Analog

August 2008, 370590G-01

Use the VIs on the **Analog Modulation** subpalette to configure the RF signal analyzer (RFSA) to acquire I/Q data and perform analog modulation and demodulation operations. VIs are included for modulation/demodulation of amplitude-, frequency-, and phase-modulated signals.

Subpalette	Description
Modulation	Use the VIs on the Modulation subpalette to perform analog modulation of amplitude- (AM), frequency- (FM), and phase-modulated (PM) signals.
Demodulation	Use the VIs on the Demodulation palette to perform analog demodulation of amplitude- (AM), frequency-(FM), and phase-modulated (PM) signals.
<u>Utilities</u>	Use the VIs on the Utilities palette to extract and visualize I/Q data information.

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Modulation

Owning Palette: <u>Analog</u>

Use the VIs on the **Modulation** subpalette to perform analog modulation of amplitude- (AM), frequency- (FM), and phase-modulated (PM) signals.

Palette Object	Description
<u>MT</u> <u>Modulate</u> <u>AM</u>	Performs amplitude <u>modulation</u> (AM) on an RF carrier wave, with optional suppression of the carrier wave, according to a <u>baseband</u> information signal specified by the message signal parameter. The complex envelope of the amplitude- modulated signal is returned in the AM modulated waveform indicator.
<u>MT</u> <u>Modulate</u> FM	Performs frequency modulation on an RF carrier wave according to a baseband information signal passed to the message signal parameter. It returns the complex envelope of the FM modulated signal in the FM modulated waveform parameter.
MT <u>Modulate</u> PM	Performs phase modulation (PM) on an RF carrier wave according to the baseband information signal specified by the message signal parameter. This VI returns the complex envelope of the phase-modulated signal in the PM modulated waveform indicator. This VI performs signal processing on data and operates independently of hardware settings. This VI can be used in simulated as well as hardware-equipped applications.
<u>MT</u> <u>Upconvert</u> <u>Baseband</u>	Upconverts baseband I/Q (complex envelope) signal data to its real passband equivalent or to a nonzero center frequency within the Nyquist bandwidth of the specified signal (resulting in another complex baseband). Upconverted data of the specified bandwidth is returned in the passband waveform or upconverted baseband parameter.

MT Modulate AM VI

Performs amplitude <u>modulation</u> (AM) on an RF carrier wave, with optional suppression of the carrier wave, according to a <u>baseband</u> information signal specified by the **message signal** parameter. The complex envelope of the amplitude-modulated signal is returned in the **AM modulated waveform** indicator.

This VI performs signal processing on data and operates independently of hardware settings. This VI can be used in simulated as well as hardware-equipped applications.

Use the pull-down menu to select an instance of this VI.

Select an instance

Details

MT Modulate AM (DSB)

This polymorphic instance performs double sideband (DSB) amplitude modulation.



- message signal specifies the message signal used to modulate the carrier wave.
 - **t0** specifies the trigger (start) time of the signal data.
 - **dt** specifies the time interval between data points in the signal data.
 - **Y** specifies the normalized message signal array.
- **modulation index** specifies the desired <u>modulation index</u> of the **AM modulated waveform** parameter. A value of 0.7, for example, corresponds to a modulation index of 70%. A value greater than unity (1) may cause overmodulation and distortion. This parameter is ignored when **suppress carrier?** is set to TRUE. The default is 1.0.
- **peak message amplitude** specifies the peak message amplitude of the **message signal**. This value is used to scale (normalize) the input message signal prior to modulation. This value must be positive. The default is 1.0.

suppress carrier? specifies whether to suppress the carrier of the modulated signal. When **suppress carrier?** is set to FALSE (the default), the output amplitude-modulated baseband signal consists of a DC component corresponding to the carrier tone.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in**

control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- AM modulated waveform returns the AM-DSB-modulated complex baseband time-domain data for demodulation.
 - **ID** returns the trigger (start) time of the **Y** array.
 - **besize the set whe set and the set whether a set of the between set o**
 - Y returns the complex-valued signal-only baseband modulated waveform. The real and imaginary parts of this complex data array correspond to the in-phase (<u>1</u>) and quadrature-phase (<u>Q</u>) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - source describes the origin of the error or warning. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more

information about the error displayed.

MT Modulate AM (SSB)

This polymorphic instance performs single sideband (SSB) amplitude modulation.

Instance Details



- message signal specifies the message signal used to modulate the carrier wave.
 - **t0** specifies the trigger (start) time of the signal data.
 - **dt** specifies the time interval between data points in the signal data.
 - **Y** specifies the normalized message signal array.
- **modulation index** specifies the desired <u>modulation index</u> of the **AM modulated waveform** parameter. A value of 0.7, for example, corresponds to a modulation index of 70%. A value greater than unity (1) may cause overmodulation and distortion. This parameter is ignored when **suppress carrier?** is set to TRUE. The default is 1.0.

hilbert filter specifies the complex-valued Hilbert filter used for sideband cancellation during generation of the AM-SSB baseband complex signal. This filter is internally applied to the message signal to generate the baseband complex analytic signal.

- Note Changes to the Hilbert filter take effect when reset? is set to TRUE.
- **taps** specifies the length, in taps, of the Hilbert filter (N).

design specifies the underlying design of the Hilbert filter.

Windowed Hilbert Transformer (0)	Generates the length <i>N</i> Hilbert filter based on the impulse response.

Equiripple Hilbert Generates an equiripple Hilbert filter. **transformer** (1)

- **peak message amplitude** specifies the peak message amplitude of the **message signal**. This value is used to scale (normalize) the input message signal prior to modulation. This value must be positive. The default is 1.0.
- **pilot tone** specifies the parameters for specifying pilot tone generation. The pilot tone is added to the Hilbert-filtered complex baseband signal to generate the AM-SSB modulated waveform. The pilot tone provides a coherent phase reference during AM-SSB demodulation for performing carrier phase and carrier frequency offset correction. Set amplitude to 0 to disable addition of the pilot tone.
 - **Tip** Adding a pilot tone is optional when **suppress carrier?** is set to FALSE. In this case, the presence of the DC component in the AM-SSB signal (corresponding to the pure carrier tone) provides a coherent reference for phase and frequency offset correction, so the pilot tone is not needed.
 - **frequency** specifies the frequency of the complex exponential tone that is added to the complex baseband signal. Ensure that the absolute value of this tone frequency is less than the Nyquist frequency $1/(2 \times dt)$.
 - $\overline{\mathbb{N}}$
 - Note When specifying pilot tone parameters, ensure that the pilot tone is added to a portion of the spectrum where the message component of the signal is absent. Conflict between the pilot tone and message signals can cause a residual carrier phase and frequency offset error after AM-SSB demodulation. For example, if you specify a negative pilot tone frequency, specify an upper sideband in the sideband input.

amplitude specifies the amplitude of the complex exponential tone that is added to the complex analytic baseband signal.

sideband specifies whether the AM-SSB modulator retains the lower or upper sideband of the message spectrum to generate the AM-SSB baseband complex analytic signal.

lower sideband (0)	Retains the portion of the message spectrum lying in the negative frequency range $[-(1/2dt),0]$ and eliminate the positive sideband spectrum.
upper sideband (1)	Retains the message spectrum spanning the positive frequency range [0,1/2 <i>dt</i>]. This is the default value.

- **suppress carrier?** specifies whether to suppress the carrier of the modulated signal. When **suppress carrier?** is set to FALSE (the default), the output amplitude-modulated baseband signal consists of a DC component corresponding to the carrier tone.
- **reset?** specifies whether the VI continues AM-SSB modulation using internal states from previous iterations.

TRUE	When reset? is TRUE, the VI restarts AM-SSB modulation, redesigns the Hilbert filter, and clears internal filter states on each call. This is the default value.
FALSE	When reset? is FALSE, the Hilbert filter design is unchanged across multiple calls, and the internal filter state is set to ensure continuous filter operation.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- AM modulated waveform returns the AM-SSB-modulated complex baseband time-domain data for demodulation.
 - **ID** returns the trigger (start) time of the **Y** array.
 - **DEED IN THE INTER SET UP:** IN THE INTER SET IN THE INTERNATION I
 - Y returns the complex-valued signal-only baseband modulated waveform. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **Source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Modulate AM (SSB) Details

MT Modulate AM (VSB)

This polymorphic instance performs vestigial sideband (VSB) amplitude modulation.

Instance Details



message signal specifies the message signal used to modulate the carrier wave.

- **t0** specifies the trigger (start) time of the signal data.
- **dt** specifies the time interval between data points in the signal data.
- **Y** specifies the normalized message signal array.
- **modulation index** specifies the desired <u>modulation index</u> of the **AM modulated waveform** parameter. A value of 0.7, for example, corresponds to a modulation index of 70%. A value greater than unity (1) may cause overmodulation and distortion. This parameter is ignored when **suppress carrier?** is set to TRUE. The default is 1.0.

VSB FIR filter design specifies the vestigial filter design parameters corresponding to the desired VSB spectrum. The vestigial filter is generated when **reset?** is set to TRUE, and the filter is applied to the input message signal. Default values in this cluster correspond to NTSC analog picture carrier specifications.



Note The normalized frequencies are specified with respect to a 1 S/s sampling rate.

- Tip Changes to the FIR filter design take effect when reset? is set to TRUE.
- #taps specifies the number of taps used to generate the VSB filter. For error-free operation, specify a filter length of 85 taps or greater.

- **Iower PB** specifies the normalized lower passband frequency, in hertz, of the VSB filter spectrum, relative to the carrier frequency.
- **upper PB** specifies the normalized upper passband frequency, in hertz, of the VSB filter spectrum, relative to the carrier frequency.
- **Iower SB** specifies the normalized lower stopband frequency, in hertz, of the VSB filter spectrum, relative to the carrier frequency.
- **upper SB** specifies the normalized upper stopband frequency, in hertz, of the VSB filter spectrum, relative to the carrier frequency.
- **peak message amplitude** specifies the peak message amplitude of the **message signal**. This value is used to scale (normalize) the input message signal prior to modulation. This value must be positive. The default is 1.0.
- **suppress carrier?** specifies whether to suppress the carrier of the modulated signal. When **suppress carrier?** is set to FALSE (the default), the output amplitude-modulated baseband signal consists of a DC component corresponding to the carrier tone.
- **reset?** specifies whether the VI continues AM-VSB modulation using internal states from previous iterations.

