cadence®

Virtuoso Functional Block Library Reference Manual

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1

Introduction to Functional Block Library

The functional block library is a library within the Virtuoso ADE and is used by analog designers as a high-level design tool.

The Functional Blocks contain the essential functionality of the parts they are modelling. However, the models are not fully representative of the equivalent parts. For example, an amplifier functional block has no differential pair on its input, so input biases such as CMRR (Common Mode Rejection Ratio) are not accounted for. Also, a majority of these blocks is assumed to be ideal. The amplifier amplifies with no drift, the input impedance is infinite, and the output impedance is zero. However, you can use the functional block library with all other installed analog libraries and with basic SPICE primitives so you can add complexity and effects, such as frequency response.

Each functional block consists of at least two parts: the symbol and its associated model. The models directory must be in the model path of the Environment Options form. Also, the library directory must be present in the search path of the Set Library Search Path form.

For *spectre* simulation, the models directory path is:

`your_install_dir/tools/dfII/etc/cdslib/artist/functional/allFunc.scs`

You can specify the path to the model libraries in the Model Library Setup form. To open the form, choose *Setup – Model Libraries* from the simulation window.

The library directory path is:

`your_install_dir/tools/dfII/etc/cdslib/artist`

You can specify the path to the library in the Library Path Editor window. To open the window, choose *Tools – Library Path Editor* from the Virtuoso Studio CIW.

Licensing Requirements

For information about licensing in the Virtuoso Studio design environment, see Virtuoso Software Licensing and Configuration Guide.

Functional Block Library Components and Symbols

The functional block library contains several components. These components are divided into four categories- Amplifiers, Math, Misc, and Pole.

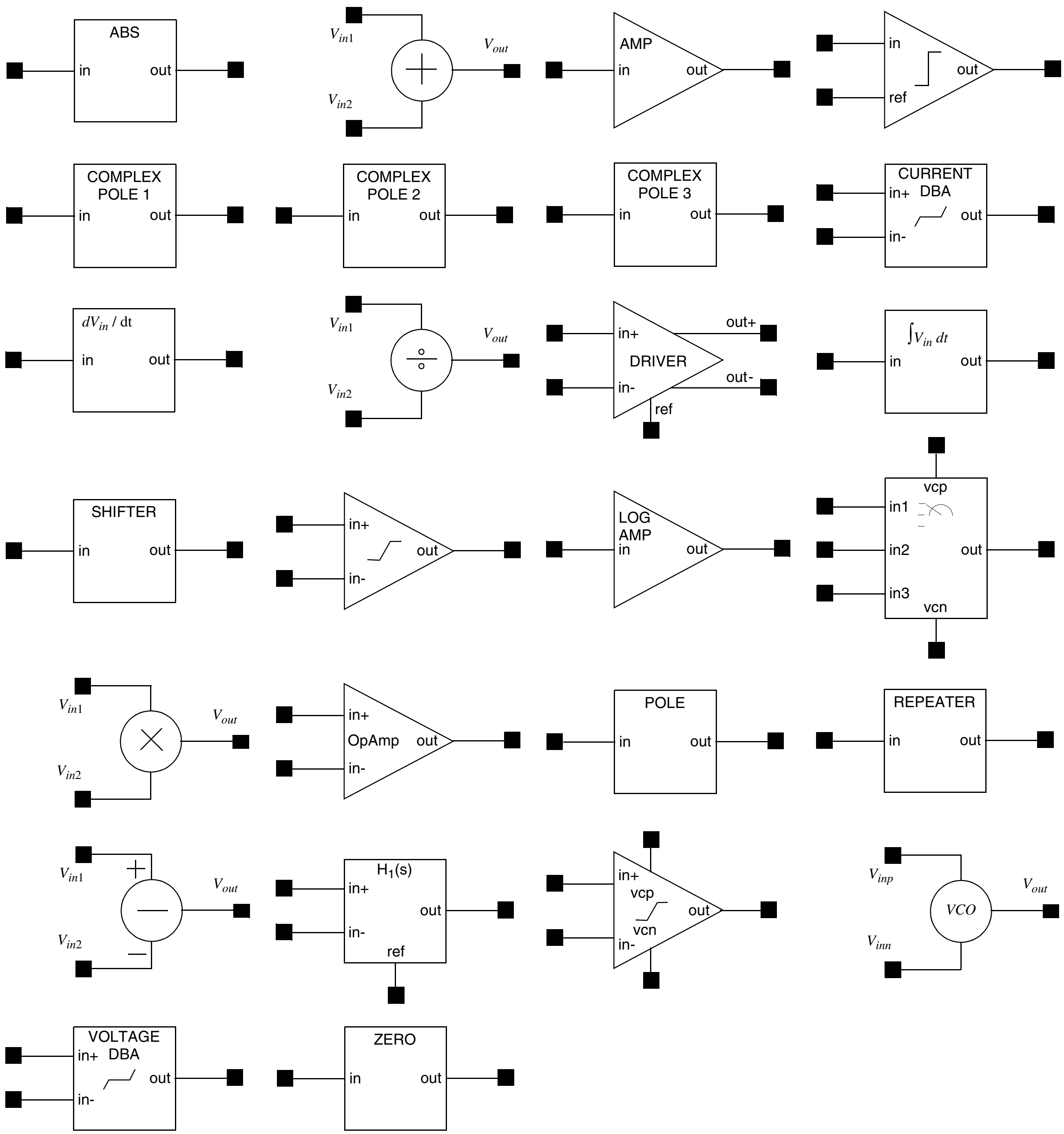
For each component, multiple views, such as symbol view and simulator specific views are available. For some components, the schematic view is also available.

The following list shows the library names of these components. These components are described in detail in Introduction to Functional Library.

- Absolute Value Symbol
- Adder Symbol
- Amplifier Symbol
- Comparator Symbol
- Complex Pole 1 Symbol
- Complex Pole 2 Symbol
- Complex Pole 3 Symbol
- Current Dead-Band Amplifier (currentDba) Symbol
- Differentiator Symbol
- Divider Symbol
- Driver Symbol
- Integrator Symbol
- Level Shifter Symbol
- Limiting Amplifier Symbol
- Logarithmic Amplifier Symbol
- Multiplexer Symbol
- Multiplier Symbol
- Operational Amplifier (opAmp) Symbol
- Pole Symbol
- Repeat Waveform Symbol

- Subtractor Symbol
- Transfer Function 1 Symbol
- Voltage-Controlled Variable-Gain Amplifier
- Voltage-Controlled Oscillator (VCO) Symbol
- Voltage Dead-Band Amplifier (VoltageDba) Symbol
- Zero Symbol

The following figure shows all the components symbols of the Functional Block Library.

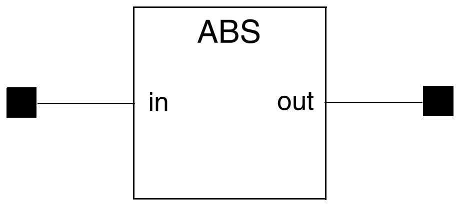


Related Topics

Comparator Macromodel

OpAmp Macromodel

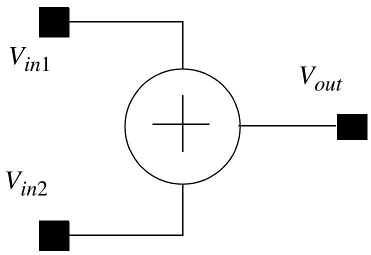
Absolute Value Symbol



The following table summarizes the details of this symbol.

Description	■ Output voltage is the absolute value of the input voltage. ■ The absolute value function (ABS) always returns a positive output. Its operation is that of an ideal full-wave rectifier.
Library name	`absoluteValue`
Transfer function	$V_{out} = \lvert V_{in} \rvert$
Properties (Defaults)	None
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

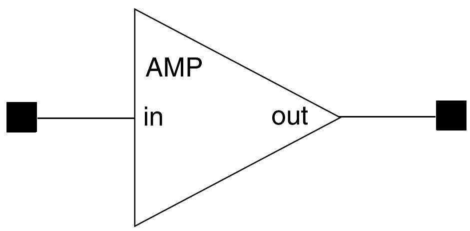
Adder Symbol



The following table summarizes the details of this symbol.

Description	Output voltage is the sum of the two input voltages.
Library name	`adder`
Transfer function	$V_{out} = V_{in1} + V_{in2}$
Properties (Defaults)	None
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

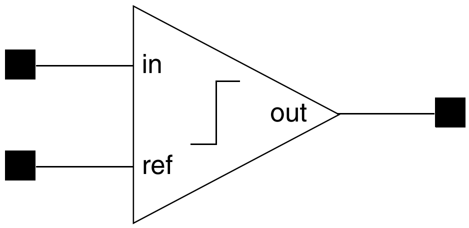
Amplifier Symbol



The following table summarizes the details of this symbol.

Description	■ Output voltage can be an amplified, attenuated, or inverted version of the input.
Library name	`amplifier`
Properties (Defaults)	*gain* (2) Do not express *gain* in decibels. The amplifier is ideal, with no output limiting. ■ if *gain* ≥ 1.0: gives a non-inverting amplifier ■ if 0.0 < *gain* < 1.0: gives an attenuator ■ if *gain* < 0.0: results in an inverting amplifier
Transfer function	$V_{out} = gain \times V_{in}$
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

Comparator Symbol

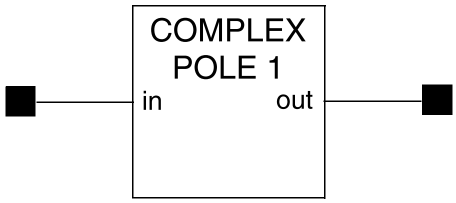


The following table summarizes the details of this symbol.

Description	■ Output voltage rapidly approaches one of two allowed states when the two input voltages are compared. ■ This comparator does not include hysteresis effects. ■ This comparator is not the same device created by the comparator macromodel product.The comparator macromodel product can create a new device each time you use it. The symbol and accompanying models for the comparator macromodel are different from those used within this comparator component of the functional block library.
Library name	`comparator`
Transfer function	$V_{out} = \frac{(V_{OH} - V_{OL})}{2} \times \tanh\left(slope \times (V_{in} - V_{ref})\right) + \frac{(V_{OH} + V_{OL})}{2}$
Properties (Defaults)	$output_{High}$ (10) $output_{Low}$ (-10) *slope* (1000) ■ *slope* determines the slope of the transfer region. The single-sided switching region for V_{out} within approximately 99.5 percent of the limits is V_{in} = 0.003. ■ V_{OH} is the high level of output voltage. ■ V_{OL} is the low level of output voltage.

Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

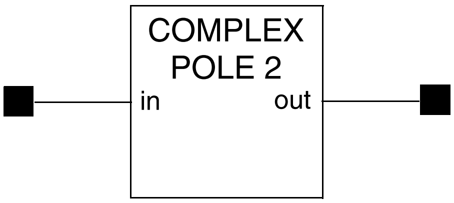
Complex Pole 1 Symbol



The following table summarizes the details of this symbol.

Description	■ Complex-pole transfer function, using σ and ω_n. ■ σ is the (exponential) damping coefficient. ■ ω_n is the damped natural frequency, in radians. ■ For left-hand half-plane poles, enter negative values for σ.
Library name	`complexPole`
Transfer function	$\frac{\sigma^2 + \omega_n^2}{[s - (\sigma - j\omega_n)][s - (\sigma + j\omega_n)]}$
Properties (Defaults)	σ (-5) ω_n (6283.1853)
Input impedance	Infinite
Output impedance	Zero
Frequency response	Function of σ and ω_n.

Complex Pole 2 Symbol

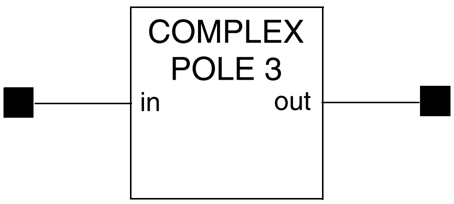


The following table summarizes the details of this symbol.

Description	Complex-pole transfer function, using ς and ω_0.
Library name	`complexPole2`
Transfer function	$\dfrac{\omega_0^2}{s^2 + 2\zeta\omega_0 s + \omega_0^2}$ Where you can calculate ω_0 and ς using $2\pi f_0 = \omega_0\sqrt{1 - \dfrac{1}{2Q_0^2}}$ and $Q_0 = \dfrac{1}{2\zeta}$ ■ Q_0 is the quality factor at resonance. ■ f_0 is the frequency at which l H(j2pf)l is maximum.
Properties (Defaults)	ς (5E-3) ω_0 (6283.1853) ■ ς is the damping coefficient. ■ ω_0 is the undamped natural frequency, in radians.
Input impedance	Infinite
Output impedance	Zero

Frequency response	Function of ς and ω_0

Complex Pole 3 Symbol

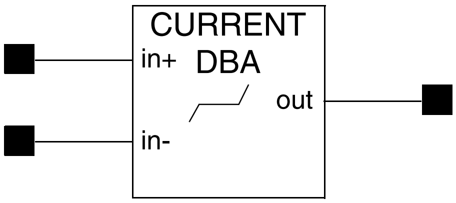


The following table summarizes the details of this symbol.

Description	Complex-pole transfer function, using bandwidth and center frequency.
Library name	`complexPole3`
Transfer function	$\frac{\omega_0^2}{s^2 + 2\zeta\omega_0 + \omega_0^2}$ Where you can calculate ω_0 and ς using $2\pi f_0 = \omega_0\sqrt{1 - \frac{1}{2Q_0^2}}$ and $Q_0 = \frac{1}{2\zeta}$
Properties (Defaults)	Q_0 (50) f_0(1000) *peakGain*(0) ■ Q_0 is the quality factor at resonance. ■ f_0 is the frequency at which */H(j2pf)/*is maximum. ■ *peakGain* is the gain at */ H(j2pf$_0$) /*.
Input impedance	Infinite

Output impedance	Zero
Frequency response	Function of Q_0 and f_0

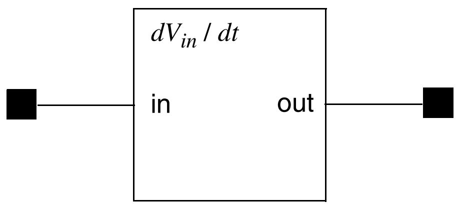
Current Dead-Band Amplifier (currentDba) Symbol



The following table summarizes the details of this symbol.

Description	Current dead-band amplifier, across specified range, with separately controllable gains in the amplifying regions.
Library name	`currentDba`
Transfer function	$I_{out} = I_{ol}$ ■ If $I_{in} \geq I_{inHigh}$: $I_{out} = gain_2 \times (I_{in} - I_{inHigh}) + I_{ol}$ ■ If $I_{in} \leq I_{inlow}$: $I_{out} = gain_1 \times (I_{in} - I_{inlow}) + I_{ol}$ $I_{in} = I_{in+} - I_{in-}$
Properties (Defaults)	I_{inlow} (-1E-3) I_{inHigh} (1E-3) I_{ol} (0) $gain_1$ (1) $gain_2$ (1)
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

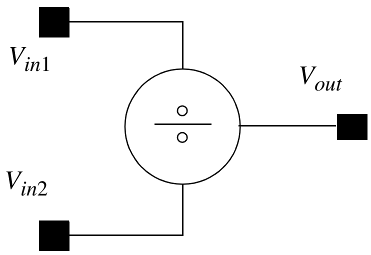
Differentiator Symbol



The following table summarizes the details of this symbol.

Description	Output voltage is the derivative of the input voltage.
Library name	`differentiator`
Transfer function	$V_{out} = \frac{d(V_{in})}{dt}$
Properties (Defaults)	None
Input impedance	Infinite
Output impedance	Zero
Frequency response	Function of frequency.

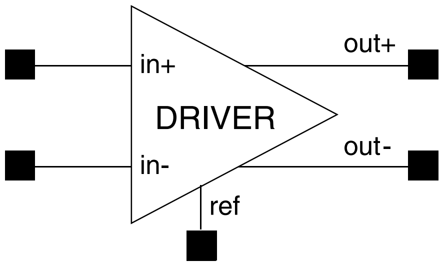
Divider Symbol



The following table summarizes the details of this symbol.

Description	Output is the quotient of the two input voltages. You need to consider the expected output when using this function; the output can become large even for simple inputs.
Library name	`divider`
Transfer function	$V_{out} = \frac{V_{in1}}{V_{in2}}$ If V_{in2} is equal to zero, then V_{in2} is set to 1E-12.
Properties (Defaults)	None
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

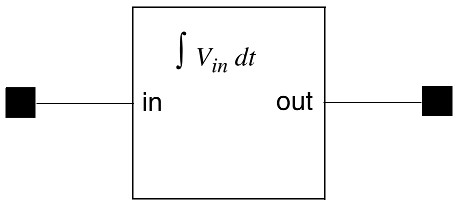
Driver Symbol



The following table summarizes the details of this symbol.

Description	The differential output voltage is gain times that of the differential input. The differential input is fully floating, while the output is center-tapped about V_{ref}.
Library name	`driver`
Transfer function	$V_{out} = \left[V_{in+} - V_{in-}\right] \times gain$
Properties (Defaults)	*gain (1)*
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

Integrator Symbol



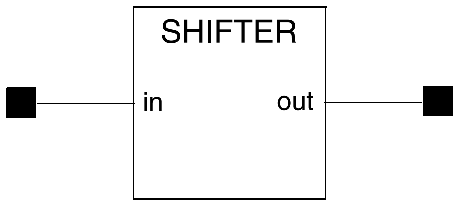
Caution

Be careful when using this function. This function is implemented as a perfect integrator. However, if you use unreasonable (electrical) values, this might cause convergence problems.

The following table summarizes the details of this symbol.

Description	Output voltage is the integral of the input voltage.
Library name	`integrator`
Transfer function	$V_{out} = \int V_{in} \; dt$
Properties (Defaults)	None
Input impedance	Infinite
Output impedance	Zero
Frequency response	Function of frequency.

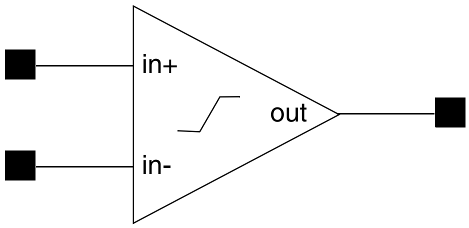
Level Shifter Symbol



The following table summarizes the details of this symbol.

Description	Output is a DC level-shifted version of the input voltage.
Library name	`levelShifter`
Transfer function	$V_{out} = V_{in} + shift$
Properties (Defaults)	shift (1)
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

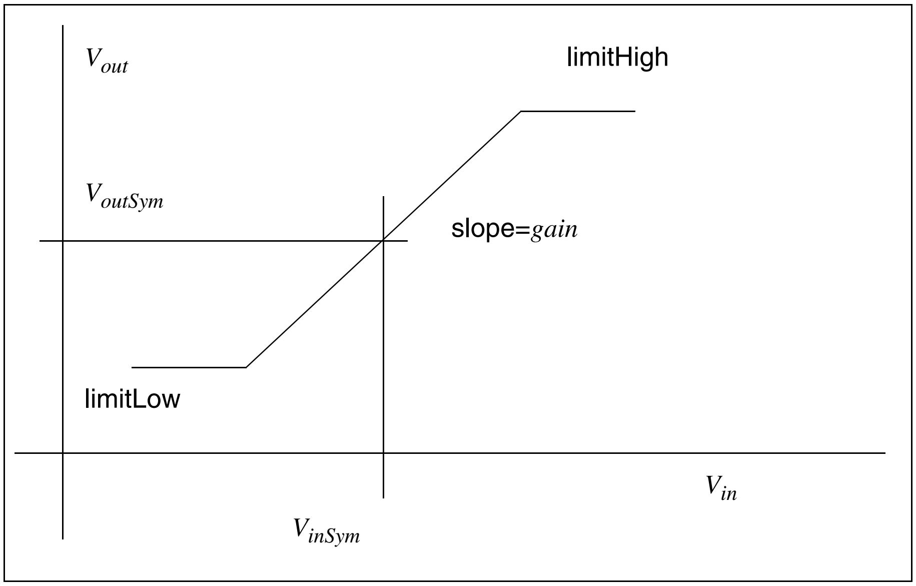
Limiting Amplifier Symbol



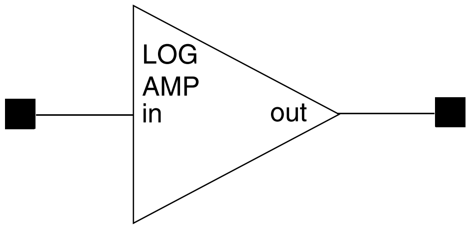
The following table summarizes the details of this symbol.

