Advanced Design System 1.5
Circuit Components
Distributed Components

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Chapter 1: Finline Components

Finline Model Basis

For each finline component, the model is a rectangular waveguide with the cutoff frequency and the dielectric constant at cutoff modified by the dielectric slab and conducting strip. Conductor and dielectric losses are not included.

Spectral domain numerical results provide the basis for unilateral and bilateral finlines. The quoted accuracy, with respect to spectral domain, are ±0.6 percent for equivalent dielectric constant at cutoff and cutoff wavelength for unilateral finline and ±0.1 percent for phase velocity of bilateral finline. The equations for insulated finlines are analytical curve-fits to numerical results of transmission line matrix analysis (TLM). The cited accuracy for equivalent dielectric constant and cutoff frequency is 0.6 percent compared to the TLM results. All accuracies are for parameter values within the range of usage.
Finline Components

**BFINL (Bilateral Finline)**

**Symbol**

![Symbol Illustration]

**Illustration**

![Illustration]

**Parameters**

- **Subst** = substrate instance name
- **D** = width of gap, in specified units
- **L** = length of finline, in specified units
- **Temp** = physical temperature, in °C

**Range of Usage**

\[
\frac{B}{32} \leq D \leq B
\]

\[
\frac{A}{64} \leq S \leq \frac{A}{8}
\]

where

- **D** = gap width
- **A** = inside enclosure width (from associated FSUB)
- **B** = inside enclosure height (from associated FSUB)
- **S** = thickness of substrate (from associated FSUB)

**Notes/Equations/References**

1. See the section “Finline Model Basis” on page 1-1 at the beginning of this chapter.
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component has no default artwork associated with it.


Finline Components

BFINLT (Bilateral Finline Termination)

Symbol

Illustration

Parameters

Subst = substrate instance name
D = width of gap, in specified units
Temp = physical temperature, in °C

Range of Usage

\[
\frac{B}{32} \leq D \leq B
\]

\[
\frac{A}{64} \leq S \leq \frac{A}{8}
\]

where

D = gap width
A = inside enclosure width (from associated FSUB)
B = inside enclosure height (from associated FSUB)
S = thickness of substrate (from associated FSUB)

Notes/Equations/References

1. See the section “Finline Model Basis” on page 1-1 at the beginning of this chapter.
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component has no default artwork associated with it.


Finline Components

FSUB (Finline Substrate)

Symbol

Illustration

Parameters
Er = substrate dielectric constant
Fdw = thickness of slab, in specified units
Fa = inside width of enclosure, in specified units
Fb = inside height of enclosure, in specified units
Cond = conductor conductivity

Range of Usage
Er ≥ 1.0
Fdw > 0
Fa > 0
Fb > 0
Cond ≥ 0

Notes/Equations/References
1. Refer to the section “Finline Model Basis” on page 1-1 at the beginning of this chapter.
2. FSUB is required for all finline components.


IFINL (Insulated Finline)

Symbol

![Illustration of IFINL](image)

Parameters

Subst = substrate instance name

\( D \) = width of gap, in specified units

\( L \) = length of finline, in specified units

Temp = physical temperature, in °C

Range of Usage

\[
\frac{B}{32} \leq D \leq B \\
\frac{A}{64} \leq S \leq \frac{A}{4}
\]

where

\( D \) = gap width

\( A \) = inside enclosure width (from associated FSUB)

\( B \) = inside enclosure height (from associated FSUB)

\( S \) = thickness of substrate (from associated FSUB)

Notes/Equations/References

1. Refer to the section “Finline Model Basis” on page 1-1 at the beginning of this chapter.

2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component has no default artwork associated with it.


Finline Components

IFINLT (Insulated Finline Termination)

Symbol

Illustration

Parameters

Subst = substrate instance name
D = width of gap, in specified units
Temp = physical temperature, in °C

Range of Usage

\[
\frac{B}{32} \leq D \leq B
\]

\[
\frac{A}{64} \leq S \leq \frac{A}{4}
\]

where

D = gap width
A = inside enclosure width (from associated FSUB)
B = inside enclosure height (from associated FSUB)
S = thickness of substrate (from associated FSUB)

Notes/Equations/References

1. Refer to the section “Finline Model Basis” on page 1-1 at the beginning of this chapter.
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component has no default artwork associated with it.


Finline Components

UFINL (Unilateral Finline)

Symbol

Illustration

Parameters

Subst = substrate instance name
D = width of gap, in specified units
L = length of finline, in specified units
Temp = physical temperature, in °C

Range of Usage

\[
\frac{B}{32} \leq D \leq B
\]

\[
\frac{A}{64} \leq S \leq \frac{A}{4}
\]

where

D = gap width
A = inside enclosure width (from associated FSUB)
B = inside enclosure height (from associated FSUB)
S = thickness of substrate (from associated FSUB)

Notes/Equations/References

1. Refer to the section “Finline Model Basis” on page 1-1 at the beginning of this chapter.
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component has no default artwork associated with it.


Finline Components

UFINLT (Unilateral Finline Termination)

Symbol

Illustration

Parameters
Subst = substrate instance name
D = width of gap, in specified units
Temp = physical temperature, in °C

Range of Usage

\[
\frac{B}{32} \leq D \leq B
\]
\[
\frac{A}{64} \leq S \leq \frac{A}{4}
\]

where
D = gap width
A = inside enclosure width (from associated FSUB)
B = inside enclosure height (from associated FSUB)
S = thickness of substrate (from associated FSUB)

Notes/Equations/References
1. Refer to the section “Finline Model Basis” on page 1-1 at the beginning of this chapter.
2. For time-domain analysis, the frequency-domain analytical model is used.
3. This component has no default artwork associated with it.


Finline Components
Chapter 2: Microstrip Components
MACLIN (Microstrip Asymmetric Coupled Lines)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W1 = width of conductor 1, in specified units
W2 = width of conductor 2, in specified units
S = conductor spacing, in specified units
L = conductor length, in specified units
Temp = physical temperature, in °C
WA = (for Layout Option) width of line that connects to pin 1
WB = (for Layout Option) width of line that connects to pin 2
WC = (for Layout Option) width of line that connects to pin 3
WD = (for Layout Option) width of line that connects to pin 4

Range of Usage
1 ≤ Er ≤ 18
T ≥ 0
0.1 × H ≤ W1 ≤ 10.0 × H
0.1 × H ≤ W2 ≤ 10.0 × H
0.1 \times H \leq S \leq 10.0 \times H

\text{Er} = \text{dielectric constant (from associated Subst)}

H = \text{substrate thickness (from associated Subst)}

T = \text{conductor thickness (from associated Subst)}

\text{Simulation frequency} \leq \frac{25}{H (\text{mm})} \text{ (GHz)}

W_1 > 0, W_2 > 0, S > 0, L > 0 \text{ for layout}

W_A \geq 0, W_B \geq 0, W_C \geq 0, W_D \geq 0

\textbf{Notes/Equations/References}

1. The frequency-domain analytical model is a distributed, coupled-line model. The even- and odd-mode characteristics of the microstrip lines are calculated using the formula developed by Kirschning and Jansen for parallel coupled microstrip lines, and the formula developed by Hammerstad and Jensen for single microstrip line. Dispersion of the effective dielectric constant is included. The per-unit-length coupling capacitances are then derived for the asymmetric case using a model developed for Agilent by Vijai Tripathi. The even- and odd-mode impedance and admittance matrices are calculated based on the coupling capacitances. The result is used to calculate the network parameters of the distributed, coupled-line model by Tripathi’s method. Conductor losses are ignored.

2. To turn off noise contribution, set Temp to \(-273.15^\circ\text{C}\).

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. In generating a layout, adjacent transmission lines will be lined up with the inner edges of the conductor strips; if the connecting transmission lines are narrower than the coupled lines, they will be centered on the conductor strips.


Microstrip Components


MACLIN3 (Microstrip 3-Conductor Asymmetric Coupled Lines)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W1 = width of conductor 1, in specified units
W2 = width of conductor 2, in specified units
W3 = width of conductor 3, in specified units
S1 = spacing between conductors 1 and 2, in specified units
S2 = spacing between conductors 2 and 3, in specified units
L = conductor length, in specified units
Temp = physical temperature, in °C
WA = (for Layout Option) width of line that connects to pin 1
WB = (for Layout Option) width of line that connects to pin 2
WC = (for Layout Option) width of line that connects to pin 3
WD = (for Layout Option) width of line that connects to pin 4
Microstrip Components

Range of Usage

\[ 0.1 \times H \leq W_1 \leq 10.0 \times H \]
\[ 0.1 \times H \leq W_2 \leq 10.0 \times H \]
\[ 0.1 \times H \leq W_3 \leq 10.0 \times H \]
\[ 0.1 \times H \leq S_1 \leq 10.0 \times H \]
\[ 0.1 \times H \leq S_2 \leq 10.0 \times H \]
\[ 1.01 \leq E_r \leq 18 \]
\[ T \geq 0 \]

where

\[ E_r = \text{dielectric constant (from associated Subst)} \]
\[ H = \text{substrate thickness (from associated Subst)} \]
\[ T = \text{conductor thickness (from associated Subst)} \]

Simulation frequency \( \leq \frac{25}{H \text{(mm)}} \) (GHz)

\[ W_1 > 0, W_2 > 0, W_3 > 0, S_1 > 0, S_2 > 0, L > 0 \quad \text{for layout} \]
\[ W_A \geq 0, W_B \geq 0, W_C \geq 0, W_D \geq 0 \]

Notes/Equations/References

1. The frequency-domain analytical model is a distributed, coupled-line model. The even- and odd-mode characteristics of the microstrip lines are calculated using the formula developed by Kirschning and Janssen for parallel coupled microstrip lines, and the formula developed by Hammerstad and Jensen for single microstrip line. The per-unit-length coupling capacitances are then derived for the asymmetric case using a model developed for Agilent by Vijai Tripathi. The even- and odd-mode impedance and admittance matrices are calculated based on the coupling capacitances. The result is used to calculate the network parameters of the distributed, coupled-line model by Tripathi's method. Conductor loss and dispersion are ignored.

2. To turn off noise contribution, set Temp to \(-273.15^\circ C\).

3. In generating a layout, adjacent transmission lines will be lined up with inner edges of the conductor strips at pins 1, 3, 4 and 6. If the connecting transmission lines are narrower than the coupled lines, they will be centered on
the conductor strips. At pins 2 and 5, the assumption is that the abutting transmission lines are narrower or the same width as the center coupled line.


Microstrip Components

MBEND (Microstrip Bend (Arbitrary Angle/Miter))

Symbol

Illustration

"SMALL" MITERS
\[ M < M_s \]
\[ \omega = \frac{X}{D} \]
\[ M_s = \sin^2 \left( \frac{\text{Angle}}{2} \right) \]

"LARGE" MITERS
\[ M \geq M_s \]

Parameters
Subst = microstrip substrate name
W = conductor width, in specified units
Angle = angle of bend, in degrees
M = miter fraction \( M = \frac{X}{D} \)
Temp = physical temperature, in °C

Range of Usage
\[ 1 \leq E_r \leq 128 \]
\[ -90^\circ \leq \text{Angle} \leq 90^\circ \]
$0.01 \leq \frac{W}{H} \leq 100$

where

- $\varepsilon_r =$ dielectric constant (from associated Subst)
- $H =$ substrate thickness (from associated Subst)
- $W \geq 0$ for layout
- $\text{Angle} =$ any value for layout

Notes/Equations/References

1. For the unmitered, 90° condition, the frequency-domain analytical model is the lumped component, right-angle bend model proposed by Gupta et al. Otherwise, the lumped component model proposed by Jansen is used. The Hammerstad and Jensen microstrip formulas are used to calculate reference plane shifts in the Jansen model. Dispersion and conductor loss are not included in the model.

2. For right-angle bends, use MBEND2, MBEND3, or MCORN.

3. Two possible reference plane locations are available:
   - Small miters where the reference planes line up with the inner corner of the bend, or
   - Large miters where the reference planes line up with the corner between the connecting strip and the mitered section

4. To turn off noise contribution, set Temp to $-273.15°C$.

5. In layout, a positive value for Angle draws a bend in the counterclockwise direction from pin 1 to 2; a negative value for Angle draws a bend in the clockwise direction.


Equivalent Circuit
MBEND2 (90-degree Microstrip Bend (Mitered))

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = conductor width, in specified units
Temp = physical temperature, in °C

Range of Usage

\[ 0.2 \leq \frac{W}{H} \leq 6.0 \]

\[ 2.36 \leq Er \leq 10.4 \]

Simulation frequency \( \leq \frac{12}{H (\text{mm})} \) (GHz)

where

- \( Er \) = dielectric constant (from associated Subst)
- \( H \) = substrate thickness (from associated Subst)
- \( W \geq 0 \) for layout

Notes/Equations/References

1. The frequency-domain model is an empirically-based analytical model that consists of a static, lumped, equivalent circuit. The equivalent circuit
Microstrip Components

parameters are calculated based on the expressions developed by Kirschning, Jansen and Koster according to the following formula.

\[
\frac{C}{H} = \frac{W}{H} \left[ 7.6 \varepsilon_r + 3.8 + \frac{W}{H} (3.93 \varepsilon_r + 0.62) \right] \text{ pF/m}
\]

\[
\frac{L}{H} = 441.2712 \left\{ 1 - 1.062 \exp \left( -0.177 \left( \frac{W}{H} \right)^{0.947} \right) \right\} \text{ nH/m}
\]

2. To turn off noise contribution, set Temp to \(-273.15^\circ\text{C}\).


Equivalent Circuit

![Equivalent Circuit Diagram]
MBEND3 (90-degree Microstrip Bend (Optimally Mitered))

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = conductor width, in specified units
Temp = physical temperature, in °C

Range of Usage

\[0.5 \leq \frac{W}{H} \leq 2.75\]
\[2.5 \leq \varepsilon_r \leq 25\]

Simulation frequency \[\leq \frac{15}{H(\text{mm})}\] (GHz)

where
\[\varepsilon_r = \text{dielectric constant (from associated Subst)}\]
\[H = \text{substrate thickness (from associated Subst)}\]
\[W \geq 0 \quad \text{for layout}\]
Microstrip Components

Notes/Equations/References

1. The frequency-domain model is an empirically based, analytical model. The optimal chamfered bend dimensions are calculated based on the expression developed by Douville and James. The resulting bend is modeled as a matched transmission line of length, $2\Delta l_0$. This length is calculated from curve fits to the graphical data given in the references. In addition, dispersion is accounted for in the transmission line model. Conductor losses are ignored.

2. Optimum miter is given by:

$$\frac{X}{D} = 0.52 + 0.65 \times e^{(-1.35 \times (W/H))}$$

where

$$H = \text{substrate thickness}$$

3. To turn off noise contribution, set Temp to $-273.15^\circ C$.


Equivalent Circuit

![Equivalent Circuit Diagram](image-url)
MBSTUB (Microstrip Butterfly Stub)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = width of feed line, in specified units
Ro = outer radius of circular sector, in specified units
Angle = angle subtended by circular sector, in degrees
D = insertion depth of circular sector in feed line, in specified units
Temp = physical temperature, in °C

Range of Usage

\[ 0.01 \leq \frac{W}{H} \leq 100 \]
Microstrip Components

\[ \text{Ro} > \frac{D}{\cos(\text{Angle}/2)} \]

\text{Angle} < 90

where

\[ H = \text{substrate thickness (from associated Subst)} \]

Notes/Equations/References

1. The frequency-domain analytical model accounts for conductor and dielectric losses.

2. It is assumed that only TM_{on} radial modes are excited. This requires Angle to be less than 90 degrees.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to \(-273.15\,^\circ C\).