TRUE	When reset? is TRUE, the VI restarts AM-VSB modulation, redesigns the vestigial filter, and clears internal filter states on each call. This is the default value.
FALSE	When reset? is FALSE, the vestigial filter design is unchanged across multiple calls, and the internal filter state is set to ensure continuous filter operation.

pilot tone specifies the parameters for specifying pilot tone generation. The pilot tone is added to the Hilbert-filtered complex baseband signal to generate the AM-VSB modulated waveform. The pilot tone provides a coherent phase reference during AM-VSB demodulation for performing carrier phase and carrier frequency offset correction. Set amplitude to 0 to disable addition of the pilot tone.

- **Tip** Adding a pilot tone is optional when **suppress carrier?** is set to FALSE. In this case, the presence of the DC component in the AM-VSB signal (corresponding to the pure carrier tone) provides a coherent reference for phase and frequency offset correction, so the pilot tone is not needed.
- **frequency** specifies the frequency of the complex exponential tone that is added to the complex baseband signal. Ensure that the absolute value of this tone frequency is less than the Nyquist frequency $1/(2 \times dt)$.
 - \mathbb{N}
 - Note When specifying pilot tone parameters, ensure that the pilot tone is added to a portion of the spectrum where the message component of the signal is absent. Conflict between the tone and message signals can cause a residual carrier phase and frequency offset error after AM-VSB demodulation. For example, if you specify a negative pilot tone frequency, specify upper sideband in the sideband input.
- **amplitude** specifies the amplitude of the complex exponential tone that is added to the complex analytic baseband signal.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **AM modulated waveform** returns the baseband AM vestigial sideband modulated signal data and its complex envelope.
 - **ID** returns the trigger (start) time of the **Y** array.
 - **DEED OF** dt returns the time between values in the Y array.
 - Y returns the complex-valued signal-only baseband modulated waveform. The real and imaginary parts of this complex data array correspond to the in-phase (1) and quadrature-phase (Q) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Modulate AM (VSB) Details

Details

- **Tip** To adjust the carrier phase, use the **initial phase** parameter of the <u>MT Upconvert Baseband</u> VI.
- Note To avoid distortion, amplitude normalize the **message signal** to ±1.0. This VI prescales the **message signal** by the scalar peak amplitude prior to modulation. The default value of 1.0 indicates that no prescaling occurs.

Double Sideband (DSB) Amplitude Modulation

The output amplitude-modulated signal is represented by the following equations:

$$s_{DSB}(t) = 1 + k \times \frac{m(t)}{max[m(t)]}$$
$$s_{DSBSC}(t) = \frac{m(t)}{max[m(t)]}$$

where

m(t) represents the message signal data

S _{DSB} (t) and S _{DSBSC} (t) represent the AM modulated signal

k represents the modulation index

Single Sideband (SSB) Amplitude Modulation

AM-SSB modulation ensures bandwidth reduction by only retaining either the upper or lower sideband in the message spectrum after the modulation process. The following figure illustrates the series of algorithms applied to the incoming signal m(t). The VI applies the AM-DSB algorithms and then applies the Hilbert filter to remove the signal.



When **suppress carrier?** is set to FALSE, the output amplitudemodulated signal is represented by the following formula:

 $s_{DSB}(t) = 1 + k \times \frac{m(t)}{max[m(t)]}$

 $s_{SSB}(t) = s_{DSB}(t) \otimes (h_i \pm j \times h_q(t)) + A_{pilot} e^{j \approx pilot}$

where

*m(t)*represents the message signal data

 S_{DSB} (t) represents the double sideband AM modulated signal (unsuppressed carrier)

*S*_{SSB} (*t*) represents the single sideband AM modulated signal (unsuppressed carrier)

k represents the modulation index

A pilot represents the amplitude of the pilot tone

 ω_{pilot} represents the frequency of the pilot tone

h i represents the real component of the Hilbert filter

 h_{q} represents the imaginary component of the Hilbert filter

When suppress carrier? is set to TRUE,

 $s_{DSBSC}(t) = k \times \frac{m(t)}{max|m(t)|}$

 $s_{SSBSC}(t) = s_{DSBSC}(t) \otimes (h_i \pm j \times h_j(t)) + A_{pilot} e^{j \omega_{pilot}}$

where

*m(t)*represents the message signal data

S _{DSBSC} (t) represents the double sideband AM modulated signal (unsuppressed carrier)

S _{SSBSC} (t) represents the single sideband AM modulated signal (unsuppressed carrier)

k represents the modulation index

A pilot represents the amplitude of the pilot tone

 $\omega_{\rm pilot}$ represents the frequency of the pilot tone

h i represents the real component of the Hilbert filter

 h_q represents the imaginary component of the Hilbert filter

In both suppressed and unsuppressed carrier cases, one of two possible Hilbert filter designs is specified using the design element in the **Hilbert**

filter cluster. Select either a Windowed Hilbert transformer or an Equiripple Hilbert transformer.

The Windowed Hilbert transformer generates a length N Hilbert filter with an impulse response h(n) given by the following equation:

$$h(n) = \delta\left(n - \frac{N}{2}\right) + j \times \left\{ \frac{2}{\pi} \frac{\sin^2\left(\frac{\pi n}{2}\right)}{n}, \ n \neq 0 \\ 0, \ n = 0 \right\}$$

The Equiripple Hilbert transformer generates a length N Hilbert filter with an impulse response h(n) given by the following equation:

$$h(n) = g(n)e^{\pm j \times 0.25 \times n}$$

where g(n) represents an equiripple lowpass filter with a normalized cutoff frequency of 0.25 Hz.

Vestigial Sideband (VSB) Amplitude Modulation

VSB amplitude modulation involves retaining a portion of the unwanted sideband (called the vestige) in the message spectrum prior to transmission, rather than completely eliminating it as in single-sideband modulation. The following figure illustrates the series of algorithms applied to the incoming signal m(t). The VI applies the AM-DSB algorithms and then applies the Vestigial filter to remove the vestige.



The output amplitude-modulated signal is represented by the following equation:

With suppress carrier? set to FALSE:

$$\begin{split} S_{DSB}(t) &= 1 + k \times \frac{m(t)}{\max |m(t)|} \\ S_{VSB}(t) &= S_{DSB}(t) \left(h_i(t) + j \times h_q(t) \right) + A_{pilot} e^{j\omega_{pilot}t} \end{split}$$

where

*m(t)*represents the message signal data

 S_{DSB} (t) represents the double sideband AM modulated signal (unsuppressed carrier)

 S_{VSB} (t) represents the vestigial sideband AM modulated signal

(unsuppressed carrier)

k represents the modulation index

A pilot represents the amplitude of the pilot tone

 $\omega_{\rm pilot}$ represents the frequency of the pilot tone

h i represents the real component of the vestigial filter

 h_{q} represents the imaginary component of the vestigial filter

With suppress carrier? set to TRUE:

$$S_{DSBSC}\left(t\right) = \frac{m(t)}{\max\left|m(t)\right|}$$

 $S_{VSBSC}(t) = S_{DSBSC}(t) \times \left(h_i(t) + j \times h_q(t)\right) + A_{pilot}e^{j\omega_{pilot}t}$

where

m(t)represents the message signal data

S _{DSBSC} (t) represents the double sideband AM modulated signal (unsuppressed carrier)

*S*_{VSBSC} (*t*) represents the vestigial sideband AM modulated signal (unsuppressed carrier)

k represents the modulation index

A pilot represents the amplitude of the pilot tone

 $\omega_{\rm pilot}$ represents the frequency of the pilot tone

h i represents the real component of the Hilbert filter

 h_{q} represents the imaginary component of the Hilbert filter

MT Modulate FM VI

Performs frequency modulation on an RF carrier wave according to a baseband information signal passed to the **message signal** parameter. It returns the complex envelope of the FM modulated signal in the **FM modulated waveform** parameter.

<u>Details</u>



- message signal specifies the message signal used to modulate the carrier wave.
- **FM deviation** specifies the desired frequency deviation, in hertz, of the frequency-modulated signal returned in the **FM modulated waveform** parameter.
- **reset?** controls initialization of internal VI states. The modulation process involves an integration operation.

TRUE	When reset? set to TRUE, the initial state of the integration is set to zero at each call to this VI.
FALSE	When reset? is FALSE, the integration begins in the final state from the previous call (this option is useful when the current block of I/Q data is contiguous with the preceding block of I/Q data). This is the default value.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **FM modulated waveform** returns the baseband signal data and the complex envelope of the frequency-modulated signal.
 - **ID** returns the trigger (start) time of the signal data.
 - **dt** returns the time interval between data points in the signal data.
 - Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (1) and quadrature-phase (Q) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **Source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

This VI performs signal processing on data and operates independently of hardware settings. This VI can be used in simulated as well as hardware-equipped applications.

The output frequency-modulated wave is described by the following equation:

$$FM = e^{i \left(2\pi \frac{frequencyDeviation}{fs} \int_{t} ((messageSignal)d\tau + carrierPhase)\right)}$$

This VI sets *carrierPhase* in the preceding equation to zero. To adjust the carrier phase, use the **initial phase** parameter of the <u>MT Upconvert</u> <u>Baseband</u> VI.

Using MT Modulate FM v2.vi in Modulation Toolkit 4.1

The Modulation Toolkit 4.0 version of the MT Modulate FM VI has been renamed to <u>MT Modulate FM v2</u> and has been moved to the deprecated folder at <LabVIEW>\vi.lib\addons\Modulation\Analog\Deprecated. If your application currently refers to MT Modulate FM, the application will use the optimized Modulation Toolkit 4.1 version of this VI that includes performance enhancements.

MT Modulate PM VI

Performs phase modulation (PM) on an RF carrier wave according to the baseband information signal specified by the **message signal** parameter. This VI returns the complex envelope of the phase-modulated signal in the **PM modulated waveform** indicator. This VI performs signal processing on data and operates independently of hardware settings. This VI can be used in simulated as well as hardware-equipped applications.

<u>Details</u>



- message signal specifies the message signal used to modulate the carrier wave.
 - **t0** specifies the trigger (start) time of the signal data.
 - **dt** specifies the time interval between data points in the signal data.
 - **Y** specifies the normalized message signal array.
- **phase deviation** specifies the maximum desired phase deviation, in degrees, of the phase-modulated signal returned in the **PM modulated waveform** parameter. The default is 1°.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error

displayed.

- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **PM modulated waveform** returns the baseband signal data and the complex envelope of the phase-modulated signal.
 - **t0** returns the trigger (start) time of the signal data.
 - **dt** returns the time interval between data points in the signal data.
 - Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (1) and quadrature-phase (Q) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

This VI performs signal processing on data and operates independently of your hardware settings. This VI can be used in simulated as well as hardware-equipped applications.

The output phase-modulated wave is described by the equation:

 $PM = e^{i\left(2\pi \frac{phaseDeviation}{360}(messageSignal) + (carrierPhase)\right)}$

This VI sets *carrierPhase* in the preceding equation to zero. To adjust the carrier phase, use the **initial phase** parameter of the <u>MT Upconvert</u> <u>Baseband</u> VI.

MT Upconvert Baseband VI

Upconverts baseband I/Q (complex envelope) signal data to its real passband equivalent or to a nonzero center frequency within the Nyquist bandwidth of the specified signal (resulting in another complex baseband). Upconverted data of the specified bandwidth is returned in the **passband waveform** or **upconverted baseband** parameter.

-



Note This VI is used with simulated data and operates independently of your hardware settings.

Use the pull-down menu to select an instance of this VI.

Select an instance

Details

MT Upconvert Baseband (Complex)

Upconverts baseband I/Q (complex envelope) signal data to a non-zero center frequency within (resulting in another complex baseband). Upconverted data of the specified bandwidth is returned in the **upconverted baseband** parameter.



- **complex waveform** specifies the complex envelope signal data for upconversion to its passband equivalent.
 - **t0** specifies the trigger (start) time of the acquired signal.
 - **dt** specifies the time interval between data points in the acquired signal.
 - Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (!) and quadrature-phase (Q) data, respectively.
- **carrier frequency** specifies the center frequency of the passband, in hertz. The incoming signal is upconverted to center around this frequency. Specify the desired carrier frequency of the outgoing signal with this parameter.
- **initial phase** specifies the initial phase, in degrees, of the software local oscillator used in the downconversion process. This parameter is ignored if the **reset?** parameter is FALSE. Use **initial phase** to match the phase of the incoming <u>modulated</u> carrier and the local oscillator(s) of the downconversion process.
- **reset?** specifies whether to use the value input to the initial phase parameter.

TRUE	When reset? is TRUE, this VI uses the initial phase value.
FALSE	Set reset? to FALSE to disregard the initial phase input and continue using values supplied in the previous call. Reusing previous values is useful when sequential data

blocks represent contiguous signal data.	This is th	ne default
value.		

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- upconverted waveform returns the upconverted signal in passband form.
 - **t0** returns the trigger (start) time of the acquired signal.
 - **besilved between data points in the acquired signal.**
 - **[(D) Y** returns the upconverted information signal array.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error

displayed.

- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Upconvert Baseband (Real)

Upconverts <u>baseband I/Q</u> (complex envelope) signal data to its real passband equivalent. Upconverted data of the specified bandwidth is returned in the **passband waveform** parameter.



- **initial phase** specifies the initial phase, in degrees, of the software local oscillator used in the downconversion process. This parameter is ignored if the **reset?** parameter is FALSE. Use **initial phase** to match the phase of the incoming <u>modulated</u> carrier and the local oscillator(s) of the downconversion process.
- **baseband waveform** specifies the complex envelope signal data for upconversion to its passband equivalent.
 - **t0** specifies the trigger (start) time of the acquired signal.
 - **dt** specifies the time interval between data points in the acquired signal.
 - Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- **carrier frequency** specifies the center frequency of the passband, in hertz. The incoming signal is upconverted to center around this frequency. Specify the desired carrier frequency of the outgoing signal with this parameter.
- **reset?** specifies whether to use the value input to the initial phase parameter.

TRUE	When reset? is TRUE, this VI uses the initial phase value.
FALSE	Set reset? to FALSE to disregard the initial phase input and continue using values supplied in the previous call. Reusing previous values is useful when sequential data blocks represent contiguous signal data. This is the default value.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **passband waveform** returns the upconverted signal in passband form.
 - **t0** returns the trigger (start) time of the acquired signal.
 - **besi** dt returns time interval between data points in the acquired signal.
 - **Y** returns the upconverted information signal array.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

code identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

source describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

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Note If the input **baseband waveform (complex)** is represented as the following equation:

m(t) = Re[m(t)] + j*Im[m(t)]

where j = sqrt(-1) and Re() and Im() denote the real and imaginary parts of m(t), respectively, the generated **passband waveform** $m_{PB}(t)$ of this VI is represented by the following equation:

 $m_{PB}(t) = Re[m(t)]cos(2f_c t) - Im[m(t)]sin(2f_c t)$

where f_c denotes the carrier frequency corresponding to the generated **passband waveform**.

Demodulation

Owning Palette: <u>Analog</u>

Use the VIs on the **Demodulation** palette to perform analog demodulation of amplitude- (AM), frequency- (FM), and phase-modulated (PM) signals.

Palette Object	Description
<u>MT</u> Demodulate AM	Demodulates an amplitude-modulated signal specified by the AM modulated waveform parameter, with optional suppression of the carrier wave. The demodulated signal is returned in the AM demodulated waveform parameter.
<u>MT</u> Demodulate FM	Performs <u>frequency demodulation</u> on the incoming <u>I/Q</u> signal. The recovered information signal is returned in the FM demodulated waveform parameter.
<u>MT</u> Demodulate PM	Performs <u>phase demodulation</u> on the incoming <u>I/Q</u> signal. The information signal is computed as a result of the <u>demodulation</u> and returned in the PM demodulated waveform output. This VI calculates any offset from the expected <u>carrier</u> frequency specified in the <u>MT Configure</u> <u>Downconversion Settings</u> VI.
<u>MT</u> Downconvert Passband	Downconverts real passband signal data of a user- specified bandwidth. The complex instance of this VI downconverts a complex baseband signal, centered around a nonzero center frequency, to a center frequency of zero. The baseband I/Q signal (complex envelope) is returned in the downconverted waveform parameter.

MT Demodulate AM VI

Demodulates an amplitude-modulated signal specified by the **AM modulated waveform** parameter, with optional suppression of the carrier wave. The demodulated signal is returned in the **AM demodulated waveform** parameter.

Use the pull-down menu to select an instance of this VI.

◄

Select an instance

MT Demodulate AM (DSB)

This polymorphic instance demodulates a double sideband (DSB) amplitude-modulated signal. Demodulation proceeds according to one of the following methods, depending on whether **suppressed carrier?** is set to TRUE or FALSE:

• suppressed carrier? = FALSE

The incoming baseband AM-DSB modulated signal r(t) can be expressed by the following equations:

$$r(t) = s_{DSB}(t) e^{j\varphi(t)},$$

where $s_{DSB}(t)$ is a DSB modulated waveform and $\varphi(t)$ is any time-varying phase ambiguity. AM-DSB demodulation involves performing envelope detection. The AM demodulated waveform (t) is given by the following equation:

$$\hat{m}(t) = \frac{1}{k} \times \left[\frac{|r(t)|}{\langle |r(t)| \rangle} - 1 \right]$$

where k represents the modulation index.

• suppressed carrier? = TRUE

The incoming baseband AM-DSBSC modulated signal r(t) can be expressed as the following equations:

 $r(t) = s_{DSBSC}(t) e^{j\varphi(t)},$

where s_{DSBSC} (*t*) is an AM-DSBSC modulated waveform, and $\varphi(t)$ is any time-varying phase ambiguity.

The VI squares the signal r(t) when computing the phase estimate of $\varphi(t)$. This squaring operation removes the 180° phase ambiguity relative to the sign of m(t). The computed phase estimate is used to generate a complex tone that is added back to the input signal r(t) to generate the equivalent DSB signal with carrier and unity modulation index. Thereon, envelope detection is performed for computing the AM demodulated waveform output $\hat{m}(t)$.

The recovered message signal m(t) can be obtained from the following relationships:

 $r(t) = s_{DSBSC}(t)e^{j\phi(t)}$



- AM modulated waveform specifies the AM-DSB-modulated complex baseband time-domain data for demodulation.
 - **t0** specifies the trigger (start) time of the **Y** array. The default is 0.00.
 - **DELT** dt specifies time interval between data points in the Y array. The default is 1.00.
 - Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- **modulation index** specifies the expected modulation index of the **AM demodulated waveform** parameter. This value is used to scale the **AM demodulated waveform** parameter. The default is 1.00.
 - Set this value to the estimated modulation index of the incoming AM modulated waveform signal to scale the AM demodulated waveform parameter by this value. The resulting scaled AM demodulated waveform can be used to quantify error between the actual and expected modulation index.
 - Set this value to 1.0 (the default) to return an AM demodulated waveform with no scaling. When suppressed carrier? is set to FALSE (the default), the peak amplitude value of the unscaled AM demodulated waveform represents the true modulation index of the incoming AM modulated waveform. If the message signal is a single tone, you can use the LabVIEW Extract Single Tone Information VI to measure the maximum amplitude of
the AM demodulated waveform.



Note This parameter is ignored when **suppressed carrier?** is set to TRUE.

- **suppressed carrier?** specifies whether the carrier has been suppressed in the incoming AM-DSB-modulated waveform. The default is FALSE.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

AM demodulated waveform returns the recovered message signal.

Note Wire the AM demodulated waveform parameter to any LabVIEW waveform measurement VI for further analysis. If the information signal is a single tone (normalized) and modulation index is set to 1.0 with suppressed carrier? set to FALSE, the peak amplitude value of the AM-demodulated waveform represents the true modulation index of the incoming AM-modulated waveform.

t0 returns the trigger (start) time of the **Y** array.

- **Description between values in the Y array.**
- Y returns the amplitude-demodulated recovered message signal array.
- **Carrier amplitude** returns the mean zero-to-peak amplitude of the IF carrier wave in volts.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Demodulate AM (SSB)

This polymorphic instance demodulates a single sideband (SSB) amplitude-modulated signal. The AM-SSB demodulation procedure uses the transmitted pilot tone $e^{j\omega}$ pilot ^t as a reference for performing coherent demodulation.



During the process of AM-SSB demodulation, the received AM-SSB signal (assumed to be sampled at the sampling frequency f_s) is first resampled to a new sampling frequency equaling $4f_s$. The resampled AM-SSB modulated baseband waveform is then upconverted to an intermediate frequency (IF) passband waveform at a carrier frequency of f_s . The IF passband waveform is passed through a real IF pilot tone extraction filter and a real IF pilot tone rejection filter. The extracted pilot tone at the output of the IF pilot tone extraction filter is passed through a carrier phase and frequency offset estimator to estimate the channel impairments. The estimated carrier phase and frequency offset corrections are applied to the extracted AM-SSB modulated signal-only component at the output of the pilot tone rejection filter. The resulting recovered message signal is obtained after downconversion and resampling to the input sampling rate f_s .