Description	Hard-limiting voltage amplifier ■ Do not express gain in decibels. ■ V_{inSym} is the input voltage about which the output is symmetrical. ■ $V_{outSym} = (Limit_{High} + Limit_{Low})/2$ ■ V_{in} = $V_{in+} - V_{in-}$
Library name	`limitingAmplifier`
Transfer function	$V_{out} = gain \times (V_{in} - V_{inSym}) + V_{outSym}$ If $V_{Out} > Limit_{High}$ then $V_{Out} = Limit_{High}$ If $V_{Out} > Limit_{Low}$ then $V_{Out} = Limit_{Low}$
Properties (Defaults)	*gain* (1) $Limit_{High}$ (10) $Limit_{Low}$ (-10) V_{inSym} (0)
Input impedance	
Output impedance	Zero
Frequency response	Flat

The following figure shows an example of Limiting Amplifier Symbol.



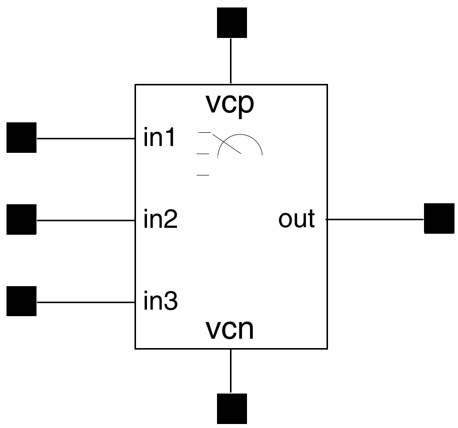
Logarithmic Amplifier Symbol



The following table summarizes the details of this symbol.

Description	■ Output voltage is the natural logarithm of the input voltage. ■ Uses the natural logarithm. ■ The use of $\lvert V_{in} \rvert$ avoids the $log_n(-V)$ problem. ■ If V_{in} is equal to zero, $V_{in} = E\text{-}9$ is used to avoid $log_n(0)$. ■ Because $log_xA = log_nA / log_nX$, obtain $log_xA = log_nA / log_x$ by using a gain block (amplifier) set to $1/log_nX$.
Library name	`logAmp`
Transfer function	$V_{out} = \log n(\lvert V_{in} \rvert)$
Properties (Defaults)	None
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

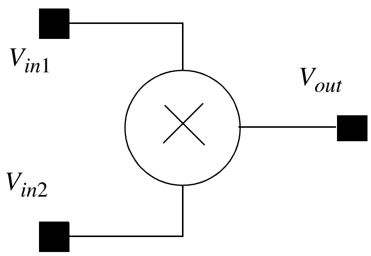
Multiplexer Symbol



The following table summarizes the details of this symbol.

Description	■ 3-to-1 analog selector ■ This multiplexer is a voltage-controlled switch, not a programmable analog selector.
Library name	`multiplexer`
Transfer function	If $V_c < threshold_1$ then $V_{out} = V_{in1}$ If $threshold_1 \leq V_c \leq threshold_2$ then $V_{out} = V_{in2}$ If $V_c > threshold_2$ then $V_{out} = V_{in3}$ $V_c = v_{cp} - v_{cn}$
Properties (Defaults)	$threshold_1$ (-1) $threshold_2$ (1)
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

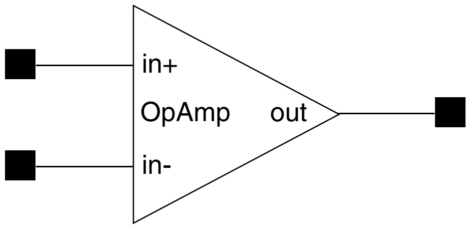
Multiplier Symbol



The following table summarizes the details of this symbol.

Description	Output voltage is the product of the two input voltages.
Library name	`multiplier`
Transfer function	$V_{out} = V_{in1} \times V_{in2}$
Properties (Defaults)	None
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

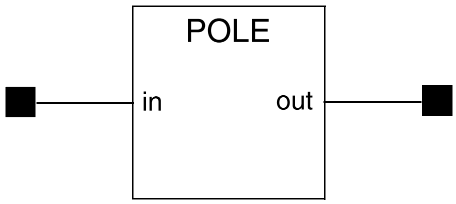
Operational Amplifier (opAmp) Symbol



The following table summarizes the details of this symbol.

Description	■ OpAmp is a high gain open-loop stage, which acts like an ideal operational amplifier; for normal operation, gain control is necessary via feedback components. ■ This block can be used as an ideal operational amplifier to produce summing stages, active filters, gain stages, and integrators. ■ OpAmp is not the same device created by the OpAmp macromodel product. The OpAmp macromodel product can create a new device each time you use it. The symbol and the accompanying models for the OpAmp macromodel are different from those used within this opAmp component.
Library name	`opAmp`
Transfer function	$V_{out} = (V_{in+} - V_{in-}) \times openLoopGain$
Properties (Defaults)	openLoopGain (1E10)
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

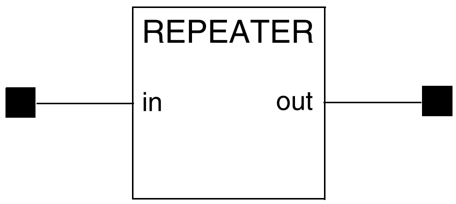
Pole Symbol



The following table summarizes the details of this symbol.

Description	Simple, single-pole transfer function.
Library name	`pole`
Transfer function	$\frac{V_{out}}{V_{in}} = \frac{1}{1 + j\frac{f}{f_c}}$ As a function of s, $\frac{V_{out}}{V_{in}} = \frac{a}{s + a}$ where, $a = 4\pi f_c$
Properties (Defaults)	f_c (1000) f_c is in Hz.
Input impedance	Infinite
Output impedance	Zero
Frequency response	Function of frequency.

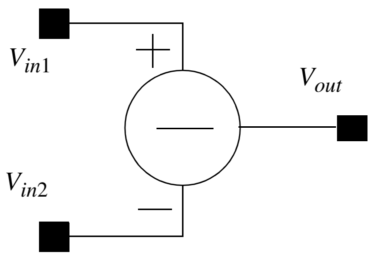
Repeat Waveform Symbol



The following table summarizes the details of this symbol.

Description	■ Output repeats the input signal with a specified periodicity. ■ This function takes a finite-duration aperiodic input signal and creates a periodic signal, with periodicity equal to period. Period must be greater than the input signal duration to avoid distortion. This function uses the SPICE transmission line element internally.
Library name	`repeatWaveform`
Transfer function	$V_{out}(t) = V_{in}\left(t - (n \times period)\right)$
Properties (Defaults)	period (1E-3)
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

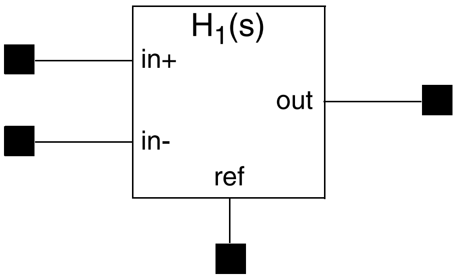
Subtractor Symbol



The following table summarizes the details of this symbol.

Description	Output voltage is the difference between the two inputs.
Library name	`subtractor`
Transfer function	$V_{out} = V_{in1} - V_{in2}$
Properties (Defaults)	None
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

Transfer Function 1 Symbol



The following table summarizes the details of this symbol.

Description	■ Complex transfer function, with up to `three` each of simple poles, simple zeroes, complex poles, and complex zeroes. ■ Higher order poles and zeroes are supported. ■ For example, enter zero frequency and zero sigma to specify second-order poles at the origin. ■ Enter zero frequency to specify single simple poles and zeroes at the origin. ■ For more complex transfer functions, cascade similar blocks or cascade with the pole, zero, complex pole, differentiator, and integrator blocks. ■ Always use the earlier numbered singularities first. For example, if the number of poles is set to 1, then only pole 1 has effect. The cases of zeroes and complex pairs are similar.
Library name	`transferFunction1`

Transfer function	$$\frac{V_{out}}{V_{in}} = dcGain\,\frac{\Pi\left(1+\frac{jf}{f_{zi}}\right)\times\Pi\left[(\sigma_{czj}^2+4\pi^2 f_{czj}^2-4\pi^2 f^2)-j(2\sigma_{czj})\right]}{\Pi\left(1+\frac{jf}{f_{pk}}\right)\times\Pi\left[(\sigma_{cpl}^2+4\pi^2 f_{cpl}^2-4\pi^2 f^2)-j(2\sigma_{cpl})\right]}$$ Where f_{zi} is the freqZero$_i$ f_{czi} is the freqConjZero$_j$ σ_{czj} is the sigmaConjZero$_j$ f_{pk} is the freqPole$_k$ f_{cpl} is the freqConjPole$_l$ σ_{cpl} is the sigmaConjPole$_l$	
Properties (Defaults)	dc_{Gain} (1)	dc and low frequency gain.
	$input_R$ (1G ohm)	input resistance.
	$input_C$ (0)	shunt input capacitance.
	$output_R$ (0.001 ohm)	series output resistance.
	$output_C$ (0)	output capacitance, parallel with $output_R$.
	nPoles (0)	number of real-valued poles. (maximum 3)
	nZeroes (0)	number of real-valued zeroes. (maximum 3)
	nConjPoles (0)	number of complex-conjugate poles. (maximum 3)
	nConjZeroes (0)	number of complex-conjugate zeroes. (maximum 3)
	$freq_{Pole1}$ (1000)	break frequency of $pole_1$.
	$freq_{Pole2}$ (2000)	break frequency of $pole_2$.
	$freq_{Pole3}$ (3000)	break frequency of $pole_3$.

