# AC Current Source: ACCS

## Symbol

## Summary

This signal source is superseded and should be replaced with one of the following: AC_V for voltage sources, AC_I for current sources, or PORT_SRC for ports, with the Signal parameter set to this signal type.

The period for tone 1 sources is the inverse of the specified simulation frequency; see "Frequency Sweep Control" for details.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Current source ID | Text | V1 |
| Mag | AC current magnitude | Current | 1 mA |
| Ang | AC current angle | Angle | 0 Deg |
| Offset | Waveform offset (does not affect DC) | Current | 0 |
| DCVal | DC Value (Used for DC analysis) | Current | 0 |

## Implementation Details

Produces an alternating current with a frequency defined by the project frequency set up for the schematic containing this element.

**NOTE:** AWR® simulators add some series resistance to this element during simulation. This may affect results if injecting current into a large resistance. To change the value of the resistance, choose **Options > Default Circuit Options** to display the Circuit Options dialog box, then click the **AWR Sim** tab and under **Convergence Aids** specify the **Series source resistance**.

**NOTE:** If a sinusoidal nonlinear source like this one has the parameter Ang=0 and is ideally terminated, then a nonlinear measurement (for example, Pcomp or Vcomp) made at the fundamental output of that source will have an angle of -90deg. This discrepancy is consistent with the definition of the sine wave sources (as in SPICE), and the Fourier based harmonic component measurements. To avoid confusion, always measure or calculate the gain, and plot its angle.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See "Assigning Artwork Cells to Layout of Schematic Elements" for details.

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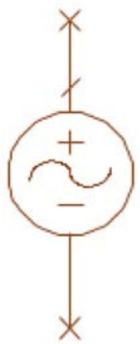
# AC Voltage Source: ACVS

## Symbol



## Summary

This signal source is superseded and should be replaced with one of the following: AC_V for voltage sources, AC_I for current sources, or PORT_SRC for ports, with the Signal parameter set to this signal type.

The period for tone 1 sources is the inverse of the specified simulation frequency; see “Frequency Sweep Control” for details.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Voltage source ID | Text | V1 |
| Mag | AC voltage magnitude | Voltage | 1 V |
| Ang | AC voltage angle | Angle | 0 Deg |
| Offset | Waveform offset (does not affect DC) | Voltage | 0 |
| DCVal | DC value (Used for DC analysis) | Voltage | 0 |

## Implementation Details

Produces an alternating voltage with a frequency defined by the project frequency set up for the schematic containing this element.

**NOTE:** If a sinusoidal nonlinear source like this one has the parameter Ang=0 and is ideally terminated, then a nonlinear measurement (e.g. Pcomp or Vcomp) made at the fundamental output of that source will have an angle of -90deg. This discrepancy is consistent with the definition of the sine wave sources (as in SPICE), and the Fourier based harmonic component measurements. To avoid confusion, always measure or calculate the gain, and plot its angle.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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# Bessel Lowpass Filter: LPFD

## Symbol

## Summary

LPFD models represent lumped-element Bessel-Thomson lowpass filters. They offer simplicity and maximally flat group delay, but suffer from poor selectivity.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | LPFD1 |
| N | Number of reactive elements in the filter | | 3 |
| FP | Passband corner frequency (when Qu is infinite). | Frequency | 1 GHz |
| AP | Passband corner attenuation (when Qu is infinite). | DB | 3.0103 dB |
| *RS | Expected source resistance. | Resistance | 50 ohm |
| *RL | Expected Load resistance | Resistance | 50 ohm |
| *QU | Average unloaded Q of reactive elements in the filter. | | 1e12 |

** indicates a secondary parameter*

## Parameter Restrictions and Recommendations

1. 0 < N < 34
2. 0 < FP

3. 0 < AP Recommend AP greater than or equal to 0.001 dB.
4. 0 < RS
5. 0 < RL
6. 0 < QU. Recommend QU less than or equal to 1e12.

## Implementation Details

The model is implemented as a short-circuit admittance matrix,

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

, whose equivalent transfer function squared magnitude is that of a Bessel-Thomson filter:

$$|\,S_{21}(s)|^2 = \frac{b_0^2}{|\,g(s)|^2} = \frac{b_0^2}{1 + \,|\,h(s)|^2}$$

where

$$g(s) = \sum_{i=0}^{N} b_i s^i$$

$$b_i = \frac{(2N-i)\,!}{2^{N-i}(i)\,!(N-i)\,!} \text{ for } i = 0,\ ...,\ N$$

Where $b_0$ = (2N-1)!!,i.e, the product of all odd integers less than 2N.

$$s = \frac{1}{\text{QU}} + j\omega$$

$$j = \sqrt{-1}$$

and a lowpass-to-lowpass frequency transformation has been applied:

$$\omega = \frac{\text{\_FREQ}}{\text{FP}}$$

_FREQ is the variable containing the project frequency, and the admittances are:

$$y_{11} = \left(\frac{1}{\text{RS}}\right)\frac{g(s) + g(-s) - h(s) - h(-s)}{g(s) - g(-s) + h(s) - h(-s)}$$

$$y_{22} = \left(\frac{1}{\text{RL}}\right)\frac{g(s) + g(-s) + h(s) + h(-s)}{g(s) - g(-s) + h(s) - h(-s)}$$

$$y_{12} = y_{21} = \left(\frac{1}{\sqrt{RS \times RL}}\right)\frac{(-2)b_0}{g(s) - g(-s) + h(s) - h(-s)}$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

Note that this model behaves as if it has ideal impedance transformers at its ports, so there is no attenuation due to mismatched source and load impedances. The model expects that the source impedance equals RS and that the load impedance equals RL, but RS need not equal RL for ideal transmission (as would normally be the case).

## References

[1] Rolf Schaumann, Mohammed S. Ghausi, and Kenneth R. Laker, Design of Analog Filters: Passive, Active RC, and Switched Capacitor, (Prentice-Hall, 1990), pp. 51-56.

[2] Louis Weinberg, Network Analysis and Synthesis, (Robert E. Krieger Publishing, 1975), pp. 499-506.

[3] Herman J. Blinchikoff and Anatol I. Zverev, Filtering in the Time and Frequency Domains, (Robert E. Krieger Publishing Co., 1987), pp. 124-127.

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# Butterworth Lowpass Filter: LPFB

## Symbol

## Summary

LPFB models represent lumped-element Butterworth lowpass filters. They offer simplicity and a compromise between high selectivity and flat group delay. The insertion loss is maximally flat at zero frequency and the stopband attenuation increases monotonically with increasing frequency at an asymptotic rate of 6N dB per octave.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Filter ID | Text | LPFB1 |
| N | Number of reactances in the filter | | 3 |
| FP | Passband corner frequency (when Qu is infinite). | Frequency | 1 GHz |
| *AP | Passband corner attenuation (when Qu is infinite). | DB | 3.0103 dB |
| *RS | Expected source resistance. | Resistance | 50 ohm |
| *RL | Expected load resistance | Resistance | 50 ohm |
| *QU | Uniform unloaded Q of lowpass reactances | | 1e12 |

** indicates a secondary parameter*

## Parameter Restrictions and Recommendations

1. 0 < N < 29

2. 0 < FP
3. 0 < AP Recommend AP greater than or equal to 0.001 dB.
4. 0 < RS
5. 0 < RL
6. 0 < QU. Recommend QU less than or equal to 1e12.

## Implementation Details

The model is implemented as a short-circuit admittance matrix, whose equivalent transfer function squared magnitude is that of a Butterworth filter:

$$|S_{21}(s)|^2 = \frac{1}{1+(-1)^N \varepsilon^2 S^{2N}} = \frac{1}{|g(s)|^2} = \frac{1}{1+|h(s)|^2}$$

where

$$\varepsilon^2 = 10^{\mathrm{AP}/10} - 1$$

$$s = \frac{1}{\mathrm{QU}} + j\omega$$

$$j = \sqrt{-1}$$

and a lowpass-to-lowpass frequency transformation has been applied:

$$\omega = -\frac{\_FREQ}{FP}$$

_FREQ is the variable containing the project frequency, and the admittances are:

$$y_{11} = \left(\frac{1}{\mathrm{RS}}\right)\frac{g(s)+g(-s)-h(s)-h(-s)}{g(s)-g(-s)+h(s)-h(-s)}$$

$$y_{22} = \left(\frac{1}{\mathrm{RL}}\right)\frac{g(s)+g(-s)+h(s)+h(-s)}{g(s)-g(-s)+h(s)-h(-s)}$$

$$y_{12} = y_{21} = \left(\frac{1}{\sqrt{\mathrm{RS}\times\mathrm{RL}}}\right)\frac{2}{g(s)-g(-s)+h(s)-h(-s)}$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

Note that this model behaves as if it has ideal impedance transformers at its ports, so there is no attenuation due to mismatched source and load impedances. The model expects that the source impedance equals RS and that the load impedance equals RL, but RS need not equal RL for ideal transmission (as would normally be the case).

## References

[1] Rolf Schaumann, Mohammed S. Ghausi, and Kenneth R. Laker, Design of Analog Filters: Passive, Active RC, and Switched Capacitor, (Prentice-Hall, 1990), pp. 40-44.

[2] Louis Weinberg, Network Analysis and Synthesis, (Robert E. Krieger Publishing, 1975), pp. 493-498.

[3] Adel S. Sedra and Peter O. Brackett, Filter Theory and Design: Active and Passive, (Matrix Publishers, 1978), pp. 105-111.

---

# Chebyshev Lowpass Filter (Closed Form): LPFC

## Symbol

## Summary

LPFC models represent lumped-element Chebyshev lowpass filters. The insertion loss ripples between zero and a specified maximum in the passband. The stopband attenuation increases rapidly beyond the passband edge, is monotonic, and is maximally flat at infinite frequency. This filter type offers simplicity and good selectivity.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | LPFC1 |
| N | Number of reactive elements in the filter | | 3 |
| FP | Passband corner frequency (when Qu is infinite). | Frequency | 1 GHz |
| AP | Passband corner attenuation (when Qu is infinite). | DB | 0.1 dB |
| *RS | Source resistance. | Resistance | 50 ohm |
| *RL | Load resistance | Resistance | 50 ohm |
| *QU | Average unloaded Q of reactive elements in the filter | | 1e12 |

** indicates a secondary parameter*

## Parameter Restrictions and Recommendations

1. 0 < N < 27

2. 0 < FP
3. 0 < AP Recommend AP greater than or equal to 0.001 dB.
4. 0 < RS
5. 0 < RL
6. 0 < QU. Recommend QU less than or equal to 1e12.

## Implementation Details

The model is implemented as a short-circuit admittance matrix, whose equivalent transfer function squared magnitude is that of a Chebyshev filter:

$$|S_{21}(s)|^2 = \frac{1}{1+\varepsilon^2 C_n^2\left(\frac{s}{j}\right)} = \frac{1}{|g(s)|^2} = \frac{1}{1+|h(s)|^2}$$

where Cn is the Chebyshev polynomial of the first kind, and

$$\varepsilon^2 = 10^{\mathrm{AP}/10} - 1$$

$$C_n(\omega) = \cos(N * \mathrm{acos}(\omega)) \qquad \text{for } 0 \le |\omega| \le 1$$

$$C_n(\omega) = \cosh(N * \mathrm{acosh}(\omega)) \qquad \text{for } 1 < |\omega|$$

$$s = \frac{1}{\mathrm{QU}} + j\omega$$

$$j = \sqrt{-1}$$

and a lowpass-to-lowpass frequency transformation has been applied:

$$\omega = -\frac{\_FREQ}{FP}$$

_FREQ is the variable containing the project frequency, and the admittances are:

$$y_{11} = \left(\frac{1}{\mathrm{RS}}\right)\frac{g(s)+g(-s)-h(s)-h(-s)}{g(s)-g(-s)+h(s)-h(-s)}$$

$$y_{22} = \left(\frac{1}{\mathrm{RL}}\right)\frac{g(s)+g(-s)+h(s)+h(-s)}{g(s)-g(-s)+h(s)-h(-s)}$$

$$y_{12} = y_{21} = \left(\frac{1}{\sqrt{\mathrm{RS} \times \mathrm{RL}}}\right)\frac{2}{g(s)-g(-s)+h(s)-h(-s)}$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

Note that this model behaves as if it has ideal impedance transformers at its ports, so there is no attenuation due to mismatched source and load impedances. The model expects that the source impedance equals RS and that the load impedance equals RL, but RS need not have any special relationship to RL for ideal transmission (as would normally be the case).