AM modulated waveform specifies the AM-SSB-modulated complex baseband time-domain data for demodulation.

- **t0** specifies the trigger (start) time of the **Y** array. The default is 0.00.
- **DEL** dt specifies time interval between data points in the Y array. The default is 1.00.
- Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (!) and quadrature-phase (Q) data, respectively.

modulation index specifies the expected modulation index of the **AM demodulated waveform** parameter. This value is used to scale the **AM demodulated waveform** parameter. The default is 1.00.

- Set this value to the estimated <u>modulation index</u> of the incoming **AM modulated waveform** signal to scale the **AM demodulated waveform** parameter by this value. The resulting scaled **AM demodulated waveform** can be used to quantify error between the actual and expected modulation index.
- Set this value to 1.0 (the default) to return an AM demodulated waveform with no scaling. When suppressed carrier? is set to FALSE (the default), the peak amplitude value of the unscaled AM demodulated waveform represents the true modulation index of the incoming AM modulated waveform. If the message signal is a single tone, you can use the LabVIEW Extract Single Tone Information VI to measure the maximum amplitude of the AM demodulated waveform.



Note This parameter is ignored when **suppressed carrier?** is set to TRUE.

pilot extraction filter specifies parameters used to locate the pilot tone and extract it from the specified AM modulated signal. The VI designs a bandpass filter for locating the pilot tone, and a bandreject filter for removing the pilot tone from the recovered signal, in a normalized frequency range:

[dt × approx freq - 0.01 × search (±% of Fsampl)

dt × approx freq + 0.01 × search (±% of Fsampl)]

where *Fsampl* is the sampling rate of the input **AM modulated waveform**.

- Note Carrier frequency offset can change the location of the pilot tone in the input **AM modulated waveform**. In such a case, specify a value for **search (+/-% of Fsampl)** large enough that the demodulator can locate the pilot tone in the presence of carrier frequency offset. For example, assuming a sample rate of 1.00 S/s, a pilot tone at 0.01 Hz, and a carrier frequency offset of 0.03 Hz, specify the following parameters for the **pilot extraction filter** cluster:
 - taps: 81
 - approx freq: 0.01
 - search (± % of Fsampl): 5
- **taps** specifies the number of taps used to design the pilot tone extraction filter. The default is 81.
- **approx freq.** specifies the estimated frequency, in hertz, of the pilot tone in the input **AM modulated waveform**. The default value is 0.
- **search (+/- % of Fsampl)** specifies the search window size as a percentage of the input sample rate 1/dt. To avoid erroneous detection of the pilot tone, ensure that this search window does not include any portion of the message spectrum. The default is 0.25.
- **costas loop parameters** specifies optional parameters controlling the Costas loop. Usually **Beta** is chosen to be less than 0.02 × **Alpha**. These parameters are used in tracking carrier phase offset in the specified **AM modulated waveform**. The default settings are typically unchanged except in the presence of severely time-varying carrier phase offset.
 - **Alpha** specifies the α parameter as required by the Costas loop design. The default is 1 m.
 - **Beta** specifies the β parameter as required by the Costas loop design. The default is 20 u.

TFI

suppressed carrier? specifies whether the carrier has been suppressed in the incoming AM-SSB-modulated waveform. The default is FALSE.

reset? specifies whether the VI continues AM-SSB demodulation using internal states from previous iterations.

TRUE	When reset? is TRUE, the VI redesigns the pilot extraction filter and clears the internal filter states on each call. This is the default value.
FALSE	When reset? is FALSE, the pilot extraction filter design is unchanged across multiple calls, and the internal filter state is set to ensure continuous filter operation.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

AM demodulated waveform returns the recovered message signal.

Note Wire the AM demodulated waveform parameter to any LabVIEW waveform measurement VI for further analysis.

If the information signal is a single tone (normalized) and **modulation index** is set to 1.0 with **suppressed carrier?** set to FALSE, the peak amplitude value of the AM-demodulated waveform represents the true modulation index of the incoming AM-modulated waveform.

- **ID** returns the trigger (start) time of the **Y** array.
- **bell** dt returns the time between values in the Y array.
- Y returns the amplitude-demodulated recovered message signal array.
- measurements returns the pilot tone location, carrier offset, and phase offset.
 - **extracted pilot tone** returns the location of the pilot tone in the **AM modulated waveform** frequency spectrum.
 - **frequency offset** returns the measured carrier frequency offset in hertz of the specified **AM modulated waveform**.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Demodulate AM (VSB)

This polymorphic instance demodulates a vestigial sideband (VSB) amplitude-modulated signal. The AM-VSB demodulation procedure uses the transmitted pilot tone $e^{j\omega}$ pilot ^t as a reference for performing coherent demodulation.



During the process of AM-VSB demodulation, the received AM-VSB signal (assumed to be sampled at the sampling frequency f_s) is first resampled to a new sampling frequency equaling $4f_s$. The resampled AM-VSB modulated baseband waveform is then upconverted to an intermediate frequency (IF) passband waveform at a carrier frequency of f_s . The IF passband waveform is passed through a real IF pilot tone extraction filter and a real IF pilot tone rejection filter. The extracted pilot tone at the output of the IF pilot tone extraction filter is passed through a carrier phase and frequency offset estimator to estimate the channel impairments. The estimated carrier phase and frequency offset corrections are applied to the extracted AM-VSB modulated signal-only component at the output of the pilot tone rejection filter. The resulting recovered message signal is obtained after downconversion and resampling to the input sampling rate f_s .





- Note Wire the AM demodulated waveform parameter to any LabVIEW waveform measurement VI for further analysis. If the information signal is a single tone (normalized) and modulation index is set to 1.0 with suppressed carrier? set to FALSE, the peak amplitude value of the AM demodulated waveform represents the true modulation index of the incoming AM modulated waveform.
- **t0** specifies the trigger (start) time of the **Y** array. The default is 0.00.
- **dt** specifies time interval between data points in the **Y** array. The default is 1.00.
- Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (!) and quadrature-phase (Q) data, respectively.
- **modulation index** specifies whether to scale the **AM demodulated** waveform. The default is 1.00.
 - Set this value to the estimated modulation index of the incoming AM modulated waveform signal to scale the AM demodulated waveform output by this value. The resulting scaled AM demodulated waveform can be used to quantify error between the actual and expected modulation index.
 - Set this value to 1.0 (default) to return an AM demodulated waveform with no scaling. When suppressed carrier? is set to FALSE (default), the peak amplitude value of the unscaled AM demodulated waveform represents the true modulation index of the incoming AM modulated waveform. If the message signal is a single tone, you can use the LabVIEW Extract Single Tone Information VI to measure the maximum amplitude of the AM demodulated waveform.



Note This input is ignored when **suppressed carrier?** is set to TRUE.

pilot extraction filter specifies parameters used to locate the pilot

tone and extract it from the specified AM modulated signal. The VI designs a bandpass filter for locating the pilot tone, and a band-reject filter for removing the pilot tone from the recovered signal, in a normalized frequency range:

[*dt* × *approx freq* - 0.01 × *search* (±% *of Fsampl*)

dt × approx freq + 0.01 × search (±% of Fsampl)]

where *Fsampl* is the sampling rate of the input **AM modulated waveform**.

- Note Carrier frequency offset can change the location of the pilot tone in the input **AM modulated waveform**. In such a case, specify a value for **search (+/-% of Fsampl)** large enough that the demodulator can locate the pilot tone in the presence of carrier frequency offset. For example, assuming a sample rate of 1.00 S/s, a pilot tone at 0.01 Hz, and a carrier frequency offset of 0.03 Hz, specify the following parameters for the **pilot extraction filter** cluster:
 - taps: 81
 - approx freq: 0.01
 - search (± % of Fsampl): 5
- **taps** specifies the number of taps used to design the pilot tone extraction filter. The default is 81.
- **approx freq.** specifies the estimated frequency, in hertz, of the pilot tone in the input **AM modulated waveform**. The default value is 0.
- **search (+/- % of Fsampl)** specifies the search window size as a percentage of the input sample rate 1/*dt*. To avoid erroneous detection of the pilot tone, ensure that this search window does not include any portion of the message spectrum. The default is 0.25.

costas loop parameters specifies optional parameters controlling the Costas loop. Usually **Beta** is chosen to be less than 0.02 × **Alpha**. These parameters are used in tracking carrier phase offset in the specified **AM modulated waveform**. The default settings are typically unchanged except in the presence of severely time-varying carrier phase offset.

- **Alpha** specifies the α parameter as required by the Costas loop design. The default is 1 m.
- **Beta** specifies the β parameter as required by the Costas loop design. The default is 20 u.
- **uppressed carrier?** specifies whether the carrier has been suppressed in the incoming AM-VSB-modulated waveform. The default is FALSE.
- **reset?** specifies whether the VI continues AM-VSB demodulation using internal states from previous iterations

TRUE	When reset? is TRUE, the VI redesigns the pilot extraction filter and clears the internal filter states on each call. This is the default value.
FALSE	When reset? is FALSE, the pilot extraction filter design is unchanged across multiple calls, and the internal filter state is set to ensure continuous filter operation.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more

information about the error displayed.

AM demodulated waveform returns the recovered message signal.

- Note Wire the AM demodulated waveform parameter to any LabVIEW waveform measurement VI for further analysis. If the information signal is a single tone (normalized) and modulation index is set to 1.0 with suppressed carrier? set to FALSE, the peak amplitude value of the AM-demodulated waveform represents the true modulation index of the incoming AM-modulated waveform.
- **ID** returns the trigger (start) time of the **Y** array.
- **besilved between values in the Y array**.
- **Y** returns the amplitude-demodulated recovered message signal array.
- measurements returns the pilot tone location, carrier offset, and phase offset.
 - **extracted pilot tone** returns the location of the pilot tone in the **AM modulated waveform** frequency spectrum.
 - **frequency offset** returns the measured carrier frequency offset in hertz of the specified **AM modulated waveform**.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click

the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Demodulate FM VI

Performs <u>frequency demodulation</u> on the incoming <u>I/Q</u> signal. The recovered information signal is returned in the **FM demodulated waveform** parameter.