	$freq_{Zero1}$ (1000)	break frequency of $zero_1$.
	$freq_{Zero2}$ (2000)	break frequency of $zero_2$.
	$freq_{Zero3}$ (3000)	break frequency of $zero_3$.
	$freq_{ConjPole1}$ (1000)	damped natural frequency of complex $pole_1$.
	$sigma_{ConjPole1}$(-5)	damping (exponential) term for complex $pole_1$.
	$freq_{ConjPole2}$ (2000)	damped natural frequency of complex $pole_2$.
	$sigma_{ConjPole2}$(-5)	damping (exponential) term for complex $pole_2$.
	$freq_{ConjPole3}$ (3000)	damped natural frequency of complex $pole_3$.
	$sigma_{ConjPole3}$(-5)	damping (exponential) term for complex $pole_3$.
	$freq_{ConjZero1}$ (1000)	damped natural frequency of complex $zero_1$.
	$sigma_{ConjZero1}$(-5)	damping (exponential) term for complex $zero_1$.
	$freq_{ConjZero2}$ (2000)	damped natural frequency of complex $zero_2$.
	$sigma_{ConjZero2}$(-5)	damping (exponential) term for complex $zero_2$.
	$freq_{ConjZero3}$ (3000)	damped natural frequency of complex $zero_3$.
	$sigma_{ConjZero3}$(-5)	damping (exponential) term for complex $zero_3$.
Input impedance	Infinite	
Output impedance	Zero	
Frequency response	Function of the input properties.	

Example

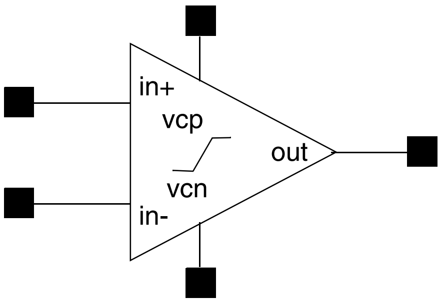
To specify a transfer function with:

- A single zero at f = 1000 Hz.
- A second-order pole at the origin.
- A complex pole at f = 3000 Hz, with sigma = -1.0.
- A dc gain of 10.

then,

```
dcGain = 10
nZeroes = 1
nConjPoles = 2
freqZero1 = 1000
freqConjPole1 = 0.0
sigmaConjPole1 = 0.0
freqConjPole2 = 3000
sigmaConjPole2 = -1.0
```

Voltage-Controlled Variable-Gain Amplifier

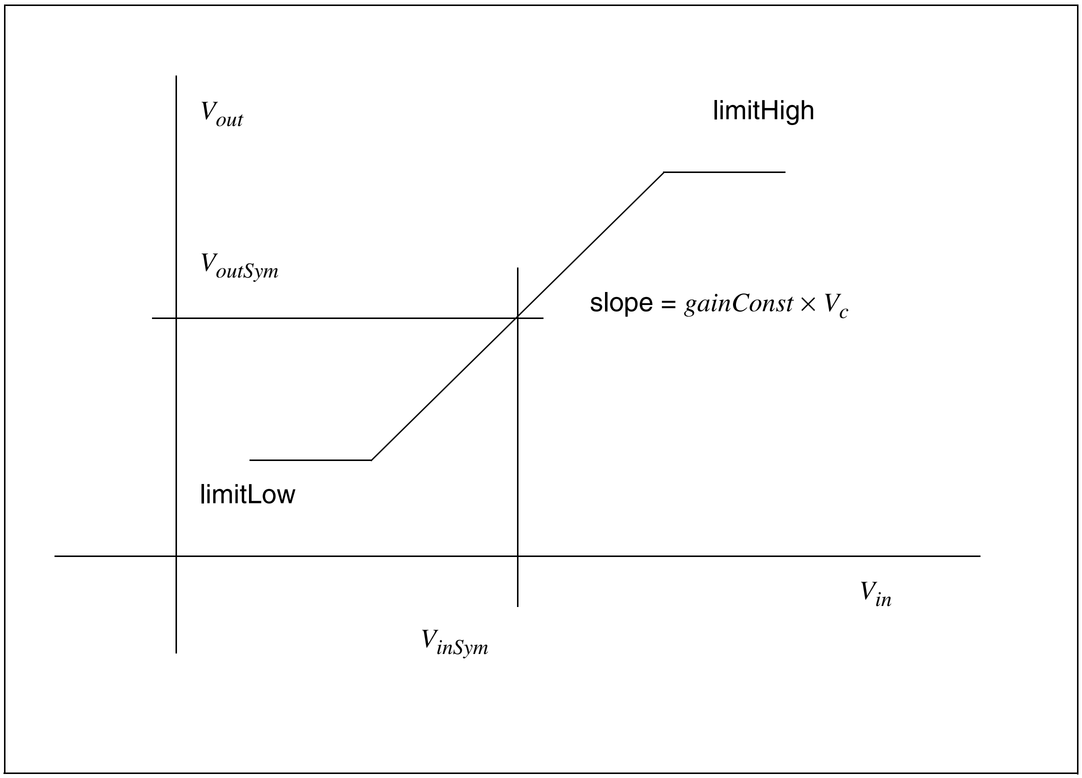


The following table summarizes the details of this symbol.

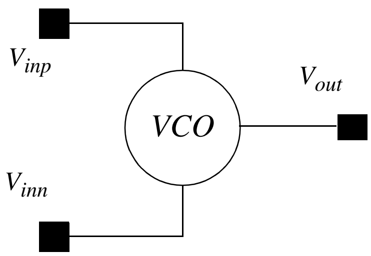
Description	The gain of this limiting voltage amplifier is a `function` of the voltage $(v_{cp}\text{-}v_{cn})$. ■ V_{inSym} is the input voltage about which the output is symmetrical. ■ $V_{outSym} = (limit_{High} + limit_{Low})/2$ ■ V_c is the control voltage, $(v_{cp}\text{-}v_{cn})$ ■ $V_{in} = V_{in+} - V_{in-}$
Library name	`variableGainAmplifier`
Properties (Defaults)	$gain_{Const}$ (1) $limit_{High}$ (10) $limit_{Low}$ (-10) V_{inSym} (0)
Transfer function	$V_{out} = gainConst \times V_c(V_{in} - V_{inSym}) + V_{outSym}$ If $V_{out} > limit_{High}$ then $V_{out} = limit_{High}$ If $V_{out} < limit_{Low}$ then $V_{out} = limit_{Low}$
Input impedance	
Output impedance	Zero

Frequency response	Flat

The following figure shows an example of Variable Gain Amplifier Operation.



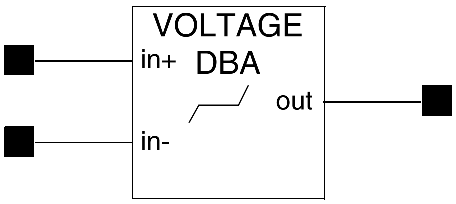
Voltage-Controlled Oscillator (VCO) Symbol



The following table summarizes the details of this symbol.

Description	Voltage-controlled oscillator VCO_{gain} is the *Hz/Volt* proportionality variable, often called *VCO* sensitivity.
Library name	`vco`
Transfer function	$V_{out} = amplitude \times \sin 2\pi(centerFreq)\left[VCOgain \times (V_{inp} - V_{inn}) \times t\right]$
Properties (Defaults)	*amplitude* (1) *centerFreq* (1000) VCO_{gain} (1000)
Input impedance	Infinite
Output impedance	Zero
Frequency response	Function of applied properties

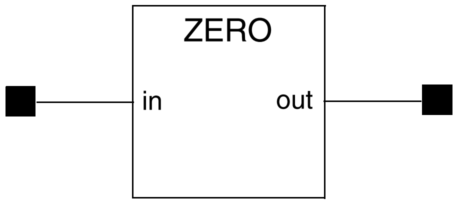
Voltage Dead-Band Amplifier (VoltageDba) Symbol



The following table summarizes the details of this symbol.

Description	Voltage dead-band amplifier, across a specified range, with separately controllable gains in the amplifying regions.
Library name	`voltageDba`
Transfer function	$V_{out} = V_{OL}$ If $V_{in} \geq V_{inHigh}$ then $V_{out} = gain_2 \times (V_{in} - V_{inHigh}) + V_{OL}$ If $V_{in} \leq V_{inLow}$ then $V_{out} = gain_1 \times (V_{in} - V_{inLow}) + V_{OL}$ $V_{in} = V_{in+} - V_{in-}$
Properties (Defaults)	V_{inLow} (-10) V_{inHigh}(10) V_{OL}(0) $gain_1$(1) $gain_2$ (1)
Input impedance	Infinite
Output impedance	Zero
Frequency response	Flat

Zero Symbol



The following table summarizes the details of this symbol.

Description	Single-zero transfer function.
Library name	`zero`
Transfer function	$\frac{V_{out}}{V_{in}} = 1 + \frac{jf}{f_c}$ As a function of s, $\frac{V_{out}}{V_{in}} = b\left(s + \frac{1}{b}\right)$ where, $b = \frac{1}{2\pi f_c}$
Properties (Defaults)	f_c (1000) f_c is in Hz.
Input impedance	Infinite
Output impedance	Zero
Frequency response	$F(j\omega)$

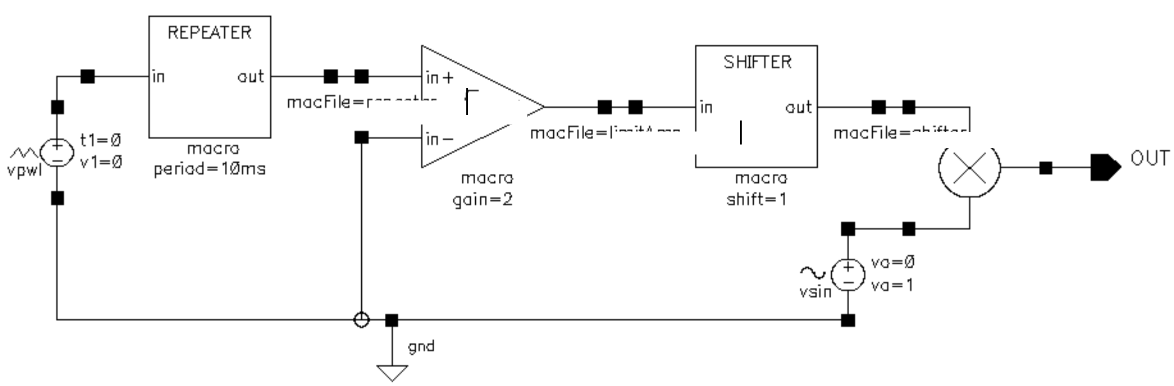
Functional Block Library Examples

Functional blocks contain the essential functionality of the parts they represent. One important application of these blocks is the creation and simulation of high-level systems. The components in the library are used as primitives to create more complex blocks. For example, you can arrange the system shown in Double-Sideband Amplitude Modulation (DSB-AM) to appear as a single symbol for use in a communication system design.