## References

[1] Rolf Schaumann, Mohammed S. Ghausi, and Kenneth R. Laker, Design of Analog Filters: Passive, Active RC, and Switched Capacitor, (Prentice-Hall, 1990), pp. 44-48.

[2] Louis Weinberg, Network Analysis and Synthesis, (Robert E. Krieger Publishing, 1975), pp. 507-529.

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# Circuit Port: PORT

## Symbol

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| P | Port number | | 0 |
| Z | Termination impedance | Resistance | 50 ohm |
| PIN_ID | Name identifier for pin | Text | |

## Implementation Details

This is a passive circuit termination that applies a load specified by Z. The port number P is set automatically. If PIN_ID is not empty, text is displayed on the pin when it is instantiated as a subcircuit.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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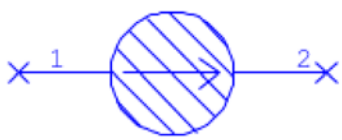
# Current Noise Source: INOISE

## Symbol




## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | IN1 |
| I | Noise current in pA/sqrt(Hz) | | 17.9 |

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Implementation Details

INOISE implements a white noise source having the stated noise spectral density.

For I=17.897294, T=290K in 50Ω.

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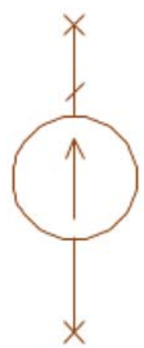
# DC Current Source: DCCS

## Symbol



## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Current source ID | Text | I1 |
| I | DC current | Current | 10 mA |

## Implementation Details

Produces a DC current.

**NOTE:** AWR® simulators add some series resistance to this element during simulation. This may affect results if injecting current into a large resistance. To change the value of the resistance, choose **Options > Default Circuit Options** to display the Circuit Options dialog box, then click the **AWR Sim** tab and under **Convergence Aids** specify the **Series source resistance**.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See "Assigning Artwork Cells to Layout of Schematic Elements" for details.

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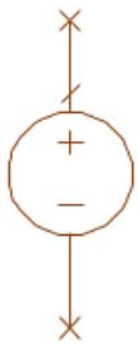
# DC Voltage Source: DCVS

## Symbol





## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Voltage source ID | Text | V1 |
| V | DC voltage | Voltage | 1 V |

## Implementation Details

Produces a DC voltage.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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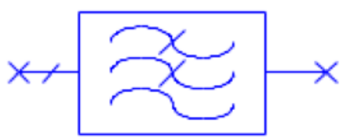
# Elliptic-Function Lowpass Filter (Closed Form): LPFE

## Symbol



## Summary

LPFE models represent lumped-element elliptic-function (Cauer) lowpass filters. The insertion loss ripples between zero and a specified maximum in the passband. The stopband attenuation increases rapidly between the passband edge and the stopband edge, and ripples between a specified minimum stopband attenuation and infinite attenuation. This type of filter offers optimum selectivity at the expense of increased complexity and poor group delay flatness.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | LPFE1 |
| N | Order of the filter. | | 3 |
| FP | Passband corner frequency (when Qu is infinite). | Frequency | 1 GHz |
| AP | Maximum Passband Insertion Loss (when Qu is infinite). | DB | 0.1 dB |
| AS | Minimum Stopband Attenuation(when Qu is infinite). | DB | 20 dB |
| *FS | Stopband corner frequency (when Qu is infinite). | Frequency | 0 GHz |
| *DM | Where to put design margin:0=AP, 1=AS, 2=FP, 3=FS. | | 1 |
| *RS | Source resistance. | Resistance | 50 ohm |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| *RL | Load resistance | Resistance | 50 ohm |
| *QU | Average unloaded Q of reactive elements in the filter. | | 1e12 |

** indicates a secondary parameter*

## Parameter Details

An elliptic function lowpass prototype filter is completely specified by any four of the five parameters: N, FP, FS, AP, and AS. That is, the value of any parameter is dependent on the value of the other four parameters.

- If zero is specified for any one of these five parameters, then the model computes its value from the value of the other four parameters.
- If a value is specified for all five parameters, then the specified value of the last parameter (AS) is ignored and is computed by the model from the values of the other four parameters.
- It is an error to specify zero for more than one of these five parameters.

**N.** In mathematical terms, N is defined as the highest exponent of the complex frequency variable s in the transfer function, S21(s0), of the filter's normalized lowpass prototype, or, equivalently, the highest exponent of s in the transfer function of the lowpass filter. And, in terms of a measurable electrical characteristic, the number of positive-frequency passband reflection (|S11|) zeros corresponds to N/2 for N even and (N+1)/2 for N odd.

**DM.** If zero is specified for N, the model will determine N. But, since N must be an integer, there will typically be some design margin available, and this margin must be assigned to some parameter other than N. The value of DM determines where the model will assign this design margin.

- DM=0. After determining N, the model will recompute AP, such that 0 < new AP ≤ AP
- DM=1. After determining N, the model will recompute AS, such that AS ≤ new AS < ∞
- DM=2. After determining N, the model will recompute FP, such that FS < new FP ≤ FP
- DM=3. After determining N, the model will recompute FS, such that FS ≤ new FS < FP

## Parameter Restrictions and Recommendations

1. N can be zero if FP, FS, AP, and AS are not, otherwise 0 < N < 27.
2. FP can be zero if N, FS, AP, and AS are not, otherwise 0 < FP, and, if FS is not zero, then FS < FP.

   FS can be zero if N, FP, AP, and AS are not, otherwise 0 < FS, and, if FP is not zero, then FS < FP.
3. AP can be zero if N, FP, FS, and AS are not, otherwise 0 < AP, and, if AS is not zero, then AP < AS.

   Recommend AP greater than or equal to 0.001 dB.
4. AS can be zero if N, FP, FS, and AP are not, otherwise AP < AS.
5. If N is set to 0, then 0 ≤ DM < 4
6. 0 < RS.

0 < RL

7. QU > 0 specifies a finite unloaded Q (recommend QU ≤ 1e12 ).

   QU = 0 specifies an infinite unloaded Q.
8. 0 ≤ DM < 4

## Implementation Details

The model is implemented as a short-circuit admittance matrix,

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

, whose equivalent normalized lowpass prototype transfer function, S21(s), is:

$$|\ S_{21}(s)|^2 = \frac{1}{1 + \varepsilon^2 R_n^2\left(\frac{s}{j}\right)} = \frac{f(s)^2}{|\ g(s)|^2} = \frac{f(s)^2}{1 +\ |\ h(s)|^2}$$

where Rn is the Elliptic Rational Function, and

$$|\ S_{21}(s)|^2 = \frac{1}{1 + \varepsilon^2 R_n^2\left(\frac{s}{j}\right)} = \frac{f(s)^2}{|\ g(s)|^2} = \frac{f(s)^2}{1 +\ |\ h(s)|^2}$$

where Rn is the Elliptic Rational Function, and

$$\varepsilon^2 = 10^{\mathrm{AP}/10} - 1$$

$$R_n(\omega) = C \times \omega^{\Pi} \times \prod_{i=1}^{\frac{N-\Pi}{2}} \left( \frac{\omega^2 - \omega_i^2}{\omega^2 - \frac{\omega_s^2}{\omega_i^2}} \right)$$

$$C = \prod_{i=1}^{\frac{N-\Pi}{2}} \left( \frac{1 - \frac{\omega_s^2}{\omega_i^2}}{1 - \omega_i^2} \right)$$

$$\omega_i = \mathrm{cd}\left( \frac{2i-1}{N} K\left( \frac{1}{\omega_s^2} \right), \frac{1}{\omega_s^2} \right)$$

$$s = 1 / \left( \frac{\sqrt{\mathrm{FP2} \times \mathrm{FP1}}}{\mathrm{QU} \times\ |\ \mathrm{FP2} - \mathrm{FP1}\ |} + j\left( \frac{-1}{\omega} \right) \right)$$

$$s = \frac{1}{\mathrm{QU}} + j\omega$$

$$j = \sqrt{-1}$$

where cd is a Jacobian elliptic function, K is Legendre's complete elliptic integral of the first kind, and a lowpass-to-lowpass frequency transformation has been applied:

$$\omega = \frac{\_FREQ}{FP}$$

and

$$\omega_s = \frac{FS}{FP}$$

_FREQ is the variable containing the project frequency. The parameters of the elliptic-function filter (N, FP, FS, AP, AS) are related by "the degree equation":

$$N = \left(\frac{K(m)}{K(1-m)}\right)\left(\frac{K(1-m_o)}{K(m_o)}\right)$$

where

$$m_o = \frac{10^{AP/10}-1}{10^{AS/10}-1}$$

and

$$m = \left(\frac{FP}{FS}\right)^2$$

The admittances are given by:

$$y_{11} = \left(\frac{1}{RS}\right)\frac{g(s)+g(-s)-h(s)-h(-s)}{g(s)-g(-s)+h(s)-h(-s)}$$

$$y_{22} = \left(\frac{1}{RL}\right)\frac{g(s)+g(-s)+h(s)+h(-s)}{g(s)-g(-s)+h(s)-h(-s)}$$

$$m = \left(\frac{FS}{FP}\right)^2$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

Note that this model behaves as if it has ideal impedance transformers at its ports, so there is no attenuation due to mismatched source and load impedances. The model expects that the source impedance equals RS and that the load impedance equals RL, but RS need not have any special relationship to RL for ideal transmission (as would normally be the case).

## References

[1] Miroslav D. Lutovac, Dejan V. Tosic, and Brian L. Evans, Filter Design For Signal Processing Using MATLAB and Mathematica, (Prentice Hall, 2001), Chapters 6, 12, and 13.

[2] Alexander J. Grossman, "Synthesis of Tchebycheff parameter symmetrical filters," Proceedings of the IRE, pp. 545-473, April 1957.

[3] Dante Youla, "A tutorial exposition of some key network-theoretic ideas underlying classical insertion-loss filter design," Proc. IEEE, vol. 59, no. 5, pp. 760-799, May 1971.

[4] Miroslav Vleck and Rolf Unbehauen, "Degree, ripple, and transition width of elliptic filters," IEEE Trans. Circuits Syst., vol. 36, no. 3, pp. 469-472, March 1989.

[5] H. J. Orchard and Alan N. Willson, Jr., "Elliptic functions for filter design," IEEE Trans. Circuits Syst., I, vol. 44, no. 4, pp. 273-287, April 1997.

[6] Rolf Schaumann, Mohammed S. Ghausi, and Kenneth R. Laker, Design of Analog Filters: Passive, Active RC, and Switched Capacitor, (Prentice-Hall, 1990), pp. 49-51.

[7] Kendall L. Su, Handbook of Tables for Elliptic-Function Filters, (Kluwer Academic, 1990).

[8] Handbook of Mathematical Functions With Formulas, Graphs, and Mathematical Tables, edited by Milton Abramowitz and Irene A. Stegun, (U. S. National Bureau of Standards, 1964), Chapters 16 and 17 by L. M. Milne-Thomson.

