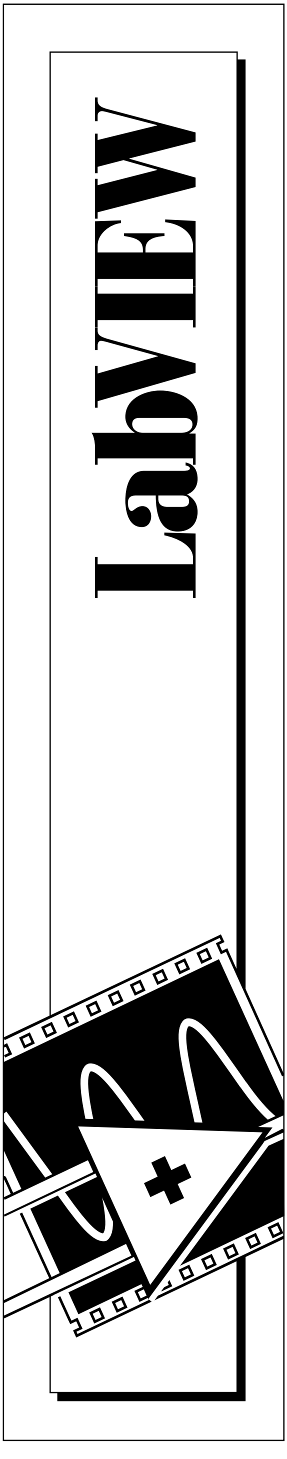

LabVIEW® Joint Time-Frequency Analysis Toolkit Reference Manual

March 1995 Edition
Part Number 320544B-01

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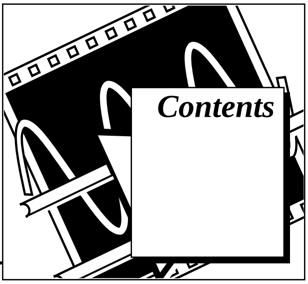

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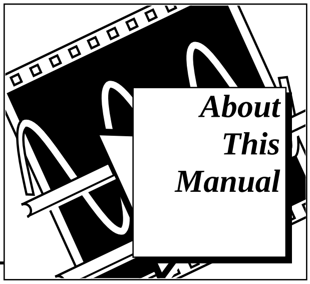

About This Manual

This manual describes the LabVIEW Joint Time-Frequency Analysis Toolkit package. You can use this program to analyze simultaneously the time and frequency behavior of a signal.

Organization of This Manual

This manual is organized as follows:

- Chapter 1, *Overview of the Joint Time-Frequency Analysis Toolkit*, lists the contents of the Joint Time-Frequency Analysis Toolkit, contains installation instructions, and introduces you to joint time-frequency analysis.
- Chapter 2, *Joint Time-Frequency Analyzer Application*, describes the stand-alone Joint Time-Frequency Analyzer application that uses the joint time-frequency analysis algorithms.
- Chapter 3, *Algorithms*, describes the algorithms used by the joint time-frequency analysis VIs.
- Chapter 4, *Joint Time-Frequency Analysis VIs*, contains descriptions of the joint time-frequency analysis VIs.
- Appendix A, *Error Codes*, lists the error codes returned by the joint time-frequency analysis VIs.
- Appendix B, *References*, lists the reference material used to produce the VIs in this manual. These references contain more information on the theories and algorithms implemented in the joint time-frequency analysis VIs.
- Appendix C, *Customer Communication*, contains forms you can use to request help from National Instruments or to comment on our products and manuals.
- The *Glossary* contains an alphabetical list and description of terms used in this manual, including abbreviations, acronyms, metric prefixes, mnemonics, and symbols.

Conventions Used in This Manual

The following conventions are used in this manual:

bold	Bold text denotes menus, menu items, and VI input and output parameters.
italic	Italic text denotes emphasis, a cross reference, or an introduction to a key concept.
bold italic	Bold italic text denotes a note, caution, or warning.

⚠ **Warning:** ***This icon to the left of bold italicized text denotes a warning, which alerts you to the possibility of damage to you or your equipment.***

⚠ **Caution:** ***This icon to the left of bold italicized text denotes a caution, which alerts you to the possibility of data loss or a system crash.***

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

Data Types — Each VI description contains a data type picture for each control and indicator within the VI. The following data type symbols are used in this manual.

Control	Indicator	Data Type
-	-	Signed 32-bit integer
-	-	Single-precision floating-point number
-	-	Boolean
[SGL]	[SGL]	Array of single-precision numbers

Abbreviations, acronyms, metric prefixes, mnemonics, symbols, and terms are listed in the *Glossary*.

Related Documentation

The following documents contain information that you may find helpful as you read this manual:

- *LabVIEW Analysis VI Reference Manual*
- *LabVIEW Data Acquisition VI Reference Manual*
- *LabVIEW Tutorial*
- *LabVIEW User Manual*

Customer Communication

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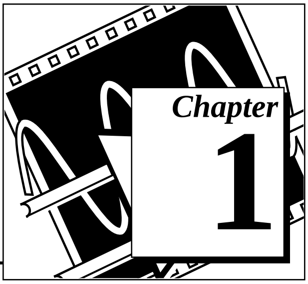


Chapter 1

Overview of the Joint Time-Frequency Analysis Toolkit

This chapter lists the contents of the Joint Time-Frequency Analysis Toolkit, contains installation instructions, and introduces you to joint time-frequency analysis.

Package Contents

Your Joint Time-Frequency Analysis Toolkit should contain the following materials.

- The Joint Time-Frequency Analysis Toolkit diskettes
- *LabVIEW Joint Time-Frequency Analysis Toolkit Reference Manual*, part number 320544B-01

Installation

The following sections contain instructions for installing the Joint Time-Frequency Analysis Toolkit on the Macintosh, Power Macintosh, Windows, HP-UX, and Sun SPARCstation platforms.

Macintosh and Power Macintosh

Complete the following steps to install the toolkit.

1. Insert diskette 1 of the Joint Time-Frequency Analysis Toolkit into your 3.5-inch diskette drive and double-click on the JTFA Toolkit Installer icon when it appears on your desktop.
2. Follow the instructions on your screen.

Once you have completed the on-screen installation instructions, you are ready to run the Joint Time-Frequency Analyzer.

Windows

Complete the following steps to install the toolkit.

1. Launch Windows.

2. Insert diskette 1 of the Joint Time-Frequency Analysis Toolkit into your 3.5-inch diskette drive.
3. From the File Manager, run `setup.exe`.
4. Follow the instructions on your screen.

Once you have completed the on-screen installation instructions, you are ready to run the Joint Time-Frequency Analyzer.

Sun and HP-UX

Complete the following steps to install the toolkit onto your hard drive.

1. Insert the Joint Time-Frequency Analysis Toolkit diskette into your 3.5-inch diskette drive.
2. In the UNIX shell, enter the following line from a directory for which you have write permission.

```
bar xvf /dev/rfd0c
```

You are ready to run the Joint Time-Frequency Analyzer.

Memory Allocation for Using the Joint Time-Frequency Analysis VIs

If you work with a Macintosh computer and intend to use the Joint Time-Frequency Analysis VIs, you must increase the amount of memory allocated to the Joint Time-Frequency Analysis Toolkit. If you use Windows, HP-UX, or a Sun SPARCstation, you do not need to reallocate memory to use these VIs, because the toolkit dynamically allocates memory from these operating systems as necessary. For more information on how to change the amount of memory allocated to LabVIEW, consult the *Performance and Disk Preferences* section of Chapter 7, *Customizing Your LabVIEW Environment,* in your *LabVIEW User Manual*.

Introduction to Joint Time-Frequency Analysis

Traditionally, signals have been analyzed in either the time or the frequency domain, but not jointly in time and frequency. For signals that do not change their spectral content in time, standard spectral analysis reveals what frequencies are present and their relative intensities.

For many signals, however, the frequency content changes over time, and while Fourier analysis indicates what frequencies were present, it does not show when those frequencies occurred in time. It is the aim of joint time-frequency analysis (JTFA) to describe and determine how the frequencies of nonstationary signals change over time.

The best way to understand how JTFA works is to look at a few examples. By examining these examples, you will also become familiar with some of the basic language used in the field.

Figure 1-1 shows the time-frequency plot of a bird sound. On the right side of the time-frequency plot you also see a plot of the standard Fourier spectrum. Beneath the time-frequency plot is a plot of the time waveform of the bird sound. From the spectrum alone, you cannot tell how the frequencies have changed over time. However, from the time-frequency plot, not only can you tell what the range of frequencies were, but also how the frequencies changed as a function of time. For this bird sound, you see that at the beginning, the bird was making a sound at a higher frequency that changed as displayed in the indicated graph.

Furthermore, in the time-frequency plot, not only can you see how the frequency changed in time, but you can see the intensity of the frequency, which is indicated by the relative brightness levels of the plot.

The standard Fourier spectrum of the same sound indicates the frequency range but gives no information about how the frequencies changed over time. Time-frequency analysis does just that—it reveals how the spectrum changes over time.

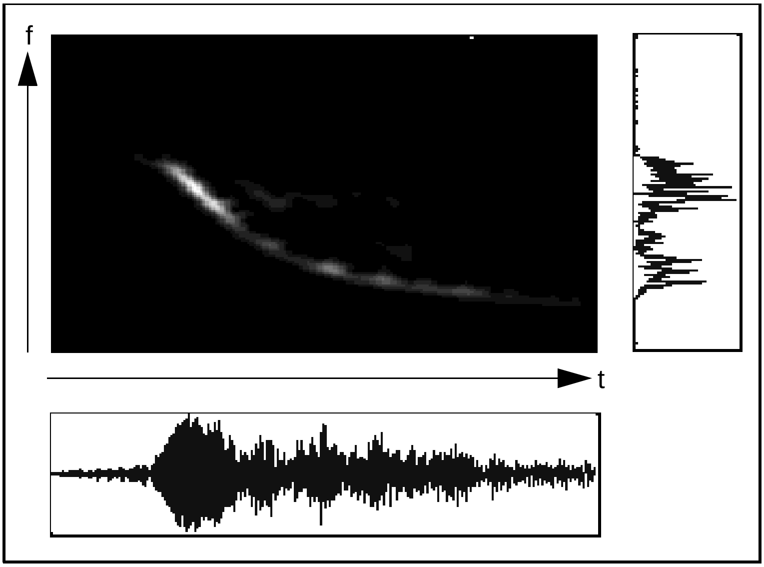


Figure 1-1. Sound of a Bird

As you can see in this example, time-frequency analysis offers a better understanding of the nature of the signal, improving classification and detection.

A common method for doing time-frequency analysis has been the short-time Fourier transform. This method breaks up the signal into small time intervals and uses Fourier analysis on each time interval. Short-time Fourier analysis is one of the options of the Joint Time-Frequency Analysis Toolkit.

Figure 1-2 demonstrates the importance of analyzing signals jointly in time and frequency. This example illustrates one of the important reasons for using time-frequency analysis—determining whether a signal is multicomponent. The sample signal plotted in Figure 1-2 is the sound of a duck. By looking at the time-frequency plot, you can immediately see that there were two main parts or tones to the signal. Such signals are called multicomponent signals. Notice that the spectrum gives no indication of the existence of distinct components.

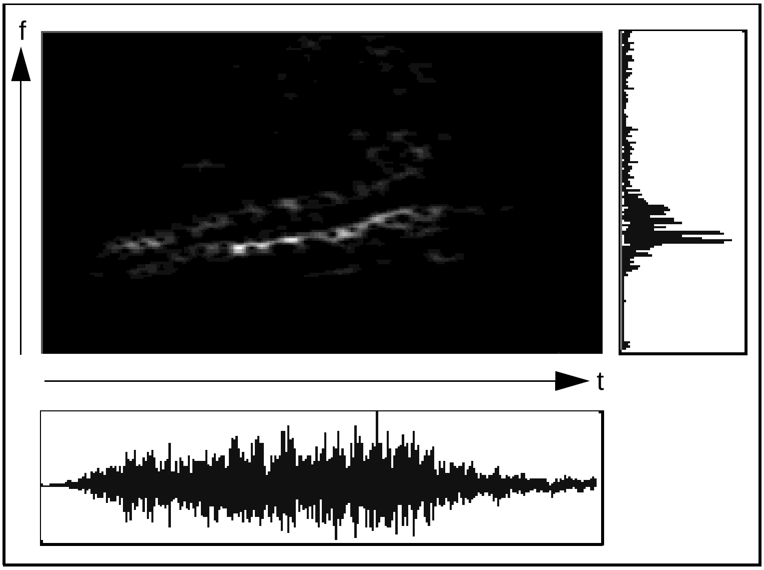


Figure 1-2. Sound of a Duck

Another important aspect of time-frequency analysis is that the Fourier spectrum can essentially be the same for signals that have very different spectral structures. Time-frequency plots, however, uncover major differences. This capability is illustrated by Figures 1-3 and 1-4, in which two different signals with the same spectrum are analyzed. By merely comparing their spectrums, you cannot tell that they are very different signals. The reason you cannot detect this difference is because temporal spectral changes are completely absent in the Fourier spectrum, which is the average energy spectrum over the sampled time period. The time-frequency plot clearly illustrates the temporal changes.

From the time-frequency plot of Figure 1-3, you see that the high frequency part of the signal existed only in the beginning, and the low frequency part was present only at the end of the time period. Figure 1-4 shows that for the second signal, all frequencies were present in the beginning of the time period, with no signal during the entire second half. If the spectrum alone was used as a classifier, no discernible difference between the two signals could be detected. By examining time-frequency plots, you can immediately see the difference and therefore would not incorrectly classify them as identical signals

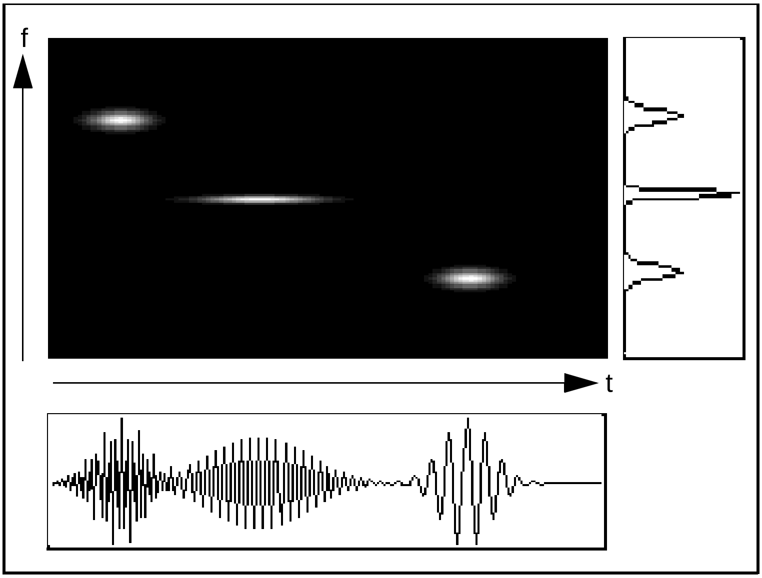


Figure 1-3. Three Gaussian Envelopes with Different Time Centers

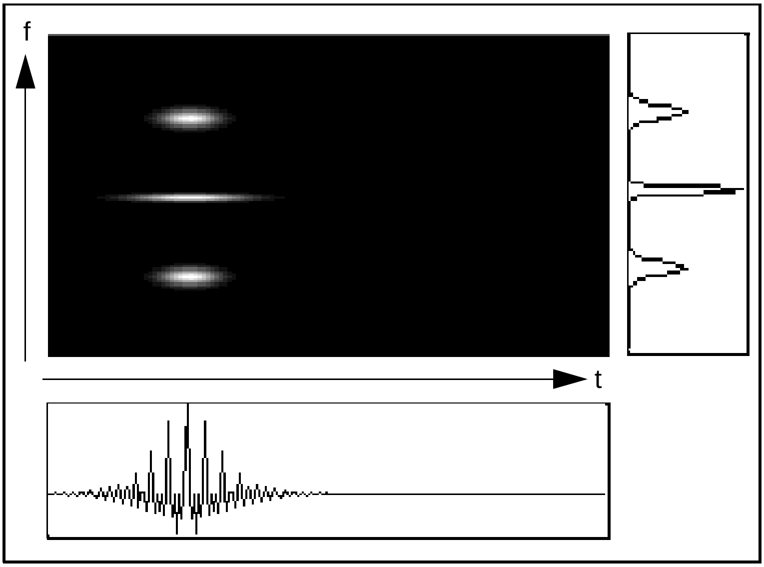


Figure 1-4. Three Gaussian Envelopes Centered at the Same Time Instant

Chapter 2

Joint Time-Frequency Analyzer Application

This chapter describes the stand-alone Joint Time-Frequency Analyzer application that uses the joint-time frequency analysis algorithms. These algorithms are described in Chapter 3, *Algorithms*.

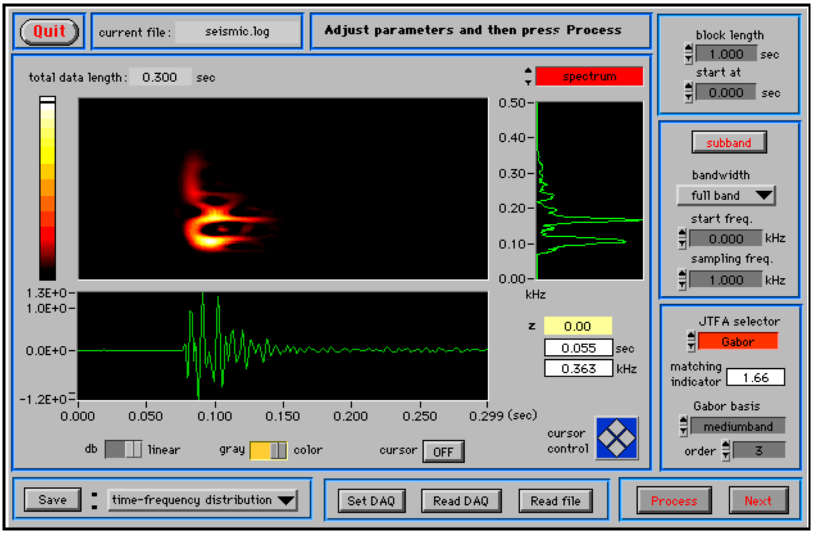
Introduction

The Joint Time-Frequency Analyzer allows you to use any of the six joint time-frequency algorithms to analyze stored data files and view the resulting spectrogram on an intensity plot. You may also save the time waveform and spectrum, as well as the spectrogram, to disk for future use.

The Joint Time-Frequency Analyzer is a run-only application that runs independently from the LabVIEW application.

Figure 2-1 shows the main window of the Joint Time-Frequency Analyzer.

☞ **Note:** ***The screens illustrated in this manual are from the Macintosh environment. If you are using Windows, HP-UX, or the Sun, your screens may look different. However, the information displayed in the screens is the same across all five platforms.***



Adjust parameters and then press Process

current file: seismic.log

total data length: 0.300 sec

block length 1.000 sec

start at 0.000 sec

bandwidth full band

start freq. 0.000 kHz

sampling freq. 1.000 kHz

JTFA selector Gabor

matching indicator 1.66

Gabor basis mediumband

order 3

z 0.00

0.055 sec

0.363 kHz

cursor OFF

Figure 2-1. Front Panel of the Time-Frequency Analyzer Application

Operation

When you start the Joint Time-Frequency Analyzer application, it prompts you for the location of the data that you want to analyze. Your data can be stored in an existing file, which must be either a datalog format file (an internal file format used by LabVIEW) or an ASCII text file. If your file is text, the Joint Time-Frequency Analyzer converts it to datalog format when you click on the Read file button. You must convert the file to a datalog, but you can save the converted file under a new name to preserve your original file. After conversion, the Joint Time-Frequency Analyzer opens your file as a datalog file.

If your computer is equipped with a National Instruments DAQ board, you can also analyze data collected from the DAQ board directly. If you click on the Read DAQ button, the Joint Time-Frequency Analyzer starts collecting data from the DAQ board. The Joint Time-Frequency Analyzer stores the collected data in any file you choose. The DAQ parameter selection panel only appears the first time you click on the Read DAQ button. The Joint Time-Frequency Analyzer remembers the DAQ parameters you select until you exit the Joint Time-Frequency Analyzer application. If you want to change the DAQ parameters during processing, click on the Set DAQ button.

After you select the file to analyze, the Joint Time-Frequency Analyzer reads a block of data, or frame of samples, from the file. See the *Changing the Time Range of the Analyzed Signal* section of this chapter for an explanation of how the Joint Time-Frequency Analyzer reads a frame.

The Joint Time-Frequency Analyzer then analyzes the samples and displays the resultant spectrogram using a two-dimensional intensity plot. Each point in the plot represents a normalized magnitude. The Joint Time-Frequency Analyzer also displays the traditional spectrum to the right of and the time waveform below the two-dimensional spectrogram.

After the Joint Time-Frequency Analyzer application processes the first frame, you can save the spectrogram, spectrum, or time waveform to a spreadsheet file by clicking on the Save button on the Joint Time-Frequency Analyzer panel. You can also process the next frame of samples by clicking on the Next button. The spectrogram from the next frame overwrites the first one if you do not save it. (See Figure 2-1 for the location of these buttons.)

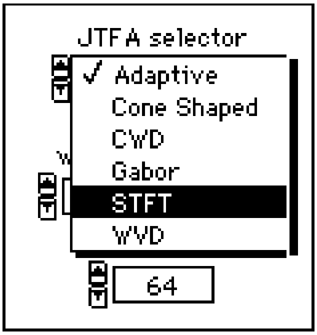
After you finish analyzing one file, you may close the current file and open a new one. To open a new file, click on the Read file button and indicate the file that you want to open. The program closes the original file automatically.

To clear all graphs and reset all controls and indicators to their original state, use the **Reinitialize all to default** option under the **Operate** menu.

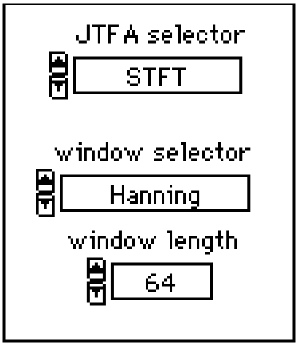
Changing the Joint Time-Frequency Analyzer Algorithm

By default, the Joint Time-Frequency Analyzer analyzes the samples in your file using the short-time Fourier transform algorithm. You may choose to analyze your files using one of the other five available algorithms—the Adaptive spectrogram, the Gabor spectrogram, the Choi-Williams distribution, the cone-shaped distribution, or the Wigner-Ville distribution. These algorithms are discussed in greater detail in Chapter 3, *Algorithms*.

Select the algorithm you want to use with the JTFA selector control.



Immediately below the JTFA selector are the JTFA parameter selection controls. Each JTFA algorithm has a different set of parameters. Only the controls related to the currently selected algorithm are displayed. For example, if you select the STFT algorithm (short-time Fourier transform), the parameter selection control changes to display the STFT **window selector** control and STFT **window length** control, as shown in the following illustration


JTFA selector: STFT

window selector: Hanning

window length: 64

Note: ***The Adaptive spectrogram does not use parameters. The JTFA selector panel does not display any parameters when you choose this algorithm.***

Acquiring Data from Your DAQ Board

The Joint Time-Frequency Analyzer can analyze data collected from analog instruments directly, if a DAQ board is installed in your computer. To analyze data collected by your DAQ board, click on the Read DAQ button, and then follow the instructions on your screen. The first time you click on the Read DAQ button, the parameter selection panel opens. The parameters you set the first time you use this feature are automatically used to analyze all other data sets collected by your DAQ board, unless you click on the Set DAQ button to change the existing settings. The *LabVIEW Data Acquisition VI Reference Manual* contains detailed descriptions of the DAQ VI parameters.

Changing the Time Range of the Analyzed Signal

The parameters **start at** and **block length** control the time range of the analyzed signal. The **start at** parameter determines the start time. The **block length** parameter determines the length of one frame of the analyzed signal. The default value for **start at** is 0 second, and for **block length** is 1 second. If the length of the signal is less than **start at** + **block length**, the Joint Time-Frequency Analyzer processes whatever is available.

Because of memory limitations, the Joint Time-Frequency Analyzer cannot process an arbitrarily long signal in one frame. If the length of signal you set to process is too long for one frame (that is, if the **block length** is too large), the Joint Time-Frequency Analyzer displays the longest time duration allowed in a status indicator dialog box and then stops processing.

Changing the Frequency Range of the Analyzed Signal

The parameters **start freq** and **bandwidth** control the frequency range of the analyzed signal. **start freq** determines the lower boundary of the frequency. The selection of the bandwidth is limited to 2-^{k} * Nyquist frequency, 0 ð k ð 5. The default values are **start freq** equals zero, and **bandwidth** equals full band. If **start freq** + **bandwidth** is greater than the Nyquist frequency, the Joint Time-Frequency Analyzer ignores the setting of **start freq** and automatically sets the lower boundary of the frequency to zero.

Applying Preemphasis

By clicking on the subband button, you select the **preemphasis** parameter. You can use the preemphasis filter to reduce the influence of the DC component and enhance the high frequency component. The formula of the preemphasis filter is

$$y[n] = x[n] - \alpha x[n-1],$$

where $y[n]$ and $x[n]$ denote the nth input and analyzed samples, respectively. The degree of preemphasis is controlled by the parameter α, where 0 ð α ð 1. For $a = 0$, $y[n] = x[n]$ (no preemphasis). When $\alpha = 1$, the Joint Time-Frequency Analyzer completely removes the DC component, and the frequency components in the vicinity of the Nyquist frequency are approximately doubled. The default setting is α equals 0.

Recomputing the Spectrogram

If you change the JTFA selector, subband, or any of the parameters, you must recompute the spectrogram to see the effect of the changes. To recompute the spectrogram, click on the Process button. The Joint Time-Frequency Analyzer computes the spectrogram using the values in the controls at the time you click on the Process button.

Saving the Results to Disk

You may want to save the data plots to a file for later use. The Joint Time-Frequency Analyzer can save the time waveform, spectrum, and spectrogram as spreadsheet files. Select the plots you want to save and then click on the Save button. The Joint Time-Frequency Analyzer prompts you to enter the name of the file.

In a spreadsheet file, the samples in a given row are separated by tab characters (ASCII value 9). Each row in a spreadsheet file is separated by a carriage return (ASCII value 13).

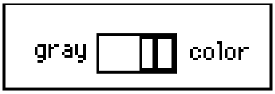
Figure 2-2 shows the first two rows of a spreadsheet file with three columns.

```
-5.4321<tab>-5.2316<tab>-5.0452<return>
-5.5378<tab>-5.4698<tab>-5.1274<return>
```

Figure 2-2. A Portion of a Spreadsheet File

Printing the Results

To print the entire main window of the Joint Time-Frequency Analyzer, choose **Print** from the **File** menu. Color printing is available on the Macintosh and Windows versions, but not on the Sun. If the spectrogram display prints incorrectly on a black and white printer, try changing the panel color to gray using the front panel switch, shown in the following illustration.



You can also print the window by capturing the screen and pasting it into another application. In Windows, pressing `Alt-Print Screen` copies the topmost window to the clipboard. This picture can then be pasted into another application. On Sun workstations, the UNIX command `xwd` creates a file of a selected window. Consult the man pages for more information on using `xwd`. There are also several screen capture utilities available through third party vendors.

Memory Usage

The Joint Time-Frequency Analyzer maintains temporary files on disk while it executes. For example, when you save a spectrogram, the Joint Time-Frequency Analyzer first saves it into a temporary file. If the save is successful, the original is replaced with the new file. If you have less than 500 KB of disk space free, the Joint Time-Frequency Analyzer alerts you and quits. If you have less than 2 MB available, the Joint Time-Frequency Analyzer warns you but continues to run. At this time, you should free disk space on your hard drive. You can turn these warnings off, but it is best to leave them on.

Help

The **Show Help** option is found under the **Help** menu. The **Show Help** option opens the Help window, which displays information about a control. Placing your cursor over a control causes the Help window to display the descriptive information.

Chapter 3

Algorithms

This chapter describes the algorithms used by the joint time-frequency analysis VIs.

Joint Time-Frequency Analysis Algorithms

The VIs described in this manual use the following joint time-frequency analysis algorithms.

- Wigner-Ville distribution
- Cone-shaped distribution
- Choi-Williams distribution
- Short-time Fourier transform (STFT)
- Gabor spectrogram
- Adaptive spectrogram

The following sections explain each algorithm.

Cohen's Class

The Wigner-Ville distribution, Choi-Williams distribution, and cone-shaped distribution are special cases of the general bilinear transform (also named Cohen's class). For signal $s(i)$, Cohen's class is defined as

$$P(i,k) = \sum_{m=-\frac{L}{2}}^{\frac{L}{2}-1} W_L^{-2mk} \sum_{n} \phi(n,m) R(i-n,m) \tag{3-1}$$

where

$$W_L = \exp\{j2\pi/L\} \ .$$

$R(i,m)$ is a time-dependent autocorrelated function given by

$$R(i,m) = Z_s(i+m)Z_s(i-m) \ ,$$

where $Zs(i)$ denotes the oversampled or analytical sequence corresponding to $s(i)$. To obtain the oversampled version, first insert zero between each sample and then use a half-band lowpass filter to remove the image.

The analytical sequence is obtained by the equation

$$Z_s(i) = s(i) + jH\{s(i)\} \quad ,$$

where $H\{\ \}$ denotes the Hilbert transform.

Using analytical signals reduces the cross-term interference caused by the negative frequency components; however, it also introduces distortions, particularly in the low frequency band.

The kernel function, $\phi(i,m)$, determines the particular transform. In this toolkit, we limit the kernel function by declaring
$\phi(i,m) = \phi(-i,m) = \phi(i,-m) = \phi(-i,-m)$.

Wigner-Ville Distribution

When $\phi(i,m) = \delta(i)$ for all m, equation (3-1) becomes the Wigner-Ville distribution.

$$\boldsymbol{WVD}(i,k) = \sum_{m=\frac{-L}{2}}^{\frac{L}{2}-1} W_L^{-2mk} R(i,m) \qquad (3\text{-}2)$$

You can think of the Wigner-Ville distribution as the Fourier transform of the time-dependent autocorrelation function $Z_s(i+m)Z_S(i-m)$.

Figure 3-1 shows the time waveform of a frequency hopper signal, the corresponding spectrum (calculated by the FFT), and the Wigner-Ville distribution of this signal. From the time waveform, you cannot see the frequency information. From the spectrum, you can see four distinct frequency components, but you cannot tell when those components occurred. The Wigner-Ville distribution provides both the time and frequency information in the same plot. However, the cross terms cause considerable interference.

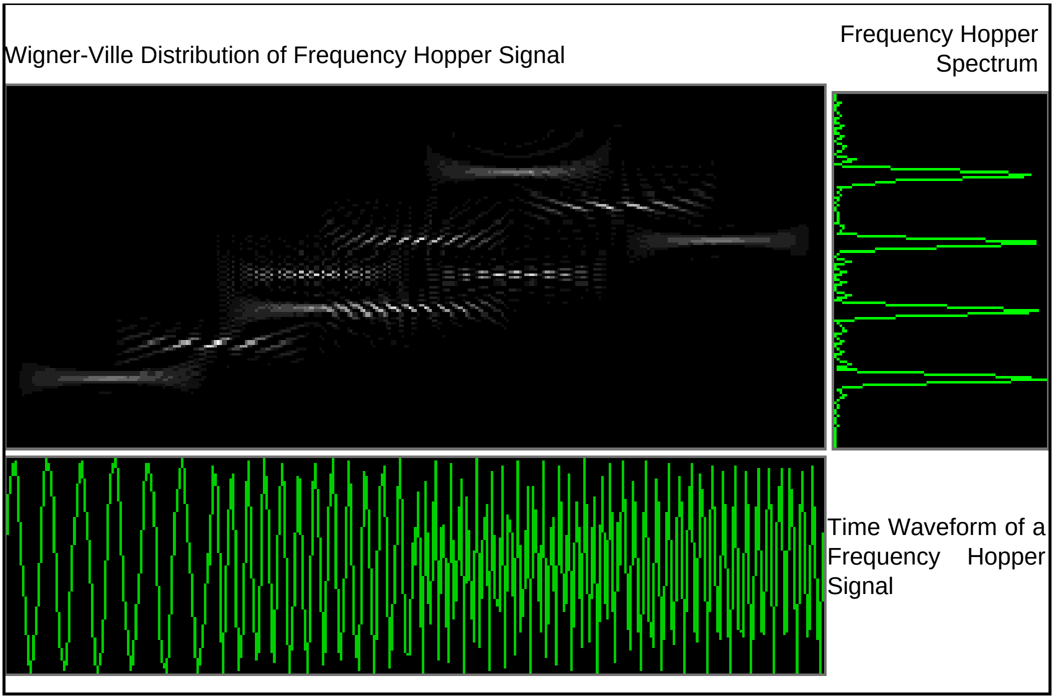


Figure 3-1. Combined Analysis of a Frequency Hopper Signal

Cone-Shaped Distribution

When

$$\phi(i,m) = \begin{cases} \exp\left\{-\frac{\alpha m^2}{500}\right\} & \text{for } i < |m| \\ 0 & \text{otherwise} \end{cases},$$

equation (3-1) becomes the cone-shaped distribution.

$$P(i, k) = \sum_{m=-\frac{L}{2}}^{\frac{L}{2}-1} W_L^{-2mk} \exp\left\{-\frac{\alpha m^2}{500}\right\} \sum_{n \le |m|} R(i-n,m) \qquad (3\text{-}3)$$

The α parameter controls the degree of smoothing. The bigger α is, the less smoothing and interference occur. The recommended α value is 0.5 ð α ð 100. The cone-shaped distribution can also be negative. Figure 3-2 shows the cone-shaped distribution of the frequency hopper signal

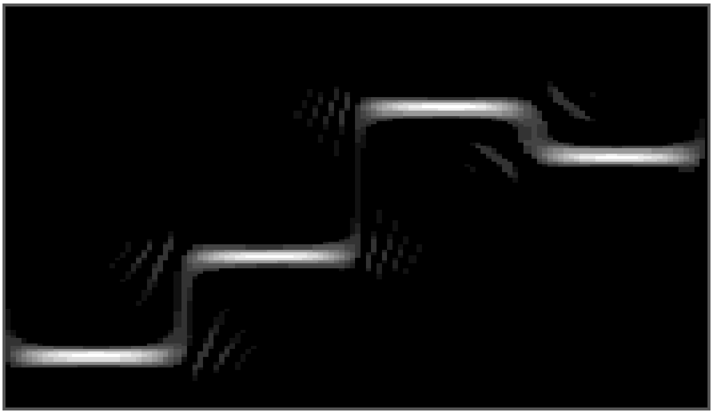


Figure 3-2. Cone-Shaped Distribution of the Frequency Hopper Signal

Choi-Williams Distribution

For

$$\phi(i,m) = \sqrt{\frac{\alpha}{4\pi m^2}}\exp\left\{-\frac{\alpha i^2}{4m^2}\right\}$$

equation (3-1) becomes the Choi-Williams distribution.

$$P(i, k) = \sum_{m=-\frac{L}{2}}^{\frac{L}{2}-1} \sqrt{\frac{\alpha}{4\pi m^2}}\sum_{n} \exp\left\{\frac{-\alpha n^2}{4m^2}\right\}R(i-n,m) \tag{3-4}$$

The parameter α controls the degree of smoothing. The bigger α is, the less smoothing occurs. The smoothing contained in the Choi-Williams distribution reduces the interference obtained by the Wigner-Ville distribution at the price of heavy computations. The Choi-Williams distribution can also be negative. Figure 3-3 shows the Choi-Williams distribution of the frequency hopper signal. This transform reduces the interference significantly but is usually much slower than the Wigner-Ville distribution.

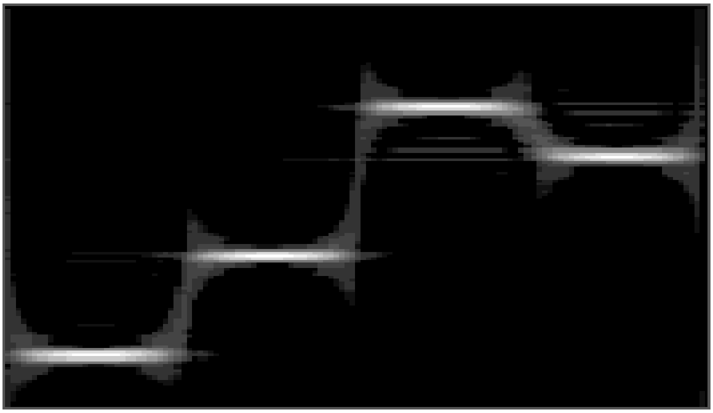


Figure 3-3. Choi-Williams Distribution of the Frequency Hopper Signal

Short-Time Fourier Transform

The most common method of joint time-frequency analysis is the short-time Fourier transform (STFT) spectrogram. For a given discrete signal *s*(*i*), the following equation defines the STFT.

$$\mathrm{STFT}(i,k) = \left| \sum_{m=-\frac{L}{2}}^{\frac{L}{2}-1} s(i-m)g(m)\mathrm{W}_L^{-mk} \right|^2 \tag{3-5}$$

for

$$0 \le k \le \frac{L}{2}$$

where *g*(*m*) is an analysis window function.

The STFT is also called a sliding-window fast Fourier transform (FFT) because a window function breaks the signal into several time slices. The FFT computes the frequency spectrum for each slice of windowed data, and only the square magnitude of the FFT is kept for the STFT. The frequency information is associated with the time index in the middle of each slice of windowed data. Therefore, you can establish a complete three-dimensional spectrogram by sliding the window to the right one point at a time and computing a new spectrum.

The STFT is positive, but its resolution is inferior to the Wigner-Ville, Choi-Williams, and cone-shaped distributions, as Figure 3-4 shows.

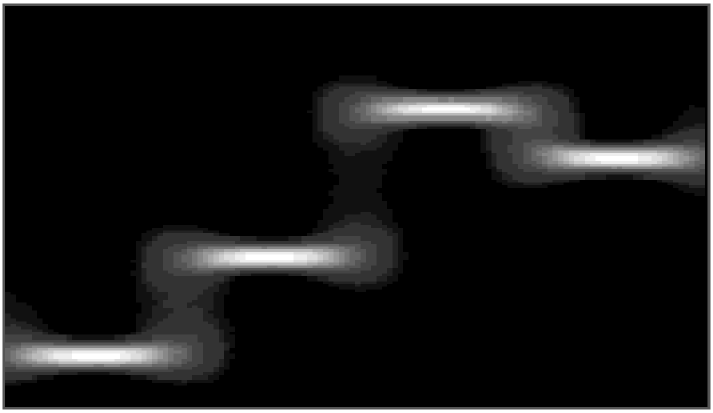


Figure 3-4. STSF Using a Hamming Window of the Frequency Hopper Signal

The window type and length you choose affects the resolution of the STFT. A wide window gives good resolution in the frequency domain but poor resolution in the time domain. Conversely, a narrow window gives good time domain resolution but poor frequency domain resolution.

Gabor Spectrogram

The Gabor spectrogram (also known as the time-frequency distribution series) represents the time-dependent power spectrum of a signal in terms of a series of time-frequency functions. For a given discrete signal *s*(*i*), the Gabor spectrogram is defined as

$$GS_D(i, k) = \sum_{d=0}^{D} P_d(i, k)$$

where *D* denotes the order of the Gabor spectrogram. The time-frequency function $P_d(i,k)$ is a 2D interpolation filter given by

$$P_d(i, k) = \sum_{\lambda(d)} a(t_\mu, f_\mu) H(i - t_\mu, k - f_\mu) \tag{3-6}$$

where

$$a(t_\mu, f_\mu) = C_{m,n} C^*_{m',n'} \exp\left\{ j \frac{2\pi}{L} f_d t_\mu \right\} \quad .$$

The $C_{m,n}$ are discrete orthogonal-like Gabor coefficients. (See reference [4] in *Appendix B* for more information about Gabor expansion.) The function $\lambda(d)$ is a set of pairs of the coordinates, (m,n) and (m',n'), which are separated in d, that is,

$$\lambda(d) = \{(m, n), (m', n') \,|\, |m - m'| + |n - n'| = d\} \ .$$

The $t\mu$ and $f\mu$ are time and frequency centers, respectively, that is,

$$t_\mu = \frac{m + m'}{2} \Delta M \ \text{ and } \ f_\mu = \frac{n + n'}{2} \Delta N$$

The t_d and f_d are the difference in time and frequency between two individual Gabor basis functions, $h_{m,n}$ and $h_{m'n'}$, that is,

$$t_d = (m - m')\Delta M \ \text{ and } \ f_d = (n - n')\Delta N$$

The impulse response of the 2D interpolation filter $H(i,k)$ in equation (3-6) is given by

$$H(i, k) = 2\exp\left\{ -\left[\frac{i^2}{\delta^2} + \left(\frac{2\pi}{L} \delta k \right)^2 \right] \right\} \exp\left\{ -j\left[\frac{2\pi}{L} (t_d k - f_d i) \right] \right\}$$

For $D = 0$, $GS0(i,k) = P0(i,k)$ is nonnegative and similar to the STFT when using the Gaussian window function. As D gets larger, the Gabor spectrogram converges to the Wigner-Ville distribution. In fact, the Gabor spectrogram decomposes the Wigner-Ville distribution as DC plus a group of oscillated time-frequency functions.

The lower order Gabor spectrogram has less cross-term interference but lower resolution. The higher order Gabor spectrogram has better resolution but more cross-term interference. Moreover, the higher the order is, the more the computation is required. The best choice usually is order three to four. In this case, the Gabor spectrogram not only has better resolution than the STFT, but also possesses much less cross-term interference than the cone-shaped, Choi-Williams, and Wigner-Ville distributions.

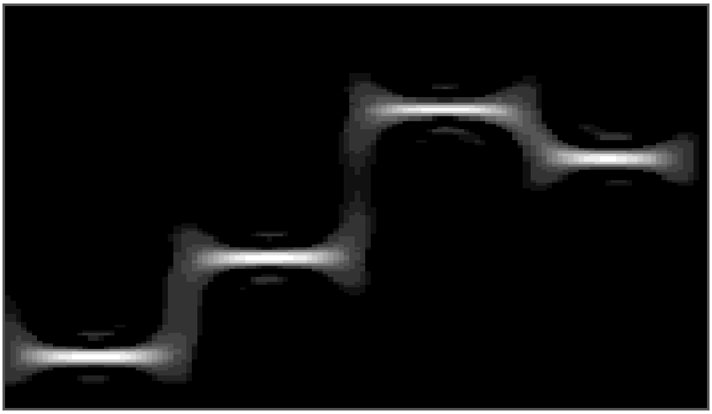


Figure 3-5. Third-Order GAvor Spectrogram of the Frequency Hopper Signal

Adaptive Spectrogram

Unlike the Gabor spectrogram, which uses a Gaussian function with uniform variance to compare the analyzed signals at a fixed time-frequency grid, the adaptive approach adjusts the variance, time, and frequency centers of the Gaussian functions to best match the analysis signal. Consequently, the Adaptive spectrogram algorithm has the best resolution of all the joint-time frequency algorithms in this package and does not cause cross-term interference. The following equation defines the adjustable Gaussian basis function.

$$h_p(i) = (\pi\alpha_p)^{(-0.25)} \exp\left[-\frac{(i-i_p)^2}{2\alpha_p} - j2\pi k_p i\right]$$

The algorithm for evaluating the optimal Gaussian basis function at index $p = 0, 1, \ldots, P\text{-}1$, is discussed by Qian et al. [5]. After the $h_p(i)$ are obtained for all P, where P is the number of basis functions, the following equation computes the Adaptive spectrogram.

$$AS(i,k) = \sum_{p=0}^{P-1} |B_p|^2 \exp\left[-\left(\frac{i-i_p}{\sigma_p}\right)^2 - \left(\frac{2\pi\sigma_p}{L}\right)^2 (k-k_p)^2\right] \tag{3-7}$$

for

$$0 < k \eth \frac{L}{2} .$$

The $AS(i,k)$, or spectrogram, preserves the analysis signal energy as P approaches infinity. However, increasing P also increases computational complexity. The adaptive spectrogram has the best joint time-frequency resolution and is well suited to the analysis of quasi-stationary signals, those signals that do not change rapidly in both the time and frequency domains.

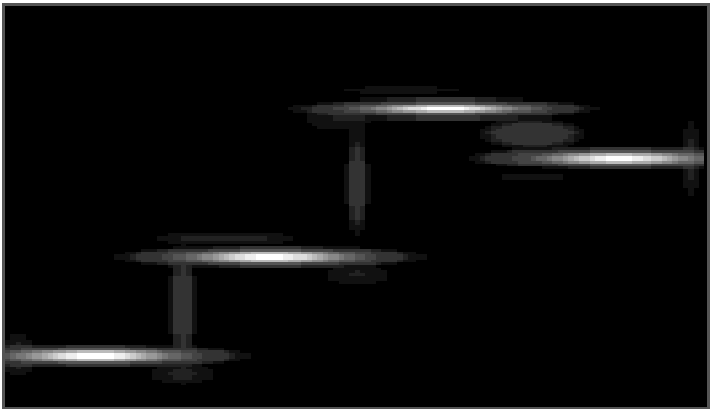


Figure 3-6. Adaptive Spectrogram of the Frequency Hopper Signal

Chapter
4

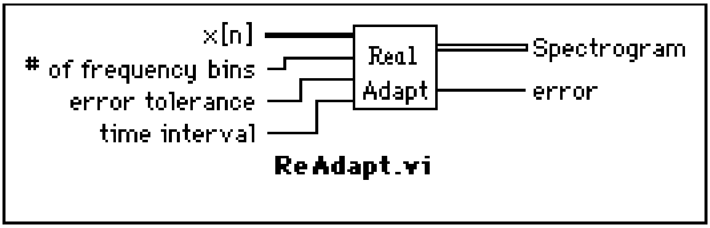
Joint Time-Frequency Analysis VIs

This chapter contains descriptions of the joint time-frequency analysis VIs.

Joint Time-Frequency Analysis VI Descriptions

Adaptive Spectrogram

Computes the signal energy distribution in the joint time-frequency domain using the Adaptive spectrogram algorithm.



[SGL] **x[n]** is the time waveform.

[SGL] **# of frequency bins** controls the frequency spacing of the columns of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the columns of **Spectrogram** is f_s/**# of frequency bins** Hz. Increasing **# of frequency bins** improves frequency resolution but increases computation time and memory requirements. Decreasing **# of frequency bins** decreases computation time and reduces memory requirements, but also reduces frequency-domain resolution. The **# of frequency bins** parameter must be a power of 2.

error tolerance is the maximum normalized error in the energy in the input time waveform and the **Spectrogram** output. Decreasing **error tolerance** improves the accuracy of the **Spectrogram** output but also increases computation time. Increasing **error tolerance** reduces computation time but degrades the accuracy of **Spectrogram**.

The **error tolerance** parameter balances the spectrogram accuracy and the computation complexity. The following equation defines the **error tolerance** parameter.

$$\textbf{error tolerance} \geq \frac{\sum_{i=0}^{\infty} |s(i)|^2 - \sum_{i=0}^{\infty} \sum_{k=0}^{\frac{L}{2}} \mathrm{AS}(i, k)}{\sum_{i=0}^{\infty} |s(i)|^2}.$$

As you decrease **error tolerance**, the number of basis functions (P in equation (3-7)) is increased by the algorithm until the preceding inequality is satisfied.

I32

time interval is the base 2 logarithm of the time spacing, in samples, between each row of the **Spectrogram** output. For example, if you sampled the time waveform at f_S Hz, the spacing between the rows of **Spectrogram** is **time interval**/f_S seconds.

Increasing **time interval** decreases computation time and reduces memory requirements, but also reduces time-domain resolution. Decreasing **time interval** improves time-domain resolution but increases computation time and memory requirements.

[SGL]

Spectrogram is a 2D array that describes the time waveform energy distribution in the joint time-frequency domain.

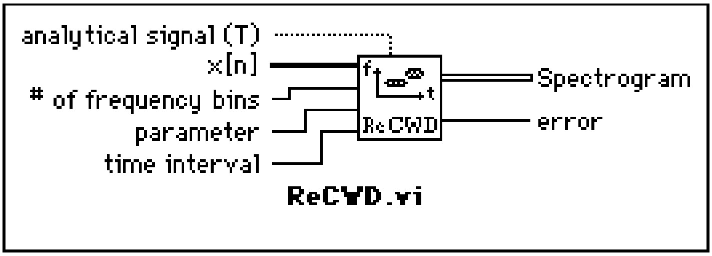
The number of rows (time axis) in **Spectrogram** is equal to the number of elements in the time waveform divided by **time interval**, and then rounded up. The number of columns (frequency axis) in **Spectrogram** is equal to

$$\frac{\textbf{\# of frequency bins}}{2}$$

error.

Choi-Williams Distribution

Computes the signal energy distribution in the joint time-frequency domain using the Choi-Williams distribution algorithm.



This VI first computes the analytical sequence of the time waveform **x[n]** and then evaluates the kernel function, which is a smoothed version of the Wigner-Ville distribution kernel.

TF

analytical signal (T) determines whether to convert real-valued samples to the oversampling sequence or to the analytical sequence. Using the analytical sequence can reduce the cross-term interference; however, it can cause significant distortion in the lower frequency band.

[SGL]

x[n] is the time waveform.

# of frequency bins controls the frequency spacing of the columns of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the columns of **Spectrogram** is f_s/**# of frequency bins** Hz. Increasing **# of frequency bins** improves frequency resolution but increases computation time and memory requirements. Decreasing **# of frequency bins** decreases computation time and reduces memory requirements, but also reduces frequency-domain resolution. The **# of frequency bins** parameter must be a power of 2.

parameter controls the degree of smoothing of the interference terms inherent in the Wigner-Ville distribution.

Decreasing **parameter** increases the smoothing of the interference that appears in **Spectrogram** but also increases computation time. Increasing **parameter** decreases computation time but also increases the interference in **Spectrogram**.

parameter must be greater than zero.

[SGL]

time interval is the base 2 logarithm of the time spacing, in samples, between each row of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the rows of **Spectrogram** is **time interval**/f_s seconds.

Increasing **time interval** decreases computation time and reduces memory requirements, but also reduces time-domain resolution. Decreasing **time interval** improves time-domain resolution but increases computation time and memory requirements.

Spectrogram is a 2D array that describes the time waveform energy distribution in the joint time-frequency domain.

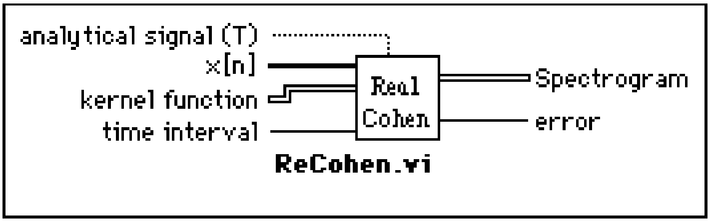
The number of rows (time axis) in **Spectrogram** is equal to the number of elements in the time waveform divided by **time interval**, and then rounded up. The number of columns (frequency axis) in **Spectrogram** is equal to

$$\frac{\textbf{\# of frequency bins}}{2}$$

error.

Cohen's Class

The Choi-Williams distribution, cone-shaped distribution, and Wigner-Ville distribution all belong to Cohen's Class with different kernel functions, $\phi(i,m)$. You can test your own algorithm using the Cohen's Class VI. The kernel function is limited in the symmetry case, in other words, $\phi(i,m) = \phi(-i,m) = \phi(i,-m) = \phi(-i,-m)$.



TF

analytical signal (T) determines whether to convert real-valued samples to the oversampling sequence or to the analytical sequence. Using the analytical sequence can reduce the cross-term interference; however, it can cause significant distortion in the lower frequency band.

[SGL]

x[n] is the time waveform.

[SGL]

kernel function is a two-dimensional array, $\phi(i,m)$, where $i, m \geq 0$. The value of m determines the number of frequency bins. The performance of the resulting transform is completely determined by the kernel function $\phi(i,m)$.

[SGL]

time interval is the base 2 logarithm of the time spacing, in samples, between each row of the **Spectrogram** output. For example, if you sampled the time waveform at f_S Hz, the spacing between the rows of **Spectrogram** is **time interval**/f_S seconds.

Increasing **time interval** decreases computation time and reduces memory requirements, but also reduces time-domain resolution. Decreasing **time interval** improves time-domain resolution but increases computation time and memory requirements.

Spectrogram is a 2D array that describes the time waveform energy distribution in the joint time-frequency domain.

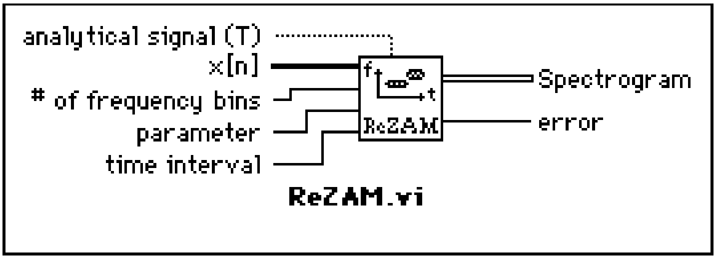
The number of rows (time axis) in **Spectrogram** is equal to the number of elements in the time waveform divided by **time interval**, and then rounded up. The number of columns (frequency axis) in **Spectrogram** is equal to

$$\frac{\textbf{\# of frequency bins}}{2}$$

error.

Cone-Shaped Distribution

Computes the signal energy distribution in the joint time-frequency domain using the cone-shaped distribution algorithm.



This VI first computes the analytical sequence of the time waveform **x[n]** and then evaluates the kernel function, which is a smoothed version of the Wigner-Ville distribution kernel.

TF

analytical signal (T) determines whether to convert real-valued samples to the oversampling sequence or to the analytical sequence. Using the analytical sequence can reduce the cross-term interference; however, it can cause significant distortion in the lower frequency band.

[SGL]

x[n] is the time waveform.

# of frequency bins controls the frequency spacing of the columns of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the columns of **Spectrogram** is f_s/**# of frequency bins** Hz. Increasing **# of frequency bins** improves frequency resolution but increases computation time and memory requirements. Decreasing **# of frequency bins** decreases computation time and reduces memory requirements, but also reduces frequency-domain resolution. The **# of frequency bins** parameter must be a power of 2.

parameter controls the degree of smoothing of the interference terms inherent in the Wigner-Ville distribution.

Decreasing **parameter** increases the smoothing of the interference that appears in **Spectrogram** but also increases computation time. Increasing **parameter** decreases computation time but also increases the interference in **Spectrogram**.

parameter must be greater than zero.

[SGL]

time interval is the base 2 logarithm of the time spacing, in samples, between each row of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the rows of **Spectrogram** is **time interval**/f_s seconds.

Increasing **time interval** decreases computation time and reduces memory requirements, but also reduces time-domain resolution. Decreasing **time interval** improves time-domain resolution but increases computation time and memory requirements.

Spectrogram is a 2D array that describes the time waveform energy distribution in the joint time-frequency domain.

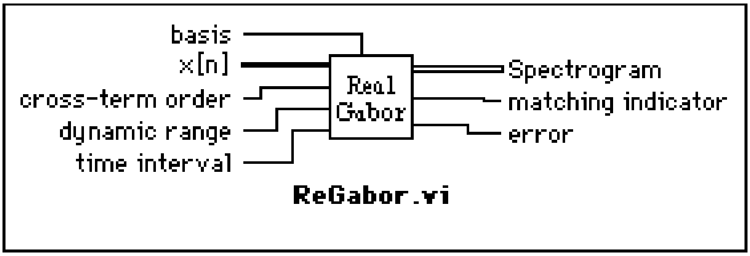
The number of rows (time axis) in **Spectrogram** is equal to the number of elements in the time waveform divided by **time interval**, and then rounded up. The number of columns (frequency axis) in **Spectrogram** is equal to

$$\frac{\textbf{\# of frequency bins}}{2}$$

error.

Gabor Spectrogram

Computes a discrete signal energy distribution in the joint time-frequency domain using the Gabor spectrogram algorithm.



This VI first computes the magnitude of the Gabor coefficients using equation (3-6).

I32

basis controls what kind of window the Gabor spectrogram uses internally. The valid choices are:

0: wide band
1: medium band
2: narrow band

[SGL]

x[n] is the time waveform.

I32

cross-term order controls how many cross terms can be permitted in the final spectrogram. When it is zero, the Gabor spectrogram does not have any cross terms. When it is infinity, the Gabor spectrogram becomes the Wagner-Ville distribution. The optimal order may be between 0 and 4.

I32

dynamic range is the base 10 logarithm of the ratio between the largest and the smallest value in **Spectrogram**.

GSmax/GSmin Š 10^(**dynamic range**)

Increasing **dynamic range** improves the accuracy of **Spectrogram** but increases computation time. Decreasing **dynamic range** decreases computation time but degrades the accuracy of **Spectrogram.**

I32

time interval is the base 2 logarithm of the time spacing, in samples, between each row of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the rows of **Spectrogram** is **time interval**/f_s seconds.

Increasing **time interval** decreases computation time and reduces memory requirements, but also reduces time-domain resolution. Decreasing **time**

interval improves time-domain resolution but increases computation time and memory requirements.

[SGL] **Spectrogram** is a 2D array that describes the time waveform energy distribution in the joint time-frequency domain.

The number of rows (time axis) in **Spectrogram** is equal to the number of elements in the time waveform divided by **time interval**, and then rounded up. The number of columns (frequency axis) in **Spectrogram** is equal to

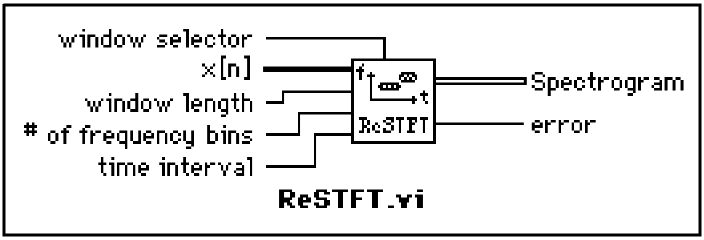
$$\frac{\textbf{\# of frequency bins}}{2}$$

[SGL] **matching indicator** is the measure of how the Gabor basis function used is closer to the analyzed signals. Usually, the basis function is selected so that the resulting **matching indicator** is maximum.

error.

STFT

Computes the signal energy distribution in the joint time-frequency domain using the short-time Fourier transform algorithm. This VI performs a sliding FFT.



I32

window selector determines the analysis window the VI used to compute the **Spectrogram**. The **window selector** parameter can have the following values.

0: Rectangular
1: Blackman
2: Hamming
3: Hanning
4: Gaussian

[SGL]

x[n] is the time waveform.

I32

window length is the actual length of the selected window. The **window length** parameter must be less than or equal to the **# of frequency bins** parameter. The analysis is centered and padded to **# of frequency bins**.

I32

# of frequency bins controls the frequency spacing of the columns of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the columns of **Spectrogram** is f_s/**# of frequency bins** Hz. Increasing **# of frequency bins** improves frequency resolution but increases computation time and memory requirements. Decreasing **# of frequency bins** decreases computation time and reduces memory requirements, but also reduces frequency-domain resolution. The **# of frequency bins** parameter must be a power of 2.

I32

time interval is the base 2 logarithm of the time spacing, in samples, between each row of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the rows of **Spectrogram** is **time interval**/f_s seconds.

Increasing **time interval** decreases computation time and reduces memory requirements, but also reduces time-domain resolution. Decreasing **time**

interval improves time-domain resolution but increases computation time and memory requirements.

[SGL]

Spectrogram is a 2D array that describes the time waveform energy distribution in the joint time-frequency domain.

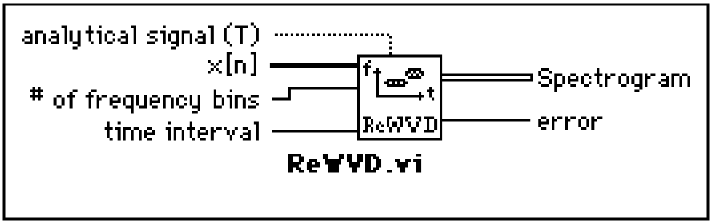
The number of rows (time axis) in **Spectrogram** is equal to the number of elements in the time waveform divided by **time interval**, and then rounded up. The number of columns (frequency axis) in **Spectrogram** is equal to

$$\frac{\textbf{\# of frequency bins}}{2}$$

error.

Wigner-Ville Distribution

Computes the signal energy distribution in the joint time-frequency domain using the Wigner-Ville distribution algorithm.



This VI first computes the analytical sequence of the time waveform **x[n]** and then evaluates the Wigner-Ville distribution.

TF

analytical signal (T) determines whether to convert real-valued samples to the oversampling sequence or to the analytical sequence. Using the analytical sequence can reduce the cross-term interference; however, it can cause significant distortion in the lower frequency band.

[SGL]

x[n] is the time waveform.

I32

# of frequency bins controls the frequency spacing of the columns of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the columns of **Spectrogram** is f_s/**# of frequency bins** Hz. Increasing **# of frequency bins** improves frequency resolution but increases computation time and memory requirements. Decreasing **# of frequency bins** decreases computation time and reduces memory requirements, but also reduces frequency-domain resolution. The **# of frequency bins** parameter must be a power of 2.

I32

time interval is the base 2 logarithm of the time spacing, in samples, between each row of the **Spectrogram** output. For example, if you sampled the time waveform at f_s Hz, the spacing between the rows of **Spectrogram** is **time interval**/f_s seconds

Increasing **time interval** decreases computation time and reduces memory requirements, but also reduces time-domain resolution. Decreasing **time interval** improves time-domain resolution but increases computation time and memory requirements.

[SGL]

Spectrogram is a 2D array that describes the time waveform energy distribution in the joint time-frequency domain.

The number of rows (time axis) in **Spectrogram** is equal to the number of elements in the time waveform divided by **time interval**, and then rounded up. The number of columns (frequency axis) in **Spectrogram** is equal to

$$\frac{\textbf{\# of frequency bins}}{2}$$

error.

Appendix A

Error Codes

This appendix lists the error codes returned by the joint time-frequency analysis VIs.

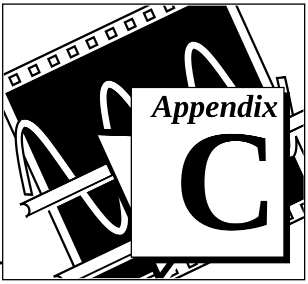
Code	Name	Description
-20081	GaborDNErr	dN must be greater than 0.
-20082	GaborTIErr	**time interval**, dM, must be greater than 0.
-20083	JTFAWindowLErr	**window length** must be greater than 4 and a power of 2.
-20084	JTFATIErr	**time interval** must not be greater than $\frac{\textbf{\# of frequency bins}}{4}$
-20086	STFTWindowLErr	**window length** must be greater than 2 and a power of 2.

Appendix B

References

This appendix lists the reference material used to produce the VIs in this manual. These references contain more information on the theories and algorithms implemented in the joint time-frequency analysis VIs.

1. Choi, H. and Williams, W. J., “Improved Time-Frequency Representation of Multicomponent Signals Using Exponential Kernels,” *IEEE Trans. ASSP*, Vol. 37, No. 6, June 1989, pp. 862-871.
2. Cohen, L., *Time-Frequency Analysis*, Prentice Hall, Englewood Cliffs, New Jersey, 1995.
3. Qian, S. and Chen, D., “Decomposition of the Wigner-Ville Distribution and Time-Frequency Distribution Series,” IEEE Transactions on Signal Processing, Vol. 42, No. 10, October 1994, pp. 2836-2842.
4. Qian, S. and Chen, D., “Discrete Gabor Transform,” IEEE Transactions on Signal Processing, Vol. 41, No. 7, July 1993, pp. 2429-2439.
5. Qian, S. and Chen, D., “Signal Representation via Adaptive Normalized Gaussian Functions,” Signal Processing, Vol. 36, No. 1, March 1994, pp. 1-12.
6. Qian, S. and Morris, J.M., “Wigner Distribution Decomposition and Cross-Term Deleted Representation,” Signal Processing, Vol. 25, No. 2, May 1992, pp. 125-144.
7. Zhao, Y., Atlas, L.E., and Marks, R., “The Use of Cone-Shaped Kernels for Generalized Time-Frequency Representations of Nonstationary Signals,” IEEE Trans. on Acoustics, Speech, and Signal Processing, Vol. 38, No. 7, July 1990, pp. 1084-1091.



Appendix C

Customer Communication

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

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

Electronic Services

Bulletin Board Support

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

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

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

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

FTP Support

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

Fax-on-Demand Support

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

E-Mail Support (currently U.S. only)

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

`support@natinst.com`

Telephone and Fax Support

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

	Telephone	**Fax**
Australia	03 9879 5166	02 9874 4455
Austria	0662 45 79 90 0	0662 45 79 90 19
Belgium	02 757 00 20	02 757 03 11
Canada (Ontario)	905 785 0085	905 785 0086
Canada (Quebec)	514 694 8521	514 694 4399
Denmark	45 76 26 00	45 76 26 02
Finland	09 725 725 11	09 725 725 55
France	01 48 14 24 24	01 48 14 24 14
Germany	089 741 31 30	089 714 60 35
Hong Kong	2645 3186	2686 8505
Israel	03 5734815	03 5734816
Italy	02 413091	06 57284309
Japan	03 5472 2970	03 5472 2977
Korea	02 596 7456	02 596 7455
Mexico	5 520 2635	5 520 3282
Netherlands	0348 433466	0348 430673
Norway	32 84 84 00	32 84 86 00
Singapore	2265886	2265887
Spain	91 640 0085	91 640 0533
Sweden	08 730 49 70	08 730 43 70
Switzerland	056 200 51 51	056 200 51 55
Taiwan	02 377 1200	02 737 4644
United States	512 794 0100	512 794 8411
United Kingdom	01635 523545	01635 523154

Technical Support Form

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

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

Name ____

Company ____

Address ____

____

Fax (___)____________________ Phone (___)________________________________

Computer brand _________________ Model _________________ Processor____________________

Operating system (include version number) ____

Clock speed ______MHz RAM _____MB Display adapter ___________________________

Mouse ___yes ___no Other adapters installed___________________________________

Hard disk capacity _____MB Brand _______________________________________

Instruments used ____

____

National Instruments hardware product model___________ Revision ________________________

Configuration ____

National Instruments software product ______________________________Version _____________

Configuration ____

The problem is: ____

____

____

____

____

List any error messages: ____

____

____

The following steps reproduce the problem:___________________________

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Documentation Comment Form

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

Title: *LabVIEW® Joint Time-Frequency Analysis Toolkit Reference Manual*

Edition Date: March 1995

Part Number: 320544B-01

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

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

____
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Thank you for your help.

Name ____
Title ____
Company ____
Address ____
____
Phone (___)____________________________ Fax (___) __________________________________

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Austin, TX 78730-5039

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National Instruments Corporation
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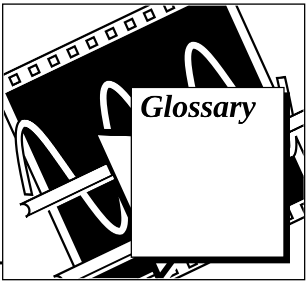

Glossary

Prefix	Meaning	Value
m-	milli-	10^{-3}
µ-	micro-	10^{-6}
n-	nano-	10^{-9}

Numbers/Symbols

°	degrees
%	percent

A

ASCII	American Standard Code for Information Interchange.

B

basis	A core or fundamental function.

D

DAQ	Data acquisition.
datalog file	A file for saving LabVIEW data in binary format.
DFT	Discrete Fourier transform.
DGT	Discrete Gabor transform.

F

FFT	Fast Fourier transform.
frame	A segment of time domain data.

J

JTFA	Joint time-frequency analysis. The simultaneous analysis of the time and frequency behavior of a signal.

M

MB	Megabytes of memory.
multicomponent	A signal containing significant energy concentrated around more than one
signal	distinct and separate frequency.

N

nonstationary signal	A signal whose frequency content changes within a captured frame.

O

oversampling rate	The ratio between the number of Gabor coefficients and the number of test samples.

P

preemphasis	Filtering before processing.

S

sampling rate	The rate at which a continuous waveform is digitized.
spectral changes	Changes in the frequency content of a signal.
spectrogram	A display of the energy distribution of a signal with one axis being time and the other being frequency.

STFT	Short-time Fourier transform.

T

temporal	Of or relating to the time domain.

V

VI	Virtual instrument.