Double-Sideband Amplitude Modulation (DSB-AM) Example and illustrate the use of the functional blocks and also demonstrate that you do not have to use the blocks in isolation. Regular circuit components and components from any other installed library can be placed on a schematic and simulated.

Double-Sideband Amplitude Modulation (DSB-AM) Example

Consider a sample system of the DSB-AM schematic as shown in the following figure.



This sample system shows how the process of double-sideband amplitude modulation `(DSB-AM)` can be performed using functional blocks.

The piecewise linear voltage source generates one cycle of a triangular wave, as shown on waveform *c*.

The repeater block takes as its input the one cycle triangular wave and repeats it, with a period of `10 ms`. The output from the repeater is the periodic triangular waveform shown in waveform *b*.

This signal is the baseband signal, $V_s(t)$, which modulates the carrier. The depth of modulation required is 100 percent, so it is necessary for the carrier amplitude and the effective baseband amplitude to be equal.

Here, the carrier is set to 1 volt at 1000 Hz. As the modulation process is performed by the multiplier block (product or balanced modulation), the amplitude of the baseband signal is raised from 0.5 volts at the output of the repeater, to 1 volt. To achieve DSB-AM, the baseband signal must also be level-shifted by an amount equal to the carrier amplitude.

Mathematically,

$$V_{mod}(t) = \left(V_c + V_s(t)\right) \times \sin(2\pi f_c t)$$

Here,

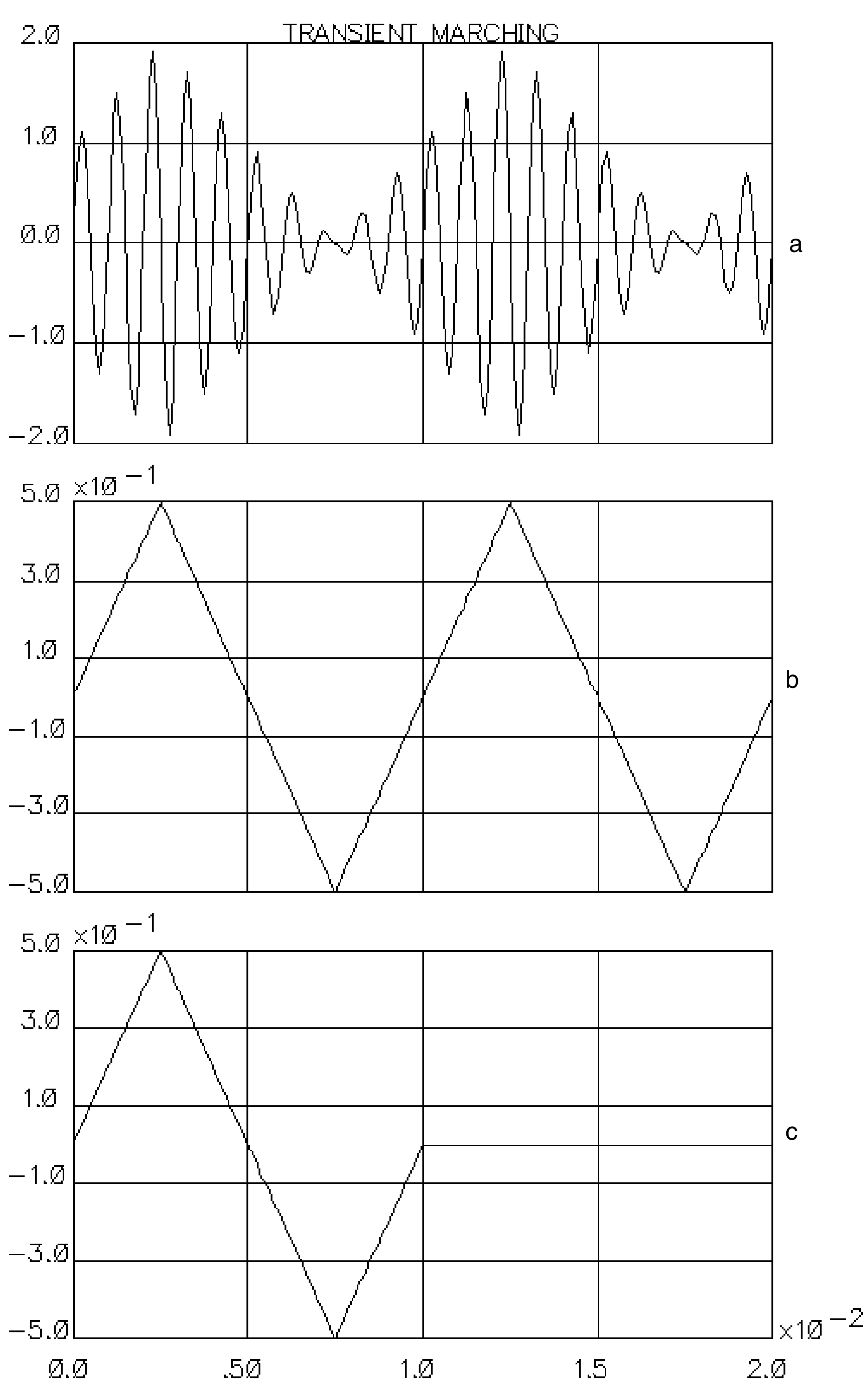
V_c = carrier amplitude

f_c = carrier frequency

$V_s(t)$ = modulating symbol

To achieve this, set the gain of the amplifier block to 2 and the amount of shift to 1 volt. The modulated result is shown in waveform *a*.

The waveforms for this example are shown in the following figure:

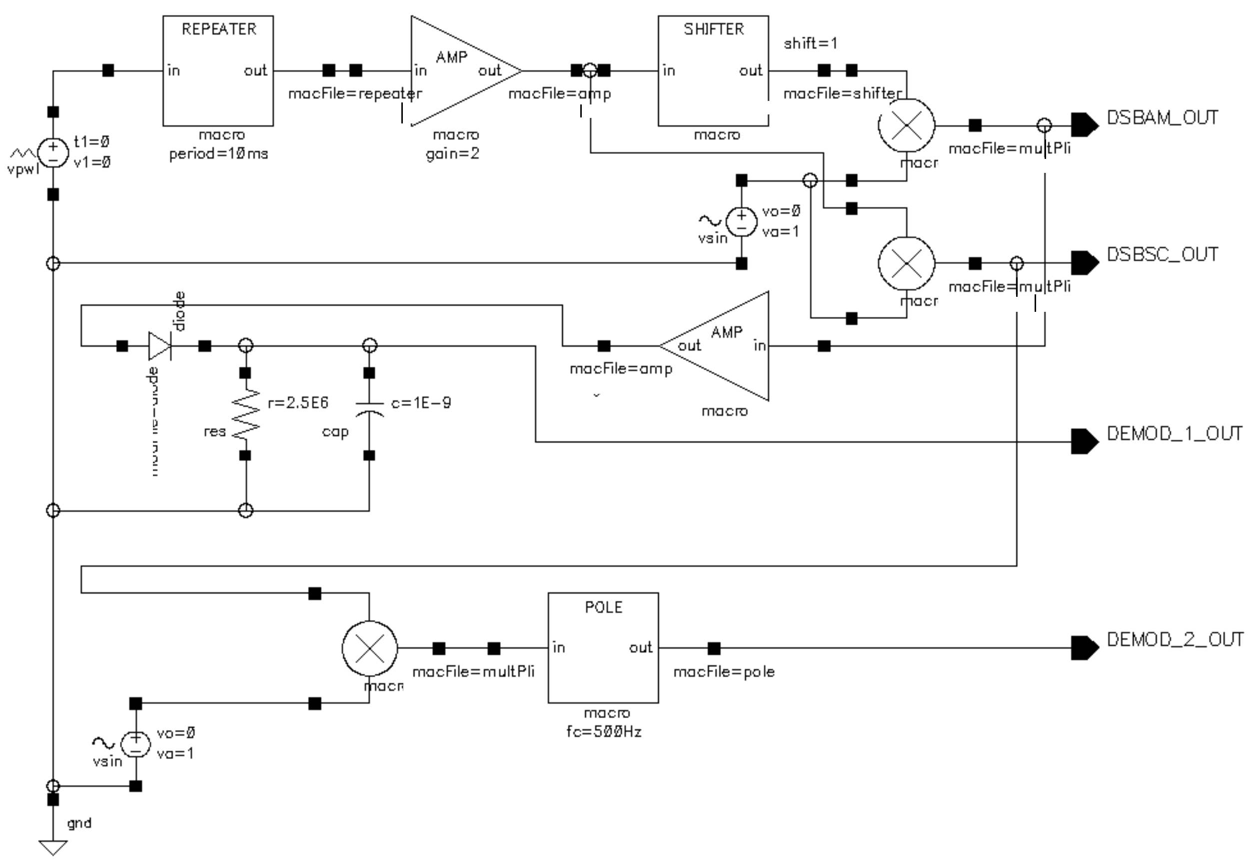

TRANSIENT MARCHING
2.Ø
1.Ø
Ø.Ø
−1.Ø
−2.Ø
a
5.Ø ×1Ø −1
3.Ø
1.Ø
−1.Ø
−3.Ø
−5.Ø
b
5.Ø ×1Ø −1
3.Ø
1.Ø
−1.Ø
−3.Ø
−5.Ø
c
×1Ø −2
Ø.Ø
.5Ø
1.Ø
1.5
2.Ø

Here,

- Waveform `a` is the modulated result of the DSB-AM modulation.
- Waveform `b` is the periodic triangular waveform that the repeater block generates as output.
- Waveform `c` is one cycle of a triangular wave that the linear voltage source generates.

Double Sideband Suppressed Carrier Transmission (DSB-SC) Example

This example uses the circuitry already described in the following figure.

