SPECTRAL MEASUREMENTS TOOLSET

The Spectral Measurements Toolset (SMT) is a collection of VIs for LabVIEW and functions for CVI that you can use for frequency-domain measurements.

Contents

Using the Spectral Measurements Toolset

The Spectral Measurements Toolset (SMT) contains VIs for LabVIEW and functions for CVI that perform the following operations:

- Zoom frequency analysis—Zoom FFT functions and VIs allow you to zoom in on a narrow frequency range in a spectrum.
- Spectrum averaging—The SMT supports averaging types such as RMS averaging, vector averaging, and peak-hold averaging.
- Spectral measurements—The SMT contains functions and VIs that can measure power in band and adjacent channel power.
- Unit conversion—SMT unit conversion supports typical RF units such as V^2rms, dB, dBm, and dBm/Hz. You can use the toolset to convert a raw FFT spectrum to a power spectrum or power spectral density for noise measurements.
- Peak power and frequency determinations—The SMT includes a spectrum peak search algorithm that determines peak levels and frequency.
- Zoom processing configuration—SMT configuration functions and VIs allow you to use conventional measurement settings such as center frequency, span, and resolution bandwidth (RBW) to configure zoom processing. The configuration functions and VIs return an acquisition size based on your spectrum settings.

Integrating the Spectral Measurements Toolset

You can use the Spectral Measurements Toolset for the following applications:

- Physical layer measurements in communication systems
- Frequency-domain measurements such as adjacent-channel power ratio, channel spectrum, power in band measurements, average and peak power, power spectral density, and spectrum limit and mask testing
- Component level measurements such as characterization of oscillators, mixer, and filters

Locating the Spectral Measurements Toolset

In LabVIEW, the SMT VIs are located on the **Functions»Spectral Measurements** palette. If you are programming in C, the SMT functions are located on the LabWindows/CVI function panel under **Library» Spectral Measurements Toolset**.

Note The Spectral Measurements Toolset contains VIs to use in LabVIEW and functions to use in LabWindows/CVI. To avoid repetition, the *Spectral Measurements Toolset User Guide* refers only to using VIs in the LabVIEW environment. In most cases, the same guidelines apply to using functions in the C programming environment.

Using Programming Flow Diagrams

Programming flow diagrams are flow charts that provide guides to the most effective order in which you can use SMT VIs. In LabVIEW, the programming flow diagrams are available within the SMT Programming Flow VI and the SMT Programming Flow Digitizer Specific VI.

SMT Programming Flow Diagram

You can use the programming flow diagram in the SMT Programming Flow VI located in the `LabVIEW\Examples\Spectral Measurements Toolset\SMT Examples.llb` for applications where you acquired the data beforehand or with simulated data. Figure 1 shows the programming flow diagram for these applications.

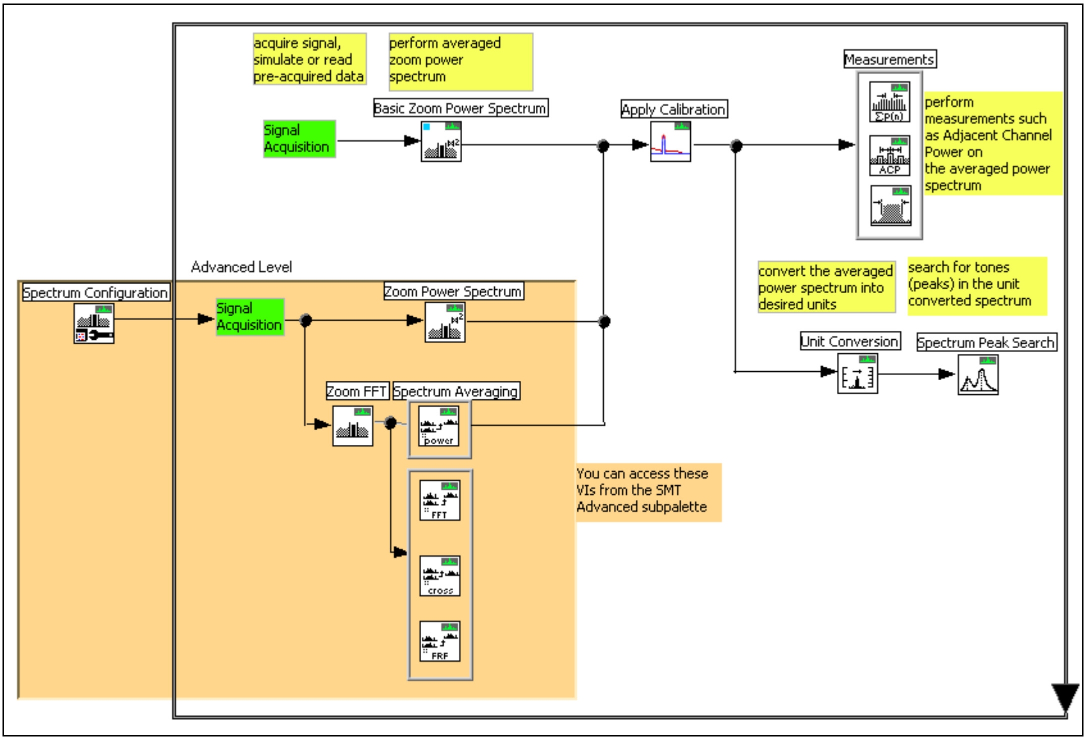


Figure 1. Programming Flow Diagram

Complete these steps when following the programming flow diagram in the SMT Programming Flow VI.

1. Enter the time-domain data into the SMT Basic Zoom Power Spectrum VI. This VI allows you to specify the zoom settings only in terms of center frequency and span. The VI performs zoom FFT processing and returns a power spectrum with units V^2rms.
2. Enter the output power spectrum into an SMT measurement VI such as the SMT Power in Band, the SMT Adjacent Channel Power, or the SMT Occupied Bandwidth VIs. The VIs accept a power spectrum with units V^2rms as input and return the requested measurements. Perform the measurements on an unscaled power spectrum only. You can specify the units in which you prefer to view the measurements.
3. Use the SMT Unit Conversion VI if you want to display the power spectrum in units other than the default V^2rms. The VI converts the raw units to units such as watts, volts, or different variations of dB such as dBm, dBW, and dbV. You can specify different scaling factors such as rms or pk.
4. Use the SMT Spectrum Peak Search VI to find specific tones or peaks in the spectrum. The Spectrum Peak Search VI accepts only a unit-converted power spectrum. You must specify the threshold level

in the same units as the power spectrum. The SMT Spectrum Peak Search VI detects any peak above the threshold level as a valid peak.

Advanced Levels

While the programming flow diagram is simple to follow, the ability of the SMT Basic Zoom Power Spectrum VI is limited by the size of the data you acquired previously. Use the VIs located on the **Functions»Spectral Measurements»SMT Advanced** palette if you want more specific control on your zoom settings or if you want to specify additional spectral settings such as window type, resolution bandwidth (RBW), and number of spectral lines for display.

Complete the following steps when following the advanced levels of the programming flow diagram in the SMT Programming Flow VI.

1. Use the SMT Config Zoom FFT VI to add control to your zoom settings. You can use the default values for the spectrum settings control if you are unsure of your preferred settings. The VI uses the values you enter to recommend an acquisition size or data size. The VI also maps measurement-specific settings to classical analysis settings.
2. Enter a time-domain signal of the size recommended by the SMT Config Zoom FFT VI into the SMT Zoom Power Spectrum VI. You must pass the **SMT zoom settings** output from the SMT Config Zoom FFT VI to subsequent VIs to ensure accurate data. The SMT Zoom Power Spectrum VI performs zoom FFT processing and returns a power spectrum with units V^2rms.
3. Enter the output power spectrum into subsequent measurement VIs using the guidelines in steps 2, 3, and 4 of the standard programming flow diagram.