MCFIL (Microstrip Coupled-Line Filter Section)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = line width, in specified units
S = spacing between lines, in specified units
L = line length, in specified units
Temp = physical temperature, in °C
W1 = (for Layout Option) width of line that connects to pin 1
W2 = (for Layout Option) width of line that connects to pin 2

Range of Usage

\[
0.1 \leq \frac{W}{H} \leq 10
\]

\[
0.1 \leq \frac{S}{H} \leq 10
\]

\[
1 \leq E_r \leq 18
\]
Microstrip Components

Simulation frequency ≤ \( \frac{25}{H} \text{(mm)} \) (GHz)

where
- \( \varepsilon_r \) = dielectric constant (from associated Subst)
- \( H \) = substrate thickness (from associated Subst)
- \( W \geq 0, S \geq 0, L \geq 0 \) for layout
- \( W_1 \geq 0, W_2 \geq 0 \)

Notes/Equations/References

1. The frequency-domain analytical model is a distributed, coupled-line model. The per-unit-length coupling capacitances are calculated using the formula developed by Kirschning and Jansen for parallel coupled microstrip lines, and the formula developed by Hammerstad and Jensen for single microstrip line. Dispersion, end effect, and conductor loss are included. The even- and odd-mode line impedances are calculated based on the coupling capacitances and conductor losses. The result is used to calculate the network parameters of the distributed, coupled-line model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to −273.15°C.

4. In generating a layout, adjacent transmission lines will be lined up with the inner edges of the conductor strips. If the connecting transmission lines are narrower than the coupled lines, they will be centered on the conductor strips.


MCLIN (Microstrip Coupled Lines)

Symbol

Illustration

Parameters

Subst = microstrip substrate name
W = line width, in specified units
S = space between lines, in specified units
L = line length, in specified units
Temp = physical temperature, in °C
W1 = (for Layout Option) width of line that connects to pin 1
W2 = (for Layout Option) width of line that connects to pin 2
W3 = (for Layout Option) width of line that connects to pin 3
W4 = (for Layout Option) width of line that connects to pin 4

Range of Usage

\[ 0.1 \times H \leq W \leq 10.0 \times H \]
\[ 0.1 \times H \leq S \leq 10.0 \times H \]
\[ 1 \leq Er \leq 18 \]
\[ T \geq 0 \]
Microstrip Components

Simulation frequency \( \leq \frac{25}{H \text{(mm)}} \) (GHz)

where

- \( E_r \) = dielectric constant (from associated Subst)
- \( H \) = substrate thickness (from associated Subst)
- \( T \) = conductor thickness (from associated Subst)
- \( W \geq 0, S \geq 0, L \geq 0 \) for layout
- \( W_1 \geq 0, W_2 \geq 0, W_3 \geq 0, W_4 \geq 0 \)

**Notes/Equations/References**

1. The frequency-domain analytical model is a distributed, coupled-line model. The per-unit-length coupling capacitances are calculated using the formula developed by Kirschning and Jansen for parallel coupled microstrip lines, and the formula developed by Hammerstad and Jensen for single microstrip line. Dispersion and conductor loss are included. The even- and odd-mode line impedances are calculated based on the coupling capacitances and conductor losses. The result is used to calculate the network parameters of the distributed, coupled-line model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to \(-273.15^\circ\text{C}\).

4. In generating a layout, adjacent transmission lines will be lined up with the inner edges of the conductor strips. If the connecting transmission lines are narrower than the coupled lines, they will be centered on the conductor strips.


MCORN 90-degree Microstrip Bend (Unmitered)

Symbol

Illustration

Parameters

Subst = microstrip substrate name
W = conductor width, in specified units
Temp = physical temperature, in °C

Range of Usage

\[ 0.2 \leq \frac{W}{H} \leq 6.0 \]

\[ 2.36 \leq E_r \leq 10.4 \]

Simulation frequency \( \leq \frac{12}{H \text{(mm)}} \) (GHz)

where

\( E_r = \) dielectric constant
\( H = \) substrate thickness
Notes/Equations/References

1. The frequency-domain model is an empirically based, analytical model which consists of a static, lumped, equivalent circuit. The equivalent circuit parameters are calculated based on the expressions developed by Kirschning, Jansen and Koster according to the following formula.

\[
\frac{C}{\mu} = \frac{W}{H} \left[ 2.6\varepsilon_r + 5.64 + \frac{W}{H} (10.35\varepsilon_r + 2.5) \right] \text{ pF/m}
\]

\[
\frac{L}{\mu} = 220.6356 \left\{ 1 - 1.35 \exp \left[ -0.18 \left( \frac{W}{H} \right)^{1.39} \right] \right\} \text{ nH/m}
\]

2. To turn off noise contribution, set Temp to $-273.15^\circ C$.


Equivalent Circuit

![Equivalent Circuit Diagram]
MCROS (Microstrip Cross-Junction)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W1 = conductor width of line at pin 1, in specified units
W2 = conductor width of line at pin 2, in specified units
W3 = conductor width of line at pin 3, in specified units
W4 = conductor width of line at pin 4, in specified units

Range of Usage
$0.25 \leq \frac{W_i}{H} \leq 8$

where
H = substrate thickness (from associated Subst)
Er $\leq 50$
Notes/Equations/References

1. This microstrip cross model is derived by curve fitting the results of microstrip cross simulations of an Agilent internal electromagnetic field solver. The new microstrip cross model can be applied to the most commonly used substrates including duriod, alumina, and GaAs. The range of validity of the model is further extended for use in microwave and RF circuit design applications.

   The inductance equations are invariant to the relative dielectric constant on the substrate. Dispersion and conductor loss are not included.

2. To turn off noise contribution, set Temp to $-273.15^\circ C$.

3. In layout, all pins are centered at the corresponding edges.


Equivalent Circuit

![Equivalent Circuit Diagram]
MCROSO (Obsolete Libra Microstrip Cross-Junction)

Symbol

![Symbol Image]

Illustration

![Illustration Image]

Parameters

Subst = microstrip substrate name

\[ W_1 = \text{conductor width of line at pin 1, in specified units} \]
\[ W_2 = \text{conductor width of line at pin 2, in specified units} \]
\[ W_3 = \text{conductor width of line at pin 3, in specified units} \]
\[ W_4 = \text{conductor width of line at pin 4, in specified units} \]

Temp = physical temperature, in °C

Range of Usage

\[ 0.4 \leq W_i/H \leq 2.5 \]

where

\[ H = \text{substrate thickness (from associated Subst)} \]
Notes/Equations/References

1. The frequency-domain model is an empirically based, analytical model that consists of a static, lumped, equivalent circuit. The equivalent circuit parameters are calculated based on the expressions developed by Gupta et al. The capacitance equations are modified to take into account the relative dielectric constant of the material according to the following formula.

\[
C_x(\varepsilon_r = \varepsilon_{r_{sub}}) = C_x(\varepsilon_r = 9.9) \left[ \frac{Z_0(\varepsilon_r = 9.9, w=Wx)}{Z_0(\varepsilon_r = \varepsilon_{r_{sub}}, w=Wx)} \right] \frac{\varepsilon_{eff}(\varepsilon_r = \varepsilon_{r_{sub}}, w=Wx)}{\varepsilon_{eff}(\varepsilon_r = 9.9, w=Wx)}
\]

The inductance equations are invariant to the relative dielectric constant on the substrate. Dispersion and conductor loss are not included.

2. To turn off noise contribution, set Temp to $-273.15^\circ C$.

3. In layout, all pins are centered at the corresponding edges.

MCURVE (Microstrip Curved Bend)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = conductor width, in specified units
Angle = angle subtended by the bend, in degrees
Radius = radius (measured to strip centerline), in specified units
Temp = physical temperature, in °C

Range of Usage
0.01 × H ≤ W ≤ 100 × H
−180° ≤ Angle ≤ 180°
Radius ≥ W/2
where
   H = substrate thickness (from associated Subst)
Notes/Equations/References

1. The microstrip curved bend is modeled in the frequency domain as an equivalent piece of straight microstrip line. The microstrip line is modeled using the MLIN component, including conductor loss, dielectric loss and dispersion. A correction for finite line thickness is applied to the line width.

   The length of the equivalent straight microstrip section is equal to the product of the centerline radius and the angle in radians.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to $-273.15^\circ C$.

4. In layout, a positive value for Angle specifies a counterclockwise curvature; a negative value specifies a clockwise curvature.
MCURVE2 (Microstrip Curved Bend)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = conductor width, in specified units
Angle = angle of bend, in degrees
Radius = radius (measured to strip centerline), in specified units
NMode = number of modes (see notes)
Temp = physical temperature, in °C

Range of Usage
0.01 × H ≤ W ≤ 100 × H
-360° ≤ Angle ≤ 360°
W ≤ Radius ≤ 100 × W
NMode = 0, 1, 2, ....

where
Microstrip Components

H = substrate thickness (from associated Subst)

Notes/Equations/References
1. The frequency-domain analytical model is based on a magnetic wall waveguide model developed by Weisshaar and Tripathi. The model includes the effect of higher order modes of propagation. Conductor loss, dielectric loss, and dispersion of both effective dielectric constant and characteristic impedance are also included.

2. NMode=1 or, at most, NMode=2 should usually provide satisfactory accuracy. Increasing NMode for improving accuracy results in significantly increased simulation time and additional memory requirements.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to −273.15°C.

5. In layout, a positive value for Angle specifies a counterclockwise curvature; a negative value specifies a clockwise curvature.


MGAP (Microstrip Gap)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = conductor width, in specified units
S = length of gap (spacing), in specified units
Temp = physical temperature, in °C

Range of Usage
1 ≤ Er ≤ 15
0.1 ≤ W/H ≤ 3.0
0.2 ≤ S/H

where
Er = dielectric constant (from associated Subst)
H = substrate thickness (from associated Subst)

Notes/Equations/References
1. The frequency-domain model is an empirically based, analytical model that consists of a lumped component, equivalent circuit. The equivalent circuit parameters are calculated based on the expressions developed by Kirschning, Jansen and Koster. Dispersion is included in the capacitance calculations.
2. This new version of the MGAP component improves the simulation accuracy of gap capacitance.

3. To turn off noise contribution, set Temp to $-273.15\,^\circ C$.


**Equivalent Circuit**

![Equivalent Circuit Diagram]

---

2-32  MGAP (Microstrip Gap)
MICAP1 (Microstrip Interdigital Capacitor (2-port))

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = finger width, in specified units
G = gap between fingers, in specified units
Ge = gap at end of fingers, in specified units
L = length of overlapped region, in specified units
Np = number of finger pairs (an integer)
Wt = width of interconnect, in specified units
Wf = width of feedline, in specified units
Temp = physical temperature, in °C

Range of Usage
Er ≤ 12.5
T ≤ 0.015 × H
Microstrip Components

\[0.05 \times H \leq W \leq 0.8 \times H\]
\[0.025 \times H \leq G \leq 0.45 \times H\]

Simulation frequency \(\leq \frac{2.4}{H \text{(mm)}}\) (GHz)

where
\[E_r = \text{dielectric constant (from associated Subst)}\]
\[H = \text{substrate thickness (from associated Subst)}\]
\[T = \text{conductor thickness (from associated Subst)}\]

Notes/Equations/References

1. The frequency-domain analytical model is a distributed, coupled-line model developed for Agilent by William J. Getsinger. References [6], [7], and [8] are supplemental.

The digits of the structure are assumed to be part of an infinite array excited on an even- and odd-mode basis. Each component in this array is a unit cell bounded by magnetic walls. The model calculates the per-unit-length admittance and impedance matrices (even and odd modes) for each cell. This calculation is based on the even and odd mode capacitances, the conductor loss and the substrate dielectric loss. The capacitances are calculated by a conformal mapping technique. Conductor losses are calculated using Wheeler’s method. Corrections for finite strip thickness and end effects are included. Network parameters of the transmission line model of each cell are calculated from the admittance and impedance matrices. The cells are combined to from the complete model including end effects. Microstrip dispersion effects are included in this model.

2. This component is intended for series connection.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to \(-273.15^\circ\text{C}\).


MICAP2 (Microstrip Interdigital Capacitor (4-port))

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = finger width, in specified units
G = gap between fingers, in specified units
Ge = gap at end of fingers, in specified units
L = length of overlapped region, in specified units
Np = number of finger pairs (an integer)
Wt = width of interconnect, in specified units
Temp = physical temperature, in °C

Range of Usage
Er ≤ 12.5
T ≤ 0.015 × H
0.05 × H ≤ W ≤ 0.8 × H
0.025 \times H \leq G \leq 0.45 \times H

\text{Simulation frequency} \leq \frac{2.4}{H \text{(mm)}} \text{ (GHz)}

where

\begin{align*}
\text{Er} &= \text{dielectric constant (from associated Subst)} \\
H &= \text{substrate thickness (from associated Subst)} \\
T &= \text{conductor thickness (from associated Subst)}
\end{align*}

\text{Notes/Equations/References}

1. The frequency-domain analytical model is a distributed, coupled-line model developed for Agilent by William J. Getsinger. References [6], [7], and [8] are supplemental.

   The digits of the structure are assumed to be part of an infinite array excited on an even- and odd-mode basis. Each component in this array is a unit cell bounded by magnetic walls. The model calculates the per-unit-length admittance and impedance matrices (even and odd modes) for each cell. This calculation is based on the even and odd mode capacitances, the conductor loss and the substrate dielectric loss. The capacitances are calculated by a conformal mapping technique. Conductor losses are calculated using Wheeler's method. Corrections for finite strip thickness and end effects are included. Network parameters of the transmission line model of each cell are calculated from the admittance and impedance matrices. The cells are combined to form the complete model including end effects. Microstrip dispersion effects are included in this model.

2. This component is used when a cascade configuration is not appropriate.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to $-273.15^\circ C$.


Microstrip Components

MICAP3 (Microstrip Interdigital Capacitor (1-port))

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = finger width, in specified units
G = gap between fingers, in specified units
Ge = gap at end of fingers, in specified units
L = length of overlapped region, in specified units
Np = number of finger pairs (an integer)
Wt = width of interconnect, in specified units
Wf = width of the feedline, in specified units
Temp = physical temperature, in °C

Range of Usage
Er ≤ 12.5
T ≤ 0.015 × H
0.05 × H ≤ W ≤ 0.8 × H
Microstrip Components

\[ 0.025 \times H \leq G \leq 0.45 \times H \]

Simulation frequency \( \leq \frac{2.4}{H \text{(mm)}} \) (GHz)

where

- \( E_r = \) dielectric constant (from associated Subst)
- \( H = \) substrate thickness (from associated Subst)
- \( T = \) conductor thickness (from associated Subst)

Notes/Equations/References

1. The frequency-domain analytical model is a distributed, coupled-line model developed for Agilent by William J. Getsinger. References [7], [8], and [9] are supplemental.

   The digits of the structure are assumed to be part of an infinite array excited on an even- and odd-mode basis. Each component in this array is a unit cell bounded by magnetic walls. The model calculates the per-unit-length admittance and impedance matrices (even and odd modes) for each cell. This calculation is based on the even and odd mode capacitances, the conductor loss and the substrate dielectric loss. The capacitances are calculated by a conformal mapping technique. Conductor losses are calculated using Wheeler's method. Corrections for finite strip thickness and end effects are included. Network parameters of the transmission line model of each cell are calculated from the admittance and impedance matrices. The cells are combined to form the complete model including end effects. Microstrip dispersion effects are included in this model.

2. This is a 1-port configuration of MICAP1 for use where one side of the interdigital capacitor is connected to ground.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to \(-273.15^\circ C\).

5. Proper grounding must be added manually in the layout. The implied ground plane is drawn on the layer mapped to the Hole parameter in the MSUB component. The ground plane is for modeling in Momentum and is not modeled separately in the circuit simulator.


## MICAP4 (Microstrip Interdigital Capacitor (Grounded 2-port))

### Symbol

![MICAP4 Symbol](image)

### Illustration

![MICAP4 Illustration](image)

### Parameters

- **Subst** = microstrip substrate name
- **W** = finger width, in specified units
- **G** = gap between fingers, in specified units
- **Ge** = gap at end of fingers, in specified units
- **L** = length of overlapped region, in specified units
- **Np** = number of finger pairs (an integer)
- **Wt** = width of interconnect, in specified units
- **Temp** = physical temperature, in °C

### Range of Usage

- **Er** ≤ 12.5
- **T** ≤ 0.015 × H

---

*2-42  MICAP4 (Microstrip Interdigital Capacitor (Grounded 2-port))*
0.05 \times H \leq W \leq 0.8 \times H
0.025 \times H \leq G \leq 0.45 \times H

Simulation frequency \leq \frac{2.4}{H (\text{mm})} \text{ (GHz)}

where

\begin{align*}
E_r &= \text{dielectric constant (from associated Subst)} \\
H &= \text{substrate thickness (from associated Subst)} \\
T &= \text{conductor thickness (from associated Subst)}
\end{align*}

Notes/Equations/References

1. The frequency-domain analytical model is a distributed, coupled-line model developed for Agilent by William J. Getsinger. References [7], [8], and [9] are supplemental.