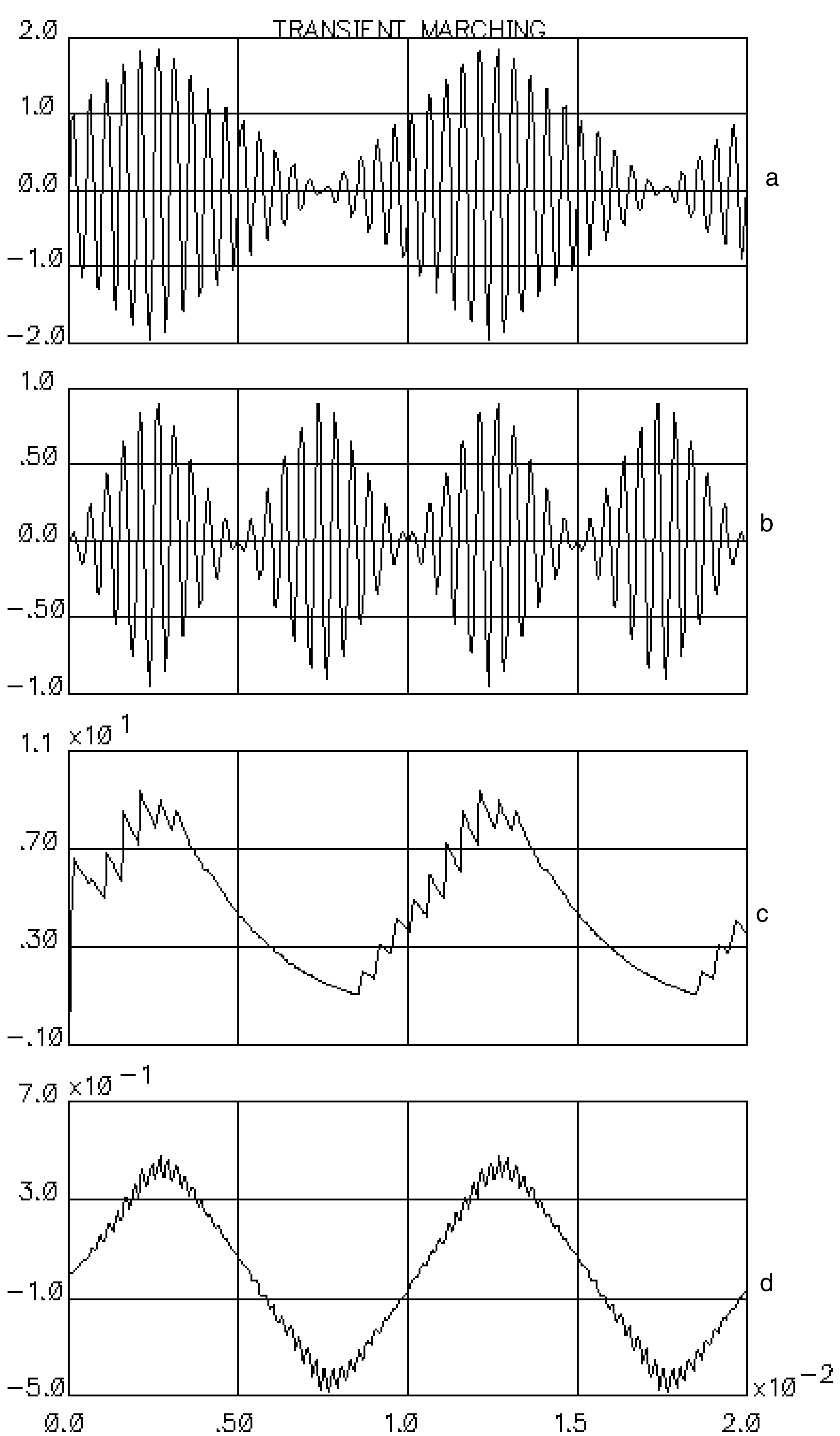


The circuitry in this example has the following additional features that enable DSB-SC modulation:

- An additional multiplier stage
- Two demodulator sections
    - Demodulator 1 is a simple noncoherent diode detector (envelope detector)
    - Demodulator 2 is a fully coherent decoder (remodulator), with low-pass filtering on its output

The frequency of the carrier reinsertion oscillator is set to 2000 Hz, which is the frequency of the carrier signal used in this example. Further, the cutoff (3 dB) frequency of the single pole (low-pass) filter at the output of the remodulator was set to 500 Hz. This allows up to the fifth harmonic of the detected triangular wave to be passed to the output.

The waveforms for this example are shown in the following figure.


TRANSIENT MARCHING
2.Ø
1.Ø
Ø.Ø
−1.Ø
−2.Ø
a
1.Ø
.5Ø
Ø.Ø
−.5Ø
−1.Ø
b
1.1 x1Ø 1
.7Ø
.3Ø
−.1Ø
c
7.Ø x1Ø −1
3.Ø
−1.Ø
−5.Ø
d
x1Ø −2
Ø.Ø
.5Ø
1.Ø
1.5
2.Ø

Related Topics

Double-Sideband Amplitude Modulation (DSB-AM) Example

Double Sideband Suppressed Carrier Transmission (DSB-SC) Example

A

Comparator Macromodel

The comparator macromodel is a parameterized macromodel in the analog circuit design environment. This macromodel uses a simplified equivalent circuit to emulate the DC, AC, and transient nature of a real comparator’s electrical performance.

A macromodel is advantageous because it reduces computation time and space, but it still retains accuracy. The comparator model shown in this topic is a modified model of the Harris level_0 comparator macromodel, which has a simple RC circuit with the clamping stage. This macromodel represents the performance of both the IC comparator and an ideal comparator as accurately as possible.

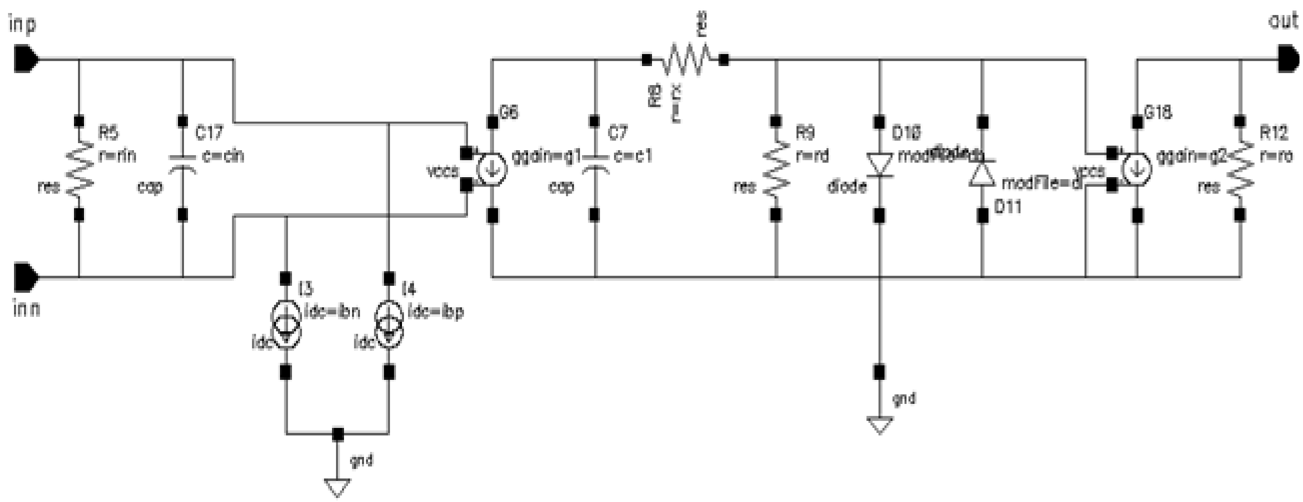
Note: The use of the comparator macromodel does not create the same device as that denoted earlier in Introduction to Functional Library. For details about the comparator component, see Comparator Symbol.

The comparator macromodel simulates the following effects:

- Input bias current
- Input offset current
- Input offset voltage
- Input resistance
- Input capacitance
- Open loop gain
- Small-signal delay time
- Small-signal rising and falling time
- Overdrive voltage for small-signal transient response test
- Output voltage swing
- Output resistance

Circuit Design

The following figure is a schematic of the comparator macromodel circuit:



Functional Description

There are three stages in the comparator macromodel:

- Input stage
- Gain and delay stage
- Output stage

Input Stage

The input stage is built with four components:

- R_{in} = input resistance
- C_{in} = input capacitance
- I_{bp} = bias current
- I_{bn} = bias current

The input stage of the comparator macromodel uses a rough linear approximation. The four components model the input current versus voltage variation around the active region. However, the input stage does not model the saturation and cutoff effects of the input currents and terminal resistances.

Gain and Delay Stage

The gain and delay stage is constructed with a voltage-controlled current source and a single RC time constant circuit.

G_1, C_1, C_x, and R_d create a single pole roll-off amplifier circuit. R_x, R_d, and G_1 model small signal gain.

The clamping voltages of the two diodes `Dh` and `Dl` are set to the value of the positive and negative output voltage swing. These diodes are built to be referenced directly to ground. If the negative output voltage swing V_{OL} is defined as `zero` like the default value, an independent voltage source of value $V_{OH}/2$ is inserted between the diodes and ground. This allows the output voltages to have symmetric limiting characteristics.

Output Stage

G_2 and R_O build the output stage, which forms a gain of one buffer. G_2 is put there to isolate the gain stage and the outside load to reduce the unwanted influence of the load to the modeling of delay time.

