan the file for any changes and operate from the data stored in memory. The **Rescan** button allows the user to rescan the input file without having to reload the file in the **File Path and Name** control. This can be useful when reading in a file for analysis that is periodically updating while ADCPro is running.

The channel data contained in the file should be available to read via the **Acquire** (or the **F5** function key) or **Continuous** function (or the **F6** function key) when a Test plug-in is loaded. The channel data are read beginning at the start of the file, regardless of how many Acquire cycles are issued or the number of data points acquired.

3.4.3   Other EVM Plug-Ins

When physical hardware is available in the form of an EVM-PDK or other evaluation platform, ADCPro support is provided through the use of an EVM plug-in that comes with its own installer. Running the installer places the EVM plug-in into the plug-ins directory of the ADCPro software. EVM plug-ins generally control any features of the ADC (for example, register settings that control onboard multiplexers or programmable gain amplifiers, as well as parameters such as sample rate). Consult the documentation that comes with the specific hardware and EVM plug-in for details on using the EVM plug-in with ADCPro.

3.5   Test Plug-Ins—Analyzing and Saving Data

In order for the ADCPro shell to enable the **Acquire** and **Continuous** buttons, both an EVM and Test plug-in must be loaded. A test can be selected from the **Test** menu, as shown in Figure 14.
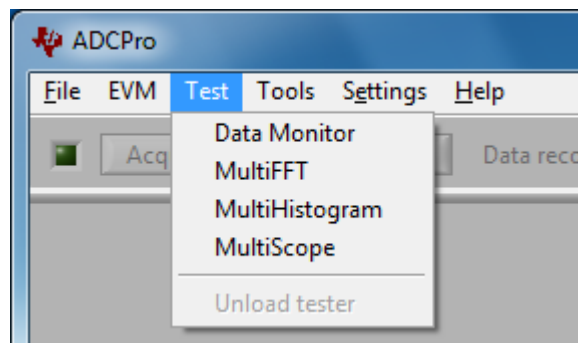
Figure 14. Selecting a Test Plug-In

ADCPro can perform an analysis in either one-shot or continuous mode. In one-shot mode, the program collects a number of samples, analyzes them, and stops. In continuous mode, the one-shot operation is performed repeatedly.

If performing one-shot analysis, all of the samples captured in a block are contiguous. In continuous analysis, some samples may be missing between blocks.

To perform a one-shot analysis, click the **Acquire** button (or the **F5** function key). To perform continuous analysis, click the **Continuous** button (or the **F6** function key); to stop continuous analysis, click the **Continuous** button again.

If no plug-in is ready for analysis, the buttons are disabled.

The number of samples taken depends on the block size set in the test plug-in and/or the number of points set to record in the data recorder.

The maximum block size for any test is 1,048,576 samples per channel.

3.5.1 Data Monitor

The Data Monitor test plug-in allows for the raw data from the ADC to be displayed in the shell. The test displays the contents of the channel that is selected from the **Channel** pull-down button. The channel data are displayed with the left side of the indicator as a decimal equivalent of the code value and the right side showing the channel data as a hexadecimal number equivalent to the code value, as shown in Figure 15. The right hand side display of the data can be modified to display the data in decimal, hexadecimal, octal, binary, or SI notation format by selecting the small gray box located just to the left of the data.

Figure 15. Data Monitor Test Plug-In

3.5.2 MultiScope

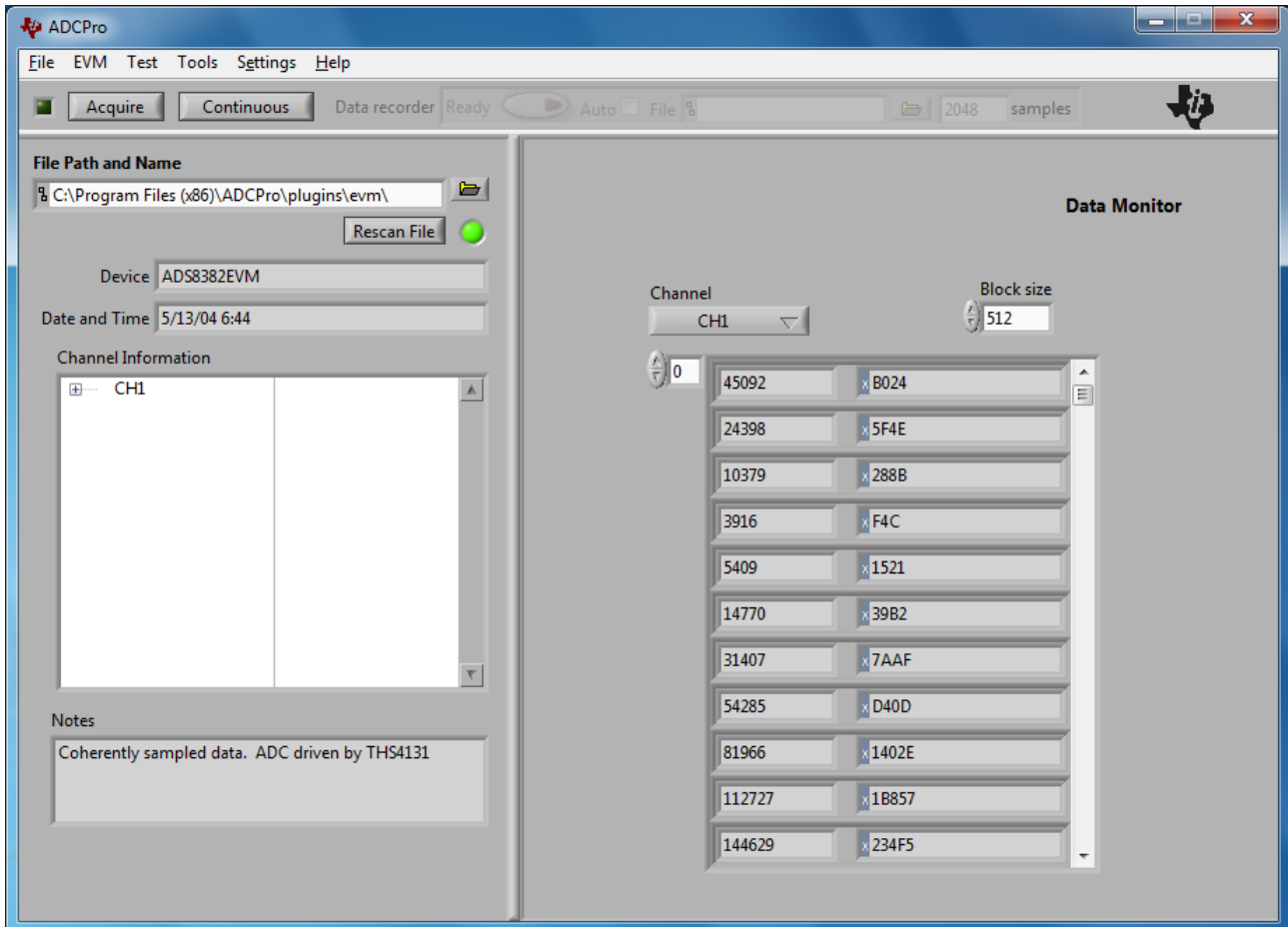The MultiScope test plug-in (shown in Figure 16) is similar to a multichannel oscilloscope. It displays the acquired data in a time domain. From this type of plot, one can determine offset and gain errors if the signal amplitude and offset are known, the same as with a conventional oscilloscope.
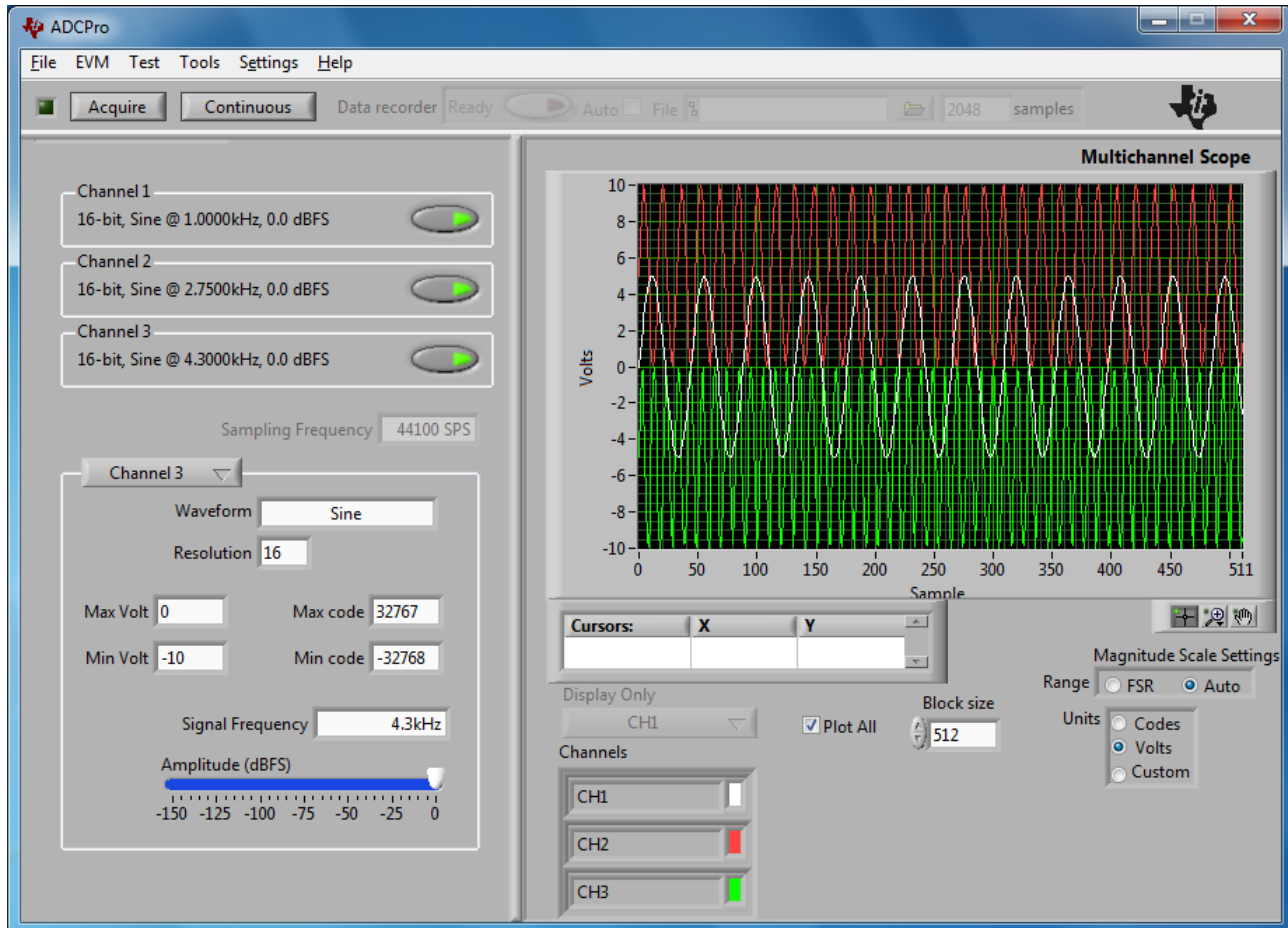
Figure 16. MultiScope Plug-In Display

Unlike an oscilloscope, however, the MultiScope plug-in can display the signal either in volts (as one would view signals with a conventional oscilloscope) , codes, or as a custom function of the codes or volts. This selection is made using the **Units** control on the right-hand side of the front panel. See Section 3.5.2.1 for details on using the *Custom* units option.

The vertical scaling of the display may be set using the **Range** control. When set to *FSR*, the vertical axis is set to the full-scale range of the converter; when set to *Auto*, the vertical axis is scaled to best fit the actual signal range being measured.

The horizontal scaling of the display is determined by the **Block Size**—the number of samples acquired in one block. Remember that when the **Acquire** button is pressed, the number of samples captured is equal to the **Block Size**.

When checked, the **Plot All** check box causes the MultiScope plug-in to display all the channels currently acquired. These channels are shown in the legend below the **Display Only** control, which is disabled when **Plot All** is checked. When **Plot All** is not checked, only a single channel (selected with the **Display Only** control) is displayed. This same option is used on several other test plug-ins.

3.5.2.1 Custom Units on the Graphic Display

To use the custom units control, select the *Custom* option in the control; notice that two additional controls appear beneath the **Units** control. These controls are shown in Figure 17. The **Equation** control displays the current equation that calculates the displayed units. The **Edit** control allows the user to open the equation editor to change the custom equation.
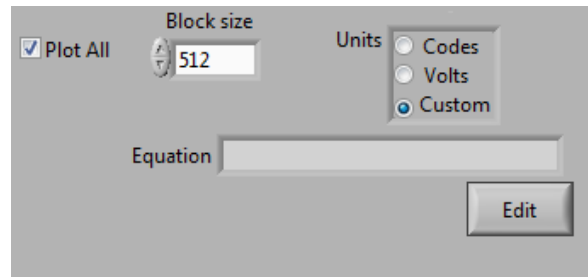
Figure 17. Custom Units Control

The equation editor is shown in Figure 18. Use the **Conversion Factor Equation** control to enter the desired equation into the plug-in. The **Custom Units** control allows the user to specify the unit label that will appear on the Y-axis of the MultiScope display. The **Clear** button clears the **Conversion Factor Equation** field if the user wants to start over or enter a new equation. The **Close** button closes the equation editor and processes the equation entered in the **Conversion Factor Equation** control. The **Available Variables** window shows variables that are available for use in the equation that relate to the data. These variables can be inserted into the custom equation using the *drag and drop* method (that is, dropping them into the **Conversion Factor Equation** control).
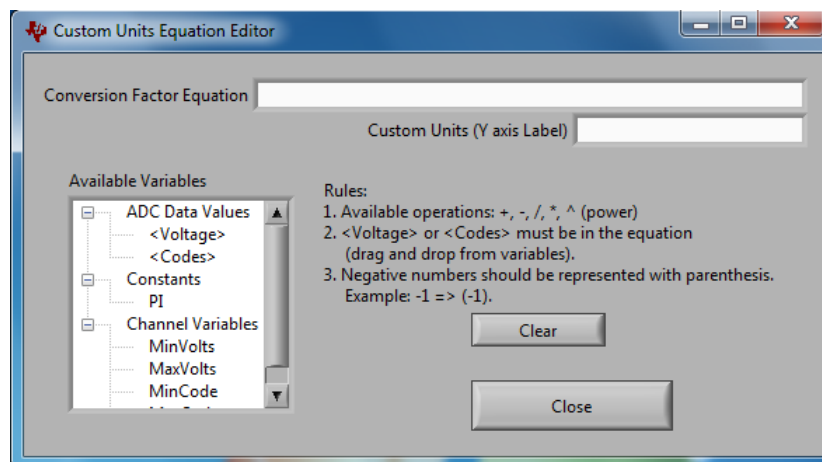
Figure 18. Equation Editor Screen

When creating the custom equation, there are several rules that must be followed in order for the equation to be recognized by the editor. These rules are displayed on the equation editor panel for reference. An example equation is shown in Figure 19.
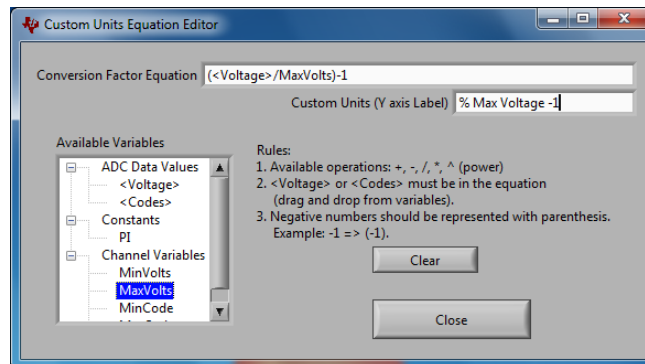
Figure 19. Equation Editor Screen—Example Equation

1. Available operations for the equation editor are addition (**+**), subtraction(**–**), multiplication (*****), division(**/**), and power(**^**). All operations follow the standard mathematical order of operations, and parentheses can be used to change the processing sequence. For example, *2+3*6 = 20*, while *(2+3)*6 = 30*.