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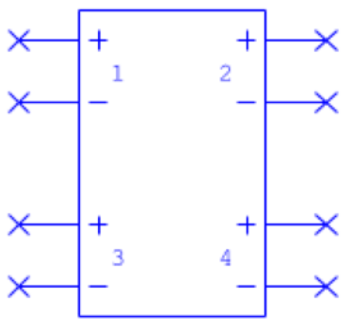
## Four-Port S-Parameter Block: S4P_BLK

### Symbol




### Summary

S4P_BLK models a generalized four-port, S-parameter network. The full four-port S-parameters are specified.

### Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | X1 |
| S11 | S(1,1) | Scalar (Complex) | 0.0 + j*0.0 |
| S21 | S(2,1) | Scalar (Complex) | 0.0 + j*0.0 |
| S31 | S(3,1) | Scalar (Complex) | 0.0 + j*0.0 |
| S41 | S(4,1) | Scalar (Complex) | 0.0 + j*0.0 |
| S12 | S(1,2) | Scalar (Complex) | 0.0 + j*0.0 |
| S22 | S(2,2) | Scalar (Complex) | 0.0 + j*0.0 |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| S32 | S(3,2) | Scalar (Complex) | 0.0 + j*0.0 |
| S42 | S(4,2) | Scalar (Complex) | 0.0 + j*0.0 |
| S13 | S(1,3) | Scalar (Complex) | 0.0 + j*0.0 |
| S23 | S(2,3) | Scalar (Complex) | 0.0 + j*0.0 |
| S33 | S(3,3) | Scalar (Complex) | 0.0 + j*0.0 |
| S43 | S(4,3) | Scalar (Complex) | 0.0 + j*0.0 |
| S14 | S(1,4) | Scalar (Complex) | 0.0 + j*0.0 |
| S24 | S(2,4) | Scalar (Complex) | 0.0 + j*0.0 |
| S34 | S(3,4) | Scalar (Complex) | 0.0 + j*0.0 |
| S44 | S(4,4) | Scalar (Complex) | 0.0 + j*0.0 |
| *Z1 | Port 1 impedance | Scalar (Complex) | 50.0 ohm |
| *Z2 | Port 2 impedance | Scalar (Complex) | 50.0 ohm |
| *Z3 | Port 3 impedance | Scalar (Complex) | 50.0 ohm |
| *Z4 | Port 4 impedance | Scalar (Complex) | 50.0 ohm |
| *ChkPassv | Switch "Do not Check passivity/Check passivity" | | No |

** indicates a secondary parameter*

## Parameter Details

**ChkPassv.** If set to Yes, tests S4P_BLK for passivity and displays a warning if there is a passivity violation. The default setting is No (Do not check passivity).

## Parameter Restrictions and Recommendations

Z1, Z2, Z3, and Z4 must not be equal to zero.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

The S4P_BLK model can be used to model any general four-port network (passive or active) by specifying the S-parameters.

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# Generalized Chebyshev Lowpass Filter (Closed Form): LPFCG

## Symbol

## Summary

LPFCG models represent lumped-element Generalized Chebyshev (or "Quasi-Elliptic") lowpass filters. The insertion loss ripples between zero and a specified maximum in the passband. The stopband attenuation is defined by arbitrarily specified transmission zeros. Real-frequency finite transmission zeros can be specified to improve selectivity at the expense of ultimate stopband attenuation and passband group delay, while complex-plane finite transmission zeros can be specified to provide passband group delay equalization at the expense of selectivity and ultimate stopband attenuation. Generalized Chebyshev filters represents a compromise between the simplicity of Chebyshev filters, the optimum amplitude response of more complicated Elliptic filters, and the phase linearity of Bessel and Gaussian filters. Because this type of filter allows one to make explicit design trade-offs between complexity, selectivity, and group delay equalization, it is often used to meet the demanding requirements of modern communications systems.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | LPFCG1 |
| N | Order of the filter | | 3 |
| FP | Passband corner frequency (when Qu is infinite). | Frequency | 1 GHz |
| *PPD | Passband parameter description:- Maximum Insertion Loss,- Minimum Return Loss, or- VSWR. | Enumerated | Maximum Insertion Loss |
| PPV | Passband parameter value (when Qu is infinite) | dB or Scalar | 0.1 dB |
| TZF | Real frequency, finite transmission zeros | (Real) Frequency | {2} GHz |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| *TZR | Real parts of complex finite transmission zeros | (Imaginary) Frequency | {0} GHz |
| *RS | Source resistance | Resistance | 50 ohm |
| *RL | Load resistance | Resistance | 50 ohm |
| *QU | Average unloaded Q of reactive element in the filter. | | 0 |

** indicates a secondary parameter*

## Parameter Details

**N.** In mathematical terms, N is defined as the highest exponent of the complex frequency variable s in the transfer function, $S_{21}(s)$, of the filter's normalized lowpass prototype, or, equivalently, the highest exponent of s in the transfer function of the lowpass filter. And, in terms of a measurable electrical characteristic, the number of positive-frequency passband reflection ($S|_{11}|$) zeros corresponds to N/2 for N even and (N+1)/2 for N odd.

**PPD & PPV.** Parameters PPD and PPV work together to specify the characteristic of the filter's passband. PPD is used to indicate what the value of PPV represents. The flexibility these parameters provide eliminates the need to manually convert from the passband specification parameter of one's preference into whatever specific parameter the software was written to accept.

**PTZF & TZR.** List parameters TZF and TZR are used to specify the complex transmission zeros, Z, of the highpass filter response. Up to (N-1)/2 complex transmission zeros, $Z_i = TZR_i + jTZF_i$, can be specified. Each consists of a real part, $TZR_i$, and an imaginary part, the real frequency $TZF_i$. If $TZR_i$ is not specified, it is assumed to be zero. And, each unspecified transmission zero is mapped to a normalized lowpass prototype frequency of infinity.

## Parameter Restrictions and Recommendations

1. 32 > N > 1.
2. FP > 0.
3. If PPD = "Maximum Insertion Loss", then PPV > 0.

   If PPD = "Minimum Return Loss", then PPV > 0.

   If PPD = "Maximum VSWR", then PPV > 1.
4. $TZF_i > 0$ .

   If $TZR_i$ is specified, then $TZF_i$ must be specified.

   If $TZR_i$ is zero, then FP $< TZF_i$ .

   If $TZR_i \neq 0$ , there must be a $TZR_k = -TZR_i$ and a $TZF_k = TZF_i$ .
5. RS > 0.

   RL > 0.
6. QU > 0 specifies a finite unloaded Q (recommend QU<1e$^{12}$).

   QU = 0 specifies an infinite unloaded Q.

## Implementation Details

The model is implemented as a short-circuit admittance matrix,

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

, whose equivalent normalized lowpass prototype transfer function, $S_{21}(s)$, is[1, 2]:

$$s_{21}^2(s) = \frac{P_N^2(s)}{P_N^2(s) + \varepsilon^2 F_N^2(s)} = \frac{P_N^2(s)}{P_N(s) + j\varepsilon F_N(s))(P_N(s) - j\varepsilon F_N(s))} = \frac{P_N^2(s)}{\varepsilon^2 E_N^2(s)}$$

where $F_N$ and $E_N$ are polynomials of order N, and

$$\exp(-s^2) \approx \sum_{i=0}^{N} \frac{(-1)^i s^{2i}}{i!} = |g(s)|^2 = 1 + |h(s)|^2$$

$$\varepsilon^2 = \frac{1}{10^{PPV/10} - 1} \text{when PPD = " Minimum Return Loss "}$$

$$\varepsilon^2 = \frac{0.25(\mathrm{PPV} - 1)^2}{\mathrm{PPV}} \text{ when PPD="Maximum VSWR"}$$

$$P_N(s) = \prod_{i=1}^{N}\left(1 - \frac{s}{z_i}\right)$$

$$s = \frac{1}{q_u} + j\omega$$

$$j = \sqrt{-1}$$

A specified lowpass transmission zero, Z[i] = TZR[i] + jTZF[i] is mapped to a normalized lowpass prototype transmission zero, z[ i ], using [5]:

$$z[i] = \frac{Z[i]}{\mathrm{FP}}$$

And, _FREQ (the variable that represents the project frequency) is mapped to the normalized lowpass prototype radian frequency, ω, using [5]:

$$\omega = \frac{\_\mathrm{FREQ}}{\mathrm{FP}}$$

Polynomial

$$F_N(s) = F_i|_{i=N}$$

is constructed using a doubly recursive algorithm [1][3]:

$$G_0 = b_1$$

$$F_1 = a_1$$

$$G_{(i-1)} = a_i G_{(i-2)} + b_i F_{(i-1)}$$

$$F_i = a_i F_{(i-1)} + c_i G_{(i-2)}$$

where i = 2 to N and, employing the normalized lowpass prototype transmission zero, $z_k$, for k = 1 to N:

$$a_k = -j\left(s + \frac{1}{z_k}\right)$$

$$b_k = \sqrt{1 + \left(\frac{1}{z_k}\right)^2}$$

$$c_k = -b_k\left(s^2 + 1\right)$$

Polynomial $E_s(s)$ is found by applying the "alternating singularity principle" [1][2][4] to the roots of

$$\left(\frac{P_N(s)}{\varepsilon} + \mathrm{j}\mathrm{F}_N(s)\right)$$

. Then, $E_N$ and $F_N$ are split into complex-even and complex-odd polynomials [2] such that $E_N$= $E_e$+$E_0$and $F_N$= $F_e$+$F_0$, where

$$E_e = \mathrm{Re}(e_0) + j \quad \mathrm{Im}(e_1)s + \mathrm{Re}(e_2)s^2 + \cdots, E_o = j \quad \mathrm{Im}(e_o) + \mathrm{Re}(e_1) + j \quad \mathrm{Im}(e_2)s^2 + \cdots$$

$$F_e = \mathrm{Re}(f_0) + j\ \mathrm{Im}(f_1)s + \mathrm{Re}(f_2)s^2 + \cdots, F_o = j\ \mathrm{Im}(f_o) + \mathrm{Re}(f_1) + j\ \mathrm{Im}(f_2)s^2 \cdots$$

and and $e_1$ and $f_1$ (i = 0 to N) are the complex coefficients of $E_N$ and $F_N$. Finally [3]:

$$y_{11} = \left(\frac{1}{\mathrm{RS}}\right)\left(\frac{E_e - F_e}{E_o + F_o}\right)$$

$$y_{22} = \left(\frac{1}{\mathrm{RL}}\right)\left(\frac{E_e + F_e}{E_o + F_o}\right)$$

$$y_{12} = y_{21} = \left(\frac{1}{\sqrt{\mathrm{RS} \times \mathrm{RL}}}\right)\left(\frac{-P_N/\varepsilon}{E_o + F_o}\right)$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

The transmission zeros can be tuned or optimized by assigning variables to the elements of the TZF and/or TZR lists and then tuning or optimizing these variables.

Note that this model behaves as if it has ideal impedance transformers at its ports, so there is no attenuation due to mismatched source and load impedances. The model expects that the source impedance equals RS and that the load impedance equals RL, but RS need not have any special relationship to RL for ideal transmission (as would normally be the case).

## References

[1] Richard J. Cameron, "Fast generation of Chebyshev filter prototypes with asymmetrically-prescribed transmission zeros," ESA J., vol. 6, pp. 83-95, 1982.

[2] Richard J. Cameron, "General coupling matrix synthesis methods for Chebyshev filtering functions," IEEE Trans. Microwave Theory Tech., vol. 47, no. 4, pp. 433-442, April 1999.

[3] Douglas R. Jachowski, unpublished notes, 1995 and 2002.