Details



FM modulated waveform specifies the <u>baseband</u> (<u>downconverted</u>) time-domain data for demodulation.

- **t0** specifies the trigger (start) time of the acquired signal.
- **dt** specifies the time interval between data points in the acquired signal.
- Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- **FM deviation** specifies whether to scale the **FM demodulated waveform**. You can set this value to 1.0 or to the expected <u>frequency deviation</u> of the incoming FM signal for demodulation.
 - Set this value equal to 1.0 to return an FM demodulated waveform parameter with no scaling. In this case, the maximum amplitude in hertz of the FM demodulated waveform is equal to the actual frequency deviation of the incoming FM signal. If the information signal is a single tone, you can use the LabVIEW Extract Single Tone Information VI to measure the maximum amplitude of the FM demodulated waveform.
 - Set this value equal to the expected frequency deviation of the incoming FM signal to divide the FM demodulated waveform parameter value by this value. You can use the resulting scaled FM demodulated waveform to quantify the degree of error between the expected frequency

deviation and the actual frequency deviation.

carrier correction? toggles carrier correction on and off.

TRUE	When carrier correction? is TRUE, the VI determines a scalar correction to the carrier frequency estimate and compensates for it in the FM demodulated waveform parameter.
	Sot carrier correction? to EALSE when performing

ALSE Set carrier correction? to FALSE when performing continuous acquisition. This is the default value.

reset? controls initialization of internal VI states. The differentiation step of the demodulation process uses a three-tap FIR filter and involves a transient response.

TRUE	When reset? is TRUE, the initial state of the filter is reset to zero at each call to this VI.
FALSE	When reset? is FALSE, the differentiation begins with the filter in its final state from the previous call to this function. This is the default value.

- **TEN** remove transient when reset? specifies whether to truncate the first several samples of the FM demodulated waveform when the VI has been reset (for example, on first call or when reset? is set to TRUE). On first call to this VI or when reset? is set to TRUE, set this parameter to TRUE to remove the transient of the FIR filter applied by the FM demodulator. The default is FALSE.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **FM demodulated waveform** returns the frequency-demodulated information signal.
 - **ID** returns the trigger (start) time of the **Y** array.
 - **besize and the time between values in the Y array.**
 - **Y** returns the frequency-demodulated information signal array.
- **Carrier offset** returns the offset between the incoming modulated carrier frequency and the estimated **carrier frequency** specified in the <u>MT Configure Downconversion Settings</u> VI. If the carrier frequency drifts as a function of time, this VI calculates the offset by performing a weighted linear fit on the phase information in the I/Q signal and then taking the slope of this linear fit. You can use this slope to monitor the drift in the carrier frequency. When **carrier correction?** is set to FALSE, this parameter returns **0**.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

source describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

The information signal is computed as a result of a <u>demodulation</u> process, which takes place in two steps internally. First the incoming I/Q data is phase-demodulated, and then the result of this phase demodulation is differentiated using a software FIR with three taps.

This VI calculates any residual carrier frequency left in the **FM modulated waveform**. If you use this VI with NI hardware, the residual frequency is the offset from the expected <u>carrier</u> frequency specified in the <u>MT Configure Downconversion Settings</u> VI. If the actual carrier frequency of the acquired signal is different from the center frequency of the receiver, a DC offset is introduced into the generated **FM demodulated waveform**. If the **carrier correction?** parameter is set to TRUE, this offset is removed. This correction is made only in software; the VI does not attempt to establish a lock with the unit under test (UUT).

You can wire the **FM demodulated waveform** parameter to any of the LabVIEW waveform measurement VIs for more measurements. If the information signal is a single tone, you can wire the **FM demodulated waveform** parameter to the Extract Single Tone Information VI to measure the amplitude, frequency, and phase of the information signal.

MT Demodulate PM VI

Performs <u>phase demodulation</u> on the incoming <u>I/Q</u> signal. The information signal is computed as a result of the <u>demodulation</u> and returned in the **PM demodulated waveform** output. This VI calculates any offset from the expected <u>carrier</u> frequency specified in the <u>MT</u> <u>Configure Downconversion Settings</u> VI.

<u>Details</u>



- **PM modulated waveform** specifies the <u>baseband</u> (<u>downconverted</u>) time-domain data for demodulation.
 - **t0** specifies the trigger (start) time of the acquired signal.
 - **dt** specifies the time interval between data points in the acquired signal.
 - Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- **phase deviation** specifies how to scale the **PM demodulated waveform**. You can set this value to 1.0 or to the expected phase deviation of the incoming PM signal for demodulation.
 - Set this value equal to 1.0 to return a PM demodulated waveform in degrees with no scaling. In this case, the maximum amplitude of the PM demodulated waveform is equal to the actual phase deviation of the incoming PM signal. If the information signal is a single tone, you can use the Extract Single Tone Information VI to measure the maximum amplitude of the PM demodulated waveform.
 - Set this value equal to the expected phase deviation of the incoming PM signal to divide the PM demodulated waveform by this value. You can use the resulting scaled PM demodulated waveform to quantify the degree of error between the expected phase deviation and the actual

phase deviation.

carrier correction? toggles **carrier correction?** on and off.

TRUE	When carrier correction? is TRUE, the VI determines a linear correction to the carrier frequency estimate and compensates for it in the PM demodulated waveform .
FALSE	Set carrier correction? to FALSE when performing continuous acquisition. This is the default value.

reset? controls initialization of an internal VI state that tracks the ending phase.

TRUE	Set reset? to TRUE to clear the state information about each call.
FALSE	When reset? is set to FALSE, the final phase from the previous call serves as the starting phase for the next call, ensuring phase continuity between calls. This is the default value.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or

Explain Warning from the shortcut menu for more information about the error displayed.

- **PM demodulated waveform** returns the phase-demodulated information signal.
- carrier offset returns the offset between the incoming modulated carrier frequency and the estimated carrier frequency passed to the MT Configure Downconversion Settings VI. Offset is returned whether carrier correction? is TRUE or FALSE. If the carrier frequency drifts as a function of time, this VI calculates the offset by performing a weighted linear fit on the phase information in the I/Q signal, and then taking the slope of this linear fit. You can use this slope to monitor drift in the carrier frequency.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

If the actual carrier frequency of the acquired signal is different from the center frequency of the receiver, a slope and offset are introduced into the **PM demodulated waveform** parameter. If the **carrier correction?** parameter is set to TRUE, this slope and offset are removed. This correction is made only in software; the VI does not attempt to establish a lock with the unit under test (UUT).

You can wire the **PM demodulated waveform** parameter to any of the <u>LabVIEW waveform measurement</u> VIs for further measurements.

MT Downconvert Passband VI

Downconverts real passband signal data of a user-specified bandwidth. The complex instance of this VI downconverts a complex baseband signal, centered around a nonzero center frequency, to a center frequency of zero. The baseband I/Q signal (complex envelope) is returned in the **downconverted waveform** parameter.



Note Using a downconversion filter with this VI may lead to the apparent loss of samples in the output waveform. Refer to <u>Filter</u> <u>Delay</u> for more information about this effect.

Use the pull-down menu to select an instance of this VI.

Select an instance

Details

MT Downconvert Passband (Complex)

Downconverts a complex baseband signal, centered around a nonzero center frequency, to a center frequency of zero.



initial phase specifies the initial phase, in degrees, of the software local oscillator used in the downconversion process. This parameter is ignored if the **reset?** parameter is FALSE. Use **initial phase** to

match the phase of the incoming <u>modulated</u> carrier and the local oscillator(s) of the downconversion process.

reset? specifies whether to use values input to the initial phase parameter, the passband bandwidth parameter, and the enable filter parameter.

TRUE	When reset? is TRUE, this VI uses these parameter values at each function call.
FALSE	Set reset? to FALSE to disregard these parameters and continue using values supplied in the previous call. Reusing previous input values is useful when sequential data blocks represent contiguous signal data. This is the default value.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **downconverted waveform (complex)** returns the downconverted signal in complex envelope format.
 - **t0** returns the trigger (start) time of the acquired signal.

- **besilt** dt returns time interval between data points in the acquired signal.
- Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- **ripple** returns the deviation of the passband gain from the nominal gain of 0 dB.
- **filter length** returns the number of taps in the filter.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **Source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Downconvert Passband (Real)

Downconverts real passband signal data of a user-specified bandwidth.



local oscillator used in the downconversion process. This parameter is ignored if the **reset?** parameter is FALSE. Use **initial phase** to match the phase of the incoming <u>modulated</u> carrier and the local oscillator(s) of the downconversion process. reset? specifies whether to use values input to the initial phase parameter, the passband bandwidth parameter, and the enable filter parameter.

TRUE	When reset? is TRUE, this VI uses these parameter values at each function call.
FALSE	Set reset? to FALSE to disregard these parameters and continue using values supplied in the previous call. Reusing previous input values is useful when sequential data blocks represent contiguous signal data. This is the default value.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **downconverted waveform (complex)** returns the downconverted signal in complex envelope format.
 - **t0** returns the trigger (start) time of the acquired signal.
 - **besi** dt returns time interval between data points in the acquired signal.

- Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (]) and quadrature-phase (Q) data, respectively.
- **ripple** returns the deviation of the passband gain from the nominal gain of 0 dB.
- **filter length** returns the number of taps in the filter.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

When the **enable filter** parameter is TRUE, the downconverted I/Q signal is filtered by a software lowpass FIR filter whose design parameters are dictated by the following considerations:

- If carrier frequency is greater than passband bandwidth, the filter stopband begins at carrier frequency.
- If carrier frequency is less than passband bandwidth, the filter stopband begins between carrier frequency and 2×carrier frequency–passband bandwidth/2.
- Note This VI performs signal processing on data and operates independently of your hardware setttings. This VI can be used in simulated as well as hardware-equipped applications. This VI is unaffected by the hardware settings configured using the MT Configure Downconversion Settings VI.

Utilities

Owning Palette: Analog

Use the VIs on the **Utilities** palette to extract and visualize I/Q data information.