2. Either the *<Voltage>* or *<Codes>* variable **MUST** be present in the final custom equation. The variable is where the data collected will be inserted into the equation for evaluation.

3. Negative numbers must be represented using parentheses to surround the negative number. For example, –1 should be represented as (–1).

Once the custom equation is entered, make sure the **Custom Units** control is filled in with the desired Y-axis label; then select the **Close** button. The equation editor will disappear and the graphic display will be updated to show the results of the custom equation (see Figure 20). The **Units** control holds the last equation entered in memory, so the user can switch back to the other options without having to re-enter the equation.

Figure 20. Multiscope Display Screen with Custom Equation

3.5.2.2   MultiScope Graphic Display Options

Three graph tools (**Cursor Movement**, **Zoom** and **Panning** Tool) are located on the lower right side of the graph display (as shown in Figure 21). The **Cursor Movement Tool**, a small crosshair, moves the cursor on the display. The **Zoom Tool** (a magnifying glass) zooms in and out of the display. The **Panning Tool** (the hand icon) picks up the plot and moves it around on the display.

Figure 21. Graph Controls

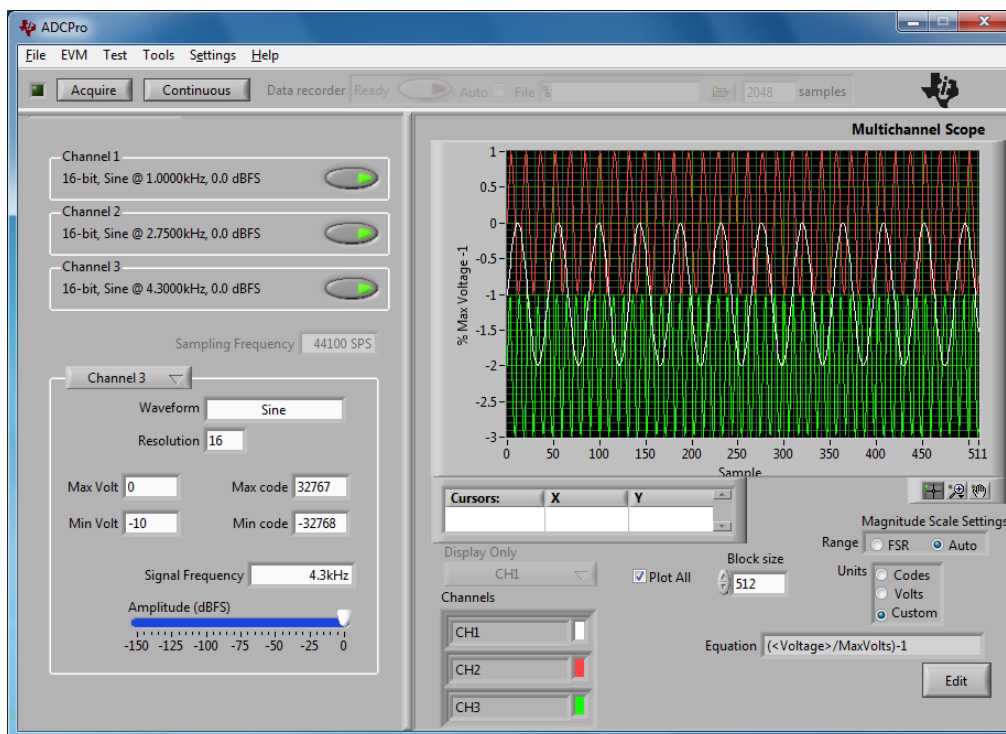The **Cursors** control box is located on the lower left side of the graph (as shown in Figure 22). This control allows users to add cursors to the graph, as can be done with oscilloscopes. Add a cursor to the graph by right-clicking in the Cursor display box and selecting *Create Cursor*. The cursor can be one of two types: *Free* and *Single Plot*.
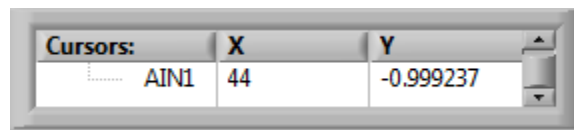
Figure 22. Cursors Display Box

The *Free* cursor type moves the cursor freely within the plot area, regardless of plot position. The *Single Plot* cursor positions the cursor only on the plot that is associated with the cursor. The cursor moves along the associated plot. If the cursor is out of view, right-click on the Cursor display box and select *Bring to Center*. The cursor is accessed by left-clicking the crosshair box located on the lower right-hand corner of the graph (that is, *Graph Tools*). More control options for cursors are available by right-clicking on the cursors box.

As with more powerful oscilloscopes, it is possible to zoom in and out of the graph display. Start by left-clicking on the magnifying glass located on the lower right-hand side of the graph (that is, *Graph Tools*). The *Zoom to Rectangle* option allows the user to click on a point on the display that is to be the corner of the zoom area, and drag the tool until the rectangle covers the zoom area.

The *X-zoom* option allows the user to zoom in on an area of the graph along the x-axis. The *Y-zoom* option allows the user to zoom in on an area of the graph along the y-axis. *Zoom In about Point* allows the user to click a point to zoom in on. Press and hold the <Shift> key to switch between *Zoom In about Point* and *Zoom Out about Point*. The *Zoom to Fit* option allows the user to auto-scale all x- and y-scales on the graph or chart.

In all of the ADCPro tests that display graphs, the user can save the graph by right-clicking on it and selecting either *Copy Data* or *Export Simplified Image*. If selecting *Copy Data*, the graph and its controls (cursor controls and graph tools) are copied to the clipboard and can then be pasted as an image into other applications. If selecting *Export Simplified Image*, only the graph image itself is copied, as black on a white background. The user can choose to copy this to the clipboard or save to a file, and a dialog box is shown that allows the user to select from several file formats.

3.5.3 MultiHisto

Histogram testing is used extensively in characterizing ADCs. A histogram is merely a count of the number of times a code has occurred in a particular data set. The MultiHisto test plug-in creates a histogram of the data in the acquired data set and displays it. This feature can be useful in two distinct ways: noise testing and linearity testing.

Noise is the uncertainty of a measurement. With earlier-generation 8-bit and 12-bit converter ICs, not much attention was usually given to this important aspect of electronic measurement because it is not difficult to make an 8-bit or 12-bit converter relatively noise-free.

Low-noise, delta-sigma (ΔΣ) converters have brought this topic to the attention of many designers. 24-bit, noise-free resolution is an extraordinarily difficult thing to obtain. Therefore, we need a way to measure and evaluate noise.

In many ac measurement applications, such as audio and radio circuits, noise measurement techniques are well-known. Typically, noise measurements are obtained by analyzing the measured signal in the frequency domain. A Fast Fourier Transform (FFT) plot taken of a high-speed converter output provides a useful estimate of the device noisiness. The figure measured here is called *signal-to-noise ratio*.

In low-frequency measurement applications, however, an FFT plot is not nearly as useful because we are measuring signals near dc. Instead, we want to measure how certain we are of the value reported by the converter. We obtain this by making many successive conversions with a single dc input applied to the converter and calculating statistical functions over the collected data.

The two most common measurements of certainty for an ADC are RMS noise and peak-to-peak noise. RMS noise is more applicable to an ADC, since it does not depend on the kind of noise present. Peak-to-peak noise calculations, however, are not as mathematically rigorous, and often assume that the noise is Gaussian in distribution, but they are essential for applications (such as weigh scales and thermometers) where the flicker or constancy of a displayed value must be known.

Ideally, a fixed dc input to an ADC should result in the same output code for every conversion. Even with a precision ADC, for a given input voltage the user should expect to see a range of output codes. This result is caused by circuit noise within the ADC. The noise is equivalent to summing the broadband noise with the input of a noiseless ADC.

If applying a dc signal to the ADC and record several thousand readings, the result is a distribution of codes similar to that shown in Figure 23. In Figure 23, the measurement is taken by shorting the differential inputs of the 24-bit ADS1258 together. Note that we can determine offset from the histogram as well—with the inputs grounded, the output code should be centered around zero, as it is here.

The **DC Analysis** box displays several parameters of the captured data set. The *StDev* column displays the standard deviation of the data set. This value is equivalent to the RMS noise of the signal when analyzing a dc data set. The *Codes (pp)* column shows the peak-to-peak spread of the codes in the data set; for a dc data set, this range would be the peak-to-peak noise. The *Mean* column displays the mean of the data set; as pointed out above, this value might be one way to measure offset.

The last two columns on the **DC Analysis** display relate to calculating ENOB (see Appendix A). The *ENOB* column displays the effective number of bits of the converter as calculated from the standard deviation or RMS noise. The *Noise Free Bits* column displays the effective bits of the converter when calculated using the peak-to-peak noise.

NOTE: The dc analysis values are only meaningful when using a dc input and a data block size of at least 1000 points.
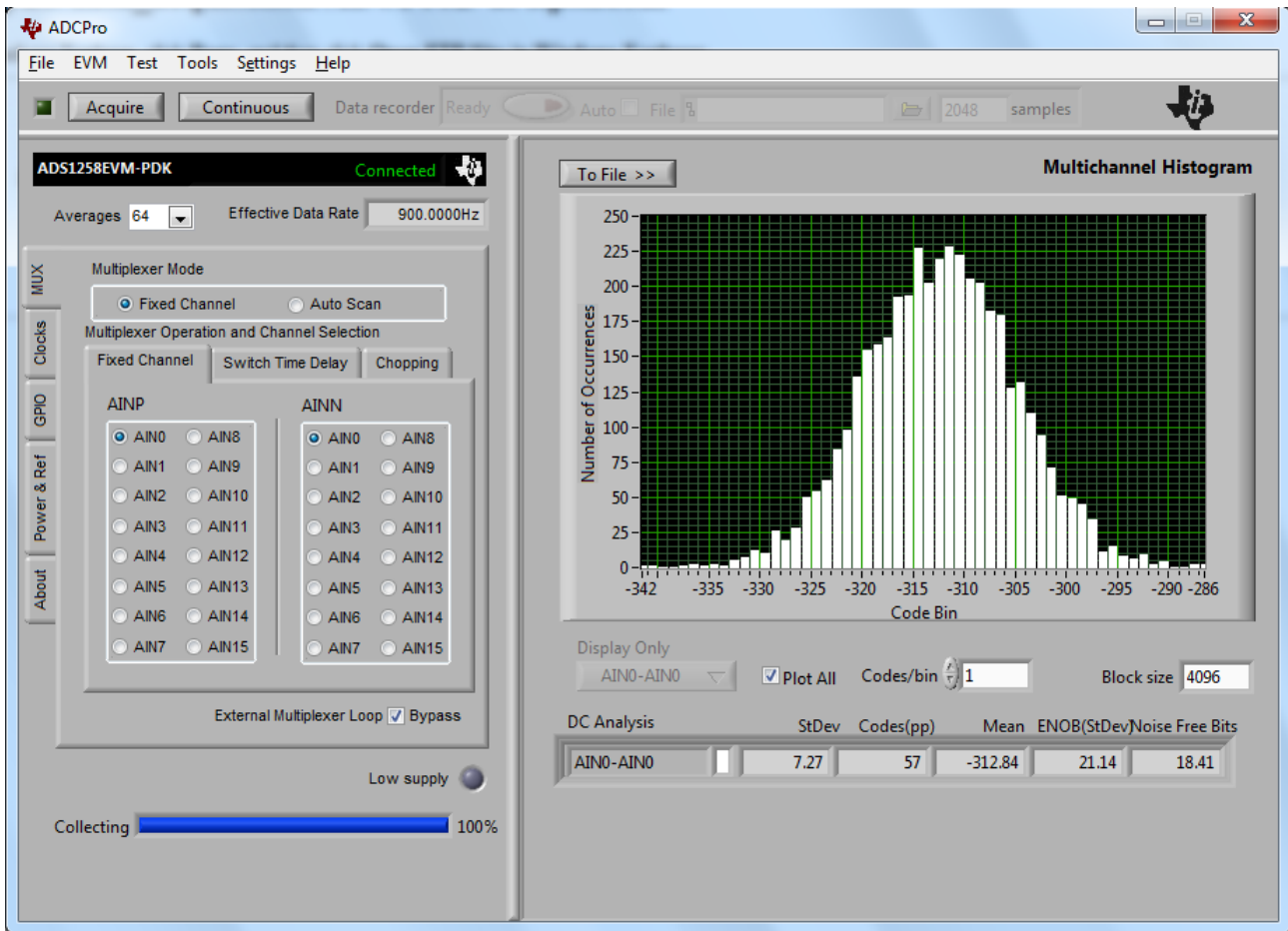
Figure 23. Noise Histogram Results

Histograms can be taken on any number of dynamic signals. Ramp signals or sine waves are the most commonly-used signals. Histograms are taken of these signals to determine linearity. A ramp input should exercise every code in the transfer function as it ramps from one end of the converter range to the other. This measurement should result in a flat histogram; variations from this ideal reveal shorter or longer codes. As the converter resolution increases, the required linearity of the ramp input signal becomes difficult to create with common test equipment. This difficulty is why a sine wave input is often used, because it is easier to create a highly accurate sine wave by filtering a high-quality signal generator. The shape of a sine wave histogram is the probability density function for a sine wave. Figure 24 shows three channels of sine wave data and the resulting respective histograms.