   The digits of the structure are assumed to be part of an infinite array excited on an even- and odd-mode basis. Each component in this array is a unit cell bounded by magnetic walls. The model calculates the per-unit-length admittance and impedance matrices (even and odd modes) for each cell. This calculation is based on the even and odd mode capacitances, the conductor loss and the substrate dielectric loss. The capacitances are calculated by a conformal mapping technique. Conductor losses are calculated using Wheeler's method. Corrections for finite strip thickness and end effects are included. Network parameters of the transmission line model of each cell are calculated from the admittance and impedance matrices. The cells are combined to from the complete model including end effects. Microstrip dispersion effects are included in this model.

2. This is a 2-port configuration of MICAP2 intended for use where one side of the interdigital capacitor is connected to ground and the other side does not have a simple single connection point.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to $-273.15^\circ C$.

5. Proper grounding must be added manually in the layout. The implied ground plane is drawn on the layer mapped to the Hole parameter in the MSUB.
component. The ground plane is for modeling in Momentum and is not modeled separately in the circuit simulator.


MLANG (Microstrip Lange Coupler)

Symbol

Illustration

Parameters

Subst = microstrip substrate name
W = finger width, in specified units
S = conductor spacing, in specified units
L = conductor length, in specified units
Temp = physical temperature, in °C
W1 = (for Layout Option) width of transmission lines that connect to pins 1, 2, 3, 4

Range of Usage

$1 \leq E_r \leq 18$

$0.01 \leq \frac{W}{H} \leq 10$
Microstrip Components

\[ 0.01 \leq \frac{S}{H} \leq 10 \]

Simulation frequency \( \leq \frac{25}{H(\text{mm})} \) (GHz)

where

\[ Er = \text{dielectric constant (from associated Subst)} \]

\[ H = \text{substrate thickness (from associated Subst)} \]

\[ (3W + 2S) \geq W_1 \geq 0 \text{ for proper layout} \]

Notes/Equations/References

1. The frequency-domain analytical model is a distributed, coupled-line model. Even- and odd-mode capacitances are calculated for each unit-cell of the interdigitated structure. Alternate fingers are assumed to be at the same potential. Only coupling between adjacent fingers is included in the model. The per-unit-length coupling capacitances are calculated using the formula developed by Kirschning and Jansen for parallel coupled microstrip lines, and the formula developed by Hammerstad and Jensen for single microstrip line. Dispersion and conductor loss are included. The even- and odd-mode line impedances are calculated based on the coupling capacitances and conductor losses. Then, this result is used to calculate the network parameters of the distributed, coupled-line model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to \(-273.15^\circ\text{C}\).

4. The conductor drawn on the layer mapped to the Cond2 parameter, as well as the transition drawn on the layer to the Diel2 parameter, in the MSUB component are for the purpose of modeling in Momentum. They are not modeled separately in the circuit simulator.


MLANG6 (Microstrip Lange Coupler (6-Fingered))

Symbol

![MLANG6 Symbol](image)

Illustration

![MLANG6 Illustration](image)

Parameters

- Subst = microstrip substrate name
- W = conductor width, in specified units
- S = conductor spacing, in specified units
- L = conductor length, in specified units
- Temp = physical temperature, in °C
- W1 = (for Layout Option) width of transmission lines that connect to pins 1, 2, 3, 4

Range of Usage

1 \leq Er \leq 18

0.01 < \frac{W}{H} < 10
0.01 < \frac{5}{H} < 10

\text{Simulation frequency} \leq \frac{25}{H (\text{mm})} \text{ (GHz)}

\text{where}

E_r = \text{dielectric constant (from associated Subst)}

H = \text{substrate thickness (from associated Subst)}

(3W + 2S) \geq W_1 \geq 0 \text{ for proper layout}

\textbf{Notes/Equations/References}

1. The frequency-domain analytical model is a distributed, coupled-line model. Even- and odd-mode capacitances are calculated for each unit-cell of the interdigitated structure. Alternate fingers are assumed to be at the same potential. Only coupling between adjacent fingers is included in the model. The per-unit-length coupling capacitances are calculated using the formula developed by Kirschning and Jansen for parallel coupled microstrip lines, and the formula developed by Hammerstad and Jensen for single microstrip line. Dispersion and conductor loss are included. The even- and odd-mode line impedances are calculated based on the coupling capacitances and conductor losses. Then, this result is used to calculate the network parameters of the distributed, coupled-line model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to \(-273.15\degree C\).

4. \textit{W}1 is a layout-only parameter and does not affect the simulation results.

5. The conductor drawn on the layer mapped to the Cond2 parameter, as well as the transition drawn on the layer to the Diel2 parameter, in the MSUB component are for the purpose of modeling in Momentum. They are not modeled separately in the circuit simulator.


MLANG8 (Microstrip Lange Coupler (8-Fingered))

Symbol

Illustration

Parameters
- Subst = microstrip substrate name
- W = conductor width, in specified units
- S = conductor spacing, in specified units
- L = conductor length, in specified units
- Temp = physical temperature, in °C
- W1 = (for Layout Option) width of transmission lines that connect to pins 1, 2, 3, 4

Range of Usage
1 ≤ Er ≤ 18
Microstrip Components

\[ 0.01 \leq \frac{W}{H} \leq 10 \]

\[ 0.01 \leq \frac{S}{H} \leq 10 \]

Simulation frequency \( \leq \frac{25}{H(\text{mm})} \) (GHz)

where

\( E_r = \) dielectric constant (from associated Subst)

\( H = \) substrate thickness (from associated Subst)

\( (5W + 4S) \geq W1 \geq 0 \) for proper layout

Notes/Equations/References

1. The frequency-domain analytical model is a distributed, coupled-line model. Even- and odd-mode capacitances are calculated for each unit-cell of the interdigitated structure. Alternate fingers are assumed to be at the same potential. Only coupling between adjacent fingers is included in the model. The per-unit-length coupling capacitances are calculated using the formula developed by Kirschning and Jansen for parallel coupled microstrip lines, and the formula developed by Hammerstad and Jensen for single microstrip line. Dispersion and conductor loss are included. The even- and odd-mode line impedances are calculated based on the coupling capacitances and conductor losses. This result is used to calculate the network parameters of the distributed, coupled-line model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to \(-273.15^\circ \text{C}\).

4. \( W1 \) is a layout-only parameter and does not affect the simulation results.

5. The conductor drawn on the layer mapped to the Cond2 parameter, as well as the transition drawn on the layer to the Die12 parameter, in the MSUB component are for the purpose of modeling in Momentum. They are not modeled separately in the circuit simulator.


MLEF (Microstrip Line Open-End Effect)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = line width, in specified units
L = line length, in specified units
Wall1 = distance from near edge of strip H to first sidewall
Wall2 = distance from near edge of strip H to second sidewall
Temp = physical temperature, in °C

Range of Usage
2 ≤ Er ≤ 50

\[
\frac{W}{H} \geq 0.2
\]

where
Er = dielectric constant (from associated Subst)
H = substrate thickness (from associated Subst)
Notes/Equations/References

1. The open-end effect in microstrip is modeled in the frequency domain as an extension to the length of the microstrip stub. The microstrip is modeled using the MLIN component, including conductor loss, dielectric loss and dispersion. A correction for finite line thickness is applied to the line width. The length of the microstrip extension, \( dl \), is based on the formula developed by Kirschning, Jansen and Koster. Fringing at the open end of the line is calculated and included in the model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to \(-273.15^\circ C\).

4. When the Hu parameter of the substrate is less than \( 100 \times \text{Thickness of substrate} \), the impedance calculation will not be properly done if WALL1 and WALL2 are left blank.


Equivalent Circuit

![Equivalent Circuit Diagram]
MLIN (Microstrip Line)

Symbol

Illustration

Parameters

Subst = microstrip substrate name

W = line width, in specified units

L = line length, in specified units

Wall1 = distance from near edge of strip H to first sidewall

Wall2 = distance from near edge of strip H to second sidewall

Temp = physical temperature, in °C

Range of Usage

\[ 1 \leq ER \leq 128 \]

\[ 0.01 \leq \frac{W}{H} \leq 100 \]

where

\( ER = \) dielectric constant (from associated Subst)

\( H = \) substrate thickness (from associated Subst)

Notes/Equations/References

1. The frequency-domain analytical model uses the Hammerstad and Jensen formula to calculate the static impedance, \( Z_0 \), and effective dielectric constant, \( \varepsilon_{\text{eff}} \). The attenuation factor, \( \alpha_c \), formula is based on the incremental inductance rule proposed by Wheeler. Dispersion effects are include by using either the
Getsinger or Kirschning and Jansen dispersion formula depending on the program configuration. The program defaults to using the Kirschning and Jansen formula. The frequency dependence of the skin effect is included in the conductor loss calculations. The formulas provide a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to \(-273.15\)°C.

4. When the Hu parameter of the substrate is less than \(100\times\text{Thickness of substrate}\), the impedance calculation will not be properly done if WALL1 and WALL2 are left blank.


Microstrip Components

MLOC (Microstrip Open-Circuited Stub)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = line width, in specified units
L = line length, in specified units
Wall1 = distance from near edge of strip H to first sidewall
Wall2 = distance from near edge of strip H to second sidewall
Temp = physical temperature, in °C

Range of Usage
Er ≤ 128

\[ 0.01 \leq \frac{W}{H} \leq 100 \]

where

\( E_r \) = dielectric constant (from associated Subst)
\( H \) = substrate thickness (from associated Subst)

Notes/Equations/References

1. The frequency-domain analytical model uses the Hammerstad and Jensen formula to calculate the static impedance, \( Z_0 \), and effective dielectric constant, \( \varepsilon_{eff} \). The attenuation factor, \( \alpha_c \), formula is based on the incremental inductance rule proposed by Wheeler. Dispersion effects are included by using either the Getsinger or Kirschning and Jansen dispersion formula depending on the program configuration. The program defaults to using the Kirschning and...
Jansen formula. The frequency dependence of the skin effect is included in the conductor loss calculations. The formulas provide a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. No end effects are included in the model.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to −273.15°C.

5. When the Hu parameter of the substrate is less than 100*Thickness_of_substrate, the impedance calculation will not be properly done if WALL1 and WALL2 are left blank.


Microstrip Components

MLSC (Microstrip Short-Circuited Stub)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W = line width, in specified units
L = line length, in specified units
Wall1 = distance from near edge of strip H to first sidewall
Wall2 = distance from near edge of strip H to second sidewall
Temp = physical temperature, in °C

Range of Usage
Er ≤ 128

\[
0.01 \leq \frac{W}{H} \leq 100
\]

where
Er = dielectric constant (from associated Subst)
H = substrate thickness (from associated Subst)

Notes/Equations/References
1. The frequency-domain analytical model uses the Hammerstad and Jensen formula to calculate the static impedance, \( Z_0 \), and effective dielectric constant, \( \varepsilon_{\text{eff}} \). The attenuation factor, \( \alpha_c \), formula is based on the incremental inductance rule proposed by Wheeler. Dispersion effects are included by using either the Getsinger or Kirschning and Jansen dispersion formula depending on the
program configuration. The program defaults to using the Kirschning and Jansen formula. The frequency dependence of the skin effect is included in the conductor loss calculations. The formulas provide a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. No end effects are included in the model.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to $-273.15^\circ C$.

5. Proper grounding must be added manually in the layout.

6. The implied ground is drawn on the layer mapped to the Hole parameter in the MSUB component. The ground is for the purpose of modeling in Momentum and is not modeled separately in the circuit simulator.

7. Wall1 and Wall2 are optional; if they are not specified, the component is simulated as if no walls exist.


Microstrip Components

**MRIND (Microstrip Rectangular Inductor)**

**Symbol**

![Symbol](image)

**Illustration**

![Illustration](image)

**Parameters**

- **Subst** = microstrip substrate name
- **N** = number of turns (need not be an integer)
- **L1** = length of second outermost segment (see illustration), in specified units
- **L2** = length of outermost segment (see illustration), in specified units
- **W** = conductor width, in specified units
- **S** = conductor spacing, in specified units
- **Temp =** physical temperature, in °C
- **W1** = (for Layout option) width of line that connects to pin 1
- **W2** = (for Layout option) width of line that connects to pin 2

**Range of Usage**

- **W > 0; S > 0; T > 0**
- **N ≤ 8** (or the highest number of turns that will fit, given W, S, L1 and L2)
- **W + S ≥ 0.01 × H**
T ≤ 0.85 × W and T ≤ 0.85 × S

where

T = conductor thickness (from associated Subst)
H = substrate thickness (from associated Subst)

**Notes/Equations/References**

1. The number of turns (N) is adjusted to the nearest quarter turn. This component does not include a connection (such as an air-bridge) from the center of the inductor to the outside.

2. The frequency-domain analytical model for this component has been developed for Agilent by William J. Getsinger. Results published in the references listed at the end of these notes were used in the development of this model. Each segment of the spiral is modeled as a lumped C-L-C π-section with mutual inductive coupling to all other parallel segments including those of an image spiral. The image spiral accounts for the effects of the microstrip ground plane. The inductive calculations include the end-effects and differing lengths of coupled segments. The capacitive components account for capacitance to ground, coupling to the parallel adjacent segments, and the coupling to the next parallel segments beyond the adjacent, on both sides. The model also accounts for conductor and dielectric loss.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to −273.15°C.

5. In layout, the number of turns is rounded to the nearest quarter-turn. The connection will align at the inside edge at pin 1 and the outside edge at pin 2, unless W1 < W or W2 > W, in which case the conductors are centered.


Microstrip Components


MRINDELA (Elevated Microstrip Rectangular Inductor)

Symbol

Illustration

Parameters

Subst = microstrip substrate name
Ns = number of segments
L1 = length of first segment, in specified units
L2 = length of second segment, in specified units
L3 = length of third segment, in specified units
Ln = length of last segment, in specified units
W = conductor width, in specified units
S = conductor spacing, in specified units
Hi = elevation of inductor above substrate, in specified units
Ti = thickness of conductors, in specified units
Microstrip Components

\( R_i \) = resistivity (relative to gold) of conductors

\( S_x \) = spacing limit between support posts, in specified units (0 to ignore posts)

\( C_c \) = coefficient for capacitance of corner support posts (ratio of actual post cross-sectional area to \( W^2 \))

\( C_s \) = coefficient for capacitance of support posts along segment (ratio of actual post cross-sectional area to \( W^2 \))

\( W_u \) = width of underpass strip conductor, in specified units

\( A_u \) = angle of departure from innermost segment, in degrees

\( U_e \) = extension of underpass beyond inductor, in specified units

\( T_{\text{temp}} \) = physical temperature, in °C

**Range of Usage**

\( W > 0 \)

\( S > 0 \)

\( S_x > 2W \)

\( A_u = 0^\circ, 45^\circ, \text{ or } 90^\circ \)

\( A_u \) must be 90° if last segment (\( L_n \)) is less than full length

\[
\frac{W + S}{2} \leq L_n \leq L_{nmax} \quad \text{where } L_{nmax} \text{ is the full length of the last segment (see Note 4)}
\]

\( H_i > MSUB \) metal thickness \( T \)

\( T_i \leq W \)

**Notes/Equations/References**

1. The inductor is elevated in air above the substrate with a bridge connection that is in the form of an underpass strip conductor. Effects of support posts are included. Support posts are assumed to exist at each corner, plus along the segments, depending on the value of \( S_x \).

2. The frequency-domain analytical model for this component has been developed for Agilent by William J. Getsinger. Results published in the references listed at the end of these notes were used in the development of this model.
Each segment of the spiral is modeled as a lumped C-L-C $\pi$-section with mutual inductive coupling to all other parallel segments including those of an image spiral. The image spiral accounts for the effects of the microstrip ground plane. The inductive calculations include the end-effects and differing lengths of coupled segments. The capacitive components account for capacitance to ground, coupling to the parallel adjacent segments, and the coupling to the next parallel segments beyond the adjacent, on both sides. The model also accounts for conductor and dielectric loss.