[4] J. D. Rhodes and A. S. Alseyab, "The generalized Chebyshev low pass prototype filter," Int. J. Circuit Theory Applicat., vol. 8, pp. 113-125, 1980.

[5] H. J. Blinchikoff and A. I. Zverev, Filtering in the Time and Frequency Domains, (Robert E. Krieger Publishing Co., 1987), pp. 154-155

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# Gaussian Lowpass Filter (Closed Form): LPFG

## Symbol

## Summary

LPFG models represent lumped-element Gaussian lowpass filters. They approximate the ideal Gaussian magnitude response and offer simplicity, relatively flat group delay, and good time domain performance, but suffer from poor frequency selectivity. Although similar to Bessel-Thomson filters, Gaussian filters offer faster rise times and lower transient overshoots, but have slightly less stopband attenuation and less group delay flatness.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | LPFG1 |
| N | Number of reactive elements in the filter | | 3 |
| FP | Passband corner frequency (when Qu is infinite). | Frequency | 1 GHz |
| AP | Passband corner attenuation (when Qu is infinite). | DB | 3.0103 dB |
| *RS | Expected source resistance. | Resistance | 50 ohm |
| *RL | Expected Load resistance | Resistance | 50 ohm |
| *QU | Average unloaded Q of reactive elements in the filter. | | 1e12 |

** indicates a secondary parameter*

## Parameter Restrictions and Recommendations

1. 0 < N < 51
2. 0 < FP
3. 0 < AP Recommend AP greater than or equal to 0.001 dB.
4. 0 < RS
5. 0 < RL
6. 0 < QU. Recommend QU less than or equal to 1e12.

## Implementation Details

This model is implemented as a short-circuit admittance matrix,

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

, whose equivalent transfer function squared magnitude approximates that of an ideal Gaussian filter. The ideal Gaussian squared magnitude characteristic is:

$$|S_{21}|^2 = \frac{1}{\exp(-s^2)}$$

In the model, the denominator of this ideal Gaussian characteristic is approximated by a truncated Maclaurin series:

$$\exp(-s^2) \approx \sum_{i=0}^{N} \frac{(-1)^i s^{2i}}{i!} = |g(s)|^2 = 1 + |h(s)|^2$$

where

$$s = \frac{1}{\mathrm{QU}} + j\omega$$

$$j = \sqrt{-1}$$

and a lowpass-to-lowpass frequency transformation has been applied:

$$\omega = \frac{\_\mathrm{FREQ}}{\mathrm{FP}}$$

_FREQ is the variable containing the project frequency, and the admittances are:

$$y_{11} = \left(\frac{1}{\mathrm{RS}}\right)\frac{g(s) + g(-s) - h(s) - h(-s)}{g(s) - g(-s) + h(s) - h(-s)}$$

$$y_{22} = \left(\frac{1}{\mathrm{RL}}\right)\frac{g(s) + g(-s) + h(s) + h(-s)}{g(s) - g(-s) + h(s) - h(-s)}$$

$$y_{12} = y_{21} = \left(\frac{1}{\sqrt{\mathrm{RS} \times \mathrm{RL}}}\right)\frac{(-2)}{g(s) - g(-s) + h(s) - h(-s)}$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

This model behaves as if it has ideal impedance transformers at its ports, so there is no attenuation due to mismatched source and load impedances. The model expects that the source impedance equals RS and that the load impedance equals RL, but RS need not equal RL for ideal transmission (as would normally be the case).

## References

[1] Milton Dishal, "Gaussian-Response Filter Design," Electrical Communication, vol. 36, March 1959, pp. 3-26.

[2] Anatol I. Zverev, Handbook of Filter Synthesis, (John Wiley & Sons, 1967), pp. 67, 70, 71, 73, 74, 90, 91.

[3] DeVerl. S. Humpherys, The Analysis, Design, and Synthesis of Electrical Filters, (Prentice-Hall, 1970), pp. 413-417.

[4] Herman J. Blinchikoff and Anatol I. Zverev, Filtering in the Time and Frequency Domains, (Robert E. Krieger Publishing Co., 1987), pp. 130-132.

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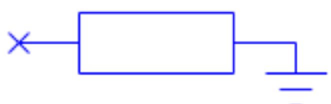
# Grounded Resistor (Closed Form): LOAD

## Symbol



## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | Z1 |
| Z | Load impedance | Resistance | 50 ohm |

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.



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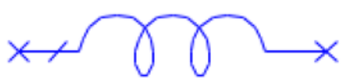
# Inductor with Frequency-dependent Inductance, Parasitic and Loss: INDQP

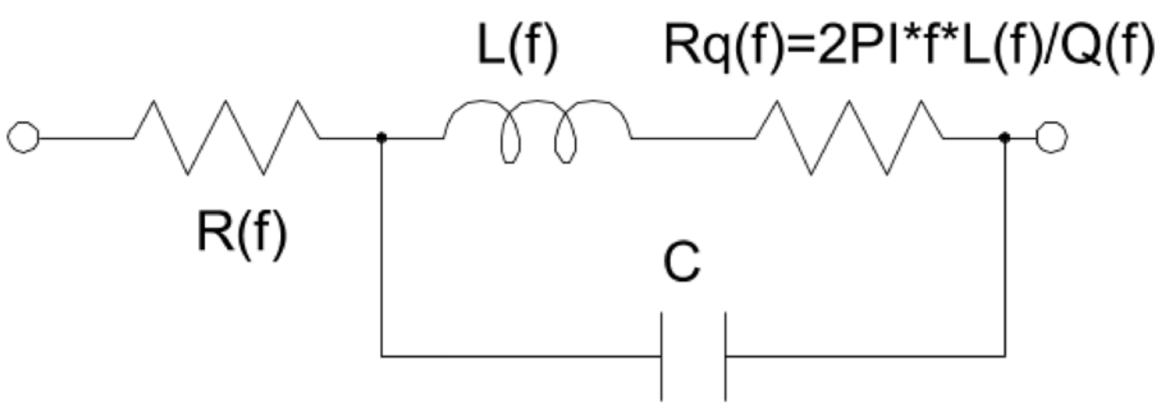
## Symbol



## Summary

INDQP models an inductor with user-specified frequency-dependence of inductance and loss. Frequency dependencies are specified as lookup tables (vectors) in model parameters. This model uses interpolation to obtain parameter values at each project evaluation frequency.

## Equivalent Circuit




## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | IND# |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| F | Vector of frequencies at which L, Q, and R are specified | Frequency | {1} |
| L | Inductance (vector) | Inductance | Li[1] |
| Q | Quality factor (vector) | Scalar | {1000} |
| C | Capacitance | Parasitic capacitance | C[1] |
| R | Series resistance (vector) | Resistance | {0} |

[1] User-modifiable default. Modify by editing under $DEFAULT_VALUES in the *default.lpf* file in the root installation directory. See the AWR Microwave Office Layout Guide for details.

## Parameter Details

**F.** Vector of frequencies at which L, Q, and R parameters are specified. Frequencies must be sequential and specified in ascending order.

**L.** Vector of series inductance L(f) (see the "Equivalent Circuit" section) specified in inductance project units. You must specify each vector entry at the corresponding frequency entry from frequency vector F.

**Q.** Vector of quality factor; specifies series resistance Rq (f) (see the "Equivalent Circuit" section). You must specify each vector entry at the corresponding frequency entry from frequency vector F.

**C.** Parasitic capacitance (see the "Equivalent Circuit" section).

**R.** Vector of series resistance R(f) (see the "Equivalent Circuit" section) specified in resistance project units. You must specify each vector entry at the corresponding frequency entry from frequency vector F.

## Parameter Restrictions and Recommendations

1. The size of vector parameters L, Q, and R must be equal to the size of frequency vector F.
2. If the project evaluation frequency is out of range of frequencies in F, then L, Q, and R parameters are extrapolated as constant values equal to the first/last entries of corresponding vectors. No warning is issued.
3. You can specify the vector in three ways: First, by entering it as a right side value of the model parameter, for example R={100,102,110,113,120}; second, by specifying the vector elsewhere in the equation; and third, by specifying the vector in a column or row of a text file. The third way provides a convenient and flexible method of specifying L, Q, and R parameters at a single location. For example, you can create the file *indqp.txt* containing space separated columns of L, Q, and R. The first column must represent frequency in project units (note that changing project default frequency units demands manual scaling of frequencies in this file). Import or link this file to your project and name it, for example, INDQP_1. Now you can specify, for example, parameter R as R = Col(datafile("INDQP_1"),4) so that values of vector R are copied to the model from column 4 of file *indqp.txt* imported under the name indqp_1. If you prefer to deploy your data row-wise use R = Row(datafile("INDQP_1"),2).
4. If your project uses a text file input to feed data to this model be aware what frequency, resistance, inductance or conductance units this file implies. Your project default units may differ from those in your data file. If this happens, you must scale input values, multiplying the call of function Col or Row by a scaling coefficient. For example, if your project uses

inductance in nanohenries and the data file contains data in microhenries you may get inductance data from column 2 of the data file INDQP_1 such as: L= 1e+3*Col(datafile("INDQP_1"),2).

## Implementation Details

This model is implemented as a series connection of lossy inductor and frequency-dependent resistor. A parasitic capacitor shunts a lossy inductor.

Model implementation is based on linear interpolation of L, Q, and R parameters at each project evaluation frequency. Interpolation uses user-supplied lookup tables via parameters. If the project evaluation frequency is out of range of frequencies in F, then L, Q, and R parameters are extrapolated as constant values equal to the first/last entries of corresponding vectors.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

Time transient analysis is sensitive to the number of frequency points. Also, time domain measurements may be inaccurate due to non-causal behavior of the model at specified parameter values.

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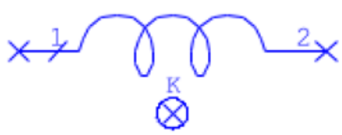
# Inductor with Series Resistive Loss and Optional Coupling (Closed Form): INDRK

## Symbol




## Summary

INDRK implements an ideal inductor in series with a resistor with an option to include coupling to other INDRK and/or INDK elements. The coupling is modeled by other elements (INDM, INDK, or INDRM) connected between the "K" ports of two INDRK (or INDK) elements.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | L1 |
| R | Resistor | Resistance | 0 ohm |
| L | Inductance | Inductance | 1 nH |

## Implementation Details

The INDRK element implements an ideal inductor in series with the resistor and with the option to be mutually coupled to other INDRK/INDK elements. The coupling between two INDRK/INDK elements can be represented by using one of three elements: the INDM element, which represents the mutual inductance between the two INDRK/INDK elements, the INDRM element, which represents the mutual inductance with resistive loss between the two INDRK/INDK elements, or the K element, which represents the coupling coefficient. If nothing is connected to the "K" port of the INDK element, the inductor L is considered ideal (in series with the resistor R.)

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

See "Recommendations for Use" for the INDK model.

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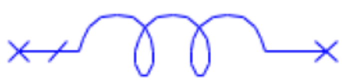
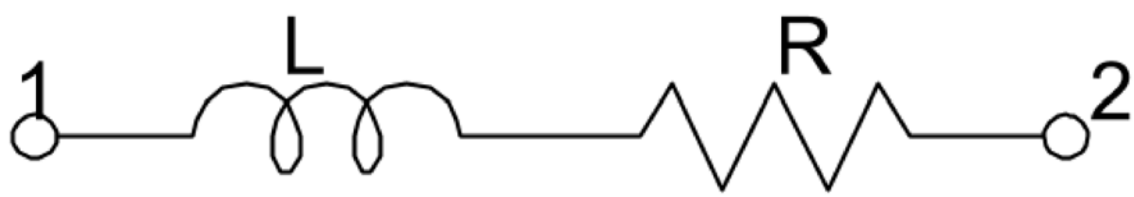
## Inductor With Q (Closed Form): INDQ

### Symbol



### Topology




### Parameters

| Name | Description | Unit Type | Default |
| --- | --- | --- | --- |
| ID | Name | Text | L1 |
| L | Inductance | Inductance | 1 nH |
| Q | Q | | 0 |
| FQ | Frequency at which Q is evaluated | Frequency | 0 GHz |
| ALPH | Scaling factor for Q | | 1 |
| DCMod | DC modeling | Vector text (pull-down) | Lossless |

### Parameter Details

**DCMod.** Specifies the DC behavior of the model. **Lossless** indicates that the model is modeled as an ideal inductor at DC. **Lossy** indicates that loss is taken into account at DC.