Figure 24. Sine Wave Histograms

By comparing the measured sine wave histogram to the ideal probability density function (PDF) for a sine wave, one can determine both integ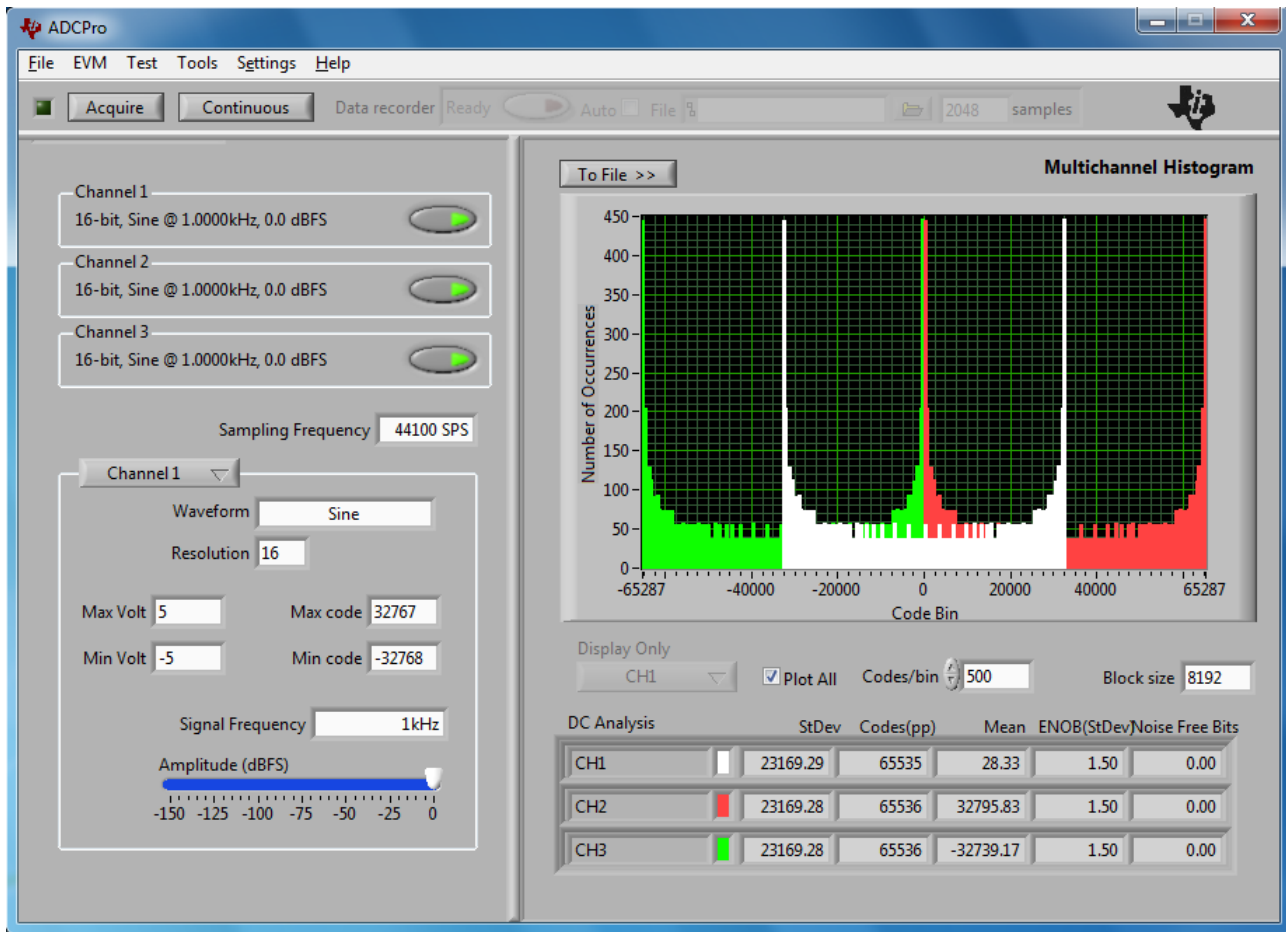ral nonlinearity (INL) and differential nonlinearity (DNL) errors. In both the ramp and sine wave methods, several hits per code (~50 or more) are required for meaningful results. This condition means that a proper measurement requires a very large data set for higher resolution converters—for example, a 16-bit converter requires a data set of approximately four million samples. The MultiHisto plug-in does not at this time calculate INL or DNL data.

The **Codes/bin** control affects the qualitative look of the histogram display. For the highest accuracy of reading the display, this control should be set to one code per bin. However, it can be set to a higher number to make it easier to see some qualitative features of the histogram. For example, in Figure 24, this control is set to 500, combining 500 codes into one bin. Having collected only 8192 points, a one code/bin display would not look like the sine wave in this example; by setting this limit higher, we can see the characteristic sine wave PDF and observe that the input was a sine wave.

The **To File >>** control allows the histogram data to be saved in a tab-delimited text file format that can be imported into Microsoft® Excel®or other spreadsheet/software tools. This file contains the processed histogram data, not the raw data, which is available via the DataRecorder plug-in. The DC Analysis statistics are also included at the beginning of the file for reference.

3.5.4 MultiFFT

The MultiFFT test plug-in performs a Fast Fourier Transform (FFT) computation on a record of data, and displays the resulting frequency domain plot on its main graph. It also calculates key performance parameters such as SNR, THD, SINAD (that is, THD + noise), and SFDR (for definitions of these parameters, see Appendix A). Figure 25 shows the MultiFFT display. Some distortion components and the measurements of the calculated parameters are available in the box near the bottom of the MultiFFT window.
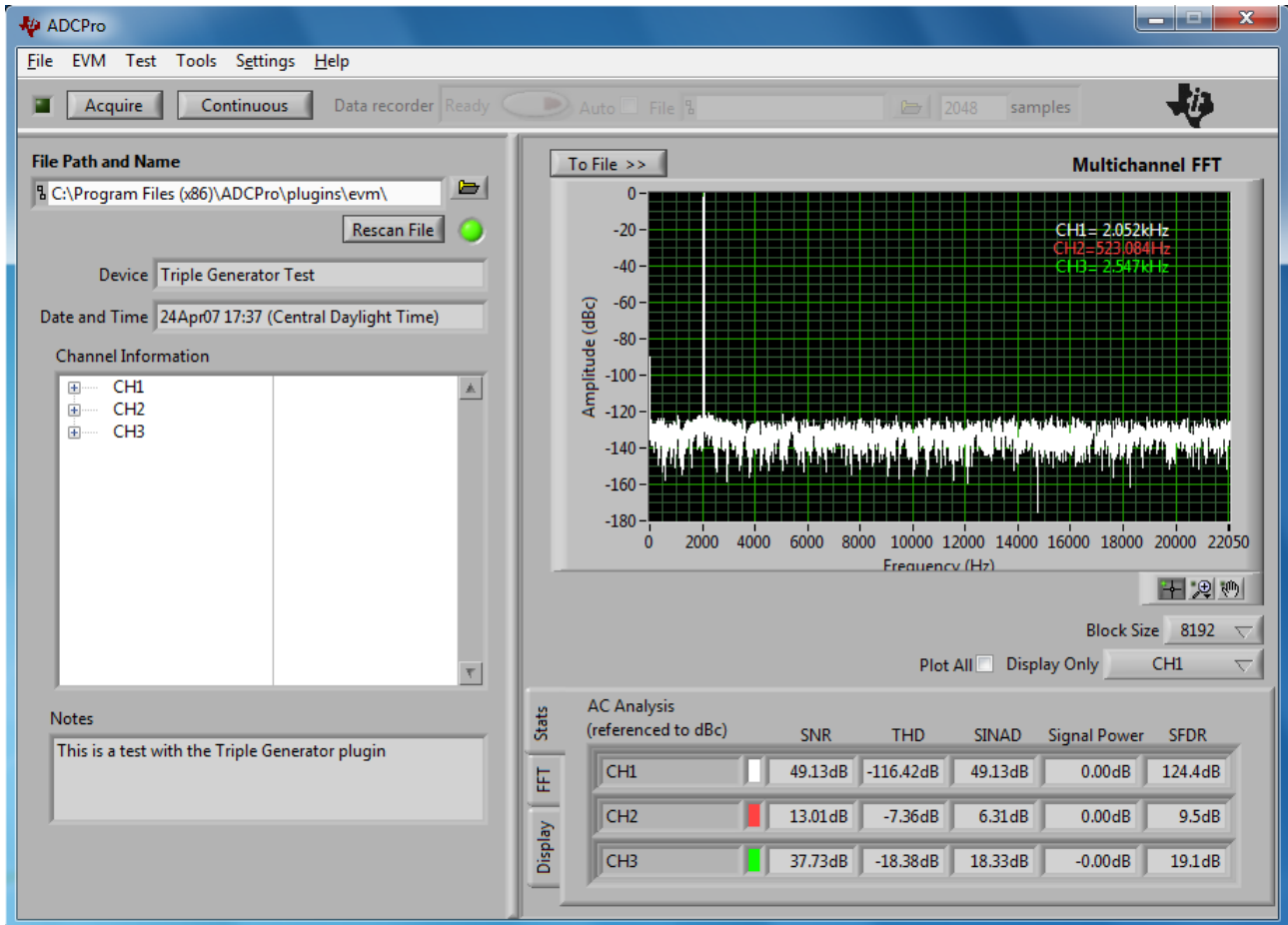

Figure 25. MultiFFT Test Plug-In

The ideal sine wave test setup for performing FFT tests includes a sine wave generator that can be phase-locked to the sample clock. In cases where this coherent sampling can be done, no windowing of the data is necessary; with converter systems where phase locking to the clock is impractical, windowing functionality is usually used. See Appendix A for details on coherent sampling and windowing.

The **To File >>** control allows the FFT data to be saved in a tab-delimited text file format that can be imported into Excel or other spreadsheet/software tools. This file contains the processed FFT data, not the raw data, which is available via the DataRecorder plug-in. The AC Analysis statistics are also included at the beginning of the file for reference.

The FFT display has several controls that allow users to manipulate the data and provide detailed information gathering. These features include:

- Harmonic Cursors
- Frequency and Amplitude Scaling
- Graph Controls
- Window Function

- Display Only and Plot All
- Block Size
- Leakage bins controls for DC, Fundamental, and Harmonic Frequencies

In addition to the controls, displays also provide statistical data and other information from the collected data.

3.5.4.1 Main Panel Graph Controls

The display also features graph controls and cursors. See Section 3.5.2 for more information about using these controls.

Display Only and Plot All

The display provides the ability to plot multiple channels or only one channel at a time. This function behaves the same as described in Section 3.5.2.

Block Size

In order to provide accurate FFT analysis, the number of data points is typically restricted to 2^n, where n is an integer. The **Block Size** control provides a drop-down list for values that satisfy this requirement.

3.5.4.2 MultiFFT Tab Graph Controls

The MultiFFT plug-in has three tabs located at the bottom of the panel: *Stats*, *FFT*, and *Display*. Figure 25, Figure 26, and Figure 27 show the different views of each tab.

The *Stats* Tab is displayed as the default and shows the channel legend and the calculated statistical data from the data collected. The *FFT* Tab contains controls that allow for the customization of the FFT display and calculated statistical data.

3.5.4.2.1 Stats Tab Controls

The **AC Analysis** box displays several parameters of the captured data set. In all but the *Signal Power* display, these parameters are displayed in terms of dBc, or decibels to carrier—in other words, referenced to the power of the input signal. The actual input *Signal Power* is displayed in terms of dBFS, that is, referenced to the full-scale range of the converter. See Figure 25 for a screenshot of the *Stats* tab.

- The *SNR* column displays the signal-to-noise ratio of the data set. See Appendix A for more information.
- The *THD* column shows the total harmonic distortion in the data set. See Appendix A for more information.
- The *SINAD* column displays the value of the signal to noise + distortion ratio. See Appendix A for more information.
- The *Tone, Hz* column shows the frequency of the largest amplitude signal (in hertz), typically the fundamental frequency.
- The *SFDR* column displays the spurious-free dynamic range of the data set. See Appendix A for more information.
- The *Signal Power(dB)* column displays the signal magnitude of the frequency in *Tone, Hz*.

3.5.4.2.2 FFT Tab Controls

Controls for windowing and leakage bins allow control over how the FFT is processed, and displays are provided for the harmonic frequency magnitudes. The FFT Tab is shown in Figure 26.
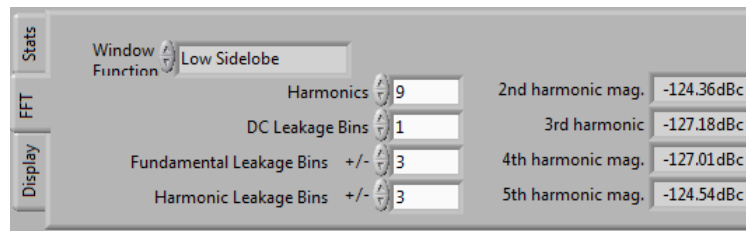
Figure 26. MultiFFT FFT Tab Controls

Window Function

Windowing of data is described in Appendix A, and is often used when coherent sampling is not an option. Essentially, the term *windowing* describes the application of a mathematical function to a given data set, such that the endpoints of the data set are driven to 0. The **Window Function** control allows selection from a list of a window functions to apply to the data set:

- None (no windowing applied; use for coherent data sets)
- Hanning
- Hamming
- Blackman-Harris
- Exact Blackman
- Blackman
- Flat Top
- 4-Term Blackman-Harris
- 7-Term Blackman-Harris
- Low Sidelobe

For a more thorough discussion of windowing, refer to IEEE1241-2000.

Harmonics and Leakage Bin Controls

The **Harmonics** control determines the number of harmonics that are included in the statistical calculations.

The leakage bin controls provide for the removal of the unwanted frequency bins that may be the result of non-coherent data sampling. The **Fundamental Leakage Bins** and **Harmonic Leakage Bins** controls should be set to the number of bins on each side of either the fundamental or harmonic frequency to include with the main frequency power. The **DC Leakage Bins** allows the number of frequency bins that are a result of the dc portion of the measurement to be excluded from calculations.

The harmonic magnitude indicators display the harmonic amplitude that corresponds to the harmonic shown to the left of the indicator.

3.5.4.2.3 Display Tab Controls
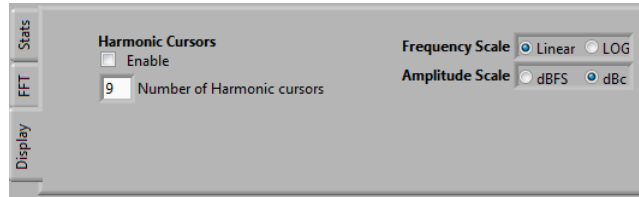
Figure 27 shows the *Display* tab controls.

Figure 27. MultiFFT Display Tab Controls

Frequency and Amplitude Scaling

Both axes of the display can be changed using the **Frequency Scale** and **Amplitude Scale** controls. The **Frequency Scale** control changes the frequency axis of the display to either *Linear* or *LOG* (logarithmic) scales.

The **Amplitude Scale** control adjusts the plot in relation to different magnitudes. The *dBFS* option shows the data with the 0dB level representing a full-scale signal. The *dBc* option shows the data with the 0dB level compensated to be the magnitude of the fundamental frequency.

Harmonic Cursors

The MultiFFT display provides the ability to mark the fundamental frequency and the harmonics on the output graph. This feature displays up to nine harmonics in addition to the fundamental frequency. The markers are labeled in terms of f0, the fundamental frequency. For example, the 5th harmonic would be *5f0*.