The SMT Zoom FFT VI and the SMT Averaged Power Spectrum VI are the building blocks for the SMT Zoom Power Spectrum VI. If you want an averaged FFT spectrum, which has a complex output for magnitude and phase calculations, you can use the SMT Zoom FFT VI first and then the SMT Averaged FFT Spectrum VI. If you have two channels of input time-domain data and want cross power spectrum or frequency response measurements, use the SMT Zoom FFT Spectrum VI first and then the SMT Averaged Cross Spectrum VI or the SMT Averaged Frequency Response VI. Figure 1 illustrates the programming flow for using the SMT Zoom FFT VI and the SMT Averaged Power Spectrum VI.

SMT Programming Flow Digitizer Specific Diagram

Use the digitizer-specific programming flow diagram in the SMT Programming Flow Digitizer Specific VI located in the `LabVIEW\Examples\Spectral Measurements Toolset\SMT Examples for niScope.llb` for applications in which you use the SMT VIs with an NI digitizer such as the NI 5620 with the NI-SCOPE 2.0 driver.

Note You must upgrade to NI-SCOPE 2.0 or higher to use VIs located on the **Functions» Spectral Measurements»SMT Digitizer Specific** palette.

Figure 2 shows the programming flow diagram in the SMT Programming Flow Digitizer Specific VI.

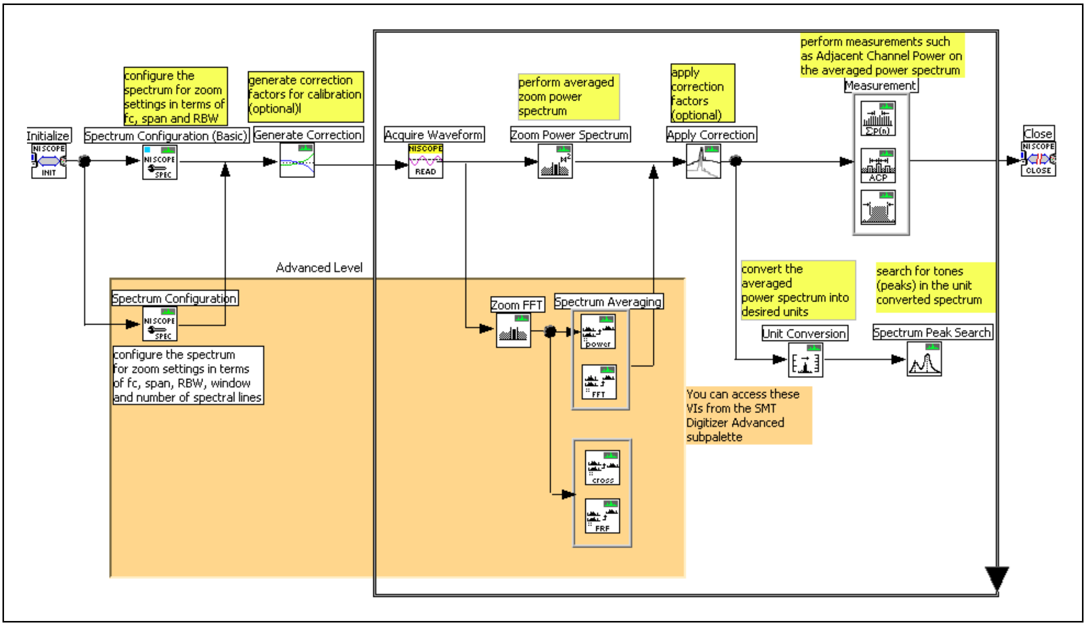


Figure 2. Digitizer-Specific Programming Flow Diagram

Complete the following steps to use the digitizer-specific programming flow diagram.

1. Use the niScope Init VI to initialize your digitizer.
2. Use the SMT Basic Config niScope for Spectrum VI to configure the spectrum with measurement-specific settings. You can use the default values for the spectrum settings control if you are unsure of your preferred settings.

   The SMT Basic Config niScope for Spectrum VI allows you to specify zoom settings in terms of center frequency, span, and RBW. The VI configures the sample rate and the minimum record length on the digitizer and returns the exact number of data points that you must acquire so that subsequent VIs can correctly compute the spectrum.

3. Use the SMT Calculate Correction VI to calculate the correction values required to calibrate the spectrum. Configure the spectrum and generate the correction factors only on the first iteration of the loop.
4. Enter a time-domain signal of the size recommended by the SMT Basic Config niScope for Spectrum VI into the SMT Zoom Power Spectrum VI. You must pass the **SMT zoom settings** output from the SMT Basic Config niScope for Spectrum VI to subsequent VIs to ensure accurate data.
5. Use the SMT Apply Correction VI to correct the magnitude that the SMT Zoom Power Spectrum VI returns. You must correct the magnitude in order to receive accurate results.
6. Enter the output of the SMT Apply Correction VI into the SMT Power in Band, SMT Adjacent Channel Power, or the SMT Occupied Bandwidth VIs. The VIs accept a power spectrum with units V^2rms as an input and return the requested measurements. You can specify the units in which you prefer to view these measurements.
7. Use the SMT Unit Conversion VI if you want to display the power spectrum in units other than the default V^2rms. The VI converts the raw units to watts, volts, or different variations of dB such as dBm, dBW, and dbV. You can specify different scaling factors such as rms or pk.
8. Use the SMT Spectrum Peak Search VI to find specific tones or peaks in the spectrum. You must specify the threshold level in the same units as the power spectrum. The SMT Spectrum Peak Search VI detects any peak above the threshold level as a valid peak.

Advanced Levels

Use the SMT Config niScope for Spectrum VI to control advanced settings such as number of spectral lines for display and effective bandwidth.

The SMT Zoom FFT VI and the SMT Averaged Power Spectrum VI are the building blocks for the SMT Zoom Power Spectrum VI. If you want an averaged FFT spectrum, which has a complex output for magnitude and phase calculations, you can use the SMT Zoom FFT VI first and then the SMT Averaged FFT Spectrum VI. If you have two channels of input time-domain data and want cross power spectrum or frequency response measurements, use the SMT Zoom FFT Spectrum VI first and then the SMT Averaged Cross Spectrum VI or the SMT Averaged Frequency Response VI. Figure 2 illustrates the programming flow for using the VIs.

Using LabVIEW Spectral Measurements Examples

This section describes some of the examples located in the `LabVIEW\Examples\Spectral Measurements Toolset` folder. Refer to the examples located in the `CVI\Samples\SMT` folder if you are programming in C.

SMT Examples for niScope.llb contains examples that require you to use an NI high-speed digitizer such as the NI 5620 with the NI-SCOPE 2.0 driver. The examples all contain the words “for niScope” in their names.

SMT Examples.llb contains examples that use a simulated source. The examples all contain the word “simulated” in their names.

SMT Spectrum Analyzer (Simulated) Example

The SMT Spectrum Analyzer (simulated) example located in `LabVIEW\Examples\Spectral Measurements Toolset\SMT Examples.llb` demonstrates how you can use SMT VIs to build a spectrum analyzer with zoom and averaging capabilities.

The **spectrum settings** control allows you to specify the zoom settings in terms of center frequency, span, and resolution bandwidth (RBW). The example uses the default value for the RBW input, –1.0. The SMT Config Zoom FFT VI located on the **Functions»Spectral Measurements»SMT Advanced** palette uses these settings to recommend an acquisition size. The VI also returns the actual spectrum settings, which appear directly above the spectrum graph. In the example the VI calculates actual span as 4.97 MHz and the RBW as 43.51 KHz.

The **averaging parameters** control allows you to specify the averaging type, such as vector averaging, RMS averaging, or peak hold, the weighting type, such as linear or exponential, and the averaging size. The **linear weighting mode** control allows you to choose a specific type of linear weighting.

The SMT Zoom Power Spectrum VI located on the **Functions»Spectral Measurements»SMT Advanced** palette returns the spectrum in units of V^2rms. The **unit conversion settings** control allows you to specify the units in which you want to display the spectrum. For example, you can set **units** to dBm, **peak scaling** to rms, and **psd?** to on to view the power spectrum as power spectral density (PSD).

The spectrum indicator is a waveform graph that shows the spectrum of the simulated signal, which is a 12.01 MHz sine wave with some added white noise. The center of the spectrum appears at 12.01 MHz, the center frequency, and the spectrum spans from 9.523 MHz to 14.483 MHz. You can use the **peak search setting** control if you want to find the peaks in the example spectrum. In the control, specify whether you want to find a single or multiple peaks and enter the threshold level value above which a peak is valid. The peak threshold level uses the same unit of measurement as the spectrum.

The number of peaks indicator shows the number of peaks that meet the threshold criteria and the peaks indicator shows the frequency and Y-axis values for these peaks.

Figure 3 shows the block diagram for the SMT Spectrum Analyzer (simulated) example. The SMT Config Zoom FFT VI specifies the zoom settings. The VI returns the cluster **SMT zoom settings**, which you connect to the **SMT zoom settings** input of the SMT Zoom Power Spectrum VI. Connect the **spectral info** cluster that the SMT Zoom Power Spectrum VI returns to the **spectral info** input on the SMT Unit Conversion VI.

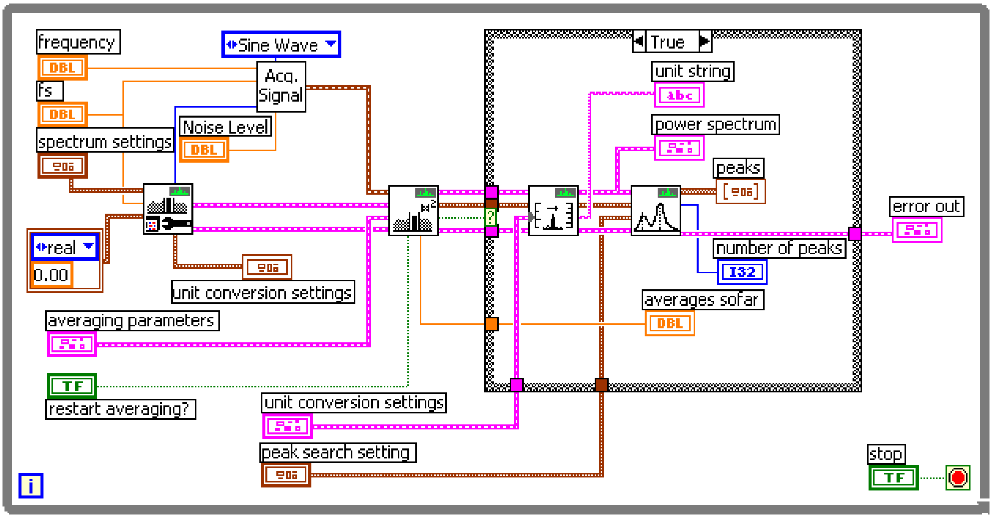


Figure 3. SMT Spectrum Analyzer (Simulated) Block Diagram

SMT ACP (Simulated) Example

The SMT ACP (simulated) example located in `LabVIEW\Examples\Spectral Measurements Toolset\SMT Examples.llb` demonstrates how you can use SMT VIs to perform measurements on a spectrum. The example shows one specific measurement, the adjacent channel power (ACP). You also can perform other measurements such as power in band and occupied bandwidth (OBW).

The **channel specification** control specifies the center frequency, bandwidth, and spacing for the ACP measurement. Bandwidth specifies the width of each channel. Spacing specifies the separation between the center frequencies of each channel. The **channel power units** control specifies the units for the ACP measurement. The Advanced Settings tab of the example includes some of the same controls as the SMT Spectrum Analyzer (simulated) example. The **unit conversion settings** control specifies the units for the power spectrum. The power spectrum indicator is a waveform graph that shows the power spectrum with the three channels or bands and the power in each channel.

Figure 4 shows the block diagram for the example. The example uses the SMT Config Zoom FFT VI to configure the zoom FFT. The **SMT zoom settings** output from the SMT Config Zoom FFT VI connects to the **SMT zoom settings** input of the SMT Zoom Power Spectrum VI. The **spectral info** parameter also connects from one VI to the other. The example performs the ACP measurement on the raw power spectrum before the unit conversion.

Note The example performs the Adjacent Channel Power measurement on an unscaled power spectrum before calling the SMT Spectrum Unit Conversion VI.

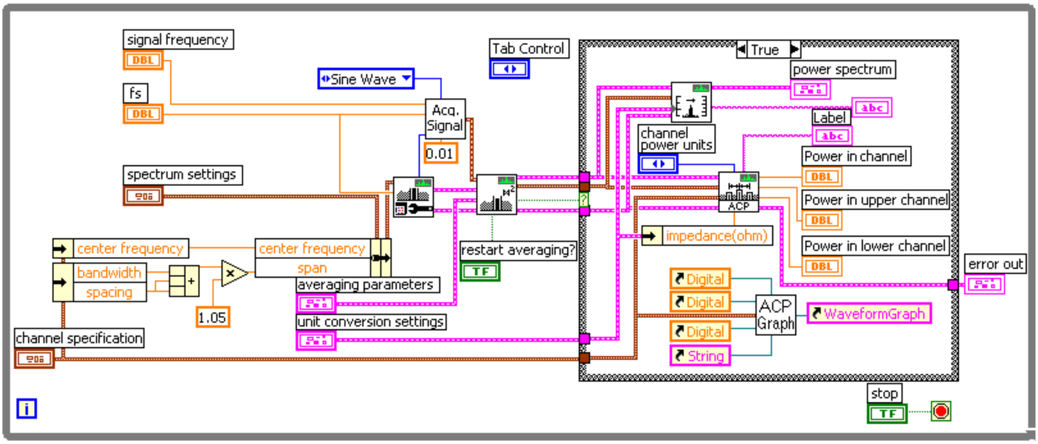


Figure 4. SMT ACP Example (Simulated) Block Diagram

SMT Simple Peak Search Example for niScope

The SMT Simple Peak Search Example for niScope located in `LabVIEW\Examples\Spectral Measurements Toolset\SMT Examples for niScope.llb` demonstrates how you can use SMT VIs with the NI-SCOPE 2.0 driver to compute the spectrum of a signal and then perform peak search on the spectrum.

The **min sample rate** control specifies the sampling rate of your data acquisition. You can use the **center frequency** and **span** controls to specify the frequency range on which you want to zoom in.

The **unit conversion setting** control specifies the units in which you would like to display the spectrum. The spectrum indicator is a graph that shows the power spectrum with the requested units.

The **peak search setting** control specifies criteria for finding peaks in the spectrum. The threshold level for the peak search uses the same units as the power spectrum after unit conversion.

Figure 5 shows the block diagram for the example. The SMT Simple Peak Search example uses the SMT Config niScope for Spectrum VI to map the conventional measurement settings to low-level analysis settings. The VI also returns a recommended acquisition size. You can use any of the acquisition VIs to gather the number of data points that the SMT Config niScope for Spectrum VI returns. The example connects the **waveform** output from an niScope acquisition VI to the SMT Zoom Power Spectrum VI. The example also connects the **SMT zoom settings** output of the SMT Config niScope for Spectrum VI to the same input on the SMT Zoom Power Spectrum VI.

Note Use the SMT Spectrum Peak Search VI after you use the SMT Spectrum Unit Conversion VI.

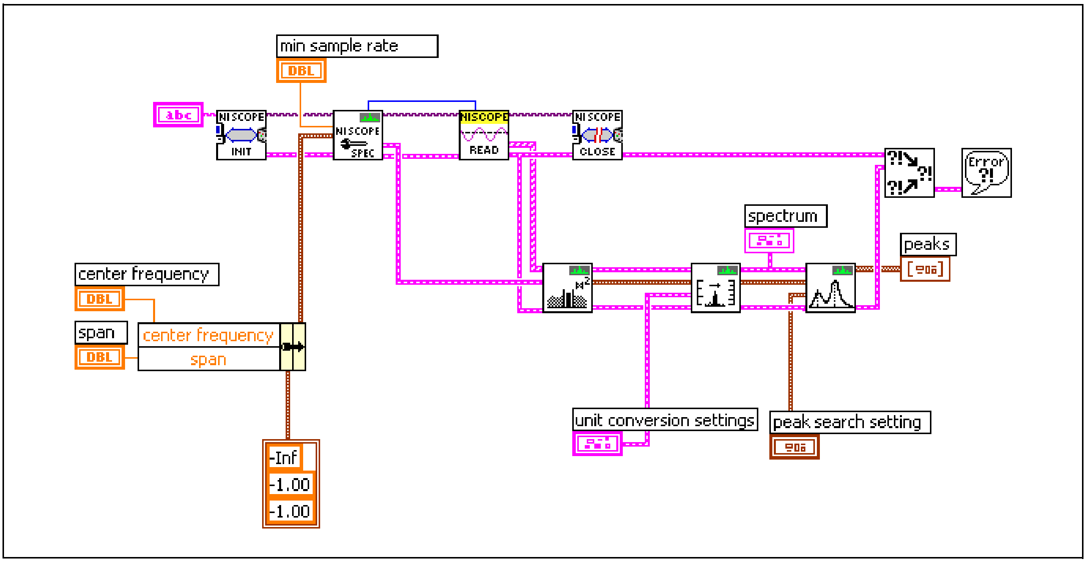


Figure 5. SMT Simple Peak Search Example Block Diagram

Using Spectral Measurements Techniques

The Spectral Measurements Toolset contains VIs for block and continuous zoom processing and spectrum averaging. You can specify the zoom characteristics in terms of center frequency, span, and resolution bandwidth. You can use spectrum averaging to reduce the effect of noise on your measurement system.

Zoom FFT

Zoom FFT (Fast Fourier Transform) is a technique that the Spectral Measurements Toolset uses to analyze the frequency spectra of stationary signals. The technique allows you to zoom in on a small portion of the frequency spectrum with high frequency resolution by using fewer calculations than with a standard FFT. Figure 6 illustrates how a zoom FFT detects the presence of two tones of closely spaced frequencies. The standard FFT indicates a single peak while the zoom FFT clearly indicates the presence of two separate tones in the signal.

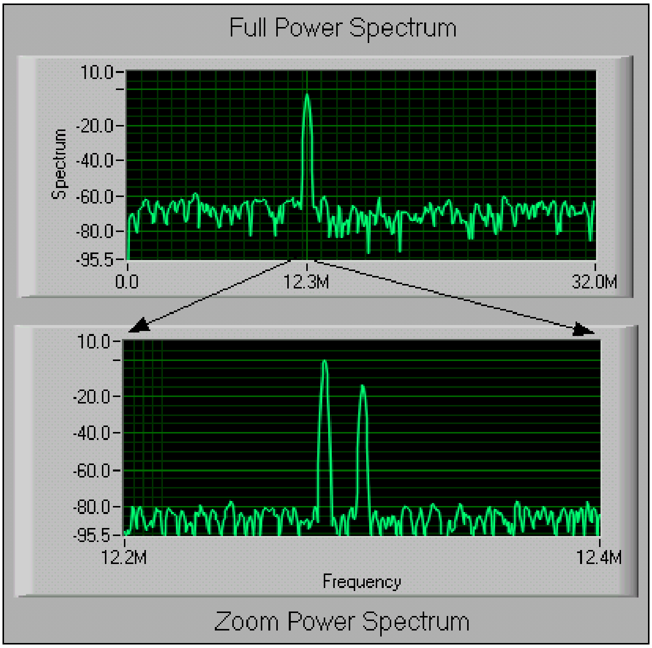


Figure 6. Zoom FFT Technique

FFT algorithms usually perform baseband analysis by displaying the spectrum from zero frequency to the Nyquist frequency. However, a standard FFT might not be effective if you need to obtain a higher frequency resolution over a limited portion of the spectrum or to zoom in to observe details of a spectral region. The zoom FFT uses algorithms to avoid the amount of calculation required if you use a long standard FFT to obtain high frequency resolution over an entire spectrum.

You can define the frequency resolution of an analysis using the following example. Using a signal sampled with frequency f_s, within a time duration T you acquire N samples, so $T = N/f_s$, and from the properties of the Fourier transform, the analysis resolution df is

$$df = f_s/N = 1/T$$

Only the acquisition time determines the analysis resolution. You can either decrease f_s or increase N to improve the frequency resolution df.

The Spectral Measurements Toolset supports two algorithms for zoom FFT processing: continuous zoom FFT and block zoom FFT.

Continuous Zoom FFT

Continuous zoom FFT is a technique that is useful in situations where you need to analyze the data quickly as it arrives. A decimation process reduces the sampling rate in real time. After the process acquires all the data and decimates it in time T, a relatively small FFT remains. The term continuous refers to the fact that you begin the process while data arrives. With a standard FFT, you must wait for all the data to arrive before you can begin calculations.

The continuous zoom FFT first shifts the spectral region of interest into the baseband. The technique then applies a lowpass anti-aliasing filter and decimates or downsamples the data by a factor of M. The zoom factor of M yields a new effective sample rate f_s/M. The anti-aliasing filter has a cutoff frequency of $f_s/(2*M)$ because the Nyquist frequency decreased by a factor of M.

After the lowpass filtering, the continuous zoom FFT performs an FFT on the reduced sampling rate data to produce the zoomed spectrum. The technique is destructive because the original data changes as the result of the filtering and decimation. If you store the data and batch process it offline you lose the primary benefit of the technique, which is its real-time capability. Figure 7 shows the basic steps of frequency shifting, decimation, and FFT.

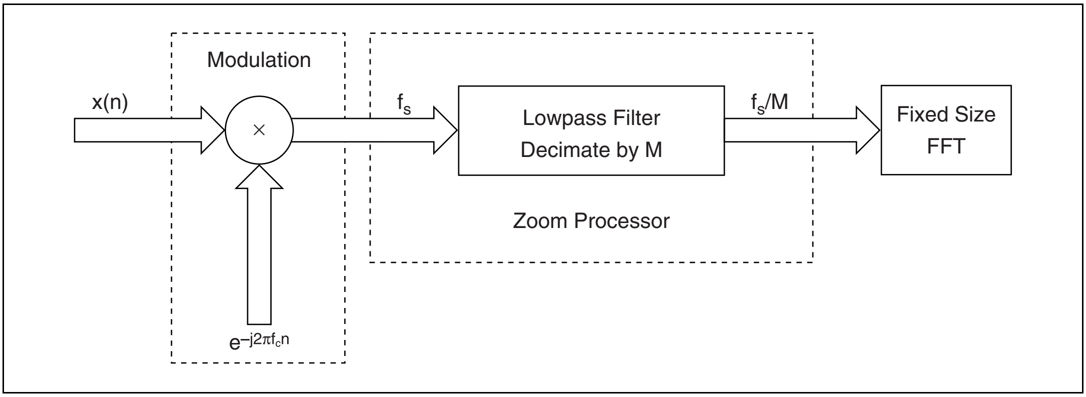


Figure 7. Continuous Zoom FFT Diagram

Although it might seem possible to reduce the sample rate f_s to improve frequency resolution, this method does not work. You cannot acquire the data with a lower sample rate to increase resolution because the Nyquist sampling theorem applies. In the original acquisition, you must sample at least twice as fast as the highest frequency of our desired zoom region in order to obtain the frequency information you need. You cannot reduce the sample rate until after frequency shifting occurs if you want to improve the frequency resolution of the zoom region. The continuous zoom FFT shifts a high frequency signal into the baseband before adjusting the sampling rate.

The continuous zoom FFT technique is sometimes called the real-time zoom FFT because it continuously performs the frequency shifting, decimation, and filtering processes on the arriving data. The FFT operation itself cannot proceed until you acquire all the data. The FFT operation then occurs in parallel with the next data acquisition.

You can use the SMT Cont Zoom FFT VI to perform the continuous zoom FFT technique.

Block Zoom FFT

Use a block zoom FFT in situations where you cannot access data until data acquisition is complete. The block zoom FFT is a non-destructive zoom FFT because it stores data before processing. The data is available in its original form if you need it for other operations. The block zoom FFT is an algorithm that calculates a portion of a large FFT. The operation allows you to improve the frequency resolution *df* by increasing the number of points that the FFT processes.

A block zoom FFT uses only the part of a large FFT that represents the frequency range you want to analyze. For example, if the input data has a length $L*M$, an FFT on the original data results in $L*M$ points of FFT spectrum. If you want to analyze only $1/M$ of the whole spectrum, or L frequency bins, you can use a block zoom FFT. The block zoom FFT computes L points of the original $L*M$ point spectrum faster and with fewer calculations than if you perform a large FFT on the entire data set and remove the unwanted portion.

You can use the SMT Zoom FFT VI to perform the block zoom FFT technique.

Determining When to Use Continuous or Block Zoom FFT

Choosing the zoom FFT to use for a particular application depends on many factors including system speed, memory, acquisition rate, and user requirements. You cannot predict which method best suits a particular measurement application.

One advantage of the continuous zoom FFT is that you can update the results continuously to give a smooth display and minimize the time it takes for transients to appear in the displayed spectrum. You can control the update time with the **% overlap** input of the **advanced settings** of the SMT Config Cont Zoom FFT VI. A setting of `0%` updates like a block zoom FFT, waiting for the VI to process an entire new data set before returning a result. A setting of `50%` updates twice as fast as a setting of `0%` by reusing the last half of the previous data block to return an updated result after the VI acquires and processes half of the new data set.

You cannot predict whether the continuous zoom FFT can keep up with a certain acquisition rate in real time, so the best option is to try running the application using the SMT Cont Zoom FFT VI. If you receive buffer overflow errors from the acquisition VI, either reduce the acquisition rate or use the SMT Zoom FFT VI instead.

The block zoom FFT is a general-purpose tool that works best as a post-processing method. The block zoom FFT is also useful for real-time applications where the data rate is too high for a continuous zoom FFT to keep up in real time. If you need to process the entire data set, provide enough memory to store the data until the FFT can process it. If processing every data point is not critical, you can use the block zoom FFT with the latest data available.

Configuring Zoom FFT VIs

When using Spectral Measurements Toolset VIs, you must enter several values to specify a zoom FFT completely. The toolset provides two configuration VIs that select values for each setting and that require you to enter a minimal number of values. The SMT Config Zoom FFT VI allows you to configure the block zoom FFT. The SMT Config Cont Zoom FFT VI allows you to configure the continuous zoom FFT. The configuration VIs ensure that the input values are compatible and yield results that make sense. You can enter values for specific settings and let the configuration VIs calculate the rest.

Center Frequency and Span

The two fundamental characteristics of a zoom FFT are center frequency, which is the location of the zoom within the spectrum, and span, which is the degree to which the FFT zooms in. Center frequency and span are often the only values you need to enter for basic zoom applications. The following restrictions apply to the input values for center frequency and span:

- Center frequency must fall within the effective band of the input signal. The effective band is the frequency band in which the data from the input signal is valid. You can use the effective band to exclude the roll-off region of an analog anti-aliasing filter from consideration. The effective band defaults to the full bandwidth of the input signal, up to half the sample rate. If the specified frequency falls outside of the effective band, the configuration VI uses the center of the effective band as the center frequency.
- Span must be smaller than the effective band because you only zoom in on the spectrum. You cannot zoom out. If span is larger than the effective band, the configuration VI sets the span to the largest value that does not fall outside of the effective band.
- When you combine center frequency and span, neither endpoint of the desired frequency span can fall outside of the frequency range of the effective band. If both center frequency and span meet the above restrictions but a portion of the zoom span region falls outside of the effective band, the configuration VI moves the center frequency far enough to ensure that the entire span is inside the effective band.

The left column of Figure 8 shows the four combinations of center frequency and span that you can encounter in the case of a real input signal. The right column shows the actual values of center frequency and span that the VI sets in each example. In the first example, if you enter appropriate values for both center frequency and span, the values do not change. The spectrum represents the frequency response of the input anti-aliasing filter on the data acquisition device. In the second example, if you enter a center frequency value that is outside the effective band, the span changes to the default center frequency, which is the center of the effective band. In the third example, if you request a span that is wider than the effective band, the span decreases until it falls entirely within the effective band without moving the center frequency. In the fourth example, if you enter center frequency and span values that fall within acceptable limits but a portion of the span falls outside the effective band, the center frequency moves until the span falls entirely within the effective band.

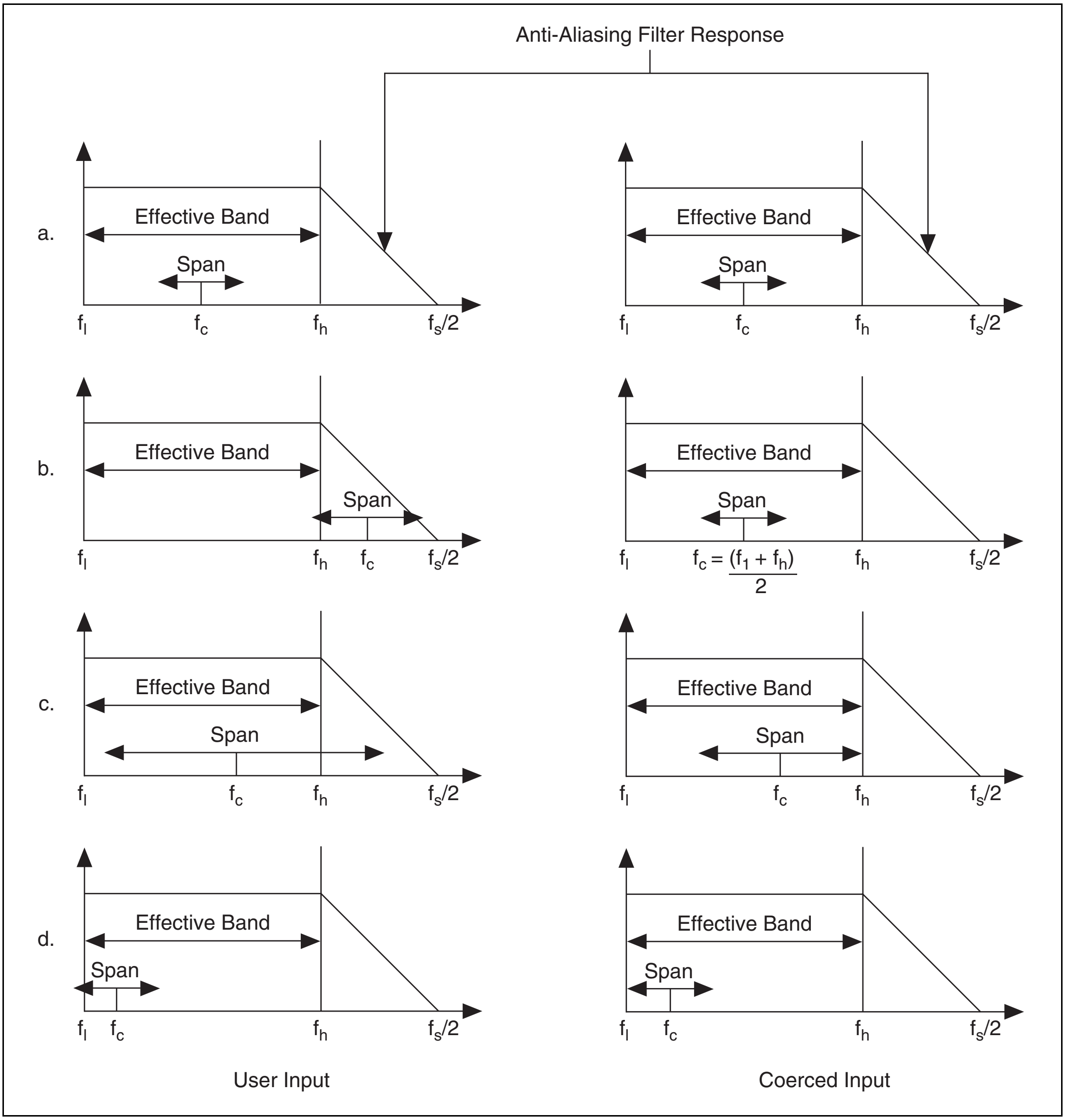


Figure 8. Center Frequency and Span Combinations

Resolution Bandwidth and Spectral Lines

resolution bandwidth is a parameter that represents the frequency width at which you can distinguish two adjacent tones of equal amplitude. The value is the –6 dB width of the spectral peak corresponding to a single windowed tone.

spectral lines is a parameter that controls how many frequency bins are present in the zoom spectrum result that the VI displays. If you request more spectral lines than **resolution bandwidth** requires, the parameter zero-pads the FFT to interpolate the spectrum to the desired number of lines.

The configuration VIs use **resolution bandwidth** and **spectral lines** to determine the acquisition size, which is the number of points that you must acquire for a particular zoom operation. You must specify a value in at least one of the two parameters, **resolution bandwidth** or **spectral lines**. If you specify a value in only one of the parameters, the value determines the acquisition size, and the acquisition size value determines the value of the other parameter. If you specify both **resolution bandwidth** and **spectral lines**, the VI compares the acquisition size that each parameter requires and uses the smaller of the two results as the actual acquisition size. For a real input signal, the acquisition size that the spectral lines value determines is the following:

$$\textit{acquisition size} = 2 * \textit{spectral lines} * \textit{zoom factor}$$

where *zoom factor* relates the zoom span to the full spectrum as follows:

$$\textit{zoom factor} = \frac{f_s/2}{\textit{span}}$$

For a real input signal, the acquisition size that the **resolution bandwidth** value determines is the following:

$$\textit{acquisition size} = \frac{[6\ dB\ BW]f_s}{RBW}$$

The acquisition size comes from the basic relation

$$df = f_s/N = 1/T$$

where you set N to equal acquisition size and where RBW is the frequency resolution df multiplied by the window spectral leakage correction factor of 6 dB BW.

If the **spectral lines** value requires a larger acquisition size than the **resolution bandwidth** value requires, the VI uses zero-padding to determine the number of FFT lines you need. If the **resolution bandwidth** value requires a larger acquisition size than the **spectral lines** value requires, the VI coerces **resolution bandwidth** to a value consistent with the acquisition size you need and returns the value as **actual resolution bandwidth**.

You might see actual values differ slightly from the values you need in two cases. If the **span** and **sampling frequency** you need correspond to a zoom factor that is not an integer, the VI coerces the zoom factor to an integer value and the span varies accordingly. The acquisition size also might vary slightly to ensure that you can use an efficient FFT algorithm to optimize performance.

Zoom FFT Window

The issues that affect the choice of window for a zoom FFT are similar to issues that affect a full spectrum FFT. The main considerations are the width of the main lobe of the window spectrum and the degree of suppression of the side lobes. A wide main lobe causes spectral leakage so that a single tone can appear to have a wider spectrum than usual. Large side lobes reduce the height of the signal tones relative to the noise floor.

The RBW calculation takes into account the window type by quantifying the amount of spectral leakage that the window introduces. The calculation uses 6 dB BW as the metric to measure the effect of spectral leakage. The 6 dB BW is the bandwidth at which the window amplitude spectrum falls to half its peak amplitude or to a quarter of its peak power. The actual zoom FFT does not use the 6 dB BW calculation but incorporates it as a correction factor to increase the accuracy of the returned RBW value.

Spectral Domain Averaging

Averaging is an important part of spectrum domain measurements because of the effects of noise on a signal and its spectrum. The Spectral Measurements Toolset includes several averaging VIs that average several records of data to reduce the noise effects. You can use the following two forms of averaging: vector and RMS. Peak hold is not an averaging process but is logically grouped with averaging VIs and functions because of its similarities with averaging processes.

Vector averaging lowers the noise floor while retaining the signal spectrum. In the time domain, a running average reduces the effect of zero-mean white noise on a signal. The noise is averaged out while the signal is retained. The signal must be triggered, meaning that each data record starts at a consistent point in the periodic signal, preserving the signal integrity during an averaging process. Because the FFT is a linear transform, averaging spectral records in the frequency domain is equivalent to averaging data records in the time domain. The signal must be triggered for vector averaging to work properly. Vector averaging requires a complex spectrum input and produces a complex result that you can convert to a real power spectrum.

If the signal is not triggered in the time domain, phase noise appears in the resulting spectrum. You can use RMS averaging to eliminate the effect of phase noise. The magnitude of the spectrum is independent of time shifts of the input signal, but the phase can change dramatically with each data record. If you average the power spectra and take the square root of the result, you eliminate the effect of phase variations. You can no longer reduce the noise floor, but you reduce the magnitude variance of the noise. Reducing the noise variance helps to distinguish small frequency peaks from the largest noise peaks. RMS averaging eliminates all phase information and returns a real spectrum. If the averaging process returns results in a complex data type, the imaginary portion is zero.

Peak hold refers to a method of retaining the maximum magnitude value of every frequency bin over several data records. Peak hold is most useful for capturing transient phenomena that do not appear in individual spectra. In a monitoring application, the peak hold display allows an operator to tell at a glance if a transient at a certain frequency occurred since the last reset. However, peak hold cannot specify when the transient happened. Like RMS averaging, peak hold results in a real spectrum.

When you apply a zoom FFT VI to a signal, you receive the instantaneous complex FFT spectrum. The spectrum domain averaging functions can operate on the FFT spectrum to return different types of spectra such as averaged FFT spectrum, power spectrum, cross spectrum, and frequency response.

The averaging VIs require that you enter an FFT spectrum as a complex array. You can perform spectrum unit conversion before or after the averaging process.

Averaging Conventions

For SMT VIs, the term averaging refers to the average of several different sets of data from the same process. The following list contains averaging operations that apply independently to each frequency bin of the Fourier transform.

$F_R + jF_I$	The complex representation of the Fourier transform of a signal $f(t)$ using real and imaginary values.
$< F >_k = \overline{F}_R + j\overline{F}_I$	For vector averaging, real and imaginary parts of the Fourier transform are averaged separately using either linear or exponential weighting over k data records.

$\mid F \mid$	The magnitude of the Fourier transform.
X_k, Y_k	*k*th instance of input spectrum *X* and its averaged output *Y*.
$\max(X_k, Y_k)$	Each complex frequency of spectrum X_k is compared in magnitude to its counterpart in Y_k.The larger value is retained. The result is a real spectrum.
conj( )	Complex conjugate.

Averaging Options

Figure 9 illustrates the hierarchy of options available for spectrum averaging.

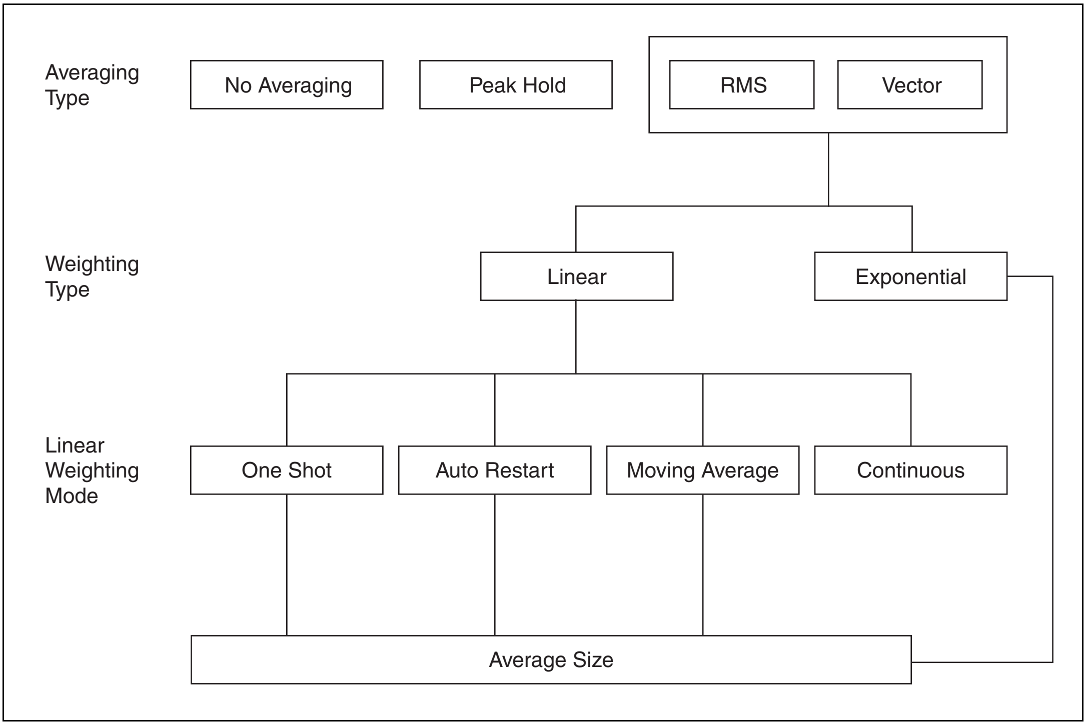


Figure 9. Spectrum Averaging Options

The averaging processes apply weighting to the < > operator in either RMS or vector averaging in the following way:

$$Y_k = \langle X \rangle_k = a_1 * Y_{k-1} + a_2 * X_k$$

where Y_k is the new average, Y_{k-1} is the previous average, and X_k is the new measurement. For linear weighting,

$$a_1 = (k-1)/k, \text{ and } a_2 = 1/k$$

For exponential weighting,

$$a_1 = (k-1)/k \text{ and } a_2 = 1/N \text{ for } k \le N,$$

$$a_1 = (N-1)/N \text{ and } a_2 = 1/N \text{ for } k > N$$

where N is a user-specified constant that determines how much weight is given to recent data relative to older data. Small values of N place more emphasis on the most recent data. The averages so far indicator stops incrementing at N while the averaging continues.

Linear weighting modes include the following:

- **One-shot linear averaging**—Average once for the specified duration of N measurements. When the duration is over, the averaging stops.
- **Auto restart linear averaging**—Automatically repeat the one-shot linear averaging after every N measurements.
- **Moving average**—Average the most recent N measurements.
- **Continuous**—Average all measurements taken with equal weight.

Averaged FFT Spectrum

The following equations describe the three averaging methods applied to a complex FFT spectrum:

vector averaging	$Y_k = \langle X \rangle_k$
RMS averaging	$Y_k = \sqrt{(\langle X \operatorname{conj}(X) \rangle_k)}$
peak hold	$Y_k = \max(X_k, Y_{k-1})$

The RMS and peak hold averaging methods produce real spectra while vector averaging produces a complex spectrum.

All of the averaging operations in the Spectral Measurements Toolset operate on a complex FFT input spectrum. To create an averaged FFT spectrum, use the SMT Averaged FFT Spectrum VI to apply one of the averaging operations to an FFT spectrum.

Averaged Power Spectrum

The following equations describe the averaging methods you can apply to a complex FFT spectrum to yield an averaged power spectrum. The no averaging method converts the complex FFT spectrum to a real power spectrum.

no averaging	$Y = X \, \mathrm{conj}(X)$
vector averaging	$Y_k = \langle X \rangle_k \, \mathrm{conj}(\langle X \rangle_k)$
RMS averaging	$Y_k = \langle X \, \mathrm{conj}(X) \rangle_k$
peak hold	$Y_k = \max(X_k, Y_{k-1})^2$

The averaged power spectrum is equivalent to the square of the magnitude of the averaged FFT spectrum.

Averaged Cross Spectrum

If you have two FFT spectra X and Y, the cross spectrum S_{xy} results from multiplying one spectrum by the complex conjugate of the other as follows:

$$S_{xy} = \mathrm{conj}(X)^* \; Y$$

For RMS averaging, an averaged cross spectrum consists of the average of the individual cross spectra as follows:

$$S_{xy} = < \mathrm{conj}(X)^* \; Y >$$

For vector averaging, an average cross spectrum consists of the vector average of each spectrum computed before multiplying the two averaged spectra together as follows:

$$S_{xy} = \mathrm{conj}(\langle X \rangle)^* \; \langle Y \rangle$$

A cross spectrum has no peak hold average.

Averaged Frequency Response

If you have a stimulus to a system with spectrum X and the system response Y, the frequency response H of the system is

$$H = \frac{Y}{X}$$

You can use the following equations to obtain the vector and RMS averaged frequency response:

RMS averaging	$H = \langle Y\text{conj}(X)\rangle / \langle X\,\text{conj}(X)\rangle$
vector averaging	$H = \langle Y\rangle / \langle X\rangle$

Frequency response has no peak hold average.

Spectral Domain Measurements

The Spectral Measurements Toolset contains VIs that perform power measurements such as power in band, adjacent channel power, and occupied bandwidth. The toolset also contains VIs that perform searches for single or multiple peaks in a spectrum.

Units Conversion

You can represent the magnitude scale of a spectrum in many ways depending on the nature of the measured signal and the aspect of the signal that you need to quantify. The SMT Spectrum Unit Conversion VI allows you to convert and scale a spectrum to the representation you need for your application. Unit conversion always results in a real spectrum without phase information.

The basic units associated with a spectrum are volts (V) and watts (W). Always associate units of watts with a specific impedance. If you do not know the impedance, you cannot make a statement about the power in watts. Power spectrum units are typically volts squared (V^2). If you assume an impedance of 1 ohm, you can represent the same power spectrum in watts. Volts and watts use either a linear or logarithmic scale. Logarithmic scales are in units such as dBV, which means the magnitude of the spectrum is in decibels (dB) with a reference level of one volt.

Spectrum scaling options are combinations of the following basic choices:

- **RMS or peak**—An FFT returns an amplitude spectrum scaled such that a frequency bin represents the RMS value of a sine wave at that frequency. It also can represent the peak value if you scale the spectrum by the square root of 2.
- **Amplitude or power**—The power spectrum is the squared magnitude of the amplitude spectrum. For example, an amplitude spectrum would have units of Vrms while its power spectrum units would be Vrms^2. If you divide by the impedance, you get Wrms^2.
- **Spectrum or spectral density**—Power spectral density (PSD) is the power spectrum divided by the frequency resolution. PSD units are usually Vrms^2/Hz or Wrms^2/Hz. You also can obtain an amplitude spectral density by choosing units such as $\text{Vrms}/(\sqrt{\text{Hz}})$.

Obtain input values for the SMT Spectrum Unit Conversion VI from the **spectral info** output of the zoom FFT VIs. Input parameters include the following:

- **window** is a parameter that you need to determine the equivalent noise bandwidth (ENBW) of the window you use. The ENBW affects the spectral density calculations because of the spectral leakage effect of windowing in the frequency domain.
- The ratio of **window size** and **FFT size** is a value the SMT Unit Conversion VI uses to correct any difference between the number of frequency bins in the spectrum and the number of points in the time-domain signal. The correction ensures that you can preserve the energy of the original signal. For example, if you zero-pad a time-domain signal of length *N* or window size *N* to a length of 2*N*, your result contains twice as much energy in the 2*N* frequency bins as in the time-domain signal. Given the two sizes, you can compensate this effect.
- **impedance** is the system impedance that you need whenever you use units of watts.

For example, you can use the SMT Spectrum Units Conversion VI to perform PSD measurements with units dBm/Hz on a signal. Set **units** to dBm, **peak scaling** to rms, and **psd?** to TRUE. The PSD computation is as follows:

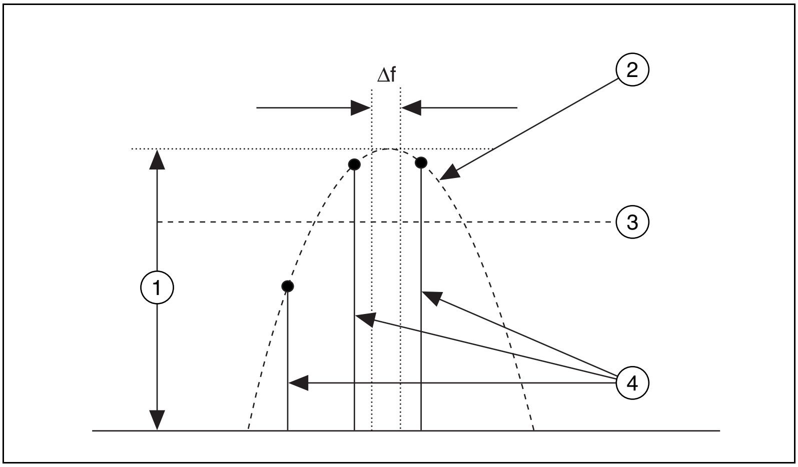
$$dBm\left(\frac{rms^2}{Hz}\right) = 10 \times \log 10\left((X[Vrms])^2 \times \frac{Window\ size}{FFT\ size} \times \frac{1000\left[\frac{mW}{W}\right]}{ENBW \times df[Hz] \times impedance[\Omega]}\right)$$

Peak Search and Amplitude/Frequency Estimation

The SMT Spectrum Peak Search VI uses interpolation to locate frequency peaks precisely in the amplitude or power spectrum and to estimate the amplitude of each peak. You can enter a real spectrum in any units or scaling. You also can specify whether to locate a single maximum peak or multiple peaks that exceed a specified threshold amplitude.

A single frequency tone appears in the frequency domain as a sampled version of the window the SMT Spectrum Peak Search VI applies to the input signal. If the VI did not apply a window, a finite sample size is equivalent to rectangular windowing. If you specify which window the VI applies to the input signal, the VI uses a curve-fitting algorithm on the three points around each detected peak to estimate true frequency and amplitude.

The amplitude/frequency estimation method works best on an averaged power spectrum because the averaging reduces the noise and provides a more consistent measurement. Figure 10 illustrates the curve-fitting algorithm. None of the three FFT bins falls exactly on the frequency peak, but the VI uses the known frequency response of the applied window to estimate the true peak location, which will be offset from the maximum FFT bin by Δf.



1	Amplitude	3	Threshold
2	Window shape	4	Three FFT bins

Figure 10. Amplitude/Frequency Estimation Algorithm

Power in Band

The SMT Power in Band VI measures the total power within some frequency range or band. *X* is the input power spectrum in $Vrms^2$. Use the VI before using the SMT Spectrum Unit Conversion VI. Provide a center frequency and bandwidth in Hz, from which you can derive the low and high bounds, f_l and f_h, of the frequency band. The SMT Power in Band VI computes the total power as follows:

$$Power\ in\ Band = \frac{\sum_{f_l}^{f_h} X(f)}{ENBW} \times \frac{Window\ size}{FFT\ size}$$

The SMT Power in Band VI calculates the powers at each of the frequencies lying in the band. The VI then applies a correction for spectral leakage from windowing and for any zero-padding. The SMT Power in Band VI can calculate power in band in units such as W, dBW, and dBm using an impedance that you supply.

Adjacent Channel Power (ACP)

The SMT ACP VI measures the way a center channel and its two adjacent channels distribute power. Use the VI before using the SMT Spectrum Unit Conversion VI. Channel refers to a particular frequency band of interest. The input parameters **center frequency**, **bandwidth** and **spacing** describe the three channels. **center frequency** refers to the center frequency of the middle channel. **bandwidth** defines the width of each channel. **spacing** defines the distance between the center of the middle channel and the center of the lower (and upper) channel. These three inputs fully define three individual frequency bands. You can specify various output units by supplying an impedance input value.

Figure 11 illustrates a typical adjacent channel power measurement and the three parameters that specify the channels.

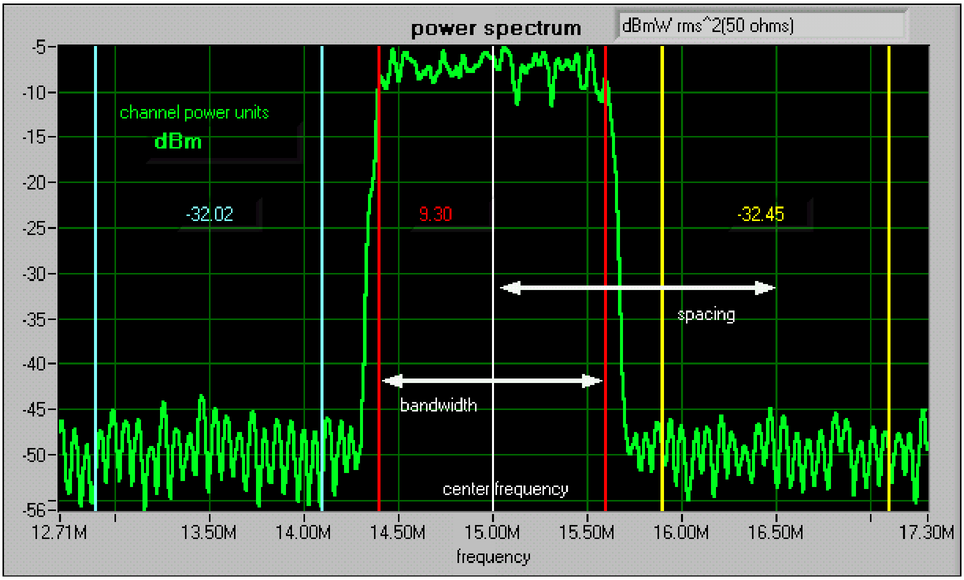


Figure 11. Adjacent Channel Power Measurement

Occupied Bandwidth

The SMT Occupied Bandwidth VI returns the bandwidth of the frequency band that contains a specified percentage of the total power of the signal. For a specified percentage *B*, the upper and lower limits of the frequency band are the frequencies above and below which $(100 - B)/2$ % of the total power is found. This measurement is sometimes known as the 99% bandwidth because B=99 is the most common input value. Use the VI before using the SMT Spectrum Unit Conversion VI.

The SMT Occupied Bandwidth VI is appropriate only for single-channel measurements such as measurements on signals that are limited to a single frequency band. For multiple-channel measurements, separate either the original signal or its spectrum into single-channel components and perform each single-channel measurement separately.

Figure 12 shows an example of an occupied bandwidth measurement. The logarithmic amplitude scale gives the appearance of a significant amount of power outside the channel, but in reality only 1% of the signal power is located there.

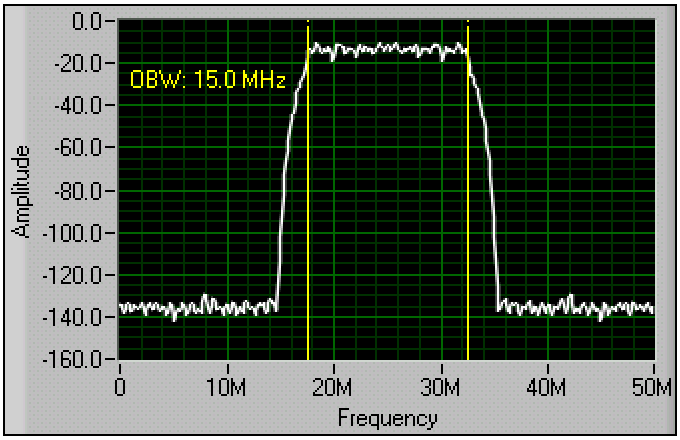


Figure 12. Occupied Bandwidth Measurement