Palette Object	Description
<u>MT IQ to</u> XY Graph	Formats I/Q data for plotting on a LabVIEW XY graph. This VI extracts the I and Q data into two arrays (X and Y, respectively), which are bundled into the I vs. Q graph cluster for display on a LabVIEW front panel graph. To place a formatted XY graph on your LabVIEW front panel, right-click the I vs. Q graph output terminal and select Create»Indicator.
<u>MT Get</u> <u>Complex</u> IQ Component	Extracts the desired component from the IQ (complex) in parameter. <u>I</u> , <u>Q</u> , magnitude, and <u>phase</u> data are available for extraction. This VI returns a complex envelope in the CE component parameter that contains the t0 , dt , and Y values for the chosen component.
MT Resample (Complex Cluster)	Specifies a complex-valued waveform and resamples and/or realigns it based on the input parameters that you specify.
<u>MT Phase</u> <u>Locked</u> <u>Loop</u>	Attempts to track the unknown phase of an input complex exponential tone by means of a feedback control system. At steady state, when the phase-locked loop (PLL) has acquired a lock to the input signal, the PLL estimates the offset of the input signal carrier phase and carrier frequency from the reference phase and frequency. The polymorphic instances of this VI accept either a complex baseband waveform or a real passband waveform.

MT IQ to XY Graph VI



- **IQ data (complex) in** specifies the <u>baseband</u> (<u>downconverted</u>) time-domain data for representation on the XY graph.
 - **t0** specifies the trigger (start) time of the acquired signal.
 - **dt** specifies the time interval between data points in the signal data.
 - Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click

the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **IQ data (complex) out** returns the baseband (downconverted) time-domain data. This VI does not modify this data, so this parameter is identical to the **IQ data (complex) in** parameter.
 - **t0** returns the trigger (start) time of the acquired signal.
 - **dt** returns the time interval between data points in the acquired signal. The I/Q sampling rate is the reciprocal of this value.
 - Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (!) and quadrature-phase (Q) data, respectively.
- **I vs. Q graph** returns the XY graph indicator. The X axis contains I data and the Y axis contains Q data.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **Source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Get Complex IQ Component VI

Extracts the desired component from the **IQ (complex) in** parameter. <u>I</u>, <u>Q</u>, magnitude, and <u>phase</u> data are available for extraction. This VI returns a complex envelope in the **CE component** parameter that contains the **t0**, **dt**, and **Y** values for the chosen component.



- **IQ data (complex) in** specifies the baseband (downconverted) time-domain data.
 - **t0** specifies the trigger (start) time of the acquired signal.
 - **dt** specifies the time interval between data points in the acquired signal.
 - Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (1) and quadrature-phase (Q) data, respectively.
- **component choice** specifies which complex envelope data component to extract from the complex envelope contained in the **IQ Data (complex) in** cluster.
 - $\overline{\mathbb{N}}$
- **Note** If you do not request phase data, phase continuity is not preserved.

I (0)	The in-phase component is extracted.
Q (1)	The quadrature component is extracted.
Magnitude (2)	The magnitude of signal is extracted.
Phase (3)	The phase of the signal is extracted.

reset? controls initialization of an internal VI state that tracks the ending phase.

TRUE	Set reset? to TRUE to clear the state information about each call.
FALSE	When reset? is set to FALSE, the final phase from the

previous call serves as the starting phase for the next call, ensuring phase continuity between calls. This is the default value.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **IQ data (complex) out** returns the baseband (downconverted) time-domain data. This VI does not modify this data, so this parameter is identical to the **IQ data (complex) in** parameter.
 - **t0** returns the trigger (start) time of the acquired signal.
 - **dt** returns the time interval between data points in the acquired signal. The I/Q sampling rate is the reciprocal of this value.
 - Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (!) and quadrature-phase (Q) data, respectively.
- **CE component** returns the complex envelope data component selected in the **component choice** parameter. You can wire this

parameter to a LabVIEW Waveform Graph to display the selected component as a function of time.

- **t0** returns the trigger (start) time of the acquired signal.
- **besilt** dt returns time interval between data points in the acquired signal.
- Y returns the data array corresponding to the component selected. This array can contain real (<u>I</u>), imaginary (<u>Q</u>), magnitude, or phase data.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **Source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
MT Resample (Complex Cluster) VI

Specifies a complex-valued waveform and resamples and/or realigns it based on the input parameters that you specify.

<u>Details</u>



states of the algorithms such that you cannot perform continuous processing on the signal during subsequent iterations. If **flush buffers?** is set to TRUE, you must set **reset?** to TRUE on the subsequent iteration.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **output complex waveform** returns the resampled complex baseband waveform data.
 - **ID** returns the time of first value in Y array.
 - **besize the set whe set and the time between values in the Y array.**
 - Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (!) and quadrature-phase (Q) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.

- **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

To realign the input waveform in time, specify a nonzero value to the **initial sample offset** parameter. Positive (negative values are invalid) offset values push the **output complex waveform** forward relative to the **input complex waveform**.

To resample a waveform, specify a desired sample rate that differs from the existing sample rate of the **input complex waveform**. To realign a waveform without changing its sample rate, specify a value for the **desired sample rate** parameter equal to the existing sample rate. To resample a waveform without changing the relative timing offset between the input and output complex waveforms, specify **initial sample offset** parameter as 0.

Using MT Fractional Resample in Modulation Toolkit 4.1

The Modulation Toolkit 4.0 version of <u>MT Fractional Resample VI</u> has been deprecated for Modulation Toolkit 4.1. If your application currently uses the MT Fractional Resample VI, the application continues to refer to the Modulation Toolkit 4.0 version of the MT Fractional Resample VI located at <*LabVIEW*>\vi.lib\addons\Modulation\Analog\Deprecated. Use the MT Resample (Complex Cluster) VI for Modulation Toolkit 4.1 or later applications.

Note The FIR filters used in the resampling algorithms in the MT Resample (Complex Cluster) and the MT Fractional Resample VIs have different delays. If your application depends on the specific filter delay value of the MT Fractional Resample VI, review your application and evaluate if you can use the MT Resample (Complex Cluster) VI with the **flush buffers?** parameter set to TRUE instead. To switch to using the MT Resample (Complex Cluster), replace the MT Fractional Resample with this VI and carefully review and modify the parts of your application that depend on specific values of filter delays.

Because of the difference in the FIR filters, comparing data from the MT Fractional Resample VI and MT Resample (Complex Cluster) VI does not produce numerically exact matches.

MT Phase Locked Loop VI

Attempts to track the unknown phase of an input complex exponential tone by means of a feedback control system. At steady state, when the phase-locked loop (PLL) has acquired a lock to the input signal, the PLL estimates the offset of the input signal carrier phase and carrier frequency from the reference phase and frequency. The polymorphic instances of this VI accept either a complex baseband waveform or a real passband waveform.

Use the pull-down menu to select an instance of this VI.

Select an instance 🔽

<u>Details</u>

MT Baseband PLL

This polymorphic instance simulates the operation of the PLL in response to an input complex baseband waveform with an unknown phase and frequency offset.

The baseband waveform is assumed to consist of a tone at a userspecified nominal carrier phase and frequency, which is used as a reference to the PLL. The PLL is a feedback control system that employs a phase detector, loop filter, and a voltage-controlled oscillator (VCO) for its operation. The PLL tracks the instantaneous phase and frequency of the input waveform and returns an estimate of the carrier phase and frequency. You can use these estimates to adjust/correct the phase of the input waveform (for example, carrier phase/frequency offset correction in M-ary PSK digital communication systems).



- **baseband waveform** specifies a cluster comprising the I/Q baseband waveform values that represent the complex envelope. The complex envelope is assumed to consist of a tone with a frequency and phase that are to be estimated by the PLL. The default is empty.
 - **t0** specifies the trigger (start) time of the **Y** array. The default is 0.00.
 - **DEL** dt specifies time interval between data points in the Y array. The default is 1.00.
 - Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- **VCO gain** specifies the gain applied to the error signal inside the VCO prior to generating the **estimated initial phase** parameter. The default is 1.

VCO carrier frequency specifies the reference carrier frequency used by the VCO to track the carrier phase of the input signal. The default is 0 Hz.

- **VCO initial phase** specifies the reference initial carrier phase used by the VCO to track the carrier phase of the input signal. The default is 0 degrees.
- **Ioop filter (forward coefficients)** specifies the forward coefficients of the IIR loop filter. The default is (1.05 -0.95)
- **Ioop filter (reverse coefficients)** specifies the reverse coefficients of the IIR loop filter. The default is (1 -1).
- **reset ?** specifies whether to clear the internal state of the PLL prior to starting operation.

TRUE	When reset ? is set to TRUE, all state information is cleared, and the PLL is initialized with the initial phase given in the PLL settings cluster. This is the default value.
FALSE	When reset ? is set to FALSE (as in a continuous operation), the VI uses the state information at the end of the previous iteration to initialize the PLL at the beginning of the current iteration.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **VCO phase** returns the overall phase of the input signal estimated by the PLL, including the effects of any carrier phase and frequency offsets.
- **phase error** returns the carrier phase error signal at the phase detector output inside the PLL. You can use this value to estimate the phase difference between the input signal and the regenerated phase at the PLL output. When the PLL locks, **phase error** values approach zero.
- estimated carrier frequency returns the actual carrier frequency of the input signal, as estimated by the PLL, accounting for any carrier frequency offset. Use the difference between the estimated carrier frequency and the nominal input carrier frequency to estimate the carrier frequency offset.
- estimated initial phase returns the actual carrier phase of the input signal, as estimated by the PLL, with respect to the specified nominal carrier phase. Use the difference between the estimated carrier phase and the input nominal carrier phase to estimate the scalar carrier phase offset.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click

the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Passband PLL

This polymorphic instance simulates the operation of the phase-locked loop (PLL) in response to an input real passband waveform that has an unknown phase and frequency offset.

The passband waveform is assumed to consist of a tone at a userspecified nominal carrier phase and frequency, which is used as a reference to the passband PLL. The PLL is a feedback control system that employs a phase detector, loop filter, and a voltage-controlled oscillator (VCO) for its operation. The passband PLL tracks the instantaneous phase and frequency of the input waveform and returns an estimate of the carrier phase and frequency. You can use these estimates to adjust/correct the phase of the input waveform (for example, carrier phase/frequency offset correction in M-ary PSK digital communication systems).



- **passband waveform** specifies a passband waveform comprising a tone at the carrier, with a frequency and phase that are to be tracked by the PLL.
- **VCO carrier frequency** specifies the reference carrier frequency used by the VCO to track the carrier phase of the input signal. The default is 0 Hz.
- **VCO initial phase** specifies the reference initial carrier phase used by the VCO to track the carrier phase of the input signal. The default is 0 degrees.
- **VCO gain** specifies the gain applied to the error signal inside the VCO prior to generating the **estimated initial phase** parameter. The default is 1.
- **Ioop filter (reverse coefficients)** specifies the reverse coefficients of the IIR loop filter. The default is (1 -1).
- **Ioop filter (forward coefficients)** specifies the forward coefficients

of the IIR loop filter. The default is (1.05 -0.95)

reset ? specifies whether to clear the internal state of the PLL prior to starting operation.