Each of the frequencies are marked with a small cross and dot, as shown in Figure 28. The detailed coordinates of the cursors are shown in the bottom left window under the FFT display. Users are able to scroll this window in several directions for viewing specific harmonic information.
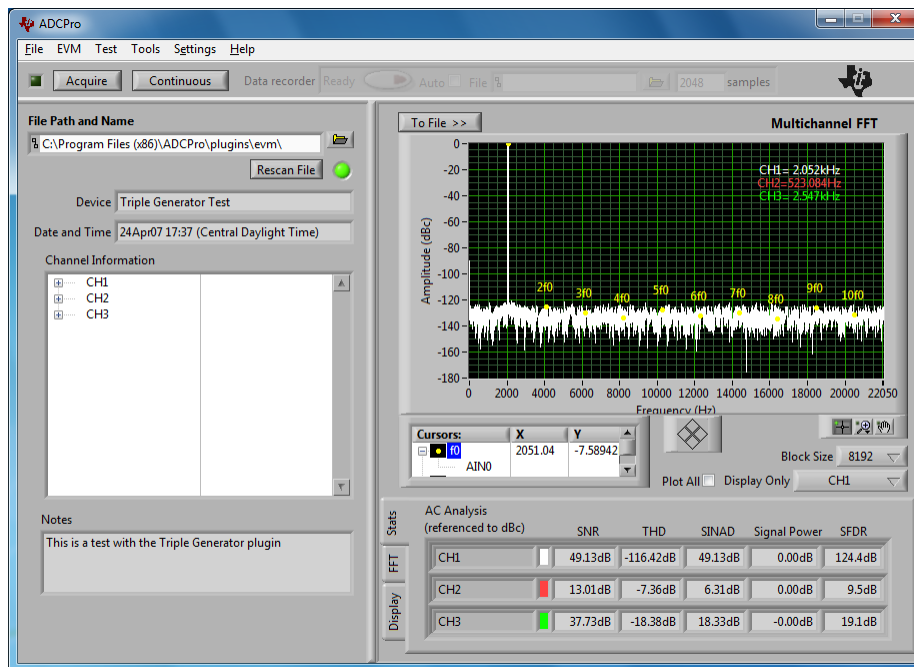

Figure 28. Harmonic Markers

In order to add the harmonic cursors, do the following:

1. Deselect the **Plot All** option beside the **Display Only** control. The cursors can only be displayed for one channel at a time. Deselecting **Plot All** should enable the **Harmonics** selection box and number control.

2. Choose the number of harmonics to display by entering the number in the **Harmonics** number control. The default setting shows nine harmonics.

3. Check the **Harmonics** selection box; the harmonic cursors should be added to the FFT display.

The number of harmonics can be changed and the display should update. Selecting the **Plot All** feature or disabling the **Harmonics** selection box removes the harmonic cursors from the FFT display.

3.5.5 Data Recorder

The Data Recorder saves acquired data samples to a file. The user does not need to load a specific test plug-in to use the Data Recorder. If a test plug-in is loaded, it analyzes samples as they are recorded.

Follow this procedure to record samples:

1. Click the small folder icon in the Data Recorder. A file dialog box opens, as displayed in Figure 29.

2. Enter the name of a file, or select a file to record to. ADCPro data files are saved as ASCII (tab-delimited) text files, so a .txt extension is the appropriate file extension to use.

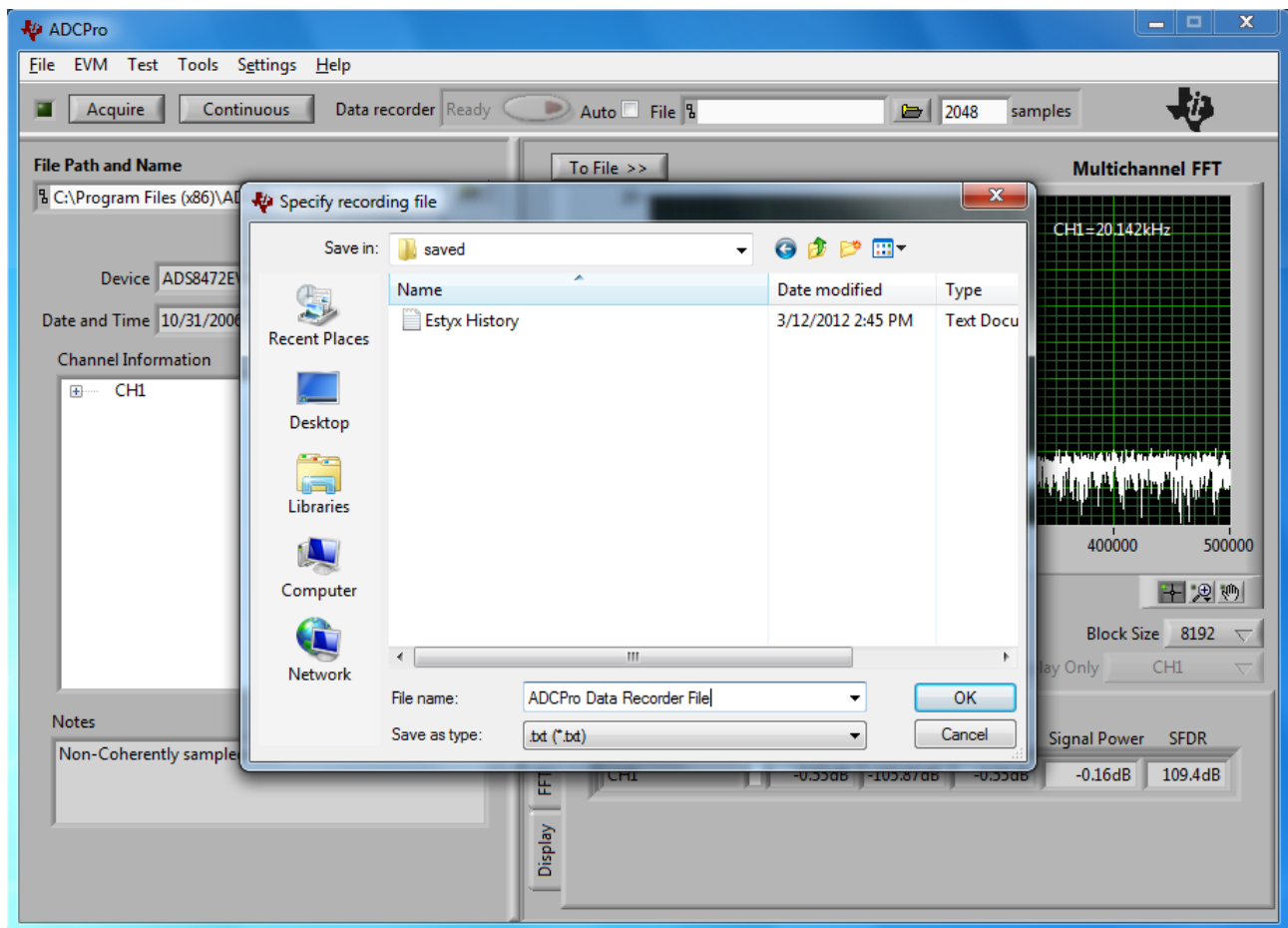**Figure 29. Selecting a File to Record Data**

3. The file path appears in the **File** box.

4. Select a number of samples to record by putting a number in the **Length** control. Note that **Length** does not have to be the same size as a loaded test block size. Figure 30 shows the Data Recorder with file and length values specified.
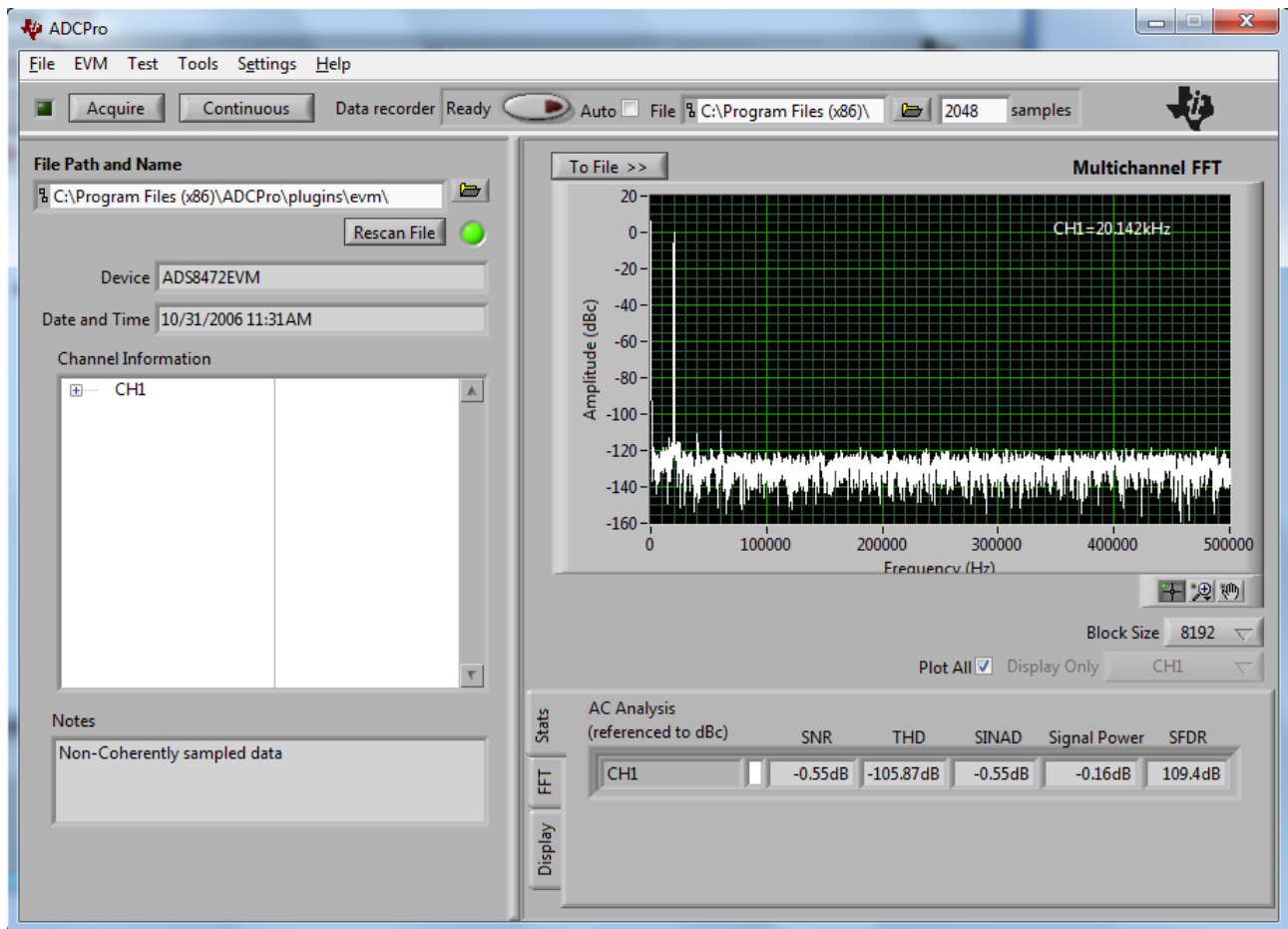

Figure 30. Data Recorder Set Up with File and Length Specified

5. Click the **Ready** button. This action opens a dialog box where the user can enter the device name and any notes or comments about the test conditions of this saved data set, as shown in Figure 31.
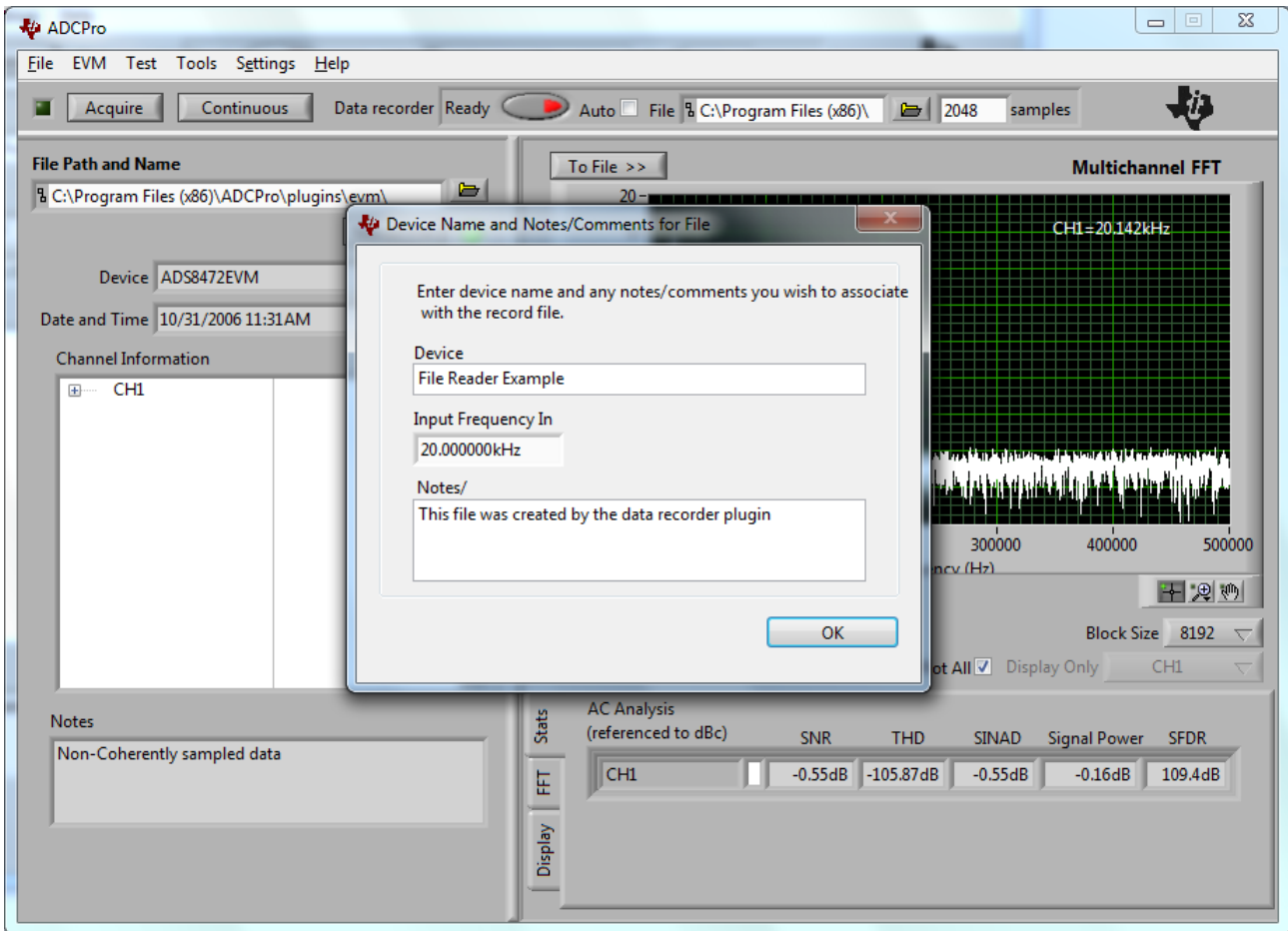

Figure 31. Device Name and Notes/Comments for File Dialog

6. Click the **Acquire** or **Continuous** button to start data collection. If **Continuous** is selected, only the first **Length** number of samples is saved.