## Implementation Details

Implements an inductor with frequency-dependent Q.

$$Q(f) = Q(\frac{f}{\mathrm{FQ}})^{\mathrm{ALPH}}$$

The impedance of the inductor is given by:

$$Z = R + \mathrm{j}\mathrm{X} = 2\pi \mathrm{fL}(\frac{1}{Q(f)} + j)$$

$$\left(Q_L = \frac{X}{R} = \frac{2\pi \mathrm{fL}}{R} \text{ or } R = \frac{2\pi \mathrm{fL}}{Q_L}\right)$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Restrictions

FQ must be greater than or equal to zero.

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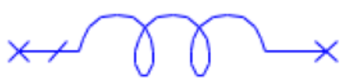
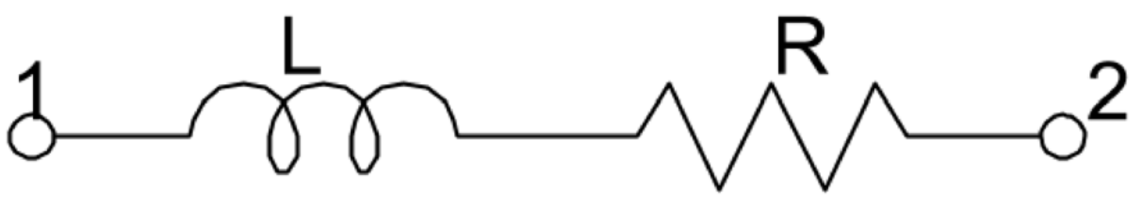
## Inductor With Q (Closed Form): INDQ2

### Symbol



### Topology




### Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | L1 |
| L | Inductance | Inductance | 1 nH |
| Q | Q | | 50 |
| FQ | Frequency at which Q is evaluated | Frequency | 0 .1 GHz |
| *MODE | Loss mode | | Constant |
| RDC | DC resistance | | 0 |

** indicates a secondary parameter*

### Parameter Details

**MODE.** Defines how R behaves as a function of frequency. Choose "Constant", "Proportional to sqrt(freq)", "Proportional to freq", or "Proportional to sqrt(freq), constant L".

**RDC.** The DC resistance (the value of R at 0 Hz). It is used only for the three frequency-dependent modes, not for "Constant" mode.

## Implementation Details

Implements an inductor with frequency-dependent Q.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Restrictions

FQ must be greater than or equal to zero.

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# Inductor Coupling Coefficient (Closed Form): K

## Symbol


## Summary

K is used to represent the mutual coupling between inductors (INDK elements).

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | K2 |
| K | Coupling Coefficienct | | 0 |
| *L1 | Inductor 1 Value | | L@1 nH |
| *L2 | Inductor 2 Value | | L@2 nH |

** indicates a secondary parameter*

## Implementation Details

K represents the mutual coupling between inductors. This element is for use between two INDK elements and should be connected to the "K" ports of those elements. The mutual inductance is calculated as:

$$M = K \cdot \sqrt{L1 \cdot L2}$$

where M is the mutual inductance, K is the coupling coefficient, L1 is the inductance connected at port 1, and L2 is the inductance connected at port 2.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

Figure 1 shows how this element is typically used.

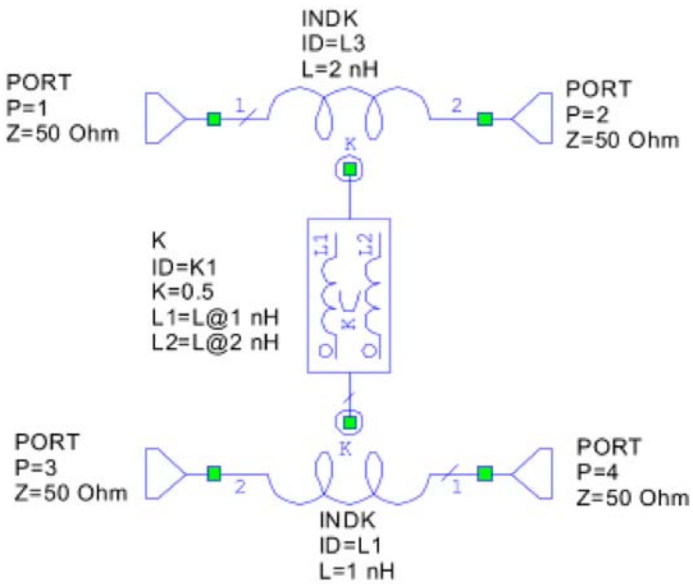


Figure 1. Typical use of the INDK and K elements to model mutual coupling between two inductors. The K element is used to model the mutual coupling between the two INDK elements by specifying the coupling coefficient, K, and the inductances of the two coupled inductors.

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# Mutual Inductance with Resistive Loss (Closed Form): INDRM

## Symbol


## Summary

INDRM is used to represent the mutual coupling between inductors if resistive coupling loss is present (INDK elements).

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | L1 |
| R | Mutual resistance | Resistance | 0 ohm |
| M | Mutual inductance | Inductance | 0 nH |

## Implementation Details

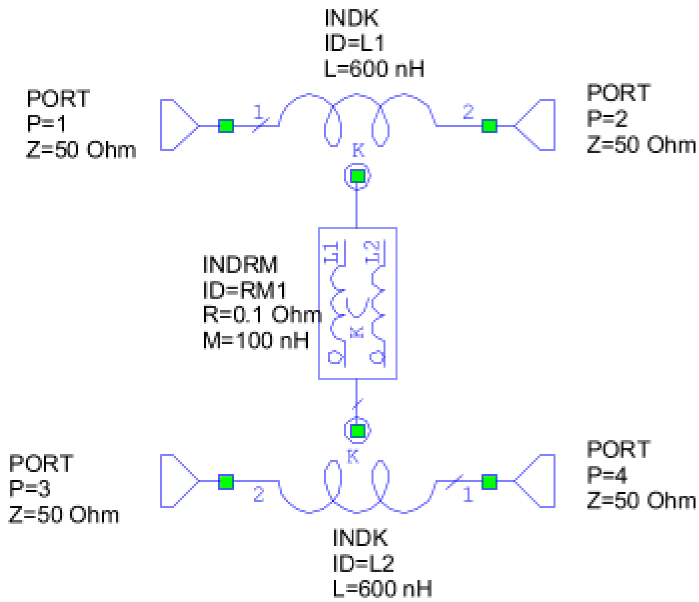
The INDRM element represents the mutual coupling between inductors. Parameter R represents the optional lossy coupling that exists, for example, in coupled Tx lines (R is in series with M). This element is meant to be used between two INDK elements and should be connected to the "K" ports of those elements.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

The following figure shows the typical use of INDK and INDM elements to model mutual coupling between two inductors.




The INDRM element is used to model the mutual coupling between the two INDK elements by specifying an actual mutual inductance and resistance.

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# Measurement Probe: M_PROBE

## Symbol

## Summary

M_PROBE identifies an element terminal for voltage and current measurements of all kinds. You must place it on an element terminal-- it does not measure voltage in the middle of a wire. The advantage of using M_PROBE is that after simulation, you can drag it around a schematic to display the same measurement at different element terminals, without editing a measurement or requiring a new simulation. To move the M_PROBE without dragging, right-click it and choose **Dynamic Probe**, then click any node or terminal to move it there, or double-click on a SUBCKT block to open the lower-level circuit and click to place the probe there. Press the **Esc** key to exit dynamic mode.

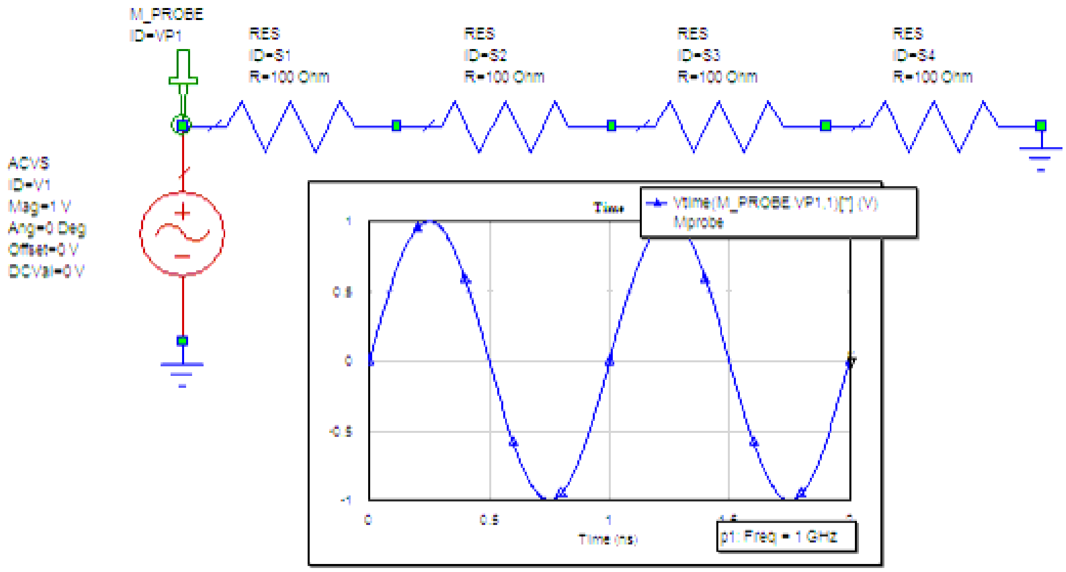
Some measurements such as VTimeD can use two M_PROBEs. To make both of the probes dynamic at the same time, select one probe, **Shift**-click the next one, right-click and choose **Dynamic Probe**. The first probe moves to the position of the mouse click and the second probe moves to the same relative location. If the second probe is not placed where you want it, **Shift**-click at the desired location.

## Parameters

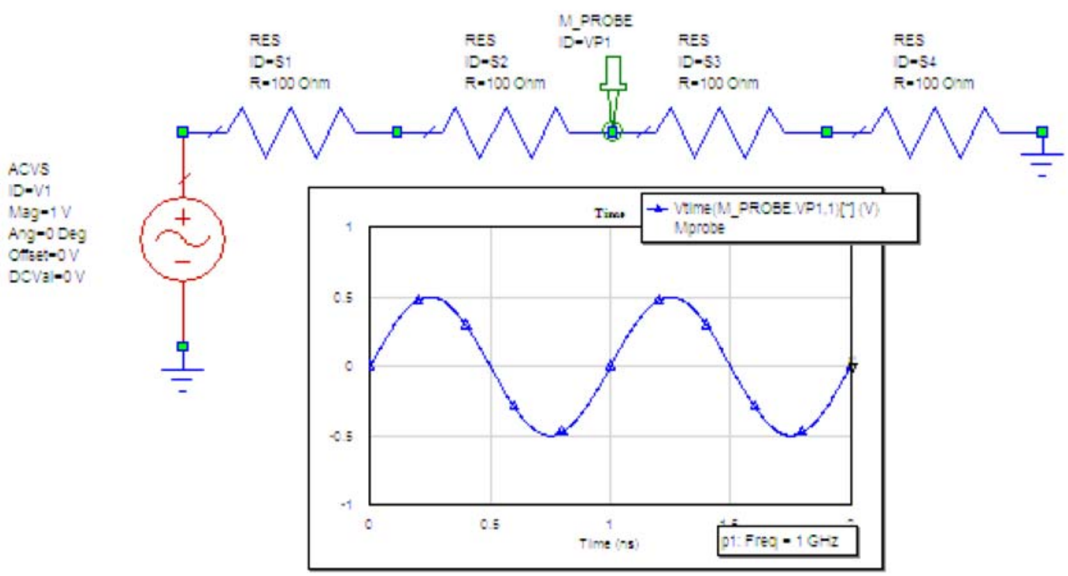
| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Measurement Probe name | Text | VP1 |

## Implementation Details

In the following schematic, the M_PROBE is at the input voltage source.