3. The underpass conductor (bridge) connects to the innermost segment and crosses the inductor from underneath the spiral. The bridge is capacitively coupled to each segment of the spiral that it crosses.

4. If $L_n$ is set to 0, it is assumed to have full length. The full length ($L_{n_{\text{max}}}$) is such that the spacing from the contact reference point to the inner edge of the fourth-from-last segment is $S+W/2$.

   If $N_s$ is even: $L_{n_{\text{max}}} = L_2 - (N_s - 2) \times (W + S)/2$

   If $N_s$ is odd: $L_{n_{\text{max}}} = L_3 - (N_s - 3) \times (W + S)/2$

5. If $W_u=0$, the effect of the underpass strip conductor is not simulated.

6. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

7. To turn off noise contribution, set Temp to $-273.15^\circ\text{C}$.

8. In layout, the segments of the spiral are drawn on the cond2 layer and the support posts are drawn on the cond layer.

   For layout purposes the last segment ($L_n$) is drawn such that it extends a distance of $W/2$ beyond the contact reference point. This allows for a square region of size $W \times W$, on which the contact to the underpass is centered.

   The inductor segments to airbridge/underpass transition is drawn on the layer mapped to the Diel2 parameter of the MSUB component. The transition is only for the purpose of modeling in Momentum and is not taken into account in the circuit simulator.

   For the transition at pin 2, if the angle of the airbridge/underpass is 0 or 45, the width of the transition is the width of the airbridge/underpass; if the angle of the airbridge/underpass is 90, the width of the transition is the width of the inductor segment.


MRINDEL (Elevated Microstrip Rectangular Inductor (Three-Layer Substrate))

Symbol

Illustration

Parameters
Subst = microstrip substrate name
Ns = number of segments
L1 = length of first segment, in length units
L2 = length of second segment, in length units
L3 = length of third segment, in length units
L_n = length of last segment, in specified units
W = conductor width, in specified units
S = conductor spacing, in specified units
WU = width of underpass conductor, in length units
AU = angle of departure from innermost segment, in angle units
UE = extension of underpass beyond inductor, in length units
Temp = physical temperature, in °C

Range of Usage (including data item parameters):
W > 0
S > 0
AU = 0°, 45°, or 90°
AU must be 90° if last segment (LN) is less than full length
\[
\frac{N + S}{2} \leq L \leq LN_{\text{max}}
\]
where LNmax is the full length of the last segment (see Note 5)

MSUBST3 substrate thickness H (1) > metal thickness T (1).

Notes/Equations/References

1. The inductor is elevated above a second substrate, as described by MSUBST3. The bridge connection is in the form of an underpass strip conductor that is printed on the bottom substrate (described by MSUBST3).

2. The frequency-domain analytical model for this element has been developed for Agilent by William J. Getsinger. Results published in the references listed at the end of these notes were used in the development of this model.

3. Each segment of the spiral is modeled as a lumped C-L-C \( \pi \)-section with mutual inductive coupling to all other parallel segments including those of an image spiral. The image spiral accounts for the effects of the microstrip ground plane. The inductive calculations include the end-effects and differing lengths of coupled segments. The capacitive elements account for capacitance to ground, coupling to the parallel adjacent segments, and the coupling to the next parallel segments beyond the adjacent, on both sides. The model also accounts for conductor and dielectric loss.

4. The underpass conductor (bridge) connects to the innermost segment and crosses the inductor from underneath the spiral. The bridge is capacitively coupled to each segment of the spiral that it crosses.
5. If LN is set to zero, it is assumed to have full length. The full length (LNmax) is such that the spacing from the contact reference point to the inner edge of the fourth-from-last segment is S+W/2.
   - If NS is even: LNmax = L2 - (NS - 2) • (W + S)/2
   - If NS is odd: LNmax = L3 - (NS - 3) • (W + S)/2

6. If WU = 0, the effect of the underpass strip conductor is not simulated.

7. For transient analysis, microstrip inductors are modeled using a lumped RLC circuit.

8. For convolution analysis, the frequency-domain analytical model is used.

9. In Layout, the spiral inductor is mapped to the layer assigned to the LayerName[1] parameter of the MSUBST3 component referenced by the MRINDELM component. The underpass is mapped to the layer assigned to the LayerName[2] parameter of the MBSUBST3 component referenced by the MRINDELM component.

   For layout purposes the last segment (LN) is drawn such that it extends a distance of W/2 beyond the contact reference point. This allows for a square region of size W x W, on which the contact to the underpass is centered.

   The inductor segments to air-bridge/underpass transition is mapped to the layer assigned to the LayerViaName[1] parameter of the MSUBST3 component referenced in the MRINDELM component. The transition is only for the purpose of modeling in Momentum and is not taken into account in the circuit simulator.

   For the transition at pin 2, if the angle of the air-bridge/underpass is 0 or 45, the width of the transition is the width of the air-bridge/underpass; if the angle of the air-bridge/underpass is 90, the width of the transition is the width of the inductor segment.


Microstrip Components


MRINDNBR (Microstrip Rectangular Inductor (No Bridge))

Symbol

Illustration

Parameters

Subst = microstrip substrate name
Ns = number of segments
L1 = length of first segment, in specified units
L2 = length of second segment, in specified units
L3 = length of third segment, in specified units
Ln = length of last segment, in specified units
W = conductor width, in specified units
S = conductor spacing, in specified units
Temp = physical temperature, in °C
Microstrip Components

Range of Usage

\[ W > 0 \]
\[ S > 0 \]
\[ \frac{W + S}{2} \leq L_n \leq L_{\text{max}} \]

where \( L_{\text{max}} \) is the full length of the last segment (see Note 3)

Notes/Equations/References

1. This component model is the same as that for MRIND. As with MRIND, this component does not include a connection (such as an airbridge) from the enter of the inductor to the outside.

2. The frequency-domain analytical model for this component has been developed for Agilent by William J. Getsinger. Results published in the references listed at the end of these notes were used in the development of this model.

Each segment of the spiral is modeled as a lumped C-L-C \( \pi \)-section with mutual inductive coupling to all other parallel segments including those of an image spiral. The image spiral accounts for the effects of the microstrip ground plane. The inductive calculations include the end-effects and differing lengths of coupled segments. The capacitive components account for capacitance to ground, coupling to the parallel adjacent segments, and the coupling to the next parallel segments beyond the adjacent, on both sides. The model also accounts for conductor and dielectric loss.

3. If \( L_n \) is set to zero, it is assumed to have full length. The full length (\( L_{\text{max}} \)) is such that the spacing from the contact reference point to the inner edge of the fourth-from-last segment is \( S + W/2 \).

   If \( N_s \) is even: \( L_{\text{max}} = L_2 - (N_s - 2) \times (W + S)/2 \)
   If \( N_s \) is odd: \( L_{\text{max}} = L_3 - (N_s - 3) \times (W + S)/2 \)

4. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

5. To turn off noise contribution, set Temp to \(-273.15^\circ C\).

6. For layout purposes, the last segment (\( L_n \)) is drawn such that it extends a distance of \( W/2 \) beyond the contact reference point. This allows for a square region of size \( W \times W \), on which the contact to the inner pin is centered.

**Microstrip Components**

**MRINDSBR (Microstrip Rectangular Inductor (Strip Bridge, Three-Layer Substrate))**

**Symbol**

![Symbol Image]

**Illustration**

![Illustration Image]

**Parameters**

Subst = microstrip substrate name  
Ns = number of segments  
L1 = length of first segment, in length units  
L2 = length of second segment, in length units  
L3 = length of third segment, in length units  
Ln = length of last segment, in length units  
W = conductor width, in length units  
S = conductor spacing, in length units
WB = width of bridge strip conductor, in length units
AB = angle of departure from innermost segment, in angle units
BE = extension of bridge beyond inductor, in length units
Temp = physical temperature, in °C

Range of Usage (including data item parameters):
W > 0
S > 0
AB = 0°, 45°, or 90°
AB must be 90° if last segment is less than full length
\[ \frac{N + S}{2} \leq LN \leq LN_{max} \]
where
LNmax is the full length of the last segment (see Note 5)

Notes/Equations/References

1. The inductor is modeled as printed on the substrate described by MSUBST3. The bridge strip is modeled as printed on a dielectric that is described by MSUBST3.

2. The frequency-domain analytical model for this element has been developed for Agilent by William J. Getsinger. Results published in the references listed at the end of these notes were used in the development of this model.

3. Each segment of the spiral is modeled as a lumped C-L-C π-section with mutual inductive coupling to all other parallel segments including those of an image spiral. The image spiral accounts for the effects of the microstrip ground plane. The inductive calculations include the end-effects and differing lengths of coupled segments. The capacitive elements account for capacitance to ground, coupling to the parallel adjacent segments, and the coupling to the next parallel segments beyond the adjacent, on both sides. The model also accounts for conductor and dielectric loss.

4. The bridge conductor connects to the innermost segment and crosses the spiral from the top. The bridge is capacitively coupled to each segment of the spiral that it crosses.
5. If LN is set to zero, it is assumed to have full length. The full length (LNmax) is such that the spacing from the contact reference point to the inner edge of the fourth-from-last segment is $S+W/2$.

   If NS is even: $LN_{max} = L2 - (NS - 2) \cdot (W + S)/2$
   If NS is odd:  $LN_{max} = L3 - (NS - 3) \cdot (W + S)/2$

6. If WB=0, the effect of the bridge strip conductor is not simulated.

7. For transient analysis, microstrip inductors are modeled using a lumped RLC circuit.

8. For convolution analysis, the frequency-domain analytical model is used.

9. In Layout, the spiral inductor is mapped to the layer assigned to the LayerName[2] parameter of the MSUBST3 component referenced by the MRINDSBR component. The strip bridge is mapped to the layer assigned to the LayerName[1] parameter of the MBSUBST3 component referenced by the MRINDSBR component.

   For layout purposes, the last segment (LN) is drawn such that it extends a distance of $W/2$ beyond the contact reference point. This allows for a square region of size $W \times W$, on which the contact to the bridge is connected.

   The inductor segments to air-bridge/underpass transition is mapped to the layer assigned to the LayerViaName[1] parameter of the MSUBST3 component referenced by the MRINDSBR component. The transition is only for the purpose of modeling in Momentum and is not taken into account in the circuit simulator.

   For the transition at pin 2, if the angle of the air-bridge/underpass is 0 or 45, the width of the transition is the width of the air-bridge/underpass; if the angle of the air-bridge/underpass is 90, the width of the transition is the width of the inductor segment.
MRINDWBR (Microstrip Rectangular Inductor (Wire Bridge))

Symbol

Illustration

Parameters
Subst = microstrip substrate name
Ns = number of segments
L1 = length of first segment, in length units
L2 = length of second segment, in length units
L3 = length of third segment, in length units
Ln = length of last segment, in length units
W = conductor width, in length units
S = conductor spacing, in length units
WB = width of bridge strip conductor, in length units
AB = angle of departure from innermost segment, in angle units
BE = extension of bridge beyond inductor, in length units
Temp = physical temperature, in °C

Range of Usage
W > 0
S > 0
Aw = 0°, 45°, or 90°
Aw must be 90° if last segment is less than full length

\[
\frac{W + S}{2} \leq L_n \leq L_{\text{max}}
\]

where \( L_{\text{max}} \) is the full length of the last segment (see Note 3)

Notes/Equations/References

1. This inductor is modeled as printed on the substrate described by Subst. The airbridge is in the form of a round wire that connects from the center of the spiral to the outside.

2. The frequency-domain analytical model for this component has been developed for Agilent by William J. Getsinger. Results published in the references listed at the end of these notes were used in the development of this model.

   Each segment of the spiral is modeled as a lumped C-L-C \( \pi \)-section with mutual inductive coupling to all other parallel segments including those of an image spiral. The image spiral accounts for the effects of the microstrip ground plane. The inductive calculations include the end-effects and differing lengths of coupled segments. The capacitive components account for capacitance to ground, coupling to the parallel adjacent segments, and the coupling to the next parallel segments beyond the adjacent, on both sides. The model also accounts for conductor and dielectric loss.

3. If \( L_n \) is set to zero, it is assumed to have full length. The full length \( (L_{\text{max}}) \) is such that the spacing from the contact reference point to the inner edge of the fourth-from-last segment is \( S+\frac{W}{2} \).

   If \( N_s \) is even: \( L_{\text{max}} = L_2 - (N_s - 2) \times (W + S)/2 \)
   If \( N_s \) is odd: \( L_{\text{max}} = L_3 - (N_s - 3) \times (W + S)/2 \)

4. If \( D_w = 0 \), the effect of the wire bridge is not simulated.
5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

6. To turn off noise contribution, set Temp to \(-273.15\)°C.

7. In layout, the segments of the spiral are drawn on cond layer. The wire bridge is drawn on the bond layer.

   For layout purposes the last segment (Ln) is drawn such that it extends a distance of \(W/2\) beyond the contact reference point. This allows for a square region of size \(W\times W\), on which the contact to the wire bridge is centered.

   The inductor segments to airbridge/underpass transition is drawn on the layer mapped to the Diel2 parameter of the MSUB component. The transition is only for the purpose of modeling in Momentum and is not taken into account in the circuit simulator.

   For the transition at pin 2, if the angle of the air-bridge/underpass is 0 or 45, the width of the transition is the width of the air-bridge/underpass; if the angle of the air-bridge/underpass is 90, the width of the transition is the width of the inductor segment.


Microstrip Components

MRSTUB (Microstrip Radial Stub)

Symbol

Illustration

Parameters

Subst = microstrip substrate name
Wi = width of input line, in specified units
L = length of stub, in specified units
Angle = angle subtended by stub, in degrees
Temp = physical temperature, in °C

Range of Usage

Er ≤ 128
10° ≤ Angle ≤ 170°

0.01 ≤ \( \frac{Wi}{H} \) ≤ 100

(\( L + D \) × Angle (radians)) ≤ 100 × H (see illustration)
where

\[ E_r = \text{dielectric constant (from associated Subst)} \]
\[ H = \text{substrate thickness (from associated Subst)} \]

**Notes/Equations/References**

1. The frequency-domain analytical model is a microstrip line macro-model developed by Agilent. The radial stub is constructed from a series of straight microstrip sections of various widths that are cascaded together. The microstrip line model is the MLIN model. The number of sections is frequency dependent. Dispersion effects in the microstrip sections are included. The frequency-domain analytical model is lossless.

2. MRSTUB should be used with MTEE or MCROS when used as a stub in shunt with a transmission line.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to \(-273.15°C\).
Microstrip Components

**MSIND (Microstrip Round Spiral Inductor)**

**Symbol**

![Symbol](image)

**Illustration**

![Illustration](image)

**Parameters**

Subst = microstrip substrate name

N = number of turns

Ri = inner radius measured to the center of the conductor, in specified units

W = conductor width, in specified units

S = conductor spacing, in specified units

Temp = physical temperature, in °C

W1 = (for Layout option) width of strip ending at pin 1

W2 = (for Layout option) width of strip ending at pin 2

**Range of Usage**

Ri > W/2

N > 1
Notes/Equations/References

1. The frequency-domain analytical model is a low-pass, series R-L and shunt C structure. Each R-L-C section corresponds to one turn of the inductor. The inductor L of each section is calculated using the formulas of Remke and Burdick, which do include ground plane inductance. Formulas given by Pettenpaul and his co-authors are used to calculate the series resistance R. These formulas provide a smooth transition from dc resistance to resistance due to skin effect at high frequencies. The value of the shunt capacitance C is based on coupled transmission line theory. Dielectric losses are not included.

2. Ri is measured to the center of the conductor.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to \(-273.15^\circ C\).


MSLIT (Microstrip Slit)

Symbol

![Illustration](image-url)

Parameters

- **Subst** = microstrip substrate name
- **W** = width, in specified units
- **D** = depth of slit, in specified units
- **L** = length of slit, in specified units
- **Temp** = physical temperature, in °C

Range of Usage

- \( D \leq (0.9 \times W) \) or \( (W - 0.01 \times H) \) whichever is smaller
- \( L < \frac{\lambda}{10} \)
- \( L \leq H \)
- \( 0.01 \leq \frac{W}{H} \leq 100 \)

where

- \( \lambda \) = wavelength in the dielectric
- \( H \) = substrate thickness (from associated Subst)

Notes/Equations/References

1. The frequency-domain analytical model consists of a static, lumped, equivalent circuit. The equivalent circuit parameters are calculated based on the
expressions given by Hoefer. The reference plane of the lumped model is at the center of the slit. Two reference plane shifts are added to move the reference plane to the outside edge of the slit, so that they are coincident with the layout dimensions. These reference plane shifts are modeled using a MLIN microstrip model that includes loss and dispersion. The characteristics of the microstrip lines are calculated based on the constricted width of the slit W-D. The formulas are given below, where $Z_0$ and $\varepsilon_{\text{eff}}$ are calculated for width W; $Z_0'$ and $\varepsilon'_{\text{eff}}$ are calculated for width W-D; and, $C_{\text{gap}}$ is the gap capacitance associated with a gap of length L and width 2D ($c_0$ is the velocity of light in air).

\[
\Delta L = \frac{\pi \mu_0}{2} \left( 1 - \frac{Z_0}{Z_0'} \sqrt{\frac{\varepsilon_{\text{eff}}}{\varepsilon'_{\text{eff}}}} \right)
\]

\[
C_s = \frac{C_{\text{gap}}}{2}
\]

\[
C_p = \frac{\varepsilon_{\text{eff}} L}{2 c_0 Z_0'}
\]

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to $-273.15^\circ\text{C}$.


Microstrip Components

Equivalent Circuit

\[ Z_0' \]

\[ Z_0' \]

\[ \Delta L \]

\[ C_s \]

\[ L/2 \]

\[ C_p \]

\[ L/2 \]

\[ C_p \]
MSOP (Microstrip Symmetric Pair of Open Stubs)

Symbol

![Symbol Image]

Illustration

![Illustration Image]

Parameters

- Subst = microstrip substrate name
- \( W_1 \) = width of input line, in specified units
- \( D_1 \) = distance between centerlines of input line and stub-pair, in specified units
- \( W_2 \) = width of output line, in specified units
- \( D_2 \) = distance between centerlines of output line and of stub-pair, in specified units
- \( W_s \) = width of stubs, in specified units
- \( L_s \) = combined length of stubs, in specified units
- Temp = physical temperature, in °C

Range of Usage

\[
0.01 \leq \frac{W_1}{H} \leq 100
\]
Microstrip Components

$$0.01 \leq \frac{W^2}{H} \leq 100$$

Ws > 0
Ls > 0
where

H = substrate thickness (from associated Subst)

Notes/Equations/References

1. The frequency-domain analytical model ignores conductor losses, dielectric losses, and metal thickness.

2. A positive (negative) D1 implies that the input line is below (above) the center of the stub-pair.
   A positive (negative) D2 implies that the output line is above (below) the center of the stub-pair.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to -273.15°C.

MSTEP (Microstrip Step in Width)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W1 = conductor width at pin 1, in specified units
W2 = conductor width at pin 2, in specified units
Temp = physical temperature, in °C

Range of Usage

0.1 ≤ \( \frac{W2}{W1} \) ≤ 10

where

\( Er = \text{dielectric constant (from associated Subst)} \)

Notes/Equations/References

1. Although the references listed here have validated the model for \( Er \leq 10 \), it does not mean that the model is inaccurate for \( Er > 10 \).

2. The frequency-domain analytical model is derived from a TEM (fundamental mode) planar waveguide model of the discontinuity. In the derivation, the planar waveguide model is transformed into a rectangular waveguide model, and the expression for the series inductance, \( L_s \), is formulated based on an analysis of the current concentration at the discontinuity. This formula is documented in Handbook of Microwave Integrated Circuits by R. Hoffman. The reference plane shift, \( \Delta l \), is calculated based on an analysis of the scattered

\[ \Delta l \]
Microstrip Components

electric fields at the front edge of the wider conductor. In addition, dispersion is accounted for in the model.

3. To turn off noise contribution, set Temp to \(-273.15^\circ\text{C}\).

4. In layout, MSTEP aligns the centerlines of the strips.


Equivalent Circuit
MSUB (Microstrip Substrate)

Symbol

Illustration

Parameters

H = substrate thickness, in specified units
Er = relative dielectric constant
Mur = relative permeability
Cond = conductor conductivity, in Siemen/meter
Hu = cover height
T = conductor thickness, in specified units
TanD = dielectric loss tangent
Rough = conductor surface roughness, in specified units; RMS value
Cond1 = (for Layout option) layer to which cond is mapped; default = 1 (cond)
Cond2 = (for Layout option) layer to which cond2 is mapped; default = 2 (cond2)
Diel1 = (for Layout option) layer to which diel is mapped; default = 4 (diel)
Diel2 = (for Layout option) layer to which diel2 is mapped; default = 12 (diel2)
Hole = (for Layout option) layer to which hole is mapped; default = 5 (hole)
Res = (for Layout option) layer to which hole is mapped; default = 5 (hole)

Range of Usage

N/A
Notes/Equations/References

1. MSUB is required for all microstrip components.

2. Conductor losses are accounted for when $\text{Cond} < 4.1 \times 10^{17} \text{ S/m}$ and $T > 10^{-9}$. Gold conductivity is $4.1 \times 10^{7} \text{ S/m}$. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^{7}$.

3. The parameters Cond1, Cond2, Diel1, Diel2, Hole, and Res control the layer on which the Mask layers are drawn. These are layout-only parameters and are not used by the simulator. Cond1 is the layer on which Metal 1 is drawn; Cond2 is for air-bridges and underpasses; Diel1 is for dielectric capacitive areas; Diel2 is for Via between cond and cond2 mask layers; Hole is for Via layers used for grounding; and Res is for resistive mask layers.

4. Microstrip cover height effect is defined in the $Hu$ parameter. The models MCFIL, MCLIN, MLEF, MLIN, MLOC, and MLSC support microstrip cover effect.

5. When the $Hu$ parameter of the substrate is less than $100 \times \text{Thickness of substrate}$, the impedance calculation will not be properly done if WALL1 and WALL2 are left blank.

6. The microstrip cover uses a perturbational technique based on the assumption that a significant portion of energy is in the substrate between the conductor and the lower ground. It assumes that a microstrip line is beneath it. The microstrip cover ($Hu$) and the $Er$ parameter were not intended to be used in the limiting case where the configuration of the MLIN with sub and cover converges to a stripline topology.
MSUBST3 (Microstrip Three-Layer Substrate)

Symbol

Illustration

Parameters

$E_r[1] = \text{dielectric constant}$

$H[1] = \text{substrate height, in specified units}$

$\tan D[1] = \text{dielectric loss tangent}$

$T[1] = \text{conductor thickness, in specified units}$

$\text{Cond}[1] = \text{conductor conductivity, in Siemen/meter}$

$E_r[2] = \text{dielectric constant}$

$H[2] = \text{substrate height, in specified units}$

$\tan D[2] = \text{dielectric loss tangent}$

$T[2] = \text{conductor thickness, in specified units}$
Microstrip Components

Cond[2] = conductor conductivity, in Siemen/meter
LayerName[1] = (for Layout option) layout layer to which conductors on the top substrate is mapped. Default is cond.
LayerName[2] = (for Layout option) layout layer to which conductors on the bottom substrate is mapped. Default is cond2.
LayerViaName[1] = (for Layout option) layout layer to which the transition between the bridge/underpass is mapped. Default is diel2.

Range of Usage
N/A

Notes/Equations/References
1. MSUBST3 is required for MRINDSBR and MRINDELM components.
2. Conductor losses are accounted for when Cond < 4.1×10^{17} S/m and T > 10^{-9}. Gold conductivity is 4.1×10^{7} S/m. Rough modifies loss calculations. Conductivity for copper is 5.8×10^{7}.
3. The microstrip cover uses a perturbational technique based on the assumption that a significant portion of energy is in the substrate between the conductor and the lower ground. It assumes that a microstrip line is beneath it. The microstrip cover [Hu] and the Er parameter were not intended to be used in the limiting case where the configuration of the MLIN with sub and cover converges to a stripline topology.
MTAPER (Microstrip Width Taper)

Symbol

Illustration

Parameters
Subst = microstrip substrate name
W1 = conductor width at pin 1, in specified units
W2 = conductor width at pin 2, in specified units
L = line length, in specified units
Temp = physical temperature, in °C

Range of Usage
Er ≤ 128
0.01 × H ≤ (W1, W2) ≤ 100 × H

where
Er = dielectric constant (from associated Subst)
H = substrate thickness (from associated Subst)

Notes/Equations/References
1. The frequency-domain analytical model is a microstrip line macro-model developed by Agilent. The taper is constructed from a series of straight microstrip sections of various widths that are cascaded together. The microstrip line model is the MLIN model. The number of sections is frequency dependent. Dispersion, conductor loss, and dielectric loss effects are included in the microstrip model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
Microstrip Components

**MTEE (Microstrip T-Junction)**

**Symbol**

![MTEE Symbol]

**Illustration**

![MTEE Illustration]

**Parameters**

Subst = microstrip substrate name  
W1 = conductor width at pin 1, in specified units  
W2 = conductor width at pin 2, in specified units  
W3 = conductor width at pin 3, in specified units  
Temp = physical temperature, in °C

**Range of Usage**

\[0.05 \times H \leq W_{1} \leq 20 \times H\]

\[0.05 \times H \leq W_{2} \leq 20 \times H\]

\[0.05 \times H \leq W_{3} \leq 20 \times H\]

\[E_r \leq 20\]

\[\frac{W_{\text{largest}}}{W_{\text{smallest}}} \leq 5\]

where

\[W_{\text{largest}}, W_{\text{smallest}}\] are the largest, smallest width among \(W_2, W_2, W_3\)

\[f(\text{GHz}) \times H \text{ (mm)} \leq 0.4 \times Z_0\]

where

\[\text{where} \]

---

2-98 MTEE (Microstrip T-Junction)
Z0 is the characteristic impedance of the line with Wlargest

Notes/Equations/References

1. The frequency-domain model is an empirically based, analytical model. The model modifies E. Hammerstad model formula to calculate the Tee junction discontinuity at the location defined in the reference for wide range validity. A reference plan shift is added to each of the ports to make the reference planes consistent with the layout.

2. The center lines of the strips connected to pins 1 and 2 are assumed to be aligned.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Equivalent Circuit
MTEE0 (Obsolete Libra Microstrip T-Junction)

Symbol

Illustration

Parameters
Subst = microstrip substrate name

W1 = conductor width at pin 1, in specified units
W2 = conductor width at pin 2, in specified units
W3 = conductor width at pin 3, in specified units

Temp = physical temperature, in °C

Range of Usage

\( W1 + W3 \leq 0.5 \lambda \)
\( W2 + W3 \leq 0.5 \lambda \)
\( 0.10 \times H \leq W1 \leq 10 \times H \)
\( 0.10 \times H \leq W2 \leq 10 \times H \)
\( 0.10 \times H \leq W3 \leq 10 \times H \)

Er \leq 128

where

\( Er = \text{dielectric constant (from associated Subst)} \)
\( H \) = substrate thickness (from associated Subst)

\( \lambda \) = wavelength in the dielectric

**Notes/Equations/References**

1. The frequency-domain model is an empirically based, analytical model. The model presented by Hammerstad is used to calculate the discontinuity model at the location defined in the reference. A reference plan shift is then added to each of the ports to make the reference planes consistent with the layout. Dispersion is accounted for in both the reference plan shifts and the shunt susceptance calculations using the formulas of Kirschning and Jansen.

2. The center lines of the strips connected to pins 1 and 2 are assumed to be aligned.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


**Equivalent Circuit**
Microstrip Components

MTFC (Microstrip Thin Film Capacitor)

Symbol

Illustration (Layout):

Parameters

Subst = microstrip substrate name
W = dielectric width common to both metal plates, in specified units
L = dielectric length common to both metal plates, in specified units
CPUA = capacitance per unit area, pF/mm²
T = thickness of capacitor dielectric, in specified units
RsT = sheet resistance of top metal plate, in ohms per square
RsB = sheet resistance of bottom metal plate, in ohms per square
TT = thickness of top metal plate, in specified units
TB = thickness of bottom metal plate, in specified units
COB = bottom conductor overlap, in specified units
Temp = physical temperature, in °C
COT = (for Layout option) top conductor overlap, in specified units
DO = (for Layout option) dielectric overlap, in specified units

**Range of Usage**

0.01 × H ≤ (W + 2.0 × COB) ≤ 100.0 × H
1 ≤ Er ≤ 128
COB > 0
T > 0

where

H = substrate thickness (from associated Subst)
Er = dielectric constant (from associated Subst)

**Notes/Equations/References**

1. This is a distributed MIM capacitor model based on the coupled-transmission-line approach. The conductor loss for both metal plates is calculated from the sheet resistance (skin-effect is not modeled.) The dielectric loss is calculated from the loss tangent. (The TanD specification applies to the dielectric between the two metal plates and not to the MSUB substrate.) Coupling capacitance from both metal plates to the ground plane is accounted for.

2. Thickness of the dielectric T is required for calculating the mutual coupling between the two metal plates. Thickness of the two metal plates, TT and TB, are used for calculating microstrip parameters.

3. The model does not include a connection (such as an air-bridge) from the top metal (pin 2) to the connecting transmission line. It must be included separately by the user for simulation as well as layout purposes.

4. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

5. To turn off noise contribution, set Temp to −273.15°C.
6. In the layout, the top metal will be on layer cond2, the bottom metal on layer cond, the capacitor dielectric on layer diel, and the dielectric via layer on layer diel2.


Equivalent Circuit

L_{11} = \text{inductance/unit length of the top plate}
L_{22} = \text{inductance/unit length of the bottom plate}
L_{12} = \text{mutual inductance between the plates/units length of the capacitor}
R_1 = \text{loss resistance/unit length of the top plate}
R_2 = \text{loss resistance/unit length of the bottom plate}
G = \text{loss conductance of the dielectric/unit length of the capacitor}
C_{12} = \text{capacitance/unit length of the capacitor}
C_{10} = \text{capacitance with respect to ground/unit length of the top plate (due to the substrate effects)}
C_{20} = \text{capacitance with respect to ground/unit length of the bottom plate (due to the substrate effects)}
RIBBON (Ribbon)

Symbol

Illustration

Parameters

\( W \) = conductor width, in specified units
\( L \) = conductor length, in specified units
\( \text{Rho} \) = metal resistivity (relative to gold)
\( \text{Temp} \) = physical temperature, in °C
\( \text{AF} \) = (for Layout option) arch factor; ratio of distance between bond points to actual ribbon length
\( \text{CO} \) = (for Layout option) conductor overlap; distance from edge connector
\( \text{A1} \) = (for Layout option) angle of departure from first pin
\( \text{A2} \) = (for Layout option) angle of departure from second pin
\( \text{BandLayer} \) = (for Layout option) layer on which the wire/ribbon is drawn; default = 6 (bond)

Range of Usage

N/A
Notes/Equations/References

1. Although this component is included in the Microstrip Components library, it does not use a microstrip substrate (MSUB).

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. To turn off noise contribution, set Temp to $-273.15^\circ C$.

4. The ribbon bond layer to the conductor layer transition is drawn on the dielectric layer. The width of the dielectric layer is CO, the conductor offset. If CO is 0, the transition is drawn as a zero width polygon. The transition is only for layout purposes and is not taken into account in the circuit simulator.

Equivalent Circuit

```
L(W,L,RHO,FREQ)  R(W,L,RHO,FREQ)
```

---

2-106 RIBBON (Ribbon)
TFC (Thin Film Capacitor)

Symbol

Illustration (Layout):

Parameters

W = conductor width, in specified units
L = conductor length, in specified units
T = dielectric thickness, in specified units
Er = relative dielectric constant
Rho = metal resistivity of conductor (relative to gold)
TanD = dielectric loss tangent value
Temp = physical temperature, in °C
CO = (for Layout option) conductor overlap
DO = (for Layout option) dielectric overlap
DielLayer = (for Layout option) layer on which the dielectric is drawn; default = 4 (diel)
Microstrip Components

Cond2Layer = (for Layout option) layer on which the airbridge is drawn; default = 2(cond2)

Range of Usage
N/A

Notes/Equations/References
1. The frequency-domain analytical model is a series R-C, lumped component network. The conductor losses with skin effect and dielectric losses are modeled by the series resistance. The parallel plate capacitance is modeled by the series capacitance.

2. Although this component is included in the Microstrip Components library, it does not use a microstrip substrate (MSUB).

3. For a distributed model, use MTFC instead of TFC.

4. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

5. To turn off noise contribution, set Temp to $-273.15^\circ C$.

6. Pins 1 and 2 are on the mask layer cond for primary metallization. The top of the capacitor is formed on the cond2 layer, with the conductor overlapping the connecting line at pin 2 by CO.


Equivalent Circuit

```
  R

  C

  _______________
```

Microstrip Components

**TFR (Thin Film Resistor)**

Symbol

![Symbol](image)

**Illustration**

![Illustration](image)

**Parameters**

Subst = microstrip substrate name  
W = conductor width, in specified units  
L = conductor length, in specified units  
Rs = sheet resistivity, in ohms/square  
Freq = frequency for scaling sheet resistivity, in hertz  
Temp = physical temperature, in °C  
CO = (for Layout option) conductor offset; in specified units

**Range of Usage**

\[ 0.01 \times H \leq W \leq 100 \times H \]

where

\[ H = \text{substrate thickness (from associated Subst)} \]

**Notes/Equations/References**

1. The frequency-domain analytical model is a lossy microstrip line model developed by Agilent. The microstrip line model is based on the formula of Hammerstad and Jensen. Conductor loss with skin effect is included; however, dispersion, dielectric loss and thickness correction are not included.

2. If Freq is set to a value other than zero, then Rs is scaled with frequency as follows:

\[
Rs (f) = Rs (Freq) \times \sqrt{(f/Freq)} \quad \text{(for microstrip)}
\]
If \( \text{Freq}=0 \), then \( R_s \) is constant with respect to frequency. Setting \( \text{Freq}=0 \) is correct in most cases.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to \(-273.15^\circ\text{C}\).

Microstrip Components

VIA (Tapered Via Hole in Microstrip)

Symbol

![Illustration]

Parameters
- $D_1 =$ diameter at pin 1, in specified units
- $D_2 =$ diameter at pin 2, in specified units
- $H =$ substrate thickness, in specified units
- $T =$ conductor thickness, in specified units
- $W =$ (for Layout option) width of conductor attached to via hole, in specified units
- $\text{Cond1Layer} =$ (for Layout option) layer on which pin 1’s transitional metal is drawn; default = 1 (cond)
- $\text{HoleLayer} =$ (for Layout option) layer on which the Via-hole is drawn; default=5(hole)
- $\text{Cond2Layer} =$ (for Layout option) layer on which pin 1’s transitional metal is drawn; default=2 (cond2)

Range of Usage
- $H \leq 2 \times \text{greater of } D_1 \text{ or } D_2$
- $H \ll \lambda$
- $\lambda =$ wavelength in the dielectric
Notes/Equations/References

1. The frequency-domain analytical model is a series, lumped inductance as shown in the symbol. Conductor and dielectric losses are not modeled. The model was developed by Vijai K. Tripathi for Agilent.

2. In addition to the two circles on the conducting layers, the artwork includes a circle for the via-hole on the hole layer. The diameter for the via-hole is set by D1, the diameter at pin 1.

3. Although this component is included in the Microstrip Components library, it does not use a microstrip substrate (MSUB).
## VIA2 (Cylindrical Via Hole in Microstrip)

### Symbol

![Symbol](image)

### Illustration

![Illustration](image)

### Parameters

- **D** = diameter at pin 1, in specified units
- **H** = substrate thickness, in specified units
- **T** = conductor thickness, in specified units
- **W** = (for Layout option) width of conductor attached to via hole, in specified units
- **Temp** = physical temperature, in °C
- **Cond1Layer** = (for Layout option) layer on which the bottom transitional metal is drawn; default = 1 (cond)
- **HoleLayer** = (for Layout option) layer on which the Via-hole is drawn; default = 5 (hole)
- **Cond2Layer** = (for Layout option) layer on which the top transitional metal is drawn; default = 2 (cond2)

### Range of Usage

- \(100 \mu M < H < 635 \mu M\)
- \(0.2 < \frac{D}{H} < 1.5\)
- \(0 \leq T < \frac{D}{2}\)
$1 < \frac{W}{H} < 2.2$

$W > D$

$2.2 < E_r < 20$

where

$E_r =$ dielectric constant (from associated Subst)

$H =$ substrate thickness

$T =$ conductor thickness

**Notes/Equations/References**

1. The frequency-domain analytical model is a series R-L, lumped component network as shown in the symbol. The model equations are based on the numerical analysis and formula of Goldfarb and Pucel. The conductor loss with skin effect is included in the resistance calculation. The model equations provide a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is not included in the model.

2. Although this component is included in the Microstrip Components library, it does not use a microstrip substrate (MSUB).

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. To turn off noise contribution, set Temp to $-273.15^\circ C$.

Microstrip Components

WIRE (Round Wire)

Symbol

Illustration

TOP VIEW

Parameters

D = wire diameter, in specified units
L = wire length, in specified units
Rho = metal resistivity (relative to gold)
Temp = physical temperature, in °C
AF = (for Layout option) arch factor; ratio of distance between two pins to wire length
CO = (for Layout option) conductor offset; distance from edge of conductor
A1 = (for Layout option) angle of departure from first pin
A2 = (for Layout option) angle between direction of first and second pins
BondLayer = (for Layout option) layer on which the wire/ribbon is drawn; default=6 (bond)

Range of Usage

N/A
Notes/Equations/References

1. Although this component is included in the Microstrip Components library, it does not use a microstrip substrate (MSUB).

2. Wire and Ribbon components serve as air bridges that are parallel to the surface of the substrate. This provides a way to connect the center of MRIND, MRINDNBR, and MSIND components.

3. Bulk resistivity of gold is used for Rho = 2.44 microhm-cm.

4. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

5. To turn off noise contribution, set Temp to $-273.15^\circ C$.

6. The wire bond layer to the conductor layer transition is drawn on the dielectric 2 layer. The width of the dielectric 2 layer is CO, the conductor offset. If CO is zero, the transition is drawn as a zero width polygon. The transition is only for layout purposes and is not taken into account in the circuit simulator.

Equivalent Circuit

![Equivalent Circuit Diagram]
Microstrip Components
Chapter 3: Multilayer Interconnects
Multilayer Interconnects

**COMBINE2ML (Combine 2 Coupled-Line Components)**

**Symbol**

![Symbol](Combine 2 into 1)

**Parameters**
- Coupled[1] = first component to be combined
- Coupled[2] = second component to be combined
- S = spacing between Coupled[1] and Coupled[2]

**Range of Usage**

N/A

**Notes/Equations/References**

1. Combining coupled-line components allows you to create a component of more coupled lines by combining several individual components into a single component. For example, to create 20 coupled lines, you can combine two 10-line components. Or, use them to combine small sets of lines instead of reinserting components with a greater number of lines.

2. You can combine coupled lines of constant width and spacing, coupled lines with varying width and spacing, and coupled pads and lines. The components to be combined must refer to the same substrate, be parallel, and be of the same length.

![Diagram]

- Two-line component
- Three-line component
- S of combined component
COMBINE3ML (Combine 3 Coupled-Line Components)

Symbol

Parameters

Coupled[1] = first component to be combined
Coupled[2] = second component to be combined
Coupled[3] = third component to be combined

Range of Usage
N/A

Notes/Equations/References

1. Combining coupled-line components allows you to create a component of more coupled lines by combining several individual components into a single component. For example, to create 20 coupled lines, you can combine two 10-line components. Or, use them to combine small sets of lines instead of reinserting components with a greater number of lines.

2. You can combine coupled lines of constant width and spacing, coupled lines with varying width and spacing, and coupled pads and lines. The components to be combined must refer to the same substrate, be parallel, and be of the same length.
Multilayer Interconnects

**COMBINE4ML (Combine 4 Coupled-Line Components)**

**Symbol**

![Combine 4 into 1](image)

**Parameters**

- Coupled[1] = first component to be combined
- Coupled[2] = second component to be combined
- Coupled[3] = third component to be combined
- Coupled[4] = fourth component to be combined

**Range of Usage**

N/A

**Notes/Equations/References**

1. Combining coupled-line components allows you to create a component of more coupled lines by combining several individual components into a single component. For example, to create 20 coupled lines, you can combine two 10-line components. Or, use them to combine small sets of lines instead of reinserting components with a greater number of lines.

2. You can combine coupled lines of constant width and spacing, coupled lines with varying width and spacing, and coupled pads and lines. The components to be combined must refer to the same substrate, be parallel, and be of the same length.
Multilayer Interconnects

**COMBINE5ML (Combine 5 Coupled-Line Components)**

**Symbol**

![Combine 5 into 1](image)

**Parameters**
- Coupled[1] = first component to be combined
- Coupled[2] = second component to be combined
- Coupled[3] = third component to be combined
- Coupled[4] = fourth component to be combined
- Coupled[5] = fifth component to be combined

**Range of Usage**

N/A

**Notes/Equations/References**

1. Combining coupled-line components allows you to create a component of more coupled lines by combining several individual components into a single component. For example, to create 20 coupled lines, you can combine two 10-line components. Or, use them to combine small sets of lines instead of reinserting components with a greater number of lines.

2. You can combine coupled lines of constant width and spacing, coupled lines with varying width and spacing, and coupled pads and lines. The components to be combined must refer to the same substrate, be parallel, and be of the same length.
### Coupled Lines, Constant Width & Spacing

**ML1CTL_C to ML8CTL_C** (1-8 Coupled Lines, Constant Width & Spacing)

**ML16CTL_C** (16 Coupled Lines, Constant Width & Spacing)

#### Symbol

![Symbol Diagram](image)

#### Parameters

- **Subst** = substrate name
- **Length** = line length, in specified units
- **W** = width of conductors, in specified units
- **S** = spacing; default: 5.0 mil; also um, mm, cm, meter, in
- **Layer** = layer number of conductor (value type: integer)
- **RLGC_File** = name of RLGC file

---

3-6  Coupled Lines, Constant Width & Spacing
Multilayer Interconnects

**R**euse **R**LGC = yes to reuse the RLGC matrices stored in RLGC_File; no to not reuse. See Note 5.

**S**ide = (for Layout option) top or bottom; specify side or board to place instance

**R**ange of **U**sage

\[ W > 0 \]

\[ S > 0 \]

**N**otes/**E**quations/**R**eferences

1. Dispersion due to skin effect and dielectric loss is calculated. Dispersion due to inhomogeneous dielectrics is not considered.

2. These models are implemented as the numerical solution of Maxwell’s Equations for the two-dimensional cross-section geometry that is defined by the model parameters. Because a new numerical computation is performed for each unique set of geometric or material parameters, the evaluation of these models may take a few seconds on some platforms. One effect of this implementation is that optimization of any set of the geometric or material parameters for these models may result in a time-consuming analysis. Only one numerical computation is required for an analysis that is only swept with respect to frequency. The evaluation time for this model is significantly reduced for conductors of 0 thickness.

3. Conductor loss (and its contribution to noise) is not considered if conductivity is infinite or conductor thickness is 0.

4. A substrate must be named as the Subst parameter and a multilayer interconnect substrate definition that corresponds to this name must appear on the schematic.

5. If Reuse_RLGC is set to yes, the RLGC matrices will be read from the file stored on your disk. If you have changed the substrate parameters or transition parameters, setting Reuse_RLGC to yes will cause invalid results. In most cases, a setting of no is recommended. In cases in which you know that the substrate and transmission parameters are fixed in your simulation, you can set Reuse_RLGC to yes to save some computer time, as the RLGC matrices will not be re-computed.
Multilayer Interconnects

Coupled Lines, Variable Width & Spacing
ML2CTL_V to ML10CTL_V (2 to 10 Coupled Lines, Variable Width & Spacing)

Symbol

Parameters
Subst = substrate name
Length = length, in specified units
W[i] = width of ith conductor, in specified units
S(i) = spacing between ith and (i+1)th conductors, in specified units. See note 5.
Layer(i) = layer number of conductor (value type: integer)
RLGC_File = name of RLGC file
Reuse RLGC = yes to reuse the RLGC matrices stored in RLGC_File; no to not reuse. See Note 5.
Side = (for Layout option) top or bottom; specify side or board to place instance

Range of Usage
Length > 0
W > 0

Notes/Equations/References
1. Dispersion due to skin effect and dielectric loss is calculated. Dispersion due to inhomogeneous dielectrics is not considered.

2. These models are implemented as the numerical solution of Maxwell’s Equations for the two-dimensional cross-section geometry that is defined by the model parameters. Because a new numerical computation is performed for each unique set of geometric or material parameters, the evaluation of these models may take a few seconds on some platforms. One effect of this implementation is that optimization of any set of the geometric or material parameters for these models may result in a time-consuming analysis. Only one numerical computation is required for an analysis that is only swept with respect to frequency. The evaluation time for this model is significantly reduced for conductors of 0 thickness.

3. Conductor loss (and its contribution to noise) is not considered if conductivity is infinite or conductor thickness is 0.

4. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must be placed in the schematic.

5. If Reuse_RLGC is set to yes, the RLGC matrices will be read from the file stored on your disk. If you have changed the substrate parameters or transition parameters, setting Reuse_RLGC to yes will cause invalid results. In most cases, a setting of no is recommended. In cases in which you know that the substrate and transmission parameters are fixed in your simulation, you can set Reuse_RLGC to yes to save some computer time, as the RLGC matrices will not be re-computed.

6. Spacing (S[i]) is measured from the right edge of the ith conductor to the left edge of (it1)th conductor. If (it1)th conductor overlays with ith conductor, S[i] will be negative, as illustrated.
Multilayer Interconnects

MLACRNR (190-degree Corner, Changing Width)

Symbol

Parameters
Subst = substrate name
W1 = width on one side, in specified units
W2 = width on the other side, in specified units
Layer = layer number of conductor (value type: integer)

Range of Usage
W1 > 0
W2 > 0

Notes/Equations/References
1. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
Coupled 90-degree Corners, Changing Pitch

MLACRNR2 to MLACRNR8 (2 to 8 Coupled 90-degree Corners, Changing Pitch)
MLACRNR16 (16 Coupled 90-degree Corners, Changing Pitch)

Symbol

Parameters
Subst = substrate name
W1 = conductor width on one side, in specified units
S1 = conductor spacing on one side, in specified units
W2 = conductor width on the other side, in specified units
S2 = conductor spacing on the other side, in specified units
Layer = layer number of conductor (value type: integer)

Range of Usage
W1 > 0
W2 > 0

Notes/Equations/References
1. Coupled line corners are modeled as staggered coupled lines. The discontinuity effect of corners is not modeled.
2. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
Multilayer Interconnects

MLCLE (Via Clearance)

Symbol

Parameters
Subst = substrate name
DiamClear = clearance diameter, in specified units
DiamPad = pad diameter, in specified units
Layer = layer number of the clearance (value type: integer)

Range of Usage
DiamClear > 0
DiamPad > 0
DiamClear > DiamPad

Notes/Equations/References
1. This component is modeled as a capacitor to ground.
2. A substrate must be named in the Subst field and a multilayer substrate
definition that corresponds to this name must appear on the circuit page.
3. A via clearance must be located on a ground layer or a power layer. The pins of
MLCLE should be connected to the pins of MLVIAHOLE. MLCLE models the
parasitic capacitance between the via hole and the power/ground plane on
which MLCLE is located.
Coupled Angled Corners, Constant Pitch

MLCRNR1 to MLCNRNR8 (1 to 8 Coupled Angled Corners, Constant Pitch)
MLCRNR16 (16 Coupled Angled Corners, Constant Pitch)

Symbol

Parameters

Subst = substrate name
Angle = angle of bend, in degrees
W = width of conductors, in specified units
S = spacing between conductors, in specified unit
layer = layer number of conductor (value type: integer)

Range of Usage

W > 0
S > 0
0 ≤ Angle ≤ 90°

Notes/Equations/References

1. Coupled line corners are modeled as staggered coupled lines. The discontinuity effect of corners is not modeled.
Multilayer Interconnects

2. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
Coupled Crossovers
MLCROSSOVER1 to MLCROSSOVER8 (1 to 8 Crossovers)

Symbol

Parameters
Subst = substrate name
W_Top = width of top conductors, in specified units
W_Bottom = width of bottom conductors, in specified units
S_Top = spacing between top conductors, in specified units
S_Bottom = spacing between bottom conductors, in specified units
LayerTop = top layer number (value type: integer)
LayerBottom = bottom layer number (value type: integer)

Range of Usage
W_Top > 0
W_Bottom > 0
S_Top > 0
S_Bottom > 0

Notes/Equations/References

3-16  Coupled Crossovers
1. An important discontinuity in high-speed digital design is the crossover between two adjacent signal layers. The crossover causes parasitic capacitance, resulting in high-frequency crosstalk. These crossover models are modeled as coupled lines cascaded with junction coupling capacitors. The models are quasi-static.

2. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.

3. Port reference planes are located at the edge of each crossover region, as shown in Figure 3-1. The capacitor is at the junction where a horizontal and vertical line cross.

![Figure 3-1. Crossover region with port reference planes](image-url)
MLJCROSS (Cross Junction)

Symbol

Parameters

Subst = substrate name
W1 = width of conductor 1, in specified units
W2 = width of conductor 2, in specified units
W3 = width of conductor 3, in specified units
W4 = width of conductor 4, in specified units
Layer = layer number (value type: integer)

Range of Usage

W1 > 0
W2 > 0
W3 > 0
W4 > 0

Notes/Equations/References

1. The cross junction is treated as an ideal connection between pins 1, 2, 3, and 4, and is provided to facilitate interconnections between lines in layout.

2. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
MLJGAP (Open Gap)

Symbol

Parameters

Subst = substrate name
G = width of gap, in specified units
W = width of conductor, in specified units
Layer = layer number (value type: integer)

Range of Usage

G > 0
W > 0

Notes/Equations/References

1. The gap is treated as an ideal open circuit between pins 1 and 2, and is provided to facilitate layout.

2. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
MLJTEE (Tee Junction)

Symbol

Parameters
Subst = substrate name
W1 = width of conductor 1, in specified units
W2 = width of conductor 2, in specified units
W3 = width of conductor 3, in specified units
Layer = layer number (value type: integer)

Range of Usage
W[n] > 0

Notes/Equations/References
1. The tee junction is treated as an ideal connection between pins 1, 2, and 3, and is provided to facilitate interconnections between lines oriented at different angles in layout.
2. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
Multilayer Interconnects

MLOPENSTUB (Open Stub)

Symbol

Parameters

Subst = substrate name
Length = length of conductor, in specified units
W = width of conductor, in specified units
Layer = layer number (value type: integer)

Range of Usage

W > 0
L > 0

Notes/Equations/References

1. If the length of the stub is zero, this component simulates an open-end effect. If the length is greater than zero, this component simulates a length of line and an open-end effect.

2. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
Multilayer Interconnects

**Coupled Radial Lines**

MLRADIAL1 to MLRADIAL5 (1 to 5 Radial Lines)

**Symbol**

![Coupled Radial Lines Symbol](image)

**Parameters**

- **Subst** = substrate name
- **X_Offset** = horizontal offset
- **Y_Offset** = vertical offset
- **W_Left** = width of conductor on left side, in specified units
- **W_Right** = width of conductor on right side, in specified units
- **S_Left** = spacing between conductors on left side, in specified units
- **S_Right** = spacing between conductors on right side, in specified units
- **Layer** = layer number of conductor (value type: integer)

**Range of Usage**

- **X_Offset** > 0
- **Y_Offset** > 0
- **W_Left** > 0
- **W_Right** > 0
S_{Left} > 0
S_{Right} > 0

Notes/Equations/References
1. Radial lines are modeled as a cascade of uniform coupled line segments. Each segment is implemented as the numerical solution of Maxwell’s Equations for the two-dimensional cross-section geometry. For optimization or tuning, zero-thickness conductor is suggested to speed up the run time.
2. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
Slanted Coupled Lines

MLSLANTED1 to MLSLANTED8 (1 to 8 Slanted Coupled Lines)
MLSLANTED16 (16 Slanted Coupled Lines)

Symbol

Parameters
Subst = substrate name
X_Offset = horizontal offset
Y_Offset = vertical offset
W = width of conductors, in specified units
S = spacing between conductors, in specified units
Layer = layer number of conductors (value type: integer)

Range of Usage
X_Offset > 0
Y_Offset > 0
W > 0
S > 0

Notes/Equations/References

1. Dispersion due to skin effect and dielectric loss is calculated. Dispersion due to inhomogeneous dielectrics is not considered.

2. These models are implemented as the numerical solution of Maxwell's Equations for the two-dimensional cross-section geometry that is defined by the model parameters. Because a new numerical computation is performed for each unique set of geometric or material parameters, the evaluation of these models may take a few seconds on some platforms. One effect of this implementation is that optimization of any set of the geometric or material parameters for these models may result in a time-consuming analysis. Only one numerical computation is required for an analysis that is only swept with respect to frequency. The evaluation time for this model is significantly reduced for conductors of 0 thickness.

3. Conductor loss (and its contribution to noise) is not considered if conductivity is infinite or conductor thickness is 0.

4. A substrate must be named in the Subst field and a multilayer interconnect substrate definition that corresponds to this name must appear on the circuit page.
MLSUBSTRATES

MLSUBSTRATE2 to MLSUBSTRATE10 (2- to 10-Layer Substrates)
MLSUBSTRATE12 (12-Layer Substrate)
MLSUBSTRATE14 (14-Layer Substrate)
MLSUBSTRATE16 (16-Layer Substrate)

Illustrations:
MLSUBSTRATE2
MLSUBSTRATE3
MLSUBSTRATE4
MLSUBSTRATE5
MLSUBSTRATE6
Multilayer Interconnects

MLSUBSTRATE7

MLSUBSTRATE8

MLSUBSTRATE9

MLSUBSTRATE10

MLSUBSTRATE12

3-27 MLsubstrates
### Parameters

- \( E_r[n] \) = dielectric constant
- \( H[n] \) = height of substrate, in specified units
- \( \tan D[n] \) = dielectric loss tangent
- \( T[n] \) = thickness, in specified units
- \( \text{Cond}[n] \) = conductance, in conductance per meters
- \( \text{LayerType}[n] \) = metal definition: blank, signal, ground, power
- \( \text{LayerName}[n] \) = (for Layout option) layer to which cond is mapped
- \( \text{LayerViaName}[n] \) = (for Layout option) layer to which via hole is mapped

### Range of Usage

- \( E_r[n] > 0 \)
- \( H[n] > 0 \)
Notes/Equations/References

1. At least one substrate component must be inserted as part of any multilayer circuit design. The name of the substrate must be inserted in the Subst field of every multilayer interconnect component displaying the field in the circuit. Substrate names can be up to 10 characters long; they must begin with a letter, not a number or a symbol.

2. If the conductor thickness $T[n]$ is set to zero or if the conductivity $\text{Cond}[n]$ is set to infinity, the conductor is assumed to have zero loss.

$T[n]$ can be used to specify the position of the trace on a substrate. If $T[n]$ is positive, the trace grows up into the dielectric material; if $T[n]$ is negative, the trace grows down into the material. For ground and power supply layers, assigning $T[n]$ as positive or negative has no effect. See Figure 3-2.

3. Gold conductivity is $4.1 \times 10^7$ S/m. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^7$.

4. The substrate schematic symbol appears as a cross-section of a substrate. Each layer is labeled, and you can easily set the parameters for each layer.

A signal layer has components on it.

A power or ground layer is a solid sheet of metal. No components are on this layer other than clearance holes.

![Figure 3-2. Effect of positive and negatives of $T[n]$](image)
Multilayer Interconnects

MLVIAHOLE (Via Hole)

Symbol

Parameters
Subst = substrate name
DiamVia = via diameter, in specified units
T = via thickness, in specified units
Cond = conductivity
Layer[1] = starting layer number (value type: integer)
Layer[2] = ending layer number (value type: integer)

Range of Usage
DiamVia > 0
T > 0
Cond > 0

Notes/Equations/References
1. This component is modeled as an inductor.
2. A substrate must be named in the Subst field and a multilayer substrate definition that corresponds to this name must be placed in the schematic.
Multilayer Interconnects

MLVIAPAD (Via Pad)

Symbol

![Symbol Image]

Parameters

Subst = substrate name
DiamVia = via diameter, in specified units
DiamPad = pad diameter, in specified units
Layer = layer number (value type: integer)
Angle = (Layout option) input pin to output pin angle, in degrees

Range of Usage

DiamVia > 0
DiamPad > 0
-180° ≤ Angle ≤ +180°

Notes/Equations/References

1. This component is modeled as a capacitor to ground.
2. A substrate must be named in the Subst field and a multilayer substrate definition that corresponds to this name must appear on the circuit page.
3. A via pad connects signal trace to a via hole. Pin 1 of MLVIAPAD should be connected to a signal trace. Pin 2 should be connected to a MLVIAHOLE.
4. Angle refers to the angle between two connecting lines and is necessary for performing layout. In Figure 3-3 the angle between the two traces is 90°. The angle parameters of the two pads used in connecting these traces must be
specified so that the difference between them is 90°. Therefore, the angle of the first pad may be −45° and the second 45°, or 0° and 90°, respectively.

Figure 3-3. The 90° angles of the connecting lines
Chapter 4: Stripline Components
**Stripline Components**

**SBCLIN (Broadside-Coupled Lines in Stripline)**

**Symbol**

![Symbol Image]

**Illustration**

![Illustration Image]

**Parameters**

- **Subst** = substrate instance name
- **W** = conductor width, in specified units
- **S** = conductor spacing, in specified units; see Notes 3 and 4.
- **L** = length, in specified units
- **Temp** = physical temperature, in °C
- **W1** = (for Layout option) offset from pin 1 to conductor centerline
- **W2** = (for Layout option) offset from pin 2 to conductor centerline
- **W3** = (for Layout option) offset from pin 3 to conductor centerline
- **W4** = (for Layout option) offset from pin 4 to conductor centerline
- **P1Layer** = (for Layout option) layer associated with pin 1 conductor; cond1, cond2
Range of Usage

\[ \frac{W}{B-S} \geq 0.35 \]

\[ \frac{S}{B} \leq 0.9 \]

\[ \frac{W}{S} \geq 0.7 \]

where

- \( E_r \) = dielectric constant (from associated SSUB(O))
- \( B \) = ground plane spacing (from associated SSUB(O))
- \( S \) = center layer thickness (conductor spacing)

Notes/Equations/References

1. Conductor thickness correction is applied in the frequency-domain analytical model.
2. Coupled lines are parallel to the ground plane.
3. Components that refer to an SSUBO with \( S=0 \) give the same simulation results as if they refer to an otherwise equivalent SSUB.
4. If the Subst parameter refers to an SSUBO, the SSUBO’s spacing parameter \( S \) value is used rather than the component spacing parameter \( S \). This is true regardless of whether the component’s \( S \) is set to a real value or to unspecified. If it is set to a real value, a warning message is displayed.
5. For coupled-stripline of negligible thickness \( (T=0) \), the even- and odd-mode characteristic line impedances are calculated from the exact formula derived by Shelton using conformal mapping. For a stripline of finite thickness, an approximate model developed by William Getsinger for Agilent and based on the formula of Shelton, Cohn, and Wheeler is used to calculate the even- and odd-mode impedances. Additionally, the attenuation formula developed by Wheeler is used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.
6. For time-domain analysis, the frequency-domain analytical model is used.
Stripline Components


**SBEND (Unmitered Stripline Bend)**

**Symbol**

![SBEND Symbol](image)

**Illustration**

![SBEND Illustration](image)

**Parameters**
- **Subst** = substrate (SSUB or SSUBO) instance name
- **W** = conductor width, in specified units
- **Angle** = angle of bend, in degrees
- **Temp** = physical temperature, in °C
- **Layer** = (for Layout option) conductor layer number: cond1, cond2

**Range of Usage**
- **W** ≥ 0
- **Angle** = any value in Layout
- \[15° \leq \text{Angle} \leq 120°\] (for \(\frac{W}{B} = 1\))
- \[0.25 \leq \frac{W}{B} \leq 1.75\] (for **Angle** = 90°)

where
- **B** = ground plane spacing (from associated SSUB)
Stripline Components

Notes/Equations/References

1. The frequency-domain analytical model is the static, lumped component model of Altschuler and Oliner. The formulas are based on a theoretical analysis of the E-plane bend in parallel-plate waveguide. Conductor and dielectric losses are not included in the simulation.

2. If the Subst parameter refers to an SSUBO whose spacing parameter S has a non-zero value, the component is considered offset for layout and electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. In layout, a positive value for Angle draws a bend in the counterclockwise direction from pin 1 to 2; a negative value for Angle draws a bend in the clockwise direction.


Equivalent Circuit
SBEND2 (Stripline Bend -- Arbitrary Angle/Miter)

Symbol

Illustration

Parameters
Subst = substrate (SSUB or SSUBO) instance name
W = conductor width, in specified units
Angle = angle of bend, in degrees
M = miter fraction
Temp = physical temperature, in °C
Layer = (for Layout option) conductor layer number: cond1, cond2

Range of Usage

\[ W \leq 5.7 \times B \]
\[ B \leq 0.2 \times \lambda \]
\[ W \leq 0.2 \times \lambda \]
Stripline Components

\[ M \leq 0.01 \times \text{Angle (degrees)} \]
\[ M \leq 0.8 \]
\[ 20^\circ \leq \text{Angle} \leq 150^\circ \]

where

\[ B = \text{ground plane spacing (from associated SSUB)} \]
\[ \lambda = \text{wavelength in the dielectric} \]
\[ W \geq 0 \text{ for Layout} \]

Notes/Equations/References

1. The frequency-domain analytical model is a static, lumped component model developed for Agilent by William J. Getsinger. The model is based on the waveguide E-plane parallel-plate model analyzed by J. Schwinger and published in Marcuvitz's book, Waveguide Handbook. Based on the work of Oliner, the waveguide model is transformed into its dual stripline model. Conductor and dielectric losses are included in the simulation. Reference plane shifts are added for large miters (\( M > M_s \)).

2. If the Subst parameter refers to an SSUBO whose spacing parameter \( S \) has a non-zero value, the component is considered offset for layout and electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. There are two possible reference plane locations available:
   - Small miters where the reference planes line up with the inner corner of the bend.
   - Large miters where the reference planes line up with the corner between the connecting strip and the mitered section.

4. In layout, a positive value for Angle draws a bend in the counterclockwise direction from pin 1 to 2; a negative value for Angle draws a bend in the clockwise direction.


Stripline Components

SCLIN (Edge-Coupled Lines in Stripline)

Symbol

Illustration

Parameters
Subst = substrate instance name
W = line width, in specified units
S = spacing between lines, in specified units
L = line length, in specified units
Temp = physical temperature, in °C
W1 = (for Layout option) width of line that connects to pin 1
W2 = (for Layout option) width of line that connects to pin 2
W3 = (for Layout option) width of line that connects to pin 3
W4 = (for Layout option) width of line that connects to pin 4
Layer = (for Layout option) conductor layer number: cond1, cond2

Range of Usage
S > 0
W ≥ 0.35 × B (for T > 0)
W > 0 (for T = 0)
T < 0.1 \times B

where

B = \text{ground plane spacing (from associated SSUB)}
T = \text{conductor thickness (from associated SSUB)}

Notes/Equations/References

1. The frequency-domain analytical model is as follows. For centered coupled-stripline of negligible thickness (T=0), the even- and odd-mode characteristic line impedances are calculated from the exact formula derived by Cohn using conformal mapping. For a centered coupled-stripline of finite thickness, Cohn’s approximate formula is used in conjunction with Wheeler’s attenuation formula. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. If the Subst parameter refers to an SSUBO whose spacing parameter S has a non-zero value, the component is considered offset for layout and electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. For time-domain analysis, the frequency-domain analytical model is used.

4. In generating a layout, adjacent transmission lines will be lined up with the inner edges of the conductor strips. If the connecting transmission lines are narrower than the coupled lines, they will be centered on the conductor strips.


Stripline Components

SCROS (Stripline Cross Junction)

Symbol

Illustration

Parameters
Subst = substrate instance name
W1 = conductor width at pin 1, in specified units
W2 = conductor width at pin 2, in specified units
W3 = conductor width at pin 3, in specified units
W4 = conductor width at pin 4, in specified units
Temp = physical temperature, in °C
Layer = (for Layout option) conductor layer number: cond1, cond2

Range of Usage
Simulation frequency (GHz) \( \leq \frac{Z_0}{B} \)

where
\( Z_0 = \) characteristic impedance of the widest strip in ohms
\( B = \) ground plane spacing in millimeters
Notes/Equations/References

1. The frequency-domain analytical model is a frequency dependent, lumped component model developed for Agilent by William J. Getsinger. The model is an extension of the stripline T-junction model. The T-junction model is based on the waveguide E-plane parallel-plate model analyzed by J. Schwinger and published in Marcuvitz's book, Waveguide Handbook. Based on the work of Oliner, the waveguide model is transformed into its dual stripline model. Conductor and dielectric losses are not included in the simulation.

2. If the Subst parameter refers to an SSUBO whose spacing parameter S has a non-zero value, the component is considered offset for layout and electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. For time-domain analysis, the frequency-domain analytical model is used.

4. In Layout, all pins are centered at the corresponding edges.


Equivalent Circuit
Stripline Components

**SCURVE (Curved Line in Stripline)**

**Symbol**

![Diagram of SCURVE symbol]

**Illustration**

![Diagram of SCURVE example]

**Parameters**

- **Subst** = substrate instance name
- **W** = conductor width, in specified units
- **Angle** = angle subtended by the bend, in degrees
- **Radius** = radius (measured to strip centerline), in specified units
- **Temp** = physical temperature, in °C
- **Layer** = (for Layout option) conductor layer number: cond1, cond2

**Range of Usage**

\[ \text{RAD} \geq \frac{W + B / 2}{2} \]

where

- **B** = ground plane spacing (from associated SSUB)
Notes/Equations/References

1. The frequency-domain analytical model consists of an equivalent piece of straight stripline. The model was developed for Agilent by William J. Getsinger and is based on the waveguide E-plane parallel-plate model analyzed by J. Schwinger and published in Marcuvitz’s book, Waveguide Handbook. Following the work of Oliner, the waveguide model is transformed into its dual stripline model. Conductor and dielectric losses are included in the simulation. Discontinuity effects accounted for are those due to radius only.

2. If the Subst parameter refers to an SSUBO whose spacing parameter S has a non-zero value, the component is considered offset for layout and electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. For time-domain analysis, the frequency-domain analytical model is used.

4. In layout, a positive value for Angle draws a curve in the counterclockwise direction; a negative value draws a curve in the clockwise direction.


Stripline Components

SLEF (Stripline Open End Effect)

Symbol

![Symbol]

Illustration

![Illustration]

Parameters
Subst = substrate instance name
W = line width, in specified units
L = line length, in specified units
Temp = physical temperature, in °C
Layer = (for Layout option) conductor layer number: cond1, cond2

Range of Usage
\[
\frac{W}{B} \geq 0.15
\]
\[
\frac{T}{B} < 0.1
\]

where
\[
B = \text{ground plane spacing (from associated SSUB)}
\]
\[
T = \text{conductor thickness (from associated SSUB)}
\]

Notes/Equations/References
1. The frequency-domain analytical model consists of an extension to the length of the stripline stub. The stripline is modeled using the SLIN model for thin (T=0) and thick (T>0) stripline, including conductor and dielectric loss. The length of
the extension of the stripline, $dl$, is based on the formula developed by Altschuler and Oliner.

2. If the Subst parameter refers to an SSUBO whose spacing parameter $S$ has a non-zero value, the component is considered offset for layout and electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. For time-domain analysis, the frequency-domain analytical model is used.


**Equivalent Circuit**

---

![Equivalent Circuit Diagram](attachment:equivalent_circuit.png)
Stripline Components

**SLIN (Stripline)**

**Symbol**

![Symbol of SLIN](image)

**Illustration**

![Illustration of SLIN](image)

**Parameters**

Subst = substrate instance name

W = line width, in specified units

L = line length, in specified units

Temp = physical temperature, in °C

Layer = (for Layout option) conductor layer number: cond1, cond2

**Range of Usage**

- W > 0 (for T = 0)
- \( W \geq 0.35 \times B \) (for \( T > 0 \))
- \( T \leq 0.25 \times B \)
- \( S > 0.9 \times B \)

where

- \( B \) = ground plane spacing (from associated SSUB)
- \( T \) = conductor thickness (from associated SSUB)

**Notes/Equations/References**

1. The frequency-domain analytical model is as follows. For centered stripline of negligible thickness (\( T = 0 \)), the characteristic line impedance is calculated from the exact formula derived by Cohn using conformal mapping. For a centered stripline of finite thickness, Wheeler's approximate formula for the
characteristic line impedance and attenuation factor are used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. For offset stripline, a model developed by William Getsinger for Agilent and based on the formula of Shelton, Cohn and Wheeler is used. For an offset stripline of negligible thickness (T=0), the characteristic line impedance is calculated from the exact formula derived by Shelton using conformal mapping. For an offset stripline of finite thickness, Shelton’s exact formula is combined with Cohn’s formula for a centered thick stripline to formulate an approximate formula. Additionally, the attenuation formula developed by Wheeler is used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

3. If the Subst parameter refers to an SSUBO whose spacing parameter S has a non-zero value, the component is considered offset for simulation and layout purposes. A reference to SSUBO with its spacing parameter S=0 is equivalent to a reference to the SSUB.


Stripline Components

**SLINO (Offset Strip Transmission Line)**

**Symbol**

![Illustration of SLINO](image)

**Parameters**

Subst = substrate instance name

W = line width, in specified units

S = middle dielectric layer thickness, in specified units; see Notes 1 and 2.

L = line length, in specified units

Temp = physical temperature, in °C

Layer = (for Layout option) conductor layer number: cond1, cond2

**Range of Usage**

\[
\frac{W}{B + S - T} \geq 0.35
\]

where

B = ground plane spacing (from associated SSUB)

T = conductor thickness (from associated SSUB)

**Notes/Equations/References**

1. The frequency-domain analytical model is as follows. For offset stripline, a model developed by William Getsinger for negligible thickness (T=0), the
characteristic line impedance is calculated from the exact and based on the formula of Shelton, Cohn and Wheeler is used. For an offset stripline of negligible thickness (T=0), the characteristic line impedance is calculated from the exact formula derived by Shelton using conformal mapping. For an offset stripline of finite thickness, Shelton's exact formula is combined with Cohn's formula for a centered thick stripline to formulate an approximate formula. Additionally, the attenuation formula developed by Wheeler is used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. Components that refer to an SSUBO with S=0 give the same simulation results as if they refer to an otherwise equivalent SSUB.

3. If the Subst parameter refers to an SSUBO, the SSUBO spacing parameter (S) value is used rather than the component spacing parameter (S). This is true regardless of whether the component's S is set to a real value or to unspecified. If it is set to a real value, a warning message is displayed. If the Subst parameter refers to an SSUB (rather than to an SSUBO), the component's value for S is used.

4. For time-domain analysis, the frequency-domain analytical model is used.


Stripline Components

SLOC (Stripline Open-Circuited Stub)

Symbol

Illustration

Parameters

Subst = substrate instance name
W = line width, in specified units
L = line length, in specified units
Temp = (physical temperature, in °C
Layer = (for Layout option) conductor layer number: cond1, cond2

Range of Usage

\[ \frac{T}{B} \leq 0.25 \]

where

B = ground plane spacing (from associated SSUB)
T = conductor thickness (from associated SSUB)

Notes/Equations/References

1. The frequency-domain analytical model is as follows. For centered stripline of negligible thickness (T=0), the characteristic line impedance is calculated from
the exact formula derived by Cohn using conformal mapping. For a centered stripline of finite thickness, Wheeler’s approximate formula for the characteristic line impedance and attenuation factor are used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. For offset stripline, a model developed by William Getsinger for Agilent and based on the formula of Shelton, Cohn and Wheeler is used. For an offset stripline of negligible thickness (T=0), the characteristic line impedance is calculated from the exact formula derived by Shelton using conformal mapping. For an offset stripline of finite thickness, Shelton’s exact formula is combined with Cohn’s formula for a centered thick stripline to formulate an approximate formula. Additionally, the attenuation formula developed by Wheeler is used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model. No end effects are included in the model.

3. If the Subst parameter refers to an SSUBO whose spacing parameter S has a non-zero value, the component is considered offset for simulation and layout purposes. A reference to SSUBO with its spacing parameter S=0 is equivalent to a reference to SSUB.

4. For time-domain analysis, the frequency-domain analytical model is used.


Stripline Components

**SLSC (Stripline Short-Circuited Stub)**

**Symbol**

![Symbol Image]

**Illustration**

![Illustration Image]

**Parameters**

- **Subst** = substrate instance name
- **W** = line width, in specified units
- **L** = line length, in specified units
- **Temp** = physical temperature, in °C
- **Layer** = (for Layout option) conductor layer number: `cond1, cond2`

**Range of Usage**

\[
\frac{T}{B} \leq 0.25
\]

where

- **B** = ground plane spacing (from associated SSUB)
- **T** = conductor thickness (from associated SSUB)

**Notes/Equations/References**

1. For centered stripline of negligible thickness (\(T = 0\)), the characteristic line impedance is calculated from the exact formula derived by Cohn using conformal mapping. For a centered stripline of finite thickness, Wheeler's
approximate formula for the characteristic line impedance and attenuation factor are used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. For offset stripline, a model developed by William Getsinger for Agilent and based on the formula of Shelton, Cohn and Wheeler is used. For an offset stripline of negligible thickness \( T=0 \), the characteristic line impedance is calculated from the exact formula derived by Shelton using conformal mapping. For an offset stripline of finite thickness, Shelton’s exact formula is combined with Cohn’s formula for a centered thick stripline to formulate an approximate formula. Additionally, the attenuation formula developed by Wheeler is used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model. No end effects are included in the model.

3. If the Subst parameter refers to an SSUBO whose spacing parameter \( S \) has a non-zero value, the component is considered offset for simulation and layout purposes. A reference to SSUBO with its spacing parameter \( S=0 \) is equivalent to a reference to SSUB.

4. For time-domain analysis, the frequency-domain analytical model is used.


Stripline Components

SMITER (90-degree Stripline Bend -- Optimally Mitered)

Symbol

Illustration

Parameters
Subst = substrate instance name
W = conductor width, in specified units
Temp = physical temperature, in °C
Layer = (for Layout option) conductor layer number: cond1, cond2

Range of Usage
0.2 ≤ W ≤ 3 × B

where
B = ground plane spacing (from associated SSUB)

Notes/Equations/References
1. The frequency-domain model is an empirically based, analytical model. The
chamfered bend is modeled as a matched stripline line of length, Δlₒ+H_{ext}. The
effective length of the bend and the optimal chamfered dimension are
calculated based on curve fits to empirical data in Matthaei, Young, and Jones.
The stripline is modeled using the SLIN model for thin (T=0) and thick (T>0)
stripline, including conductor and dielectric loss.
For $\Delta l_o$:

If $(W/B \leq 0.2)$

\[ \Delta l_o = 0.56528 + 0.023434 \times (W/B - 0.2) \]

If $(0.2 < W/B \leq 3.0)$

\[ \Delta l_o = 0.56528 + 0.01369 \times (W/B - 0.2)^{0.77684} + 0.01443 \times (W/B - 0.2)^{2.42053} \]

If $(W/B > 3.0)$

\[ \Delta l_o = 0.770175 + 0.155473 \times (W/B - 3.0) \]

For $l_{ext}$:

If $(a > W)$

\[ l_{ext} = 2 \times (a - W) \]

If $(a \leq W)$

\[ l_{ext} = 0.0 \]

2. If the Subst parameter refers to an SSUBO whose spacing parameter $S$ has a non-zero value, the component is considered offset for layout and electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. The artwork is dependent on the parameters given in the SSUB or SSUBO. Layout artwork requires placing a SSUB or SSUBO, prior to placing the component directly in the Layout window.

4. The miter fraction ($a/W$) is calculated using one of the formulae given below depending on the parameter values.

If $(W/B < 0.2)$, $a/W = 1.267472 - 0.35041 \times (W/B - 0.2)$.

If $(0.2 \leq W/B \leq 1.6)$,

\[ a/W = 1.012 + (1.6 - W/B) \times ((0.08 + (1.6 - W/B) \times 0.043)) \]

If $(1.6 \leq W/B \leq 14.25)$, $a/W = 0.884 + 0.08 \times (3.2 - W/B)$.


**Equivalent Circuit**
SOCLIN (Offset-Coupled Lines in Stripline)

Symbol

Illustration

Parameters

Subst = substrate instance name
W = conductor width, in specified units
WO = conductor offset, in specified units
S = conductor spacing, in specified units
L = conductor length, in specified units
Temp = physical temperature, in °C
W1 = (for Layout option) offset from pin 1 to conductor centerline
W2 = (for Layout option) offset from pin 2 to conductor centerline
W3 = (for Layout option) offset from pin 3 to conductor centerline
W4 = (for Layout option) offset from pin 4 to conductor centerline
P1Layer = (for Layout option) layer associated with pin 1 conductor: cond1, cond2
Stripline Components

Range of Usage

\[ E_r \geq 1 \]

\[ \frac{W}{B-S} \geq 0.35 \]

\[ \frac{S}{B} \leq 0.9 \]

where

\[ B = \text{ground plane spacing (from associated SSUB)} \]

\[ E_r = \text{dielectric constant (from associated SSUB)} \]

Notes/Equations/References

1. The frequency-domain analytical model is as follows. For laterally-offset coupled-stripline of negligible thickness (T=0), the even- and odd-mode characteristic line impedances are calculated from the exact formula derived by Shelton using conformal mapping. For a laterally-offset coupled-stripline of finite thickness, a model developed by William Getsinger for Agilent and based on the formula of Shelton, Cohn and Wheeler is used to calculate the even- and odd-mode impedances. Additionally, the attenuation formula developed by Wheeler is used. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dielectric loss is also included in the model.

2. Coupled lines are parallel to the ground plane.

3. Components that refer to an SSUBO with S=0 give the same simulation results as if they refer to an otherwise equivalent SSUB.

4. If the Subst parameter refers to an SSUBO, the SSUBO spacing parameter (S) value is used rather than the component spacing parameter (S). This is true regardless of whether the component’s S is set to a real value or to unspecified. If it is set to a real value, a warning message is displayed. If the Subst parameter refers to an SSUB (rather than to an SSUBO), the component’s value for S is used.

5. For time-domain analysis, the frequency-domain analytical model is used.

6. W1, W2, W3 and W4 are layout-only parameters and only affect the electromagnetic simulation results. W1, W2, W3 and W4 cannot exceed W/2.


Stripline Components

**SSTEP (Stripline Step in Width)**

**Symbol**

![Symbol](image)

**Illustration**

![Illustration](image)

**Parameters**

- Subst = substrate instance name
- W1 = conductor width at pin 1, in specified units
- W2 = conductor width at pin 2, in specified units
- Temp = physical temperature, in °C
- Layer = (for Layout option) conductor layer number: cond1, cond2

**Range of Usage**

\[
\frac{W_2}{W_1} \leq 10
\]

\[
W_1 \leq 0.2 \times \lambda
\]

\[
W_2 = 0.2 \times \lambda
\]

where

\[
\lambda = \text{wave length in the dielectric}
\]

**Notes/Equations/References**

1. The frequency-domain analytical model is the lumped component model of Altschuler and Oliner. The model includes reference plane adjustments to align the natural reference plane of the discontinuity with the reference plane of the layout. The SLIN stripline model is used to model these reference plane shifts.

2. If the Subst parameter refers to an SSUBO whose spacing parameter S has a non-zero value, the component is considered offset for layout and

---

4-32
electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. In layout, SSTEP aligns the centerlines of the strips.


**Equivalent Circuit**

```
<table>
<thead>
<tr>
<th>Z₁</th>
<th>------</th>
<th></th>
<th>Z₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
```

L
Stripline Components

SSUB (Stripline Substrate)

Symbol

Illustration

Parameters
Er = relative dielectric constant
Mur = relative permeability
B = ground plane spacing, in specified units
T = conductor thickness, in specified units
Cond = conductor conductivity, in Siemen/meter
TanD = dielectric loss tangent
Cond 1 (for Layout Option) layer to which cond is