The **Auto** control allows for the filename to be auto-incremented in conditions of existing files. If the control is not checked, the data recorder cannot be used in **Continuous** Acquisition Mode and it will over-write any existing file data in single Acquisition Mode. With the **Auto** control checked, both acquisition modes can be utilized. The filename of the file saved is changed by appending a number to the end of the file name in incrementing order (for example, *SavedData_1.txt*). With the **Continuous** acquisition mode, remember that the data from one acquisition cycle to the next may not be contiguous, therefore the data files will exhibit this same behavior.

Data are recorded in a tab-delimited text format, and can be easily imported into most spreadsheet programs. Data files can also be read into ADCPro using the **File Reader** plug-in that is available by default with ADCPro.

The data files are output and read back in a specific format. In order for the file to be read correctly, the data must be in the format described below. The file is tab-delimited, so all columns must contain a tab between data if the file is created using a text editor. If the file is created using the **Data Recorder** plug-in, this formatting is done automatically.

Viewing this file in a spreadsheet program makes the column separations a bit more clear, as shown in Table 1.

Table 1. Sample Tab-Delimited Text File

[Device Information]			
EVM Device Name	Triple Gen		
Date and Time	4/24/2007 5:21:58 PM		
Notes	This is a test with Triple Gen		
Number of Channels	3		
[Channel Information]			
Channel Name	CH1	CH2	CH3
Sampling Frequency	44100.000	44100.000	44100.000
Input Frequency	1001	1002	1003
Max Code	32767	32767	32767
Max Voltage	0.000	15.000	5.000
Min Code	–32768	–32768	–32768
Min Voltage	–15.000	0.000	–5.000
Data Format	Decimal	Decimal	Decimal
[Channel Data]			
	32767	–7450	14820
	32767	–9979	10563
	32767	–12444	6306
	32767	–14829	2050
	–32768	–17119	–2207

The first four rows contain the following information.

- EVM Device Name: Text describing the device used. The **Data Recorder** plug-in prompts the user for this information.
- Date and Time: Date and time the file was created.
- Notes: Notes for this test (the **Data Recorder** plug-in).
- Number of Channels: Number of data channels in this file.

A blank row is then inserted, followed by a row with the entry `[Channel Information]`. This row denotes the start of the Channel Information section. This section includes this information:

- Channel Name: Name of each channel of data.
- Sampling Frequency: Sampling frequency for each channel of data.
- Input Frequency: Main input frequency for each channel of data.
- Max Code: Maximum code value for each channel of data.
- Max Voltage: Maximum voltage for each channel of data.
- Min Code: Minimum code value for each channel of data.
- Min Voltage: Minimum voltage for each channel of data.
- Data Format: The data format for each channel, either *Hexadecimal* or *Decimal*.

Another blank row follows this field, followed by a row with the entry `[Channel Data]`. This row denotes the start of the data section. The actual data are formatted in columns with tabs separating each column. Note that there is an extra tab at the beginning of the line, making the first column of data actually start in the second column.

3.6   ADCPro Tools

ADCPro tools are applications designed to aid converter testing with ADCPro.

Presently, the only available tool is the *Coherent Frequency Calculator* (see Figure 32). This is a tool that can help find the best input frequency to use for a given sample rate, in order to do coherent sampling (see Appendix A). Even if the user cannot phase-lock the source to the sampling clock, by using the right input frequency one can often eliminate the need to window data for FFT testing (see Appendix A for details).
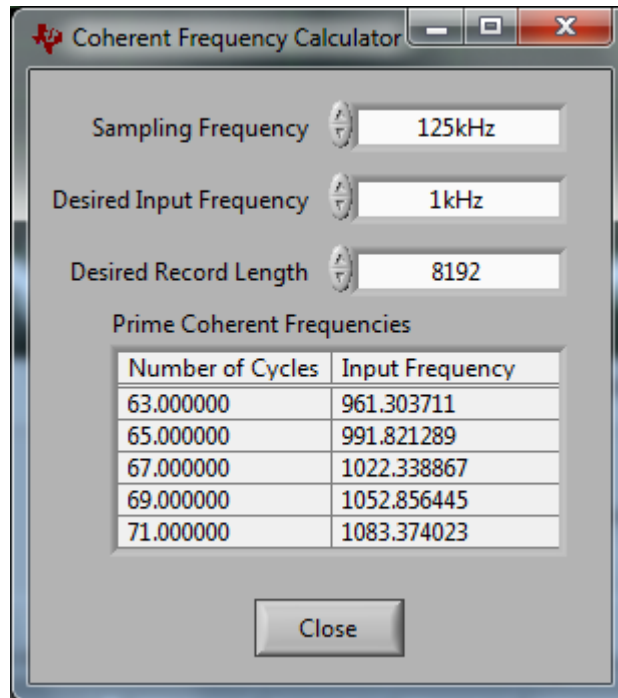

Figure 32. Coherent Frequency Calculator

Follow these Instructions to use the Coherent Frequency Calculator.

1. Enter the sampling frequency in the **Sampling Frequency** box.
2. In the **Input Frequency** box, enter the desired input frequency to be tested.
3. Enter the **Desired Record Length** by clicking on the box and selecting an option from the drop-down menu. This value should match the *Block Size* of the test (usually an FFT) being performed.

The **Prime Coherent Frequencies** table displays the frequencies that would provide a coherent data set given the input conditions. In the example shown in Figure 32, a 1000Hz frequency is desired, but a 1022.338867Hz input would be coherent. It is usually best to choose a frequency that provides a prime number of cycles—in this example, 67 cycles would be a better choice than 69 (because 69 is divisible by 3, it is not a prime number).

When the user is done using the calculator, press the **Close** button and the calculator window closes.

4   Troubleshooting

Problem: ADCPro is not responding.

Solution: If ADCPro stops responding while an EVM-PDK is connected, try unplugging the power supply from the EVM-PDK. Unload and reload the EVM plug-in before reapplying power to the PDK.

Problem: On large data captures, it takes a long time to update the graph.

Solution: Performance depends heavily on the computer memory available. For normal sinusoidal ADC analysis, it is advisable to use 16k or 32k points.

Problem: ADCPro error state memory is full for the histogram or FFT plug-ins.

Solution: For **MultiHisto** and **MultiFFT**, the data processing has a large memory requirement. Processing large data sizes for the FFT or large data ranges and small codes/bin values may cause memory limitations based on the user's computer memory resources. For the histogram, increasing the codes/bin value can help alleviate this error.

If the plug-in loads in the panel and cannot connect to the hardware, try resetting the hardware by pressing the *Reset* button on the motherboard. The plug-in should then be unloaded and reloaded. The plug-in should now proceed through the firmware download and connection.

Problem: ADCPro times out when loading my software for the first time.

Solution: ADCPro has a built-in timeout function when loading the firmware. Therefore, the software may timeout when the drivers are loaded during the first run after software installation. Unload the plug-in, reset the motherboard by pressing the *Reset* button, and reload the plug-in. The plug-in should load the firmware and connect normally.

Appendix A Basics of ADC Measurement and Evaluation

The information presented in this section is relevant for all ADC evaluation and performance characterization. For further information, please refer to the IEEE Standard 1241-2000.

NOTE: For additional examples and explanations of these measured parameters, users are encouraged to download and review a copy of Texas Instruments' application report SBAA147, *A Glossary of Analog-to-Digital Specifications and Performance Characteristics*.

A.1 Definitions of Measured Parameters

One primary task in evaluating an ADC is determining its transfer function. Ideally, a converter would have a transfer function similar to that shown in Figure 33. This graph shows a transfer function for a 3-bit converter. Ideally, the width of each code is exactly the same, and a straight line can be drawn through the midpoints of each code *plateau*. In practice, this performance is not always observed; determining the transition points and code widths is critical to ADC testing and characterization, because it lets us see where the actual transfer function deviates from the ideal.
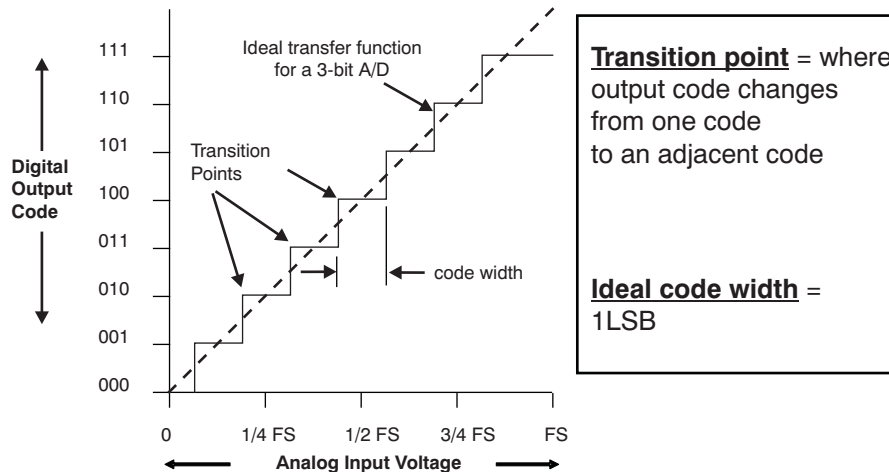

Figure 33. ADC Transfer Function

A.1.1   Quantization Noise

Because the converter can only represent certain values, it deviates from the ideal straight line; the deviation occurs in a repeatable pattern. The error varies by ±0.5 LSB, as shown in Figure 34. This error is known as *quantization error* or *quantization noise*.
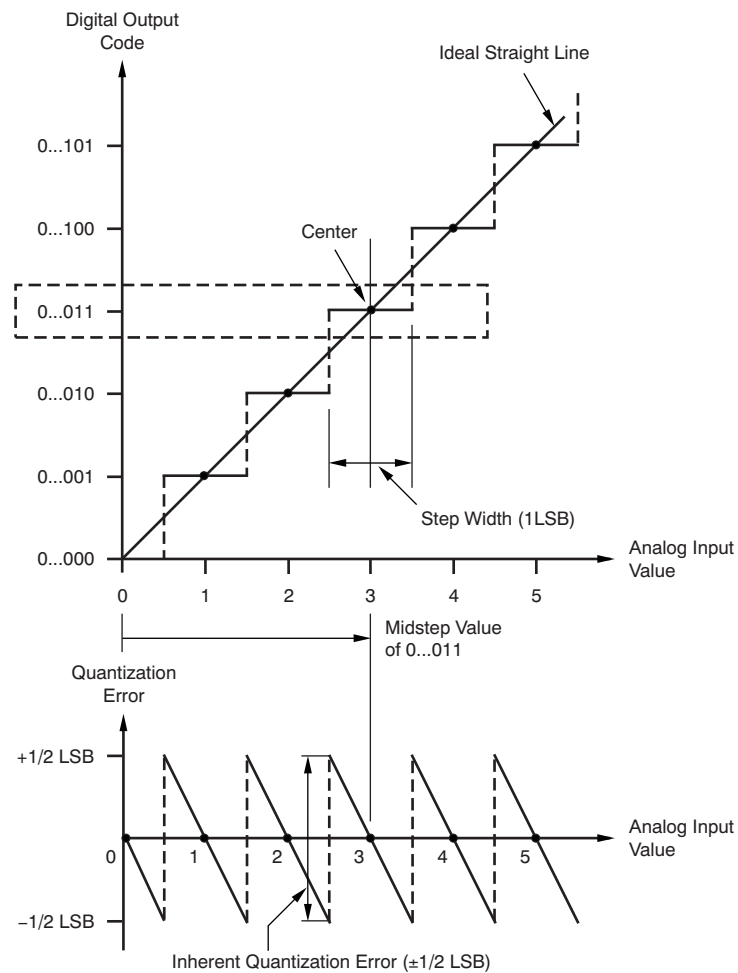

Figure 34. Quantization Error

Why would the quantization error be considered noise? If a signal varies across the full-input range, then this error signal is present as well; and anything that is not signal in the transmitted code is, by definition, noise. Thus, this error is correctly identified as quantization noise.

A.1.2   DC Parameters

The parameters described in this section are primarily tested at dc. See Section A.2 for a description of common test setups used for these parameters.

A.1.2.1   *Offset Error*

In a unipolar device, offset error is the difference between the first measured transition point (lowest in voltage) and the first ideal transition point, as shown in Figure 35.
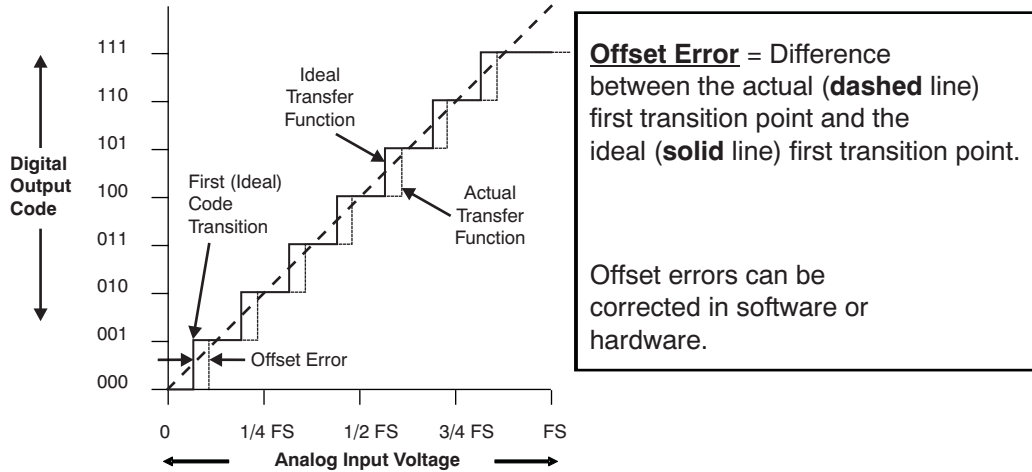

Figure 35. Offset Error

Unipolar offset error is measured and calculated as shown in Equation 1:

$$\text{Offset Error} = (V[0{:}1] - 0.5 V_{1LSB}) \tag{1}$$

where:

$$V_{1LSB} = \frac{VREF}{2^n} = \text{Ideal LSB Voltage Size} \tag{2}$$

with:

    V[0:1] = analog voltage of first transition;
    VREF = full-scale voltage; and
    n = number of converter bits.

For a bipolar device, offset error is the deviation of output code from mid-code or midscale (or zero) when both inputs are tied to a common-mode voltage.