Click and drag the M_PROBE to move it to a new location to update graphs.




In current measurements, current flowing into the selected element terminal is positive, unless the element is a voltage or current source.

If you set transient simulation options to save results only at meters, the M_PROBE is NOT included in this list since you can change its location without requiring a new simulation.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See "Assigning Artwork Cells to Layout of Schematic Elements" for details.

## Recommendations for Use

In circuit schematics, do not use "pin-to-pin" connections at element terminals where current is measured. In the previous example, you should space the elements apart and connect them by wires for current measurements. The M_PROBE current measurement are ambiguous if the desired element terminal is at the same location as one or more others.

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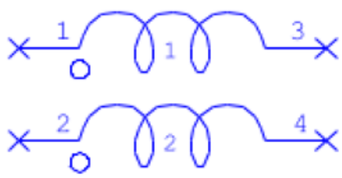
# Mutually Coupled Coils 2 Inductors (Closed Form): MUC2

## Symbol




## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | M1 |
| L1 | Self-inductance of coil 1 | Inductance | 1 nH |
| R1 | Resistance of coil 1 | Resistance | 0 ohm |
| L2 | Self-inductance of coil 2 | Inductance | 1 nH |
| R2 | Resistance of coil 2 | Resistance | 0 ohm |
| K1_2 | Coupling coefficient between coils 1 and 2 | | 0 |

## Implementation Details

$V_{ci}$ is the voltage across coil I, I=1, ...,N:

$$V_{ci} = (R_i + j\omega L_i) \cdot I_i + \sum_{j=1}^{N} j\omega M_{ij} I_j$$

$$M_{ij} = K_{ij} \cdot \sqrt{L_i \cdot L_j}$$

$$L_i > 0$$

$$R_i > 0$$

$$-1 < K_{ij} < 1$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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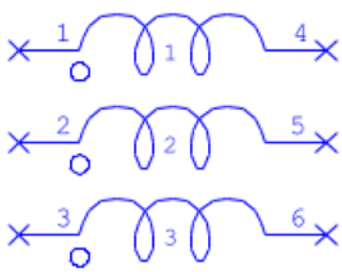
# Mutually Coupled Coils 3 Inductors (Closed Form): MUC3

## Symbol




## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | M1 |
| L1 | Self-inductance of coil 1 | Inductance | 1 nH |
| R1 | Resistance of coil 1 | Resistance | 0 ohm |
| L2 | Self-inductance of coil 2 | Inductance | 1 nH |
| R2 | Resistance of coil 2 | Resistance | 0 ohm |
| L3 | Self-inductance of coil 3 | Inductance | 1 nH |
| R3 | Resistance of coil 3 | Resistance | 0 ohm |
| K1_2 | Coupling coefficient between coils 1 and 2 | | 0 |
| K1_3 | Coupling coefficient between coils 1 and 3 | | 0 |
| K2_3 | Coupling coefficient between coils 2 and 3 | | 0 |

## Implementation Details

$V_{ci}$ is the voltage across coil I, I=1, ...,N:

$$V_{ci} = (R_i + j\omega L_i) \cdot I_i + \sum_{j=1}^{N} j\omega M_{ij} I_j$$

$$M_{\text{ij}} = K_{\text{ij}} \cdot \sqrt{L_i \cdot L_j}$$

$$L_i > 0$$

$$R_i > 0$$

$$-1 < K_{\text{ij}} < 1$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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# Mutual Inductance (Closed Form): INDM

## Symbol


## Summary

INDM is used to represent the mutual coupling between inductors (INDK elements).

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | L1 |
| M | Mutual inductance | Inductance | 1 nH |

## Implementation Details

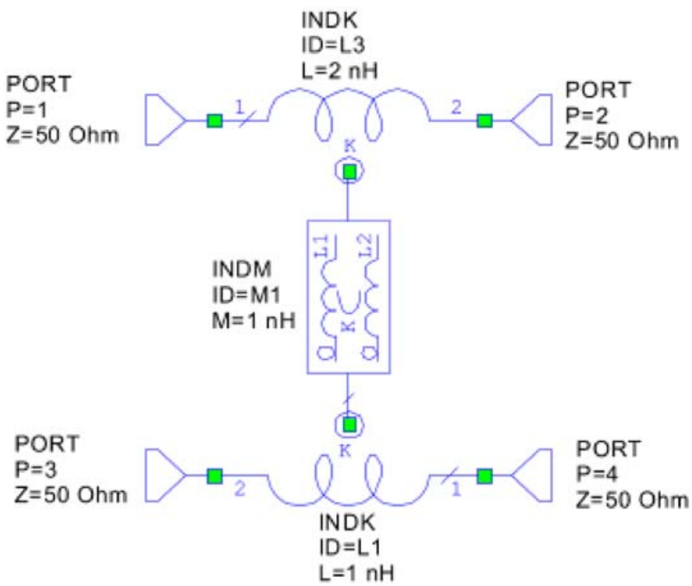
The INDM element represents the mutual coupling between inductors. This element is meant to be used between two INDK elements and should be connected to the "K" ports of those elements.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

The following figure shows a typical use of INDM.




Use of the INDK and INDM elements to model mutual coupling between two inductors. The INDM element is used to model the mutual coupling between the two INDK elements by specifying an actual mutual inductance.

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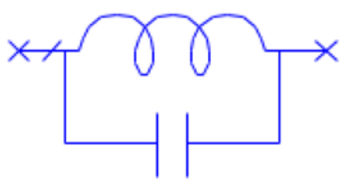
# Parallel LC (Closed Form): PLC

## Symbol



## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | LC1 |
| L | Inductance | Inductance | 1 nH |
| C | Capacitance | Capacitance | 1 pF |

## Implementation Details

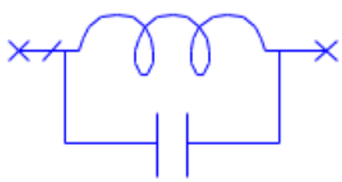
Parallel inductance and capacitance for use in high Q circuits.

## Layout

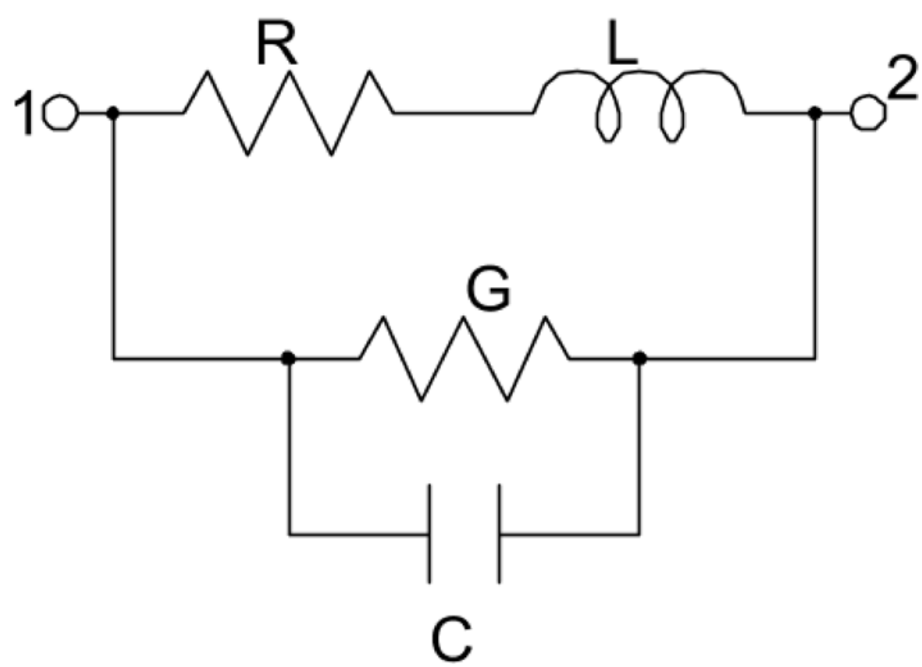
This element does not have an assigned layout cell. You can assign artwork cells to any element. See "Assigning Artwork Cells to Layout of Schematic Elements" for details.

# Parallel LC with Q (Closed Form): PLCQ

## Symbol



## Topology




## Parameters

| Name | Description | Unit Type | Default |
| --- | --- | --- | --- |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | LC1 |
| C | Capacitance | Capacitance | 1 pF |
| QC | Quality factor for capacitor | | 0 |
| FQC | Reference frequency for QC | Frequency | 0 GHz |
| ALPHC | Scaling factor for Qc | | 1 |
| L | Inductance | Inductance | 1 nH |
| QL | Quality factor for inductor | | 0 |
| FQL | Reference frequency for QL | Frequency | 0 GHz |
| ALPHL | Scaling factor for QL | | 1 |
| DCMod | DC modeling | Vector text (pull-down) | Lossless |

## Parameter Details

**DCMod.** Specifies the DC behavior of the model. **Lossless** indicates that the model is modeled as an ideal capacitor in parallel with an ideal inductor at DC. **Lossy** indicates that loss is taken into account at DC.

## Implementation Details

$$\mathrm{QL}(f) = Q\left(\frac{f}{\mathrm{FQL}}\right)^{\mathrm{ALPHL}}$$

$$\mathrm{QC}(f) = Q\left(\frac{f}{\mathrm{FQC}}\right)^{\mathrm{ALPHC}}$$

The admittance of the resonant circuit is given by:

$$Y = 2\pi f C\left(\frac{1}{\mathrm{QC}(f)} + j\right) + \frac{1}{2\pi f L\left(\frac{1}{\mathrm{QL}(f)} + j\right)}$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.



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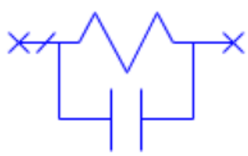
# Parallel RC (Closed Form): PRC

## Symbol



## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | RC1 |
| R | Resistance | Resistance | 1000 ohm |
| C | Capacitance | Capacitance | 1 pF |

## Implementation Details

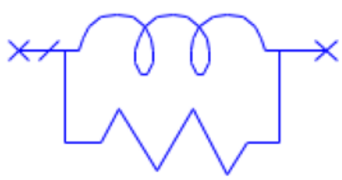
Parallel ideal resistor and capacitor.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

# Parallel RL (Closed Form): PRL

## Symbol



## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | RL1 |
| R | Resistance | Resistance | 1000 ohm |
| L | Inductance | Inductance | 1 nH |

## Implementation Details

Parallel inductance and resistance for use in high Q circuits.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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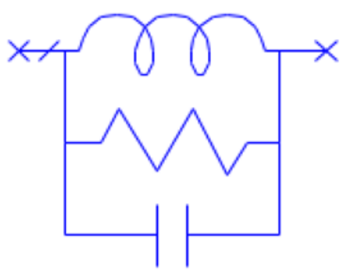
# Parallel RLC (Closed Form): PRLC

## Symbol



## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Name | Text | RLC1 |
| R | Resistance | Resistance | 1000 ohm |
| L | Inductance | Inductance | 1 nH |
| C | Capacitance | Capacitance | 1 pF |

## Implementation Details

Parallel resistance, inductance and capacitance for use in high Q circuits.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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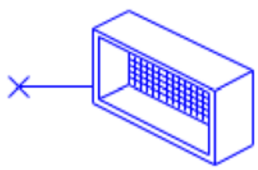
# Rectangular Waveguide Termination (TEmn): RWGT_TEmn

## Symbol



## Summary

RWG_TEmn models an input of a transmission line of infinite length. This line represents an equivalent of a transverse electric waveguide mode of the order mn (TEmn) existing in a rectangular waveguide. The mode may be either propagating or evanescent (non-propagating); waveguide metal has a final conductivity and is filled with lossy dielectric.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| Wa | Width of rectangular waveguide | Length | 22860 um |
| Wb | Height of rectangular waveguide t | Length | 10160 um |
| M | Mode order (along Wa) | | 1 |
| N | Mode order (along Wb | | 0 |
| Er | Relative dielectric constant of dielectric filling the waveguide | | 1 |
| Rho | Metal bulk resistivity of waveguide metal normalized to copper | | 1 |
| Tand | Loss tangent of dielectric filling the waveguide | | 0 |
| *Mur | Relative permeability of dielectric filling the waveguide | | 1 |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| *Tanm | Magnetic loss tangent of dielectric filling the waveguide | | 0 |
| *Sigma | Conductivity of dielectric filling the waveguide | Siemens/m | 0 |
| *ZCalc | Switch - selector of TE10 characteristic impedance definition ("Power-Voltage"/"Voltage-Current"/"Normalized") | | Power-Voltage |

*`* indicates a secondary parameter`*

## Parameter Details

**M, N.** Parameters M and N make a pair of indices that define the TEmn mode selected for modeling. M represents the number of field variation along the dimension Wa; N provides the same relative to Wb.

**Rho.** The bulk resistivity of the waveguide metal. Note that this parameter is dimensionless because it represents the resistivity normalized to that of copper (i.e. to 1.7E-8 ohm/m.)

**Er, Tand, Mur, Tanm, Sigma.** The material properties of media filling the waveguide.

**Zcalc.** Allows you to select a definition of characteristic impedance of the TE10 mode propagating in a rectangular waveguide with dimensions Wa*Wb. Options include "Power-Voltage" ,"Voltage-Current", and "Normalized." This model uses the value of characteristic impedance to denormalize the computed normalized y-matrix of modeled discontinuity. Note that this selection must match the selection of the same parameter in the RWGIRIS_TE10 and RWG_TEmn elements used around the same schematic.

The following characteristic impedance definitions are used [1]:

$$Z_{\text{power-voltage}} = Z\frac{2W_b}{W_a}$$

$$Z_{\text{voltage-current}} = Z\pi\frac{W_b}{2W_a}$$

$$Z = \frac{\eta}{\sqrt{1-(\frac{f_c}{f})^2}}$$

Here, $f_c$ is the cutoff frequency for TE10 and f is the operational frequency; η is the wave impedance of the open space filled with the waveguide dielectric.

$Z_{Normalized}=1$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

This model may be used as a subcircuit referenced in the PORT_TN port. This usage provides a port with a frequency-depended termination.

**NOTE:** Results depend on the selected definition of waveguide characteristic impedance.

Normalized characteristic impedance implies that waveguide mode is propagating. **Never set ZCalc to "Normalized" if your operational frequency gets into below-cutoff region.**

Ensure that the bulk resistivity of waveguide metal is normalized to the correct value of **copper** resistivity (**not gold**).

## References

[1] K. C. Gupta, Ramesh Garg, Rakesh Chadha, Computer Aided Design of Microwave Circuits, Artech House, Mass., 1981.

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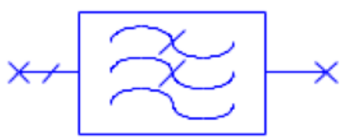
# Raised-Cosine Lowpass Filter (Closed Form): LPFRC

## Symbol



## Summary

LPFRC models represent Raised-Cosine lowpass filters. Raised-Cosine filters are applied in digital transmission system theory to represent ideal (intersymbol interference free) Nyquist filtering of impulse and pulse data transmissions. Hardware designers attempt to design channel filters which approximate these characteristics and have the smallest possible bandwidth.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Filter ID | Text | LPFRC1 |
| FP | Passband corner frequency | Frequency | 1 GHz |
| A | Roll-off factor (between 0 and 1) | | 0.5 |
| TYP | Transmission type | Vector Text(pull-down) | Impulse |
| E | Exponent of the raised-cosine response | | 1. |
| *RS | Expected source resistance | Resistance | 50 ohm |
| *RL | Expected load resistance | Resistance | 50 ohm |

** indicates a secondary parameter*

## Parameter Restrictions and Recommendations

1. $0 < FP$

2. $0 \leq A \leq 1$.

   A minimum bandwidth (A=0) filter would require an infinite number of filter sections. Approximations of a 30% excess Nyquist bandwidth (A=0.3) raised-cosine filter are considered feasible with present-day technology.

3. TYP is either {0,1} .

   TYP = 0 (Impulse) specifies the ideal raised-cosine response, the theoretical filter model for infinitesimally narrow impulses. TYP = 1 (Pulse) specifies a sinc-normalized raised-cosine response, the filter model for rectangular pulse transmission.

4. $0 < E \leq 1$ .

   The ideal raised-cosine response is raised to the exponent, E. For cascaded identical transmit and receive filters, you would typically specify E=0.5 for each filter. The composite channel response of the cascaded filters would be represented by specifying E=1.

5. 0 < RS.

   By definition, the model matches RS at its input port.

6. 0 < RL.

   By definition, the model matches RL at its output port.

## Implementation Details

The model is implemented as a short-circuit admittance matrix,

$$\begin{bmatrix} y_{11} & y_{12} \\ y_{21} & y_{22} \end{bmatrix}$$

, whose equivalent amplitude functions S21 and S12 implement the raised-cosine response for impulse or pulse data transmission, while S11 and S22 are, by definition, constant and matched to the filter port termination resistances (i.e., equal to 1). For impulses,

$$S_{21}(j\omega) = 1 \text{ for } [0 \leq \omega \leq (1-A)]$$

$$S_{21}(j\omega) = \left(\cos^2\left(\left(\frac{\pi}{4}\right)\left(\frac{\omega + A - 1}{A}\right)\right)\right)^E \text{ for } [(1-A) \leq \omega \leq (1+A)]$$

$$S_{21}(j\omega) = 0 \text{ for } [(1+A) \leq \omega]$$

For pulses,

$$S_{21}(j\omega) = 1 \text{ for } [0 \leq \omega \leq (1-A)]$$

$$S_{21}(j\omega) = \frac{\left(\cos^2\left(\left(\frac{\pi}{4}\right)\left(\frac{\omega + A - 1}{A}\right)\right)\right)^E}{\operatorname{sinc}\left(\frac{\pi}{2}\omega\right)} \text{ for } [(1-A) \leq \omega \leq (1+A)]$$

$$S_{21}(j\omega) = 0 \text{ for } [(1+A) \leq \omega]$$

where

$$\operatorname{sinc}(x) = \frac{\sin(x)}{x}$$

$$j = \sqrt{-1}$$

and a lowpass-to-lowpass frequency transformation has been applied:

$$\omega = \frac{\_FREQ}{FP}$$

_FREQ is the variable containing the project frequency, and the admittances are:

$$y_{11} = \left(\frac{1}{RS}\right)\left(\frac{-S_{21}^2(j\omega)}{S_{21}^2(j\omega) - 4}\right)$$

$$y_{22} = \left(\frac{1}{RL}\right)\left(\frac{-S_{21}^2(j\omega)}{S_{21}^2(j\omega) - 4}\right)$$

$$y_{22} = \left(\frac{1}{\sqrt{RS \times RL}}\right)\left(\frac{2S_{21}(j\omega)}{S_{21}^2(j\omega) - 4}\right)$$

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

This model expects that the source impedance equals RS and that the load impedance equals RL, but RS need not equal RL for ideal transmission.

## References

[1] Kamilo Feher, Digital Communications: Microwave Applications, (Prentice-Hall, 1981), pp. 46-51.

[2] John G. Proakis, Digital Communications, 2nd Ed., (McGraw-Hill, 1989), pp. 532-536.

[3] John Bellamy, Digital Telephony, 2nd Ed., (John Wiley & Sons, 1991), pp. 523-528.

[4] E. A. Lee and D. G. Messerschmitt, Digital Communications, 2nd Ed., (Kluwer Academic Publishers, 1994), pp. 188-191, 226-228.

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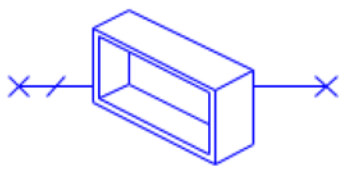
# Rectangular Waveguide (TEmn): RWG_TEmn

## Symbol



## Summary

RWG_TEmn models a transmission line equivalent to a transverse electric waveguide mode of the order mn (TEmn) existing in a section of rectangular waveguide. The mode may be either propagating or evanescent (non-propagating); waveguide metal has a final conductivity and is filled with lossy dielectric.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| Wa | Width of rectangular waveguide | Length | 22860 um |
| Wb | Height of rectangular waveguide t | Length | 10160 um |
| L | Length of rectangular waveguide l | Length | 10000 um |
| M | Mode order (along Wa) | | 1 |
| N | Mode order (along Wb | | 0 |
| Er | Relative dielectric constant filling the waveguide | | 1 |
| Rho | Metal bulk resistivity of waveguide metal normalized to copper | | 1 |
| Tand | Loss tangent of dielectric filling the waveguide | | 0 |
| *Mur | Relative permeability of dielectric filling the waveguide | | 1 |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| *Tanm | Magnetic loss tangent of dielectric filling the waveguide | | 0 |
| *Sigma | Dielectric conductivity of dielectric filling the waveguide | Siemens/m | 0 |
| *ZCalc | Switch - selector of TE10 characteristic impedance definition ("Power-Voltage"/"Voltage-Current"/"Normalized") | | Power-Voltage |

** indicates a secondary parameter*

## Parameter Details

**M, N.** Parameters M and N make a pair of indices that define the TEmn mode selected for modeling. M represents the number of field variation along the Wa dimension; N provides the same relative to Wb.

**Rho.** The bulk resistivity of the waveguide metal. Note that this parameter is dimensionless because it represents the resistivity normalized to that of copper (i.e. to 1.7E-8 ohm/m.)

**Er, Tand, Mur, Tanm, Sigma.** The material properties of media filling the waveguide.

**Zcalc.** Allows you to select a definition of characteristic impedance of the TE10 mode propagating in a rectangular waveguide with dimensions Wa*Wb. Options include "Power-Voltage" ,"Voltage-Current", and "Normalized." The default option is "Power-Voltage." This model uses the value of characteristic impedance to denormalize the computed normalized y-matrix of modeled discontinuity. Note that this selection must match the selection of the same parameter in theRWGIRIS_TE10 and RWGT_TEmn elements used around the same schematic.

The following characteristic impedance definitions are used [1]:

$$Z_{\text{power-voltage}} = Z\frac{2W_b}{W_a}$$

$$Z_{\text{voltage-current}} = Z\pi\frac{W_b}{2W_a}$$

$$Z = \frac{\eta}{\sqrt{1-(\frac{f_c}{f})^2}}$$

Here, $f_c$ is the cutoff frequency for TE10 and f is the operational frequency; η is the wave impedance of the open space filled with the waveguide dielectric.

$Z_{\text{Normalized}}=1$

## Implementation Details

## Circuit Model Synthesis

RWG_TEmn supports synthesis of physical parameters based on electrical specifications using the Transmission Line Calculator. To open the Transmission Line Calculator, right-click a transmission line element in a schematic and choose **Synthesize**.

To perform transmission line synthesis:

1. In the Electrical property grid, select **Target** check boxes for desired electrical parameters and enter a corresponding value.
2. In the Physical property grid, update frequency and substrate parameters if needed, then select **Synthesize** check boxes for transmission line physical parameters to synthesize based on the targets.
3. Click the **Synthesize** left arrow to run the synthesis program. The values in both property grids update with the synthesized results. An analysis is also performed with the final physical values. If synthesis cannot achieve the target values, it shows how close it came.
4. Click **OK** to update the selected transmission line element with the synthesized physical parameters. Expressions are overwritten with the new, evaluated values. You can click the **Undo** button on the program toolbar to revert all parameters in the schematic document to their pre-synthesized state. Parameters from substrate elements are never updated since typically substrate elements are used by more than one transmission line element. Click **Cancel** to close the dialog box without setting the parameters into the element.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

**NOTE:** Results depend on the selected definition of waveguide characteristic impedance.

Normalized characteristic impedance implies that waveguide mode is propagating. **This means: Never set ZCalc to "Normalized" if your operational frequency gets into below-cutoff region.**

Ensure that the bulk resistivity of waveguide metal is normalized to correct the value of **copper** resistivity (**not gold**).

## References

[1] K. C. Gupta, Ramesh Garg, Rakesh Chadha, Computer Aided Design of Microwave Circuits, Artech House, Mass., 1981.

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## Saw Wave Current Source: I_SAW

### Symbol

### Summary

This signal source is superseded and should be replaced with one of the following: AC_V for voltage sources, AC_I for current sources, or PORT_SRC for ports, with the Signal parameter set to this signal type.

The period for tone 1 sources is the inverse of the specified simulation frequency; see “Frequency Sweep Control” for details.

### Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Current source ID | Text | V1 |
| AMP | Signal magnitude | Current | 0 mA |
| TF | Fall time | Time | 0 ns |
| TD | Time delay | Time | 0 ns |
| WINDOW | Window type | | DEFAULT[1] |
| Offset | Waveform offset (does not affect DC) | Current | 0 |
| DCVal | DC value (used for DC analysis) | Current | 0 |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| [1] Window type options are none (NONE), Lanczos (DEFAULT, ref [1]), Triangular (TRIANG), Hanning (HANN), Hamming (HAMM), Blackman (BLACK). See I_PLS for additional details on the WINDOW parameter. | | | |

**NOTE:** AWR® simulators add some series resistance to this element during simulation. This may affect results if injecting current into a large resistance. To change the value of the resistance, choose **Options > Default Circuit Options** to display the Circuit Options dialog box, then click the **AWR Sim** tab and under **Convergence Aids** specify the **Series source resistance**.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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# Saw Wave Voltage Source: V_SAW

## Symbol

## Summary

This signal source is superseded and should be replaced with one of the following: AC_V for voltage sources, AC_I for current sources, or PORT_SRC for ports, with the Signal parameter set to this signal type.

The period for tone 1 sources is the inverse of the specified simulation frequency; see “Frequency Sweep Control” for details.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Voltage source ID | Text | V1 |
| AMP | Open circuit signal magnitude | Voltage | 1 V |
| TF | Fall time | Time | 0 ns |
| TD | Time delay | Time | 0 ns |
| WINDOW | Window type | | DEFAULT[1] |
| Offset | Waveform offset (does not affect DC) | Voltage | 0 |
| DCVal | DC value (used for DC analysis) | Voltage | 0 |

| Name | Description | Unit Type | Default |
|---|---|---|---|

[1] Window type options are none (NONE), Lanczos (DEFAULT, ref [1]), Triangular (TRIANG), Hanning (HANN), Hamming (HAMM), Blackman (BLACK). See I_PLS for additional details on the WINDOW parameter.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See "Assigning Artwork Cells to Layout of Schematic Elements" for details.

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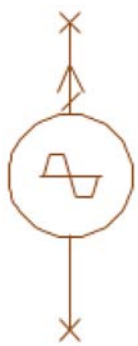
# Square Wave Current Source: I_SQR

## Symbol



## Summary

This signal source is superseded and should be replaced with one of the following: AC_V for voltage sources, AC_I for current sources, or PORT_SRC for ports, with the Signal parameter set to this signal type.

The period for tone 1 sources is the inverse of the specified simulation frequency; see "Frequency Sweep Control" for details.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Current source ID | Text | V1 |
| AMP | Signal magnitude | Current | 0 mA |
| TR | Rise time | Time | 0 ns |
| TF | Fall time | Time | 0 ns |
| TD | Time delay | Time | 0 ns |
| WINDOW | Window type | | DEFAULT[1] |
| Offset | Waveform offset (does not affect DC) | Current | 0 |
| DCVal | DC value (used for DC analysis) | Current | 0 |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| [1] Window type options are none (NONE), Lanczos (DEFAULT, ref [1]), Triangular (TRIANG), Hanning (HANN), Hamming (HAMM), Blackman (BLACK). See I_PLS for additional details on the WINDOW parameter. | | | |

**NOTE:** AWR® simulators add some series resistance to this element during simulation. This may affect results if injecting current into a large resistance. To change the value of the resistance, choose **Options > Default Circuit Options** to display the Circuit Options dialog box, then click the **AWR Sim** tab and under **Convergence Aids** specify the **Series source resistance**.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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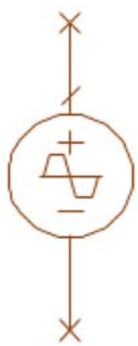
# Square Wave Voltage Source: V_SQR

## Symbol



## Summary

This signal source is superseded and should be replaced with one of the following: AC_V for voltage sources, AC_I for current sources, or PORT_SRC for ports, with the Signal parameter set to this signal type.

The period for tone 1 sources is the inverse of the specified simulation frequency; see “Frequency Sweep Control” for details.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Voltage source ID | Text | V1 |
| AMP | Open circuit signal magnitude | Voltage | 1 V |
| TR | Rise time | Time | 0 ns |
| TF | Fall time | Time | 0 ns |
| TD | Time delay | Time | 0 ns |
| WINDOW | Window type | | DEFAULT[1] |
| Offset | Waveform offset (does not affect DC) | Voltage | 0 |
| DCVal | DC value (used for DC analysis) | Voltage | 0 |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| [1] Window type options are none (NONE), Lanczos (DEFAULT, ref [1]), Triangular (TRIANG), Hanning (HANN), Hamming (HAMM), Blackman (BLACK). See I_PLS for additional details on the WINDOW parameter. | | | |

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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# Triangle Wave Current Source: I_TRI

## Symbol

## Summary

This signal source is superseded and should be replaced with one of the following: AC_V for voltage sources, AC_I for current sources, or PORT_SRC for ports, with the Signal parameter set to this signal type.

The period for tone 1 sources is the inverse of the specified simulation frequency; see "Frequency Sweep Control" for details.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Current source ID | Text | V1 |
| AMP | Signal magnitude | Current | 0 mA |
| TD | Time delay | Time | 0 ns |
| WINDOW | Window type | | DEFAULT[1] |
| Offset | Waveform offset (does not affect DC) | Current | 0 |
| DCVal | DC value (used for DC analysis) | Current | 0 |

[1] Window type options are none (NONE), Lanczos (DEFAULT, ref [1]), Triangular (TRIANG), Hanning (HANN), Hamming (HAMM), Blackman (BLACK). See I_PLS for additional details on the WINDOW parameter.

**NOTE:** AWR® simulators add some series resistance to this element during simulation. This may affect results if injecting current into a large resistance. To change the value of the resistance, choose **Options > Default Circuit Options** to display the Circuit Options dialog box, then click the **AWR Sim** tab and under **Convergence Aids** specify the **Series source resistance**.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

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# Triangle Wave Voltage Source: V_TRI

## Symbol

## Summary

This signal source is superseded and should be replaced with one of the following: AC_V for voltage sources, AC_I for current sources, or PORT_SRC for ports, with the Signal parameter set to this signal type.

The period for tone 1 sources is the inverse of the specified simulation frequency; see “Frequency Sweep Control” for details.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Voltage source ID | Text | V1 |
| AMP | Open circuit signal magnitude | Voltage | 1 V |
| TD | Time delay | Time | 0 ns |
| WINDOW | Window type | | DEFAULT[1] |
| Offset | Waveform offset (does not affect DC) | Voltage | 0 |
| DCVal | DC value (used for DC analysis) | Voltage | 0 |

[1] Window type options are none (NONE), Lanczos (DEFAULT, ref [1]), Triangular (TRIANG), Hanning (HANN), Hamming (HAMM), Blackman (BLACK). See I_PLS for additional details on the WINDOW parameter.

## Layout

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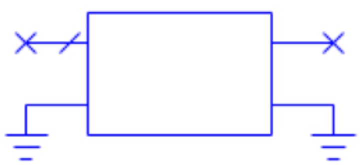
# Two-Port S-Parameter Block: S2P_BLK

## Symbol



## Summary

S2P_BLK models a generalized two-port, S-parameter network. The full two-port S-parameters are specified. Noise is also included.

## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | X1 |
| S11 | S(1,1) | Scalar (Complex) | 0.0 + j*0.0 |
| S21 | S(2,1) | Scalar (Complex) | 0.0 + j*0.0 |
| S12 | S(1,2) | Scalar (Complex) | 0.0 + j*0.0 |
| S22 | S(2,2) | Scalar (Complex) | 0.0 + j*0.0 |
| *Z1 | Port 1 impedance | Scalar (Complex) | 50.0 ohm |
| *Z2 | Port 2 impedance | Scalar (Complex) | 50.0 ohm |
| *NFMIN | Minimum noise figure in dB | dB | 0.0 |
| *GOPT | Optimum noise match | Scalar (Complex) | 0.0 + j*0.0 |

| Name | Description | Unit Type | Default |
|---|---|---|---|
| *RN | Noise resistance | Resistance | 0.0 ohm |
| *ChkPassv | Switch "Do not Check passivity/Check passivity" | | No |

** indicates a secondary parameter*

## Parameter Details

**ChkPassv.** If set to Yes, tests S2P_BLK for passivity and displays a warning if there is a passivity violation. The default setting is No (Do not check passivity).

## Parameter Restrictions and Recommendations

1. Z1 and Z2 must be greater than zero.
2. RN must be greater than the minimum noise resistance, which is calculated from the NFMIN and GOPT parameters using the following formula:

$$\mathrm{RN_{min}} = \frac{10^{\mathrm{NF_{min}}/10} - 1}{4.0 * \mathrm{Re}(Y_{\mathrm{OPT}})}$$

   where YOPT is the optimum noise match admittance calculated from GOPT. If RN is less than RNmin, RN is set equal to RNmin and a warning message is displayed to the user.

## Layout

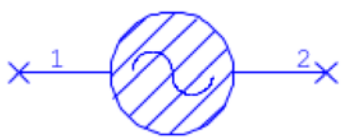
This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.

## Recommendations for Use

The S2P_BLK model can be used to model any general two-port network (passive or active) by specifying the S-parameters and the noise parameters.

# Voltage Noise Source: VNOISE

## Symbol




## Parameters

| Name | Description | Unit Type | Default |
|---|---|---|---|
| ID | Element ID | Text | VN1 |
| V | Noise voltage in nV/sqrt(Hz) | | 0.8949 |

## Implementation Details

VNOISE implements a white noise source having the stated noise spectral density.

For V=0.8949, T=290K in 50Ω.

## Layout

This element does not have an assigned layout cell. You can assign artwork cells to any element. See “Assigning Artwork Cells to Layout of Schematic Elements” for details.