TRUE	When reset ? is set to TRUE, all state information is cleared, and the PLL is initialized with the initial phase given in the PLL settings cluster. This is the default value.
FALSE	When reset ? is set to FALSE (as in a continuous operation), the VI uses the state information at the end of the previous iteration to initialize the PLL at the beginning of the current iteration.

- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **VCO phase** returns the overall phase of the input signal estimated by the PLL, including the effects of any carrier phase and frequency offsets.
- **phase error** returns the carrier phase error signal at the phase detector output inside the PLL. You can use this value to estimate

the phase difference between the input signal and the regenerated phase at the PLL output. When the PLL locks, **phase error** values approach zero.

- estimated carrier frequency returns the actual carrier frequency of the input signal, as estimated by the PLL, accounting for any carrier frequency offset. Use the difference between the estimated carrier frequency and the nominal input carrier frequency to estimate the carrier frequency offset.
- estimated initial phase returns the actual carrier phase of the input signal, as estimated by the PLL, with respect to the specified nominal carrier phase. Use the difference between the estimated carrier phase and the input nominal carrier phase to estimate the scalar carrier phase offset.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **Source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

You must set the following parameters to configure the PLL operation:

- **loop filter (reverse coefficients)**—The reverse coefficients of the IIR loop filter.
- **loop filter (forward coefficients)**—The forward coefficients of the IIR loop filter.
- **VCO gain**—The gain that is applied to the error signal inside the VCO prior to generating the estimated phase output.
- VCO carrier frequency—The reference carrier frequency used by the VCO to track the carrier phase of the input signal.
- **VCO initial phase**—The reference initial carrier phase used by the VCO to track the carrier phase of the input signal.



- **VCO phase**—The output instantaneous VCO phase estimates.
- VCO phase error—The estimated difference between the VCO phase estimate and the input phase.
- **estimated carrier frequency**—The estimated average carrier frequency at the VCO output.
- **estimated carrier phase**—The estimated initial carrier phase at the VCO output.



A PLL contains three basic elements:

- Phase detector
- IIR loop filter
- Voltage controlled oscillator (VCO)

The phase detector block measures the approximate error between the estimated phase and the actual phase of the incoming signal. The IIR loop filter block then filters out any high-frequency noise present in the error signal and helps tracking phase and frequency offset errors. A first-order lowpass filter block tracks an initial phase offset, but returns a constant phase offset in the presence of a frequency offset. Higher-order filters track both phase and frequency offsets at steady state, as summarized in the following table.

F(s)	F(z)	Remarks
1	1	(Order I) Tracks frequency error, steady state phase offset
$1+\frac{a}{s}$	$\frac{(0.5a+1)+(0.5a-1)z^{-1}}{1-z^{-1}}$	(Order II) Tracks phase and frequency error, not offset
$\frac{s+a}{s+\varepsilon}$	$M \frac{1 - \left(\frac{2-a}{2+a}\right) z^{-1}}{1 - \left(\frac{2-\varepsilon}{2+\varepsilon}\right) z^{-1}}$	(Order II) Tracks phase and frequency error, not offset
$1 + \frac{a}{s} + \frac{b}{s^2}$	$\frac{(4+2a+b)+(2b-8)z^{-1}+(b-2a+4)z^{-2}}{4(1-2z^{-1}+z^{-2})}$	(Order III) Tracks phase and frequency error, not offset

MT 5620 Specific

Use the VIs on the **IF/NI-SCOPE** palette to configure and acquire IF data using an NI-SCOPE device.

Palette Object	Description
<u>MT Initialize</u> <u>Receiver</u> <u>Info(niscope)</u>	Allocates memory resources and opens VI references for a new Modulation Toolkit (MT) session. This VI passes a receiver info parameter that carries information about the <u>downconversion</u> process, <u>carrier</u> <u>frequency</u> , and VI references used by the processing VIs from one MT VI to the next. The information in this wire is stored as attributes.
MT Configure Downconversion Settings	Configures the NI PXI-562 <i>x</i> device to acquire time- domain data for the downconversion characteristics that you specify.
<u>MT Convert IF</u> <u>to IQ</u>	Converts the IF data from the NI PXI-5620 digitizer module to <u>I/Q data</u> through a process of filtering, decimation, and downconversion. This VI can use real IF data from the NI PXI-5620 or complex I/Q data returned from the NI PXI-5620 onboard DDC.
<u>MT Clear</u> <u>Receiver Info</u>	Deallocates memory resources and ends a Modulation Toolkit (MT) session. This VI clears the information related to the <u>downconversion</u> process, <u>carrier</u> <u>frequency</u> , and VI references, and terminates the receiver info wire. Call this VI to end every MT session.

MT Clear Receiver Info VI

Deallocates memory resources and ends a Modulation Toolkit (MT) session. This VI clears the information related to the <u>downconversion</u> process, <u>carrier frequency</u>, and VI references, and terminates the **receiver info** wire. Call this VI to end every MT session.



- **receiver info in** specifies information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs. Wire the **receiver info out** of the previous MT VI to this input.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark)

for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Configure Downconversion Settings VI

Configures the NI PXI-562*x* device to acquire time-domain data for the downconversion characteristics that you specify.

Details



- receiver info in specifies information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs. Wire the receiver info out of the previous MT VI to this input.
- **carrier frequency** specifies the expected carrier frequency of the incoming signal for demodulation. The receiver tunes to this frequency. The Modulation Toolkit demodulation VIs can optionally correct for slope or offset in the carrier frequency.
- **bandwidth** specifies the 0.01 dB bandwidth of the software filter that is used in the downconversion process. Set this value to the bandwidth of the modulated wave.
- **time duration** specifies the number of seconds over which to acquire I/Q data.
- min IQ sample rate specifies the minimum sample rate of the complex I/Q data returned by the MT Convert IF to IQ VI. In auto mode (default), this VI automatically calculates the sample rate of the I/Q data based on the other parameters in this VI. If you specify a different value, this VI coerces the actual sample rate.
- **bandwidth scaling factor** specifies the factor by which the input **bandwidth** gets multiplied to account for the the rolloff of the software filter used in the downconversion process. The default value is 1.00001.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain

Warning from the shortcut menu for more information about the error displayed.

- **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **receiver info out** returns information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs from one MT VI to the next. This information is stored as attributes. Wire this parameter to the **receiver info in** parameter of the next MT VI.
- **miScope sample rate** returns the minimum sampling rate for your configuration. Wire this parameter to the **min sample rate** parameter of the niScope Configure Horizontal Timing VI. This rate may differ from the sample rate returned in the **IQ data (complex)** output of the MT Convert IF to IQ VI.
- **number of samples** returns the number of time-domain data points that you must acquire to return the requested **time duration**. Wire this parameter to the **min record length** parameter of the niScope Configure Horizontal Timing VI.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from

the shortcut menu for more information about the error displayed.

- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **Source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

You can specify the expected **carrier frequency**, the **time duration** for the acquisition, and the **bandwidth**. This VI uses these parameters to configure the hardware and to calculate the **number of samples** and the **niScope sample rate** for the IF digitizer module. The **number of samples** returned specifies how many time-domain samples you must first acquire using one of the NI-SCOPE acquisition VIs and then pass to the I/Q processing VIs.

The MT Configure Downconversion Settings VI detects the receiving device and automatically uses the appropriate subVI—either Configure Downconversion Settings (NI-RFSA) or Configure Downconversion Settings (NI-SCOPE)—for your receiver.



Note Call the <u>MT Get Attributes</u> VI to view all public attribute settings.

MT Convert IF to IQ VI

Converts the IF data from the NI PXI-5620 digitizer module to <u>I/Q data</u> through a process of filtering, decimation, and downconversion. This VI can use real IF data from the NI PXI-5620 or complex I/Q data returned from the NI PXI-5620 onboard DDC.

<u>Details</u>



receiver info in specifies information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs. Wire the **receiver info out** parameter from the previous MT VI to this input.

wfm info specifies all the timing and scaling information about the NI-SCOPE waveform. Wire this parameter to the wfm info parameter from the niScope Read Cluster VI.

- actualSamples specifies the actual number of samples in the acquired waveform; this number may be less than the niScope Read Cluster VI numSamples parameter if the number you request is not available.
- **absoluteInitialX** specifies the timestamp of the first fetched sample that is comparable between records and acquisitions. This parameter is not supported by all hardware products, in which case it is always zero.
- **relativeInitialX** specifies the time in seconds from the trigger to the first sample in the fetched waveform. The trigger always occurs at t=0.
- **xIncrement** specifies the time, in seconds, between two samples of the acquired waveform. This is 1/(sample rate) for time-domain acquisitions.
- **offset** specifies the offset factor of the given channel; useful for scaling binary data with the formula: voltage = binary data * gain factor + offset.
- **gain** specifies the gain factor of the given channel; this value

is useful for scaling binary data with the formula: voltage = binary value * gain + offset.

- **reserved1** is reserved for future use. Do not use.
- **reserved2** is reserved for future use. Do not use.
- waveform in specifies the time-domain data from the NI-SCOPE acquisition VIs.
 - **relativeInitialX** specifies the time in seconds from the trigger to the first sample in the fetched waveform. The trigger always occurs at t=0.
 - **xIncrement** specifies the time, in seconds, between two samples of the acquired waveform. This is 1/(sample rate) for time-domain acquisitions.
 - wfm specifies an array of voltage data corresponding to one waveform.
- **phase adjust** specifies the value by which the VI adjusts the phase of the I/Q data returned in the **IQ data (complex)** parameter. When the signal source and the receiver are locked, use this control to compensate for any phase difference between the incoming modulated carrier and the local oscillator(s) of the downconversion process.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **receiver info out** returns information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs from one MT VI to the next. This information is stored as attributes. Wire this parameter to the **receiver info in** parameter of the next MT VI.
- **IQ data (complex)** returns the baseband (downconverted) timedomain data for demodulation. Exported time data contains the complex modulated and filtered time data corresponding to the requested spectrum if **import time data?** is set to TRUE.
 - **t0** returns trigger (start) time of the acquired signal.
 - **dt** returns the time interval between data points in the acquired signal.
 - Y returns an array of complex-valued time-domain data. The real and imaginary parts of this complex data array correspond to the in-phase (I) and quadrature-phase (Q) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or

Explain Warning from the shortcut menu for more information about the error displayed.