A.1.2.2 Gain Error

Also known as Full-Scale Error, Gain Error is the difference between the ideal slope between zero and full-scale (as well as negative full-scale for differential-input ADCs) and the actual slope between the measured zero point and full-scale (as shown in Figure 36). Offset errors are zeroed out for this error calculation. This parameter is a dc specification, using a near-dc analog input voltage for measurements.
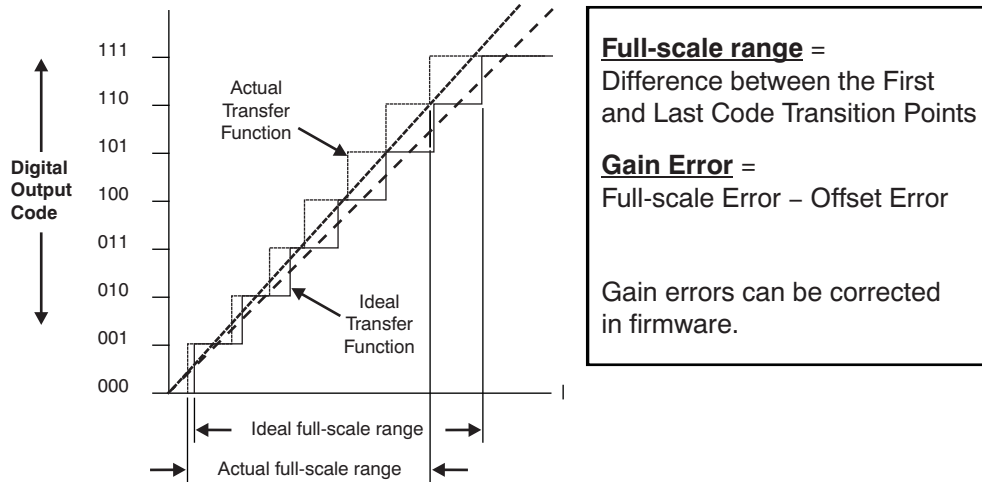

Full-scale range =
Difference between the First
and Last Code Transition Points

Gain Error =
Full-scale Error – Offset Error

Gain errors can be corrected
in firmware.

Figure 36. Gain Error

A.1.2.3 Differential Nonlinearity (DNL)

An ideal ADC exhibits code transitions at analog input values spaced exactly 1LSB apart, as shown in Equation 3:

$$\left(1\text{LSB} = \frac{V_{FS}}{2^n} \right)$$

(3)

DNL is the deviation in code width from the ideal 1LSB code width. A DNL error less than –1LSB can cause missing codes.

DNL is a critical specification for image-processing, closed-loop, and video applications. This parameter is a dc specification, where measurements are taken with near-dc analog input voltages. Figure 37 illustrates the ideal transfer function as a solid stairstep and the DNL error as a dashed stairstep.
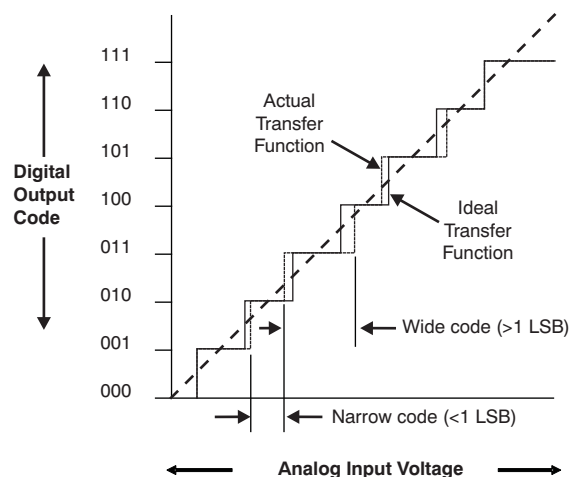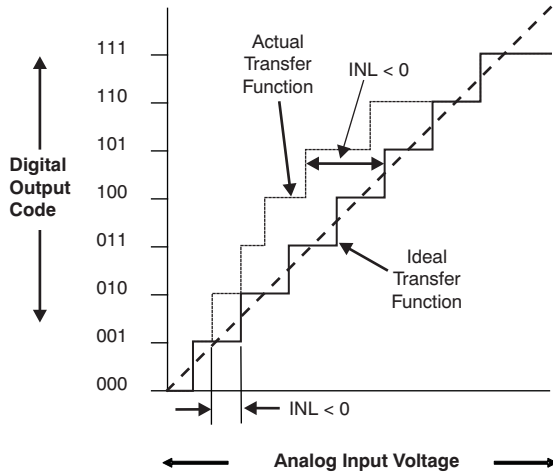

Figure 37. Differential Nonlinearity (DNL)

A.1.2.4   Integral Nonlinearity (INL)

INL is also known as *Relative Accuracy Error*. INL is the maximum deviation of a transition point from the corresponding point of the ideal transfer curve, with the measured offset and gain errors zeroed. INL is shown in Figure 38.

Figure 38. Integral Nonlinearity (INL)

This specification can be referenced to a best-fit transfer function or an end-point transfer function. The best-fit INL results will be one-half the error of the end-point measurement method for the same device. The best-fit transfer function is determined with a least squares curve fit to the transfer function. This parameter is a dc specification, where measurements are taken with near-dc analog input voltages. The units for INL are LSB.

A.1.3   AC Parameters

While Section A.1.2.4 described dc (static) characteristics, ac (dynamic) characteristics of an ADC are often more important, depending upon the application. Figure 39 shows the response of a converter to a sine wave input and shows the output data in the frequency domain.
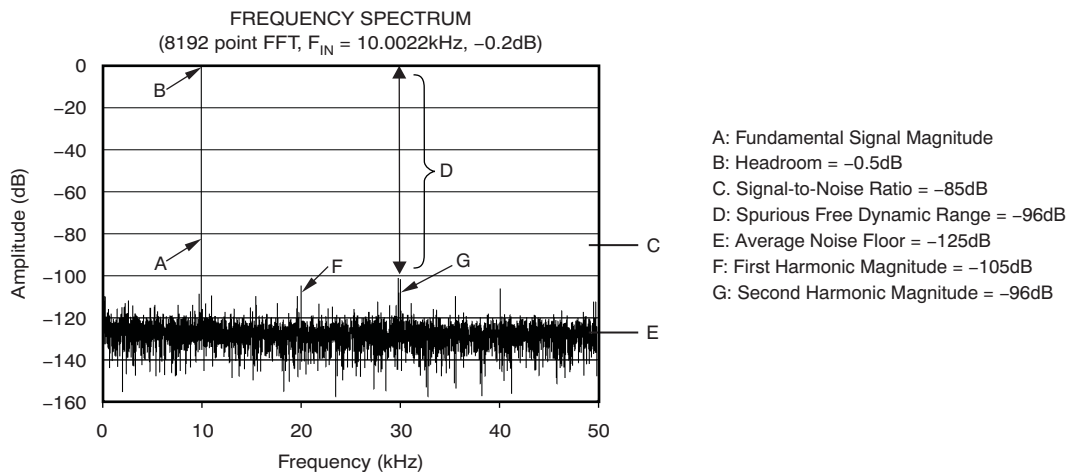

Figure 39. AC Parameters

Viewing the data in the frequency domain allows us to compare the energy in the input sine wave frequency to the energy spread across all other frequency bins. Some of those frequency bins are harmonically related to the input, and the energy in these bins can be compared to the input to determine total harmonic distortion (THD). All of the energy in the remaining bins is integrated and compared to the fundamental signal level to give a measure of signal-to-noise ratio (SNR). The difference between the fundamental level and the highest spurious frequency component is termed the spurious-free dynamic range (SFDR).

A.1.3.1   Spurious-Free Dynamic Range (SFDR)

When looking at the spectrum of the reconstructed waveform from the ADC (as shown in Figure 40), the largest spike is at the fundamental frequency or aliased frequency if greater than the Nyquist frequency. There are also several spikes as a result of harmonic distortion or noise. The SFDR is the difference, expressed in decibels (dBc), between the RMS amplitude of the fundamental frequency and the next largest frequency spike.
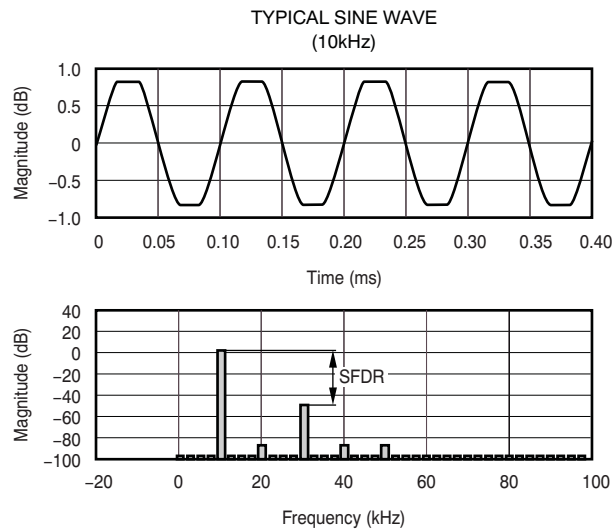

Figure 40. Spurious-Free Dynamic Range

A.1.3.2 Total Harmonic Distortion (THD)

Total Harmonic Distortion (THD) measures the distortion provided in the reconstructed ADC signal resulting from harmonics of the fundamental frequency being generated by the ADC. THD does not include noise sources in the ADC, and this separates distortion in the ADC from noise generation.

THD is defined as the ratio, expressed in decibels (dBc), between the RMS value of the fundamental frequency component and the RMS sum of the first several (possibly aliased) harmonics of the input frequency.

IEEE1241-2000 specifies that THD should be measured by including the energy in the first nine harmonic bins.
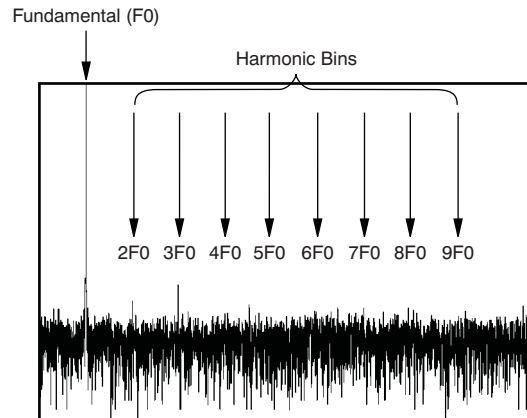

Figure 41. Fundamental and Harmonic Bins

A.1.3.3 Signal-to-Noise Ratio (SNR)

The Signal-to-Noise Ratio (SNR) is the complementary measurement to THD. Here, a ratio is taken between the RMS sum of all the noise from dc (not including dc) to the Nyquist frequency, excluding the ADC harmonics (possibly aliased) of the fundamental. That is, the RMS sum is taken over all the frequency bins that are not used in the THD calculation above; therefore, typically harmonics above the first nine bins are treated as noise. If one assumes that the noise is independent of the signal, then the SNR is appropriately expressed in terms of dBFS—decibels with respect to the power of a sine wave encompassing the full-scale of the ADC.

A.1.3.4 SINAD

Sometimes called SNRD, this measurement expresses the Signal-to-Noise Ratio of the converter considering both harmonic distortion and noise. SINAD (Signal-to-Noise + Distortion Ratio) is calculated by taking the RMS sum of all components except the fundamental summed from dc (not including dc) to the Nyquist value, divided by the power of the fundamental sine wave input.

A.1.3.5 *Equivalent Number of Bits (ENOB)*

Using either the SNR or SINAD value, the equivalent number of bits of an ideal ADC can be calculated, assuming only quantization noise exists. Generally the SINAD value is used.

IEEE-1241, and many manufacturers, use the concept of Effective Number of Bits (ENOB) to describe ADC performance. ENOB is a figure of merit that is calculated from the SINAD or THD+N measurement done using FFT testing. It attempts to describe the converter performance in terms of an ideal converter. For example, 16-bit converter that has 92dB SINAD that equates to an ideal converter of about 15 bits. This correspondence is found by using Equation 4 that simply uses the SNR equation for an ideal converter and solves it for N, and uses SINAD instead of SNR because a real converter will have artifacts other than quantization noise in the result.

$$ENOB = \frac{(SINAD - 1.76dB)}{6.02} \tag{4}$$

As a simple figure of merit, ENOB (or SINAD) has its place. It does explain actual non-idealities of the converter. For example, is there a linearity problem that causes poor THD, or does the converter just have more noise? In the latter case, the user may have a usable converter if post-processing the data by averaging or digital filtering.

Another issue with ENOB is that depending upon the type of converter the user is considering, the measurement and specification of ENOB may not be what was expected. The method approved by the IEEE is a dynamic measurement, which requires a sine wave input. This dynamic measurement is used with converters of many different architectures and applies well for comparing dynamic performance.

However, manufacturers of delta-sigma converters for use in dc measurement applications have defined a different equation for ENOB that uses a noise measurement value. Note that the full-scale range is compared to the noise:

$$2^{ENOB} = \frac{\text{Full-scale}}{\text{Noise}} = \frac{2^M}{\sigma \text{ (ADC Codes)}} \tag{5}$$

$$\left[1LSB = \frac{V_{FS}}{2^n} \right] \tag{6}$$

$$ENOB = M - \log_2 (\sigma) \tag{7}$$

Noise in these dc-precision converters can also be specified as ppm of full-scale:

$$SNR = 20 \log \left[\frac{1}{\text{Noise}} \right] = 6.02 \, N \tag{8}$$

$$ENOB = N = 20 \log \frac{\left[\frac{1}{\text{ppm}} \right]}{6.02} \tag{9}$$

For example, if noise = 0.4 ppm

$$ENOB = 20 \log \frac{\left[\frac{1}{0.4e\text{-}6} \right]}{6.02} = 21.3 \text{ Bits} \tag{10}$$

Thus, in one case (Equation 4) the user is looking at a dynamic performance measurement of linearity and noise, and in the second case (Equation 7) the user is looking at a noise measurement only.

A.1.4   THD as a Proxy for Linearity

Being able to measure the THD allows us to examine the linearity of the ADC transfer function. This method is a much easier way of looking at the device linearity than using dc techniques. In a perfectly linear system, there would be no harmonic components created when the sine wave passes through the ADC.

How exactly is THD related to linearity? This is a simple question with a complex answer. THD can be found from the linearity error at every code in the transfer function shown in Equation 11:

$$THD = \frac{\sqrt{\dfrac{1}{N}\sum_{i=1}^{N}[E_L(i)]^2}}{E_{rms}} \times 100\% \tag{11}$$

Alternatively, if including noise, the THD+N (or SINAD) can be found by including the quantization noise and residual noise sources as shown in Equation 12:

$$THD+N = \frac{\sqrt{\dfrac{1}{N}\sum_{i=1}^{N}[E_L(i) + E_Q(i) + E_N(i)]^2}}{E_{rms}} \times 100\%$$

where:
- $E_L(I)$ is the linearity error at each sample;
- $E_Q(I)$ is the quantization error at each sample; and
- $E_N(I)$ is the residual noise at each sample. (12)

If we know the linearity error at every code along the ADC transfer function, then using Equation 11 should allow us to calculate THD. If we wish to predict THD plus Noise (THD+N, also called SINAD), then we must also include random noise and quantization noise in this calculation, as illustrated in Equation 12.

Given a set of linearity data, one can predict THD; but given a THD value, one cannot determine linearity errors directly, because THD is an integrated measurement of linearity.