Comparator Macromodel Netlist

The following shows a netlist of the comparator macromodel:

```
# comparator 0.s
# Description:  Small signal model of input stage, no
#               Io limits or power supply effects, simple
#               resistive input stage, small large signal
#               delay, constant Rout and no current limit
#
# Format:
#
# USE  comparator name ibias vos ios rin cin voh vol vis trs tds gol ro
#     &1 &2 &3 &4 &5 &6 &7 &8 &9 &10 &11 &12 &13
#
# Default values of the parameters:
#
# &1   model name                                 name = &1
# &2   Input bias current                         ibias = 200n
# &3   Input offset voltage                       vos = 0
# &4   Input offset current                       ios = 10n
# &5   Input resistance                           rin = 1meg
# &6   Input capacitance                          cin = 1p
# &7   Positive output voltage swing              voh = 5
# &8   Negative output voltage swing              vol = 0
# &9   Overdrive voltage for delay time test      vis = 2m
# &10  Small signal rising and falling time test  trs = 20n
# &11  Small signal delay time                    tds = 50n
# &12  Open loop game                             gol = 100k
# &13  Output resistance                          ro = 200
#
```

```
.subckt &1 10 20 30
#
# Input stage
#
RIN   10  20   (&5)
CIN   10  20   (&6)
IBP   10  0    (&2) +(&4)/2
IBN   20  0    (&2) -(&4)/2
#
# Gain Stage
#
G1  0   2   poly    1  10  20 =-(&3)*(&12)  1E5=(&12)/1E5
C1  2   0   ((&11-&10/2)/log(2))/(1E5/&
              (&12*(&9)*(&10)/(&7-(&8))/((&11-&10/2)/log(2))-1))
RX  2   3   1E5/(&12*(&9)*&10/(&7-(&8))/((&11-&10/2)/log(2))-1)
#
If &7*(&8)<>0 then
  RD   3 0   1E5
  DH   3 0   DH
  DL   0 3   DL
 .MODEL DH D  IS = 0.3*(&12)/1E33  N = &7/VT/LOG(1E28)
 .MODEL DL D  IS = 0.3*(&12)/1E33  N = -(&8)/VT/LOG(1E28)
else
  RD   3 8    1E5
  DH   3 8    DM
  DL   8 3    DM
  VM   8 0    (&7+(&8))/2
 .MODEL DM D  IS=0.3*(&12)/1E33  N=(&7+&(&8))/2/VT/LOG(1E28)
endif
#
#   Output Stage
#
RO  0 30   (&13)
G2  0 30   poly 1 3 0  0 =1/(&13+0.1)
.ends &1
```

Example

Uses of the Comparator Macromodel

You can use the comparator macromodel by doing the following:

- Defining the common specification sheet values, available in most semiconductor product catalogs.
- Placing the comparator macromodel symbol in your schematic.
- Defining the CDF parameter values and by using default values for parameters that you do not set.

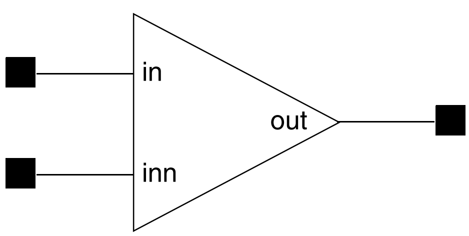
Electrical effects are modeled accurately by this macromodel. However, such a simple circuit might not work as a comprehensive model. The comparator macromodel cannot do the following:

- Model specifications that are not defined as macromodel parameters
- Model high frequency response

  The behavior of the comparator at a frequency higher than $1/(4 \times t\ ds)$ is not expected to match the circuit measurements. The capacitor of the single time constant circuit is not fully charged. The delay time might not be realistic.
- Vary delay time according to the input overdrive voltage
- Model hysteresis effects.

Setup of the Comparator Macromodel into a design

The following figure shows a comparator macromodel symbol.



For proper operation of the macromodel, you need to connect the following three I/O pins:

`IN`	Positive input terminal
`INN`	Negative input terminal
`OUT`	Output terminal

Comparator Macromodel Parameters

There are 12 parameters you can use to describe the behavior of the comparator macromodel.

Property	Typical Value	Description
`ibias`	`200n`	Input bias current

Property	Typical Value	Description
`vos`	`0`	Input offset voltage
`ios`	`10n`	Input offset current
`rin`	`1meg`	Input resistance
`cin`	`1p`	Input capacitance
`voh`	`5`	Positive output voltage swing
`vol`	`0`	Negative output voltage swing
`vis`	`2m`	Overdrive voltage for small-signal transient response test
`trs`	`20n`	Small-signal rising and falling time
`tds`	`50n`	Small-signal delay time
`gol`	`100k`	Open loop gain
`ro`	`200`	Output resistance

Related Topics

Introduction to Functional Block Library

Comparator Symbol

B

OpAmp Macromodel

The OpAmp macromodel uses a simplified equivalent circuit to emulate the DC, AC, and transient nature of real amplifier electrical performance.

The electrical performance is defined by common data sheet performance factors or parameters (such as offset voltage and slew rate) as properties on the macromodel symbol. You use these parameters as arguments in complex algebraic expressions defining the elemental values of the components making up the macromodel.

Note: The use of the OpAmp macromodel does not create the same device as that denoted earlier in Operational Amplifier (OpAmp) Symbol.

The OpAmp macromodel simulates the following effects:

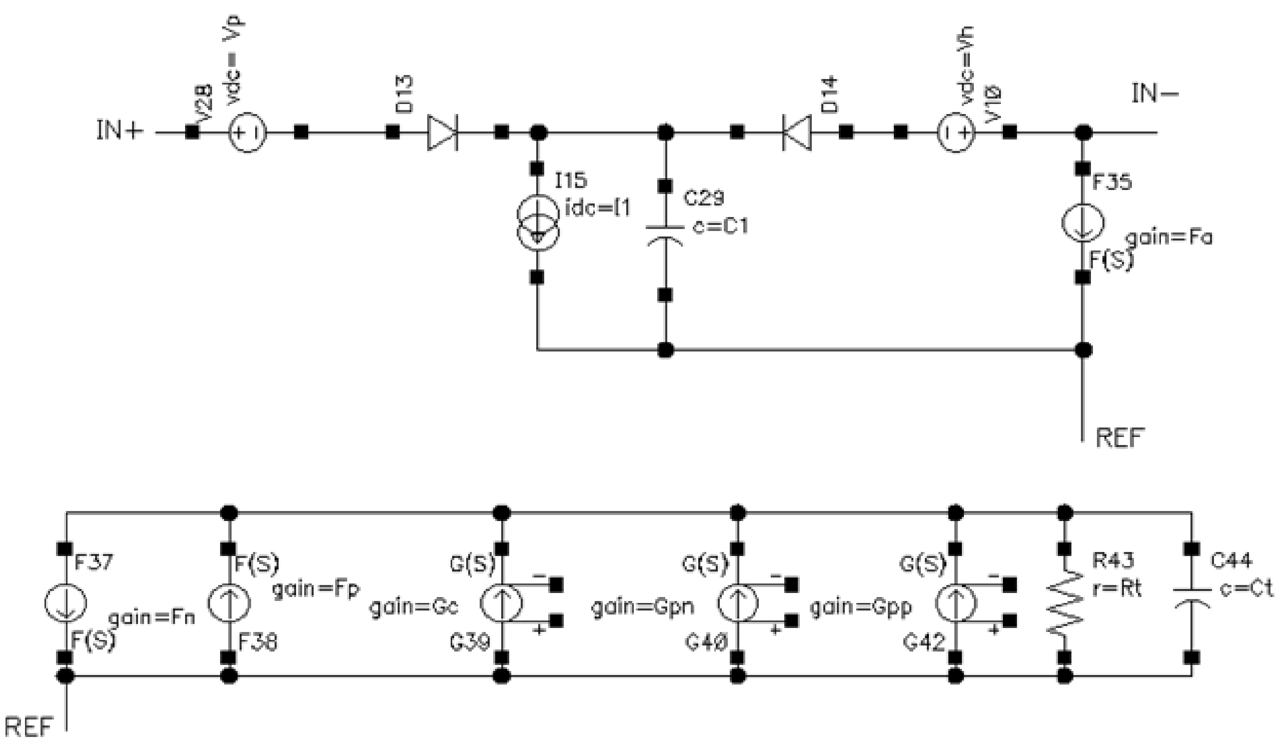
- Input bias current
- Input offset current
- Input offset voltage
- Input capacitance
- Positive and negative slew rate
- Positive feedthrough
- Open loop gain
- Common mode rejection ratio
- Gain bandwidth product
- Second pole frequency
- Saturation delay time
- High frequency output impedance
- AC output resistance
- DC output resistance

- Positive and negative output swing
- Positive and negative output current limit
- Positive and negative power supply rejection ratio
- Positive and negative power supply current

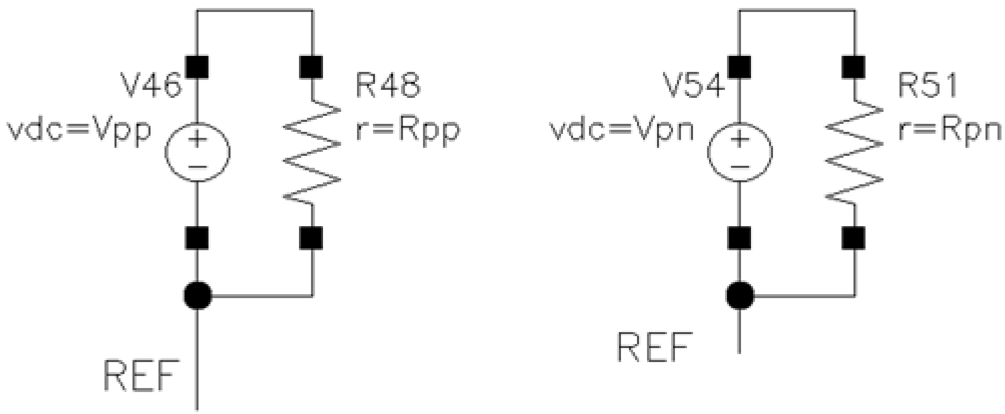
Equivalent Circuit

The following figures show the three stages in a schematic of the OpAmp macromodel circuit:

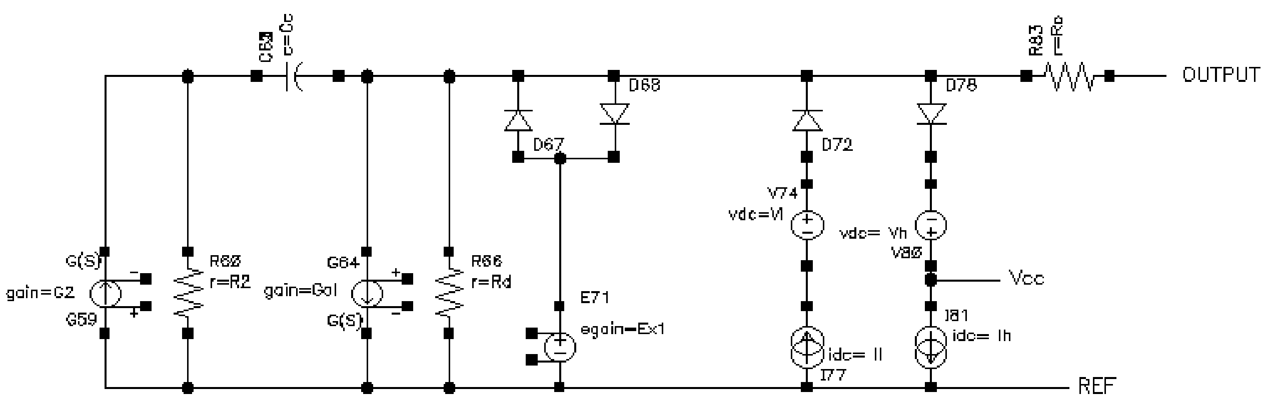
Input Stage



Supply Voltages

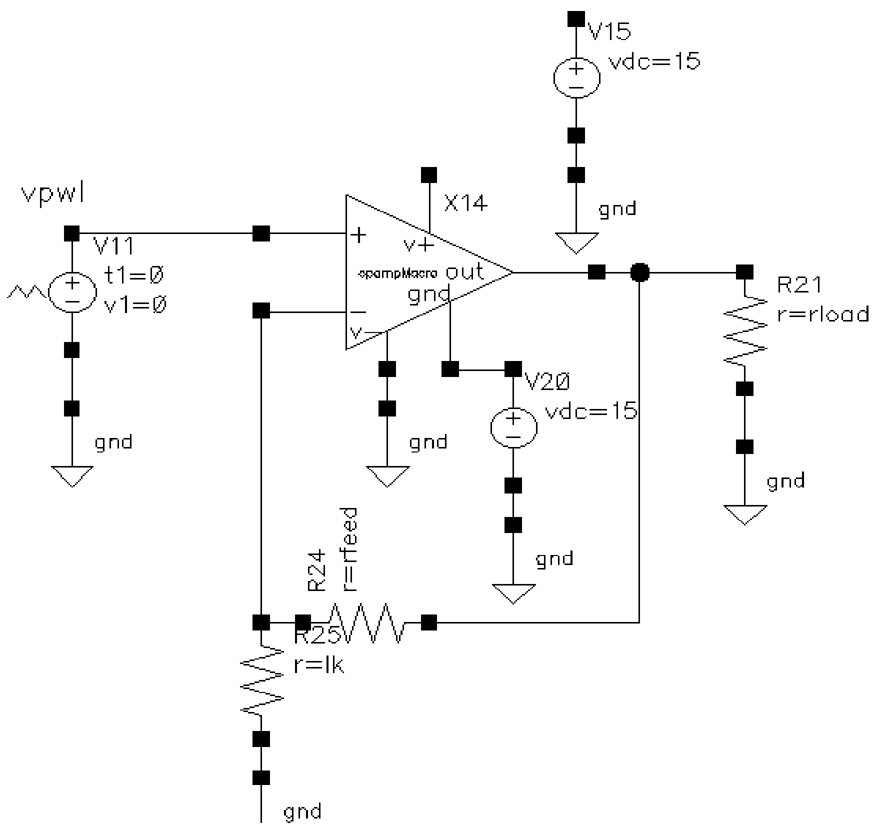


Output Stage



Example

Below is a schematic of a simple noninverting amplifier with closed-loop `DC gain = rfeed/(rfeed + 1K).`



The macromodel property list values are the typical values listed in OpAmp Macromodel Parameters.

Uses of the OpAmp Macromodel

You can use the OpAmp macromodel by doing the following:

- Defining the common specification sheet values, available in most semiconductor product catalogs
- Placing the OpAmp symbol in your schematic
- Defining the CDF parameter values and by using default values for parameters that you do not set

The OpAmp macromodel might not work as a comprehensive model. Its limitations are described here:

- Macromodel accuracy

  The OpAmp macromodel is less accurate and comprehensive than the transistor level representation, and even less accurate than the circuit measurements.

- Model scope

  Specifications not defined as macromodel parameters are not modeled, including common-mode input range, noise, transient power dissipation, and output impedance.

- Temperature

  Temperature effects are not implicitly included, but can be explicitly defined as an algebraic or table function. For example:

  ```
  offset voltage = 1m + 0.01 m * (tempdc - 25)
  ```

  OR

  ```
  offset voltage = TABLE(tempdc,-75,0,25,1m,125,2m)
  ```

- Parameter independence

  To a first order of accuracy, you can set the macromodel parameters independently, ignoring interactions.

- Small input bias currents

  When using small input bias currents `(~1E-12)`, decrease the simulation control variable `GMIN` (minimum conductance) to `~1E-15` (default is `1.0E-12`). This helps to prevent relatively large leakage currents and corresponding accuracy loss.

- Unrealistic conditions

  The macromodel is particularly good for modeling the OpAmp components. Avoid the following unrealistic parameter values or extreme conditions:

- ❑ Offset voltages less than `10 mvolts` vary due to numerical errors
- ❑ The following quantities affect the accuracy of the slew rate of the macromodel in small but measurable ways:
  - ❍ Gain-bandwidth product (GBW)
  - ❍ Large-signal saturation delay (TSD)
  - ❍ Second pole frequency (FF2)

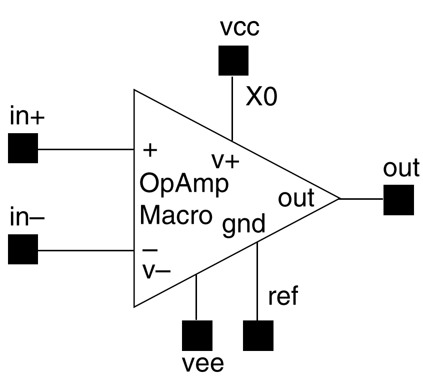
  This effect can be significant for the following examples of extreme cases:
  - ❍ TSD<<(1/GBW)
  - ❍ FF2<<GBW

  In these situations, measure the simulated macromodel response and adjust the parameters accordingly.

- ■ Additional parameter requirements
  - ❑ The slew rates must conform to the inequality `0.1` ≤ `srn/srp` ≤ `10`
  - ❑ The output DC and AC resistances must conform to the inequality `rod` > `roa` > `0`

Setup of the OpAmp Macromodel into a Design

The following figure shows an OpAmp macromodel symbol:



For proper operation of the macromodel, you need to connect the following six `I/O` pins:

`IN+`	Positive differential input pin
`IN-`	Negative differential input pin
`OUT`	OpAmp output pin
`VCC`	Positive power supply pin
`VEE`	Negative power supply pin
`REF`	Reference voltage (typically ground)

OpAmp Macromodel Parameters

There are 23 parameters you can use to describe the DC, AC, and transient behavior of the OpAmp in the macromodel.

Property	Typical Value	Description
`ccc`	`30 p farads`	Internal compensation capacitor
`ibs`	`100 n amps`	Input bias current
`ios`	`10 n amps`	Input offset current
`vos`	`1 m+.01 m* (tempdc-25) volts`	Input offset voltage
`srp`	`10 me volts/second`	Positive slew rate
`srn`	`10 me volts/second`	Negative slew rate
`ftp`	`0.1`	Positive feedthrough
`gol`	`100 k volts/volt`	Open loop gain
`cmr`	`90 db`	Common mode rejection ratio
`gbw`	`10 MHz`	Gain-bandwidth product
`ff2`	`20 MHz`	Second pole frequency
`tsd`	`500 n seconds`	Overdrive storage delay
`roa`	`20 ohms`	AC output resistance
`rod`	`30 ohms`	DC output resistance
`vsn`	`-14 volts`	Negative output swing limit

Property	Typical Value	Description
vsp	14 volts	Positive output swing limit
ion	50 m amps	Negative output current limit
iop	50 m amps	Positive output current limit
prn	90 db	Negative power supply rejection ratio
prp	90 db	Positive power supply rejection ratio
iee	5 m amps	Negative power supply current
icc	5 m amps	Positive power supply current
vnm	15 volts	Nominal power supply

You define these parameters in the cell CDF description.

The property value can be a

- Number
- Variable
- Valid expression (with variables)

For example, to define the offset voltage as a simple linear function of temperature, enter the following expression as the value of the offset voltage property:

```
vos = 1m + 0.01m * (TEMPDC - 25)
```

Procurement of OpAmp Macromodel

You can obtain model parameters in several ways, depending on your application.

- IC vendor catalog

  Obtain most of the parameters from the specific amplifier catalog data sheet

- Schematics

  Simulate and measure the performance parameters you want using the OpAmp transistor schematic and associated SPICE device models

- Component

  Make the measurements in the lab using the OpAmp component

You can use the default values or set some reasonable values for the remaining parameters. For example, you might set parameters to some typical values (or use the defaults) when exploring your system design space before selecting a particular amplifier, then modify the values later.

OpAmp System Size

A primary reason for using macromodels in large systems is for faster simulations. These simulations are faster when compared to transistor-level simulations. These simulations are about `10` to `50` times faster for complex OpAmps containing between `30` and `100` devices. Storage requirements are also reduced using macromodels.

The fast simulation time and reduced storage requirement of smaller amplifiers (fewer than `10` devices) might not compensate for the loss of accuracy from using macromodels. However, macromodels are still useful for exploratory tuning and for protecting libraries.

Application of OpAmp Macromodels

You can use operational amplifier macromodels for a variety of applications. For example, these macromodels can be used for the following:

- `What-if` exploratory system simulation
- Fast system simulation
- Library characterization and protection

These three applications are described in detail below:

What-if Exploratory System Simulation

You can perform the `what-if` exploratory system simulation with the following steps:

- Implement a circuit with generic OpAmp macromodels early in an analog system design cycle. This way, you can quickly enter the OpAmps into the schematic, simulate, and independently set and change the OpAmp parameters (such as slew rate, bandwidth, and offset voltage) to understand their effects on system performance.
- Center the design, locate an OpAmp as close as possible to the required specifications in a catalog, then enter its data sheet values to verify that your system functions with the real parameters.
- Enter or design the OpAmp transistor level circuits to the defined specifications.

Note: Because most macromodel parameters are independent, be careful not to specify difficult or unrealistic combinations of specifications, such as low power and high speed.

Fast System Simulation

It might be impractical to simulate the entire system interactively at the transistor level when the system includes many OpAmps.

- Change and simulate the system quickly using macromodels.
- Run final verification simulations on the entire system in background or noninteractive mode.

Library Characterization and Protection

The OpAmp macromodel also finds application in library characterization and protection (as described here).

- Many `CAD`, `semiconductor`, and `ASIC` vendors provide qualified macromodel libraries of commonly used catalog components or cells.
- Systems designers get faster simulations using these macromodels.
- Vendors protect their circuit designs and process parameters.

Related Topics

Operational Amplifier (opAmp) Symbol

OpAmp Macromodel