Details

When operating on real IF data from the NI PXI-5620 digitizer module, the entire process of filtration, decimation, and downconversion always occurs, and the **auto suppress SW IQ** parameter has no effect. When operating on complex I/Q data returned from the digitizer module onboard DDC, **autosuppress SW IQ** toggles filtration on and off.

This VI makes use of the receiver **auto suppress SW IQ** parameter.

Tip When the **autosuppress SW IQ** parameter is set to OFF, complex I/Q data returned from the digitizer module DDC is filtered and extraneous signal components are suppressed in software. By default, **autosuppress SW IQ** is set to OFF to lower the noise floor and reduce spurious signal artifacts in the returned I/Q data.

When the **autosuppress SW IQ** parameter is set to ON, no additional filtering takes place on the I/Q data returned from the digitizer module DDC. Set this parameter to ON to access the raw I/Q data returned from the DDC or for fastest performance.



MT Initialize Receiver Info(niscope) VI

Allocates memory resources and opens VI references for a new Modulation Toolkit (MT) session. This VI passes a **receiver info** parameter that carries information about the <u>downconversion</u> process, <u>carrier frequency</u>, and VI references used by the processing VIs from one MT VI to the next. The information in this wire is stored as attributes.

niScope handle	receiver info out
error in (no error)	error out

- **niScope handle** specifies the niScope handle that is obtained from the niScope Initialize VI and identifies a particular instrument session.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **receiver info out** returns information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs from one MT VI to the next. This information is stored as attributes. Wire this parameter to the **receiver info in** parameter of the next MT VI.

- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Analog Modulation VI Attributes for IF/NI-SCOPE

Modulation VI attributes store information related to the downconversion process, carrier frequency, and VI references used by the processing VIs. Call <u>MT Get Attributes</u> to view all public attribute settings. Set read/write attributes by calling <u>MT Set Attributes</u>.

The following table describes carrier and receiver attributes. $\hfill\square$

Carrier Attributes				
Attribute Cluster Name	Access	Data Type	Default Value	Description
carrier.frequency	read- only	double	(unconfigured)	Specifies the user- requested carrier frequency in Hz. This value may be coerced based on hardware settings and downconversion specifications.

Receiver Attributes

Attribute Cluster Name	Access	Data Type	Defa
receiver.handles. niScope handle	read-only	niscope instrument handle	null
receiver. data format	read-only	enum{real, complex modulated (array), complex modulated (interleaved)}	real
receiver. auto suppress SW IQ	read/write	enum{off, on}	off
receiver. bandwidth	read-only	double	

		(unc

MT Get Attributes VI

Retrieves all read-only and read/write Modulation Toolkit attribute settings.

To view current settings, complete the following steps:

- 1. Place the MT Get Attributes VI on a block diagram.
- 2. Right-click the Unbundle by Name primitive.
- 3. Go to the Select Item option on the pop-up menu and navigate to the attribute(s) of interest.

Note Refer to Modulation VI Attributes for a full explanation of all attributes.

receiver info in 📟 receiver info out Source of the second bandwidth scaling factor 🚽 ±₩→ error in (no error) 🚥 🚥 error out

- **receiver info in** specifies information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs. Wire the **receiver info out** of the previous MT VI to this input.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more

information about the error displayed.

- **receiver info out** returns information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs from one MT VI to the next. This information is stored as attributes. Wire this parameter to the **receiver info in** parameter of the next MT VI.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

MT Set Attributes VI

Sets and asserts user-specified values for all read/write Modulation Toolkit attributes.

To set attributes, complete the following steps:

- 1. Place the MT Set Attributes VI on a block diagram.
- 2. Right-click the Bundle by Name primitive, as shown in the following figure.
- 3. Go to the **Select Item** option on the pop-up menu and navigate to the attribute(s) of interest.

receiver info in	receiver info out
error in (no error)	→ error out

- **receiver info in** specifies information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs. Wire the **receiver info out** of the previous MT VI to this input.
- error in (no error) accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or

Note Refer to Modulation VI Attributes for a full explanation of all attributes.

Explain Warning from the shortcut menu for more information about the error displayed.

- **receiver info out** returns information related to the downconversion process, carrier frequency, and VI references used by the MT processing VIs from one MT VI to the next. This information is stored as attributes. Wire this parameter to the **receiver info in** parameter of the next MT VI.
- **attributes** returns a wire to the Unbundle by Name primitive when you drop this VI. On the block diagram, view Modulation Toolkit attribute settings by right-clicking the Unbundle by Name primitive and using the **Select Item** menu option.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **Source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
MT Modulate FM v2 (Deprecated)

Performs frequency modulation on an RF carrier wave according to a baseband information signal input to the **message signal** control. It returns the complex envelope of the FM modulated signal in the **FM modulated waveform** indicator.

<u>Details</u>



- message signal contains the message signal used to modulate the carrier wave.
- **FM deviation** specifies the desired frequency deviation of the frequency-modulated signal returned in the **FM modulated waveform** parameter.
- **reset?** controls initialization of internal VI states. The modulation process involves an integration operation. When **reset?** is FALSE (default), the integration begins in the final state from the previous call (this option is useful when the current block of I/Q data is contiguous with the preceding block of I/Q data). When this parameter is TRUE, the initial state of the integration is set to zero at each call to this VI.
- error in accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error

displayed.

- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **FM modulated waveform** contains the baseband signal data and the complex envelope of the frequency-modulated signal.
 - **ID** returns the trigger (start) time of the signal data.
 - **dt** returns the time interval between data points in the signal data.
 - Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (1) and quadrature-phase (Q) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

This VI performs signal processing on data and operates independently of hardware settings. This VI can be used in simulated as well as hardware-equipped applications.

The output frequency-modulated wave is described by the equation:

$$FM = e^{i\left(2\pi \frac{frequencyDeviation}{f_s}\int_{t} ((messageSignal)d\tau + carrierPhase)\right)}$$

This VI sets *carrierPhase* in the equation above to zero. To adjust the carrier phase, use the initial phase input of the <u>MT Upconvert</u> <u>BasebandVI</u> VI.

Using MT Modulate FM v2.vi in Modulation Toolkit 4.1

The Modulation Toolkit 4.0 version of the <u>MT Modulate FM</u> VI has been renamed to MT Modulate FM v2 and has been moved to the deprecated folder at *<LabVIEW*>\vi.lib\addons\Modulation\Analog\Deprecated. If your application currently refers to MT Modulate FM, the application will use the optimized Modulation Toolkit 4.1 version of this VI.

MT Fractional Resample (Deprecated)

Specifies a complex waveform and resamples and/or realigns it based on the input parameters that you specify.

<u>Details</u>



- **initial sample offset** specifies the initial sample offset in seconds. This positive value specifies the location in time of the first output point relative to the first input point.
- **input complex waveform** specifies the complex <u>baseband</u> waveform data.
 - **t0** specifies the trigger (start) time of the **Y** array. The default is 0.00.
 - **dt** specifies time interval between data points in the **Y** array. The default is 1.00.
 - Y specifies the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (!) and quadrature-phase (Q) data, respectively.
- desired sample rate specifies the desired sample rate of the output complex waveform data, in units Hz. This value can be an integer or a non-integer multiple of the input data sample rate. The default is 1.00.
- **reset?** controls whether the VI continues resampling using the previous iteration states. **reset?** must be set to TRUE whenever you desire to restart fractional resampling. The default is TRUE.
- error in accepts error information wired from previously called VIs. Use this information to decide if any functionality should be bypassed in the event of errors from other VIs. Right-click the front panel error in control and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.



status is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

- **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **source** describes the origin of the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
- **output complex waveform** returns the resampled complex baseband waveform data.
 - **ID** returns the trigger (start) time of the **Y** array.
 - **bell** dt returns the time between values in the Y array.
 - Y returns the complex-valued time-domain data array. The real and imaginary parts of this complex data array correspond to the in-phase (1) and quadrature-phase (Q) data, respectively.
- error out passes error or warning information out of a VI to be used by other VIs. Right-click the front panel error out indicator and select Explain Error or Explain Warning from the shortcut menu for more information about the error displayed.
 - **Status** is either TRUE (X) for an error, or FALSE (checkmark) for no error or a warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **code** identifies the error or warning. Right-click the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.
 - **source** describes the origin of the error or warning. Right-click

the front panel **error in** control and select **Explain Error** or **Explain Warning** from the shortcut menu for more information about the error displayed.

Details

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To realign the input waveform in time, specify a nonzero value in the **initial sample offset** parameter. Positive (negative values are invalid) offset values push the **output complex waveform** forward relative to the **input complex waveform**.

To resample a waveform, enter a desired sample rate that differs from the existing sample rate of the **input complex waveform**. To realign a waveform without changing its sample rate, enter a value in the **desired sample rate** parameter equal to the existing sample rate. To resample a waveform without changing the relative timing offset between the input and output complex waveforms, enter a value of 0 in the **initial sample offset** parameter.

Using MT Fractional Resample in Modulation Toolkit 4.1

The Modulation Toolkit 4.0 version of MT Fractional Resample VI has been deprecated for Modulation Toolkit 4.1. If your application currently uses the MT Fractional Resample VI, the application will continue to refer to the Modulation Toolkit 4.0 version of MT Fractional Resample located at <LabVIEW>\vi.lib\addons\Modulation\Analog\Deprecated. Use the <u>MT</u> <u>Resample (Complex Cluster)</u> VI for Modulation Toolkit 4.1 or later applications.

Note The FIR filters used in the resampling algorithms in the MT Resample (Complex Cluster) and the MT Fractional Resample VI have different delays. If your application depends on the specific filter delay value of the MT Fractional Resample VI, review your application and evaluate if you can use the MT Resample (Complex Cluster) VI with the **flush buffers?** parameter set to TRUE instead. To switch to using the MT Resample (Complex Cluster), replace the MT Fractional Resample with this VI and carefully review and modify the parts of your application that depend on specific values of filter delays.

Because of the difference in the FIR filters, comparing data from the MT Fractional Resample VI and MT Resample (Complex Cluster) VI does not produce numerically exact matches.

Note If your application uses MT Fractional Resample, NI recommends that you carefully review your application based on

the behavioral differences between the deprecated MT Fractional Resample VI and the new MT Resample (Complex Cluster) VI, and migrate your application to the new MT Resample (Complex Cluster) VI.