There is another dimension to the THD versus linearity problem as well. The plot in Figure 42 is the linearity error for every code for an 18-bit ADC. Using the first formula above, we can calculate that the expected THD is –126dB, an excellent performance.
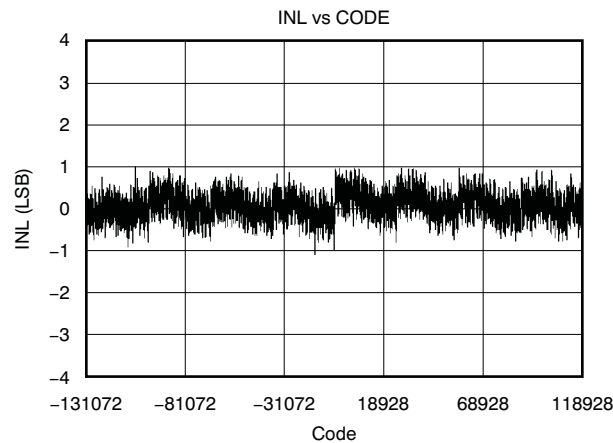

Figure 42. INL Plot versus Code for 18-Bit ADC

Examining the data sheet from this 18-bit ADC shows that the THD specification is only –116dB. This value is 10dB different than our linearity calculation predicted. What could account for this difference?

First, understand that in order to measure such low THD, the sine wave signal source must be exceptionally good. This condition requires a very high-quality signal generator. Even with high-quality generators, filtering is often done on the signal source before it is sent to the ADC to ensure that THD of the input signal is as low as possible. This configuration is quite challenging, and the results shown here may be a limitation of the measurement system.

The second factor to consider is that linearity is a dc specification and is measured using very low-frequency signals. THD, however, is a dynamic measurement, and dynamic signals place different conditions on the ADC. Linearity of an ADC can change between dc and some frequency, because of parasitics in the device, distortion effects in the sample and hold circuitry, and other factors.

A.2   Dynamic versus Static Testing

The IEEE Standard 1241-2000 defines how standard tests for data sheet specifications are to be performed. However, the standard did not exist before 2000, so for many years, the tests were defined by manufacturers.

We have seen that there are dc and ac parameters for ADCs, and the IEEE standard describes several different possible ways of testing these parameters. In this section, we examine two of the most common setups: the servo-loop, for testing dc parameters, and sine wave testing, to test ac parameters. Note, however, that the IEEE standard generally describes a way to reach the dc parameters using ac testing.

A.2.1 Servo-Loop or Code-Searching Tests

Figure 43 shows one way to perform what is commonly known as a servo-loop test. These tests are used to determine the transition points of the ADC transfer function by manufacturers. As noted previously, these are primarily dc or static tests. In this diagram, an N-bit digital-to-analog converter (DAC) generates the feedback signal. In a servo-loop test, N_1 and N_2 are equal and assigned the value N_0. The DAC value is decremented or incremented by N_0 after each conversion cycle according to the result of the comparison between the ADC output code (k) and a designated reference code (k_{IN}). Once the code transition level ($T[k_{IN}]$) has been reached, the feedback loop causes the input signal to oscillate across this transition in steps that can be chosen to be as small as desired, down to the DAC resolution. The ADC input level is calculated from the known transfer function of the DAC, or is measured by an optional voltmeter.

Obviously, performing these tests require a DAC (and voltmeter, if used) with better accuracy and resolution than the ADC under test (usually at least 10 times better) and intimate knowledge of the transfer function of the DAC. The test can be quite time-consuming, especially for high-resolution ADCs.
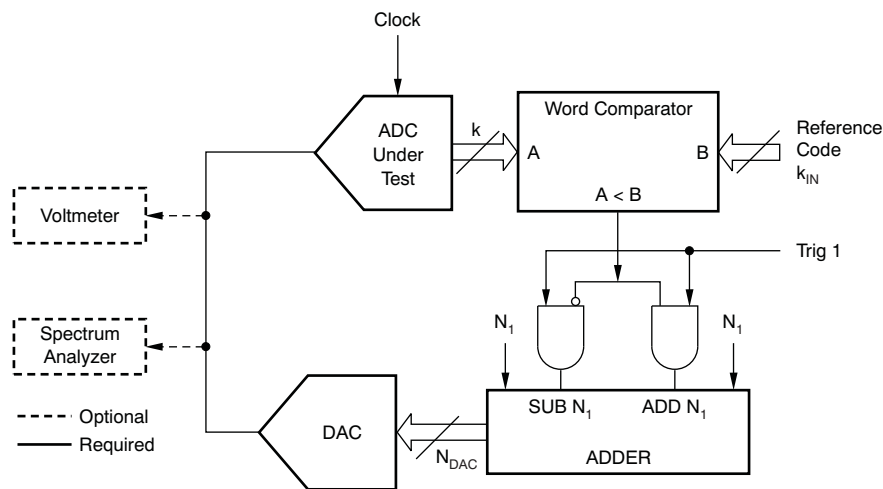

Figure 43. Servo-Loop Test Setup

A.2.2 Sine Wave Testing

As described in Section 3.5.3, sine waves are often used to test linearity when the analysis engine can collect large data sets and evaluate a histogram of the data and compare the histogram to the ideal sine wave probability density function. This method is described by IEEE 1241-2000 for testing the typical dc parameters of INL and DNL.

When a signal of frequency f_{IN} is put into an ADC sampling at a frequency f_S, the result when viewed in the frequency domain (by taking an FFT of the ADC output) consists of the fundamental frequency, harmonics of the fundamental frequency, and noise because of quantization and other noise sources in the ADC. There are a number of figures of quality defined to describe how well the ADC reproduces the fundamental frequency while minimizing harmonic distortion and noise. This section of this document describes those figures of quality.

The figures of quality are measured using a sine wave of a certain amplitude. If a sine wave that encompasses the entire input range of the ADC (or a *full-scale* amplitude sine wave) is used, it is defined as 0dBFS. Subsequent test signal amplitudes are defined as a sine wave in relationship to measurement, for example, −1dBFS, or a sine wave with 89% of the full-scale amplitude. When ADC figures of merit are discussed, typically they are tested with a −1dBFS input tone; however, this specification should be clarified when cited.

Figure 44 shows the test setup described in IEEE 1241-2000 for sine wave testing of an ADC. One sine source is used most typically, but some tests take advantage of more than one signal (for example, to test for intermodulation distortion). The clock generator is used as a clock for the ADC controlling the sample time, and may be phase-locked to the sine wave generator to achieve coherent sampling.
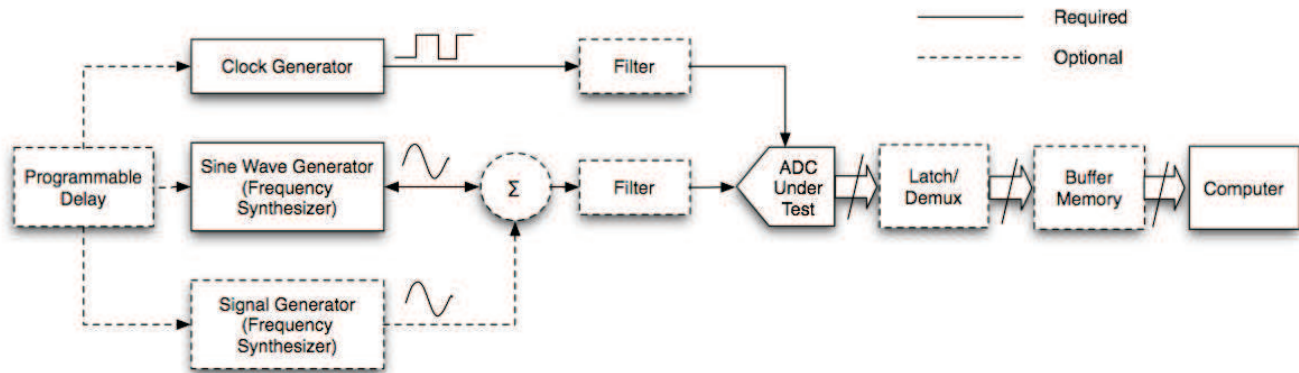

Figure 44. Sine Wave Test Setup

A.2.2.1   *Coherent Sampling*

This section describes the selection of the sampling and input frequencies for the ADC characterization that allow the user to use no window function. There are two requirements on these frequencies. The first requirement is that the two frequencies be chosen so that there is no *leakage* in the FFT spectral components. Second, the two frequencies are chosen so that an input waveform is sampled at different phases each cycle, so that more information is added to the FFT every cycle.

Implicit in an FFT analysis is the assumption that the signal being sampled is replicated infinitely in time before and after the sequence being sampled; in the characterization environment this is not the case. *Leakage* results if there are discontinuities between the beginning and end of the sequence being sampled. In order to prevent leakage in the FFT, it is necessary to sample the input frequency so that the record time covers an integer number of periods of the input waveform. That is, the waveform must be continuous when the record is duplicated forward and backward in time. The number of cycles of the input sine wave in the record is given by Equation 13:

$$N_{CYC} = N_S \, \frac{f_{IN}}{f_S}$$

(13)

where N_{cyc} is chosen be an integer to prevent spectral leakage.

An example of a waveform that meets this requirement is illustrated in Figure 45. Selecting the number of cycles (N_{CYC}) to be an integer is called *coherent sampling*. Coherent sampling meets the first requirement of preventing FFT leakage.

To meet the second requirement that the input waveform be sampled at different phases during each cycle of the input waveform, N_{CYC}/N_S is chosen to be an irreducible fraction—that is, N_{CYC} and N_S are chosen to be relatively prime. Since N_S is typically chosen to be a power of two so that a radix-2 FFT can be used, it suffices to choose N_{CYC} to be an odd number. Note that Figure 45 does not meet this requirement because it has an even number of cycles in the data record. The coherent frequency calculator included in the ADCPro (see Figure 32) allows the user to calculate a mutually prime coherent frequency to simplify the process of choosing f_{IN}.
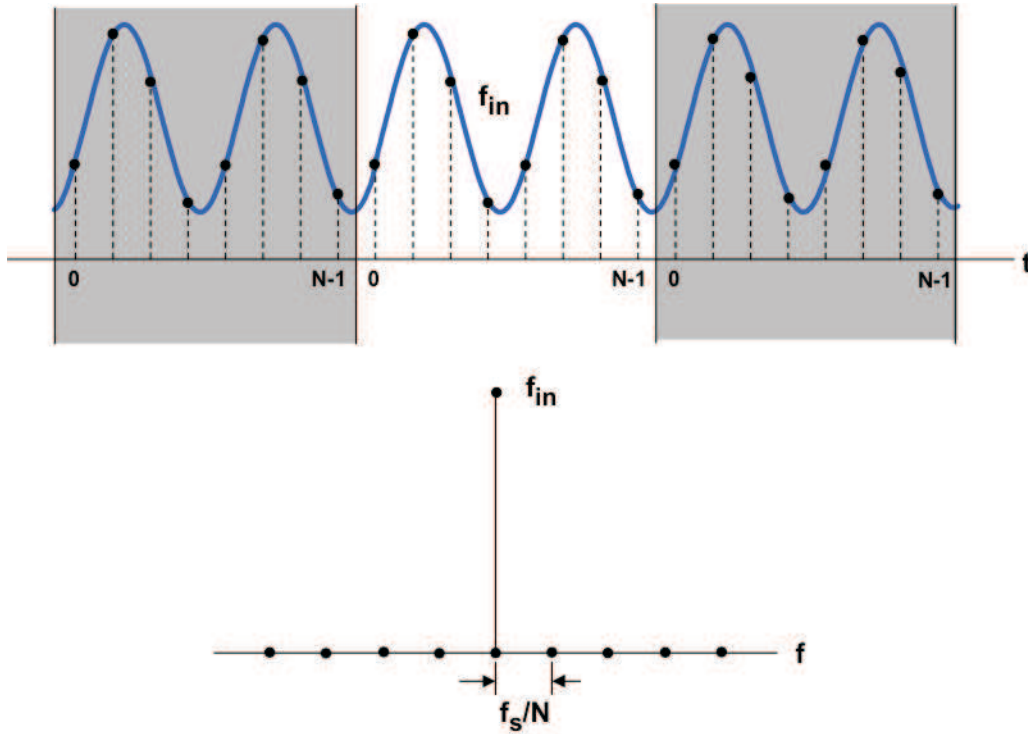
Figure 45. Coherently-Sampled Waveform

A.2.2.2   Non-Coherent Sampling

If the endpoints of the data record do not line up exactly, the FFT functions as if it is being given a discontinuous waveform similar to what is shown in Figure 46. These steps appear to the FFT as high-frequency components that actually are not in the signal. The result is an FFT where the energy of the signal is spread out across many frequency bins, producing inaccurate measurements.
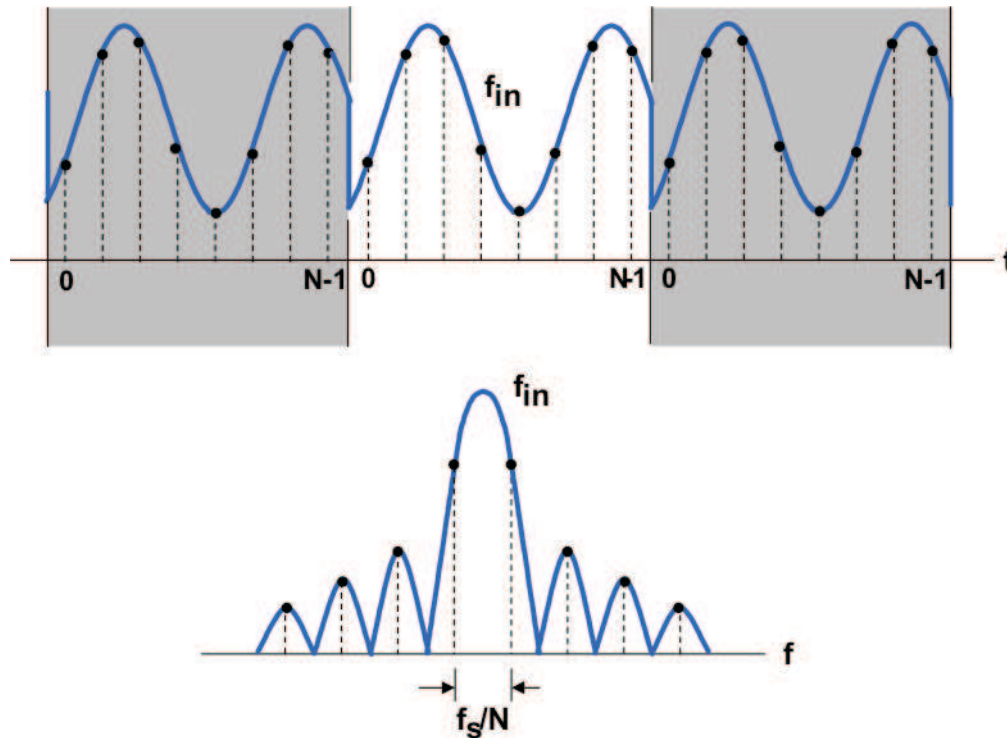

Figure 46. Non-Coherently-Sampled Waveform

A.2.2.3 Windowing

To fix this problem, a mathematical function can be applied to the data set that forces the endpoints to match, usually by driving them to zero as shown in Figure 47. This window function results in a data set as shown in the bottom trace; the frequency information of the waveform is preserved, but now the endpoints match, so the FFT gives more accurate results.

Many different windowing functions are available in the ADCPro software. For high-resolution converters (16-bits and above), high-order Blackman-Harris windows or the Low Sidelobe window give results similar to those of coherent sampling.
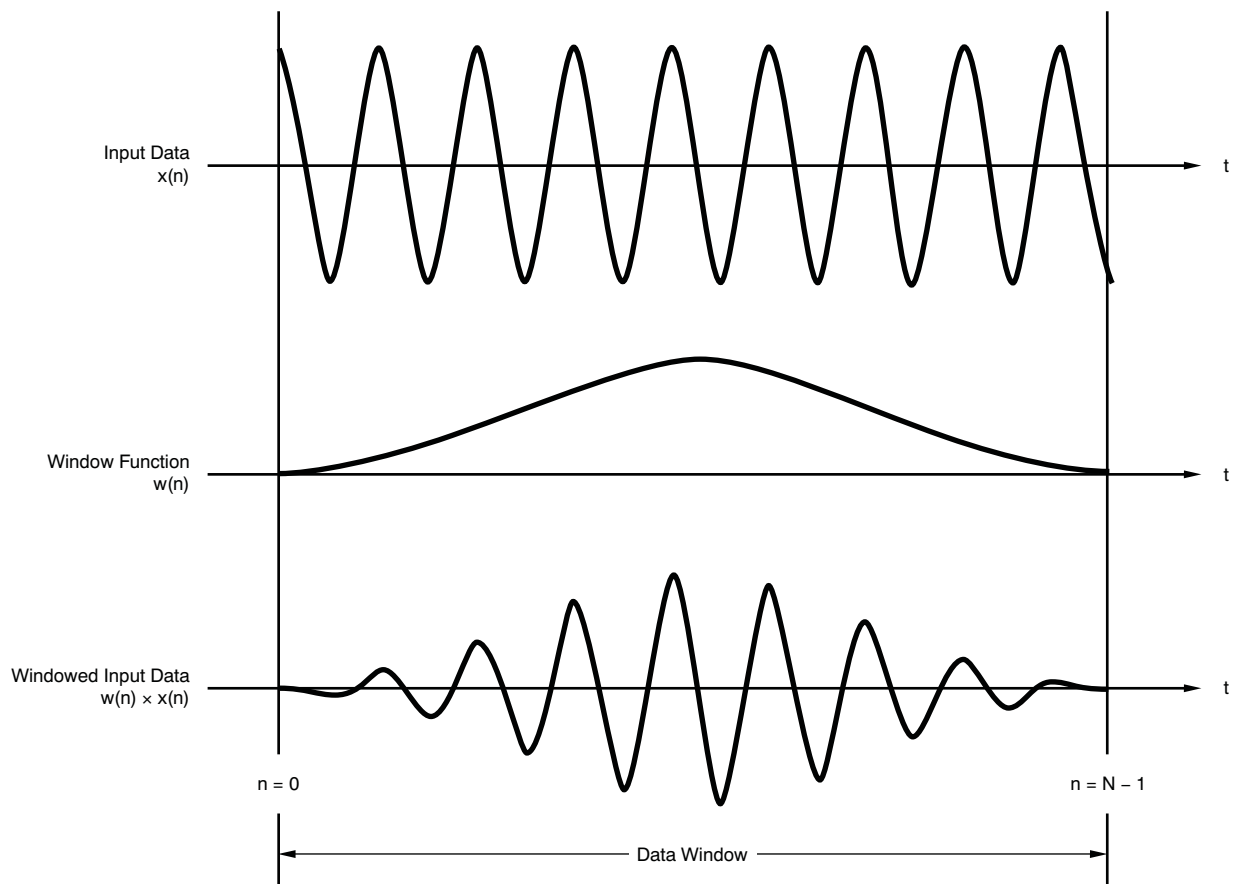
Figure 47. Windowing a Data Record

A.3 Tests and Equipment Requirements

From the preceding discussion, it should be clear that testing an ADC is complex. The simplest testing method is to use a sine wave signal source and look at the resulting data record in several ways. These methods include time domain plots, histograms, and the FFT tests described previously. Using these three methods together gives us a good indication of what the ADC transfer characteristics are.

When measuring high-performance ADCs, it is important to have a setup that can reveal the true performance of the ADC so that the test setup does not influence the results.

A.3.1 Signal Source

In order to obtain meaningful results, the sine wave generator used in these tests must have distortion at least 20dB below that expected from the ADC. For example, an ideal 16-bit converter (with no distortion at all) should measure a SINAD that is equal to the ideal SNR, or 98dB. The signal generator needed for testing this type of converter would need to have THD+N less than −118dB at a minimum.

Unfortunately, most signal generators commonly found in labs are likely to have THD+N in the −70 to −80dB range. The Agilent 33120A™, a popular signal generator used in many labs, has about −78dB THD+N at 1kHz—suitable for testing 9- or 10-bit converters, but nothing higher without following it with some sort of very low distortion bandpass filter. An Audio Precision™ audio analyzer has a very good signal source if audio frequencies are suitable for the ADC under test. At higher frequencies, it becomes harder and harder to find generators that have very low distortion.

For the selection of a signal source, there are several qualities of merit that one should look for. Phase noise, both close to the carrier and far out from the carrier, should be as low as possible and be devoid of spurs. Spurious emissions must not exist; or, if they do exist, they must be located far enough from the carrier such that they can be filtered out. A litmus test is to feed the signal source into a spectrum analyzer and verify that all spurs are indeed below the noise floor of the ADC. For best results, choose a signal source with extremely low, close-in phase noise; use a narrow, high attenuation bandpass filter centered on f_{IN}.

ADC manufacturers spend the money to buy very high quality sine sources, preferably ones that can be phase-locked to the clock that is providing the sample clock, in order to do coherent sampling. These sources can cost $20,000 US or more.

A.3.2 Clock Source

In many modern high-performance ADCs, the converter sample-and-hold stage can accept either a sinusoidal or square wave input. In these scenarios where the ADC can accept a sinusoidal input, the comparator found at the front end has an extremely low jitter specification, or time domain uncertainty. Typically, these have better jitter performance than commercially-available pulse generators. Consequently, for maximum performance, it is advisable to use a sinusoidal source with extremely low phase noise with a crystal bandpass filter centered on f_S.

A.3.3 Other Equipment

The remaining equipment needed to perform ADC testing includes suitable power supplies, an evaluation board for the ADC, and the means to collect data and analyze it. Many evaluation kits allow direct connection to a PC and software to analyze the data.

At TI, many of our ADC EVMs are produced in a modular format. This small card provides the minimal circuitry needed to make the ADC operate—in some cases a reference voltage, or a clock source (oscillator) if needed. By itself, it provides a means for customers to connect the ADC into their own systems or test platforms. Using our modular EVM interface boards, these EVMs can be connected to TI processors for use in code development and hardware prototyping.

For evaluation only, the EVM alone is not enough. To address this need, we provide complete evaluation kits (identified by *EVM-PDK*). These kits consist of the modular EVM, plus a suitable motherboard to plug them into, providing the means to collect data from the device and communicate that data to a computer, usually through a USB connection. EVM-PDKs that are supported by the ADCPro software also have an EVM plug-in installer that installs the necessary software to use the EVM-PDK with an ADCPro installation.

EVALUATION BOARD/KIT/MODULE (EVM) ADDITIONAL TERMS

Texas Instruments (TI) provides the enclosed Evaluation Board/Kit/Module (EVM) under the following conditions:

The user assumes all responsibility and liability for proper and safe handling of the goods. Further, the user indemnifies TI from all claims arising from the handling or use of the goods.

Should this evaluation board/kit not meet the specifications indicated in the User's Guide, the board/kit may be returned within 30 days from the date of delivery for a full refund. THE FOREGOING LIMITED WARRANTY IS THE EXCLUSIVE WARRANTY MADE BY SELLER TO BUYER AND IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESSED, IMPLIED, OR STATUTORY, INCLUDING ANY WARRANTY OF MERCHANTABILITY OR FITNESS FOR ANY PARTICULAR PURPOSE. EXCEPT TO THE EXTENT OF THE INDEMNITY SET FORTH ABOVE, NEITHER PARTY SHALL BE LIABLE TO THE OTHER FOR ANY INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES.

Please read the User's Guide and, specifically, the Warnings and Restrictions notice in the User's Guide prior to handling the product. This notice contains important safety information about temperatures and voltages. For additional information on TI's environmental and/or safety programs, please visit www.ti.com/esh or contact TI.

No license is granted under any patent right or other intellectual property right of TI covering or relating to any machine, process, or combination in which such TI products or services might be or are used. TI currently deals with a variety of customers for products, and therefore our arrangement with the user is not exclusive. TI assumes no liability for applications assistance, customer product design, software performance, or infringement of patents or services described herein.

REGULATORY COMPLIANCE INFORMATION

As noted in the EVM User's Guide and/or EVM itself, this EVM and/or accompanying hardware may or may not be subject to the Federal Communications Commission (FCC) and Industry Canada (IC) rules.

For EVMs **not** subject to the above rules, this evaluation board/kit/module is intended for use for ENGINEERING DEVELOPMENT, DEMONSTRATION OR EVALUATION PURPOSES ONLY and is not considered by TI to be a finished end product fit for general consumer use. It generates, uses, and can radiate radio frequency energy and has not been tested for compliance with the limits of computing devices pursuant to part 15 of FCC or ICES-003 rules, which are designed to provide reasonable protection against radio frequency interference. Operation of the equipment may cause interference with radio communications, in which case the user at his own expense will be required to take whatever measures may be required to correct this interference.

General Statement for EVMs including a radio

User Power/Frequency Use Obligations: This radio is intended for development/professional use only in legally allocated frequency and power limits. Any use of radio frequencies and/or power availability of this EVM and its development application(s) must comply with local laws governing radio spectrum allocation and power limits for this evaluation module. It is the user's sole responsibility to only operate this radio in legally acceptable frequency space and within legally mandated power limitations. Any exceptions to this are strictly prohibited and unauthorized by Texas Instruments unless user has obtained appropriate experimental/development licenses from local regulatory authorities, which is responsibility of user including its acceptable authorization.

For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant

Caution

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

【Important Notice for Users of this Product in Japan】

This development kit is NOT certified as Confirming to Technical Regulations of Radio Law of Japan

If you use this product in Japan, you are required by Radio Law of Japan to follow the instructions below with respect to this product:

1. Use this product in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,

2. Use this product only after you obtained the license of Test Radio Station as provided in Radio Law of Japan with respect to this product, or

3. Use of this product only after you obtained the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to this product. Also, please do not transfer this product, unless you give the same notice above to the transferee. Please note that if you could not follow the instructions above, you will be subject to penalties of Radio Law of Japan.

Texas Instruments Japan Limited
(address) 24-1, Nishi-Shinjuku 6 chome, Shinjukku-ku, Tokyo, Japan

http://www.tij.co.jp

【ご使用にあたっての注】

本開発キットは技術基準適合証明を受けておりません。

本製品のご使用に際しては、電波法遵守のため、以下のいずれかの措置を取っていただく必要がありますのでご注意ください。
1. 電波法施行規則第6条第1項第1号に基づく平成18年3月28日総務省告示第173号で定められた電波暗室等の試験設備でご使用いただく。
2. 実験局の免許を取得後ご使用いただく。
3. 技術基準適合証明を取得後ご使用いただく。

なお、本製品は、上記の「ご使用にあたっての注意」を譲渡先、移転先に通知しない限り、譲渡、移転できないものとします。

上記を遵守頂けない場合は、電波法の罰則が適用される可能性があることをご留意ください。

日本テキサス・インスツルメンツ株式会社
東京都新宿区西新宿６丁目２４番１号
西新宿三井ビル
http://www.tij.co.jp

EVALUATION BOARD/KIT/MODULE (EVM)
WARNINGS, RESTRICTIONS AND DISCLAIMERS

For Feasibility Evaluation Only, in Laboratory/Development Environments. Unless otherwise indicated, this EVM is not a finished electrical equipment and not intended for consumer use. It is intended solely for use for preliminary feasibility evaluation in laboratory/development environments by technically qualified electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems and subsystems. It should not be used as all or part of a finished end product.

Your Sole Responsibility and Risk. You acknowledge, represent and agree that:

1. You have unique knowledge concerning Federal, State and local regulatory requirements (including but not limited to Food and Drug Administration regulations, if applicable) which relate to your products and which relate to your use (and/or that of your employees, affiliates, contractors or designees) of the EVM for evaluation, testing and other purposes.

2. You have full and exclusive responsibility to assure the safety and compliance of your products with all such laws and other applicable regulatory requirements, and also to assure the safety of any activities to be conducted by you and/or your employees, affiliates, contractors or designees, using the EVM. Further, you are responsible to assure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard.

3. You will employ reasonable safeguards to ensure that your use of the EVM will not result in any property damage, injury or death, even if the EVM should fail to perform as described or expected.

4. You will take care of proper disposal and recycling of the EVM's electronic components and packing materials.

Certain Instructions. It is important to operate this EVM within TI's recommended specifications and environmental considerations per the user guidelines. Exceeding the specified EVM ratings (including but not limited to input and output voltage, current, power, and environmental ranges) may cause property damage, personal injury or death. If there are questions concerning these ratings please contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM User's Guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, some circuit components may have case temperatures greater than 60°C as long as the input and output are maintained at a normal ambient operating temperature. These components include but are not limited to linear regulators, switching transistors, pass transistors, and current sense resistors which can be identified using the EVM schematic located in the EVM User's Guide. When placing measurement probes near these devices during normal operation, please be aware that these devices may be very warm to the touch. As with all electronic evaluation tools, only qualified personnel knowledgeable in electronic measurement and diagnostics normally found in development environments should use these EVMs.

Agreement to Defend, Indemnify and Hold Harmless. You agree to defend, indemnify and hold TI, its licensors and their representatives harmless from and against any and all claims, damages, losses, expenses, costs and liabilities (collectively, "Claims") arising out of or in connection with any use of the EVM that is not in accordance with the terms of the agreement. This obligation shall apply whether Claims arise under law of tort or contract or any other legal theory, and even if the EVM fails to perform as described or expected.

Safety-Critical or Life-Critical Applications. If you intend to evaluate the components for possible use in safety critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, such as devices which are classified as FDA Class III or similar classification, then you must specifically notify TI of such intent and enter into a separate Assurance and Indemnity Agreement.

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		Applications	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Mobile Processors	www.ti.com/omap		
Wireless Connectivity	www.ti.com/wirelessconnectivity		

TI E2E Community Home Page   e2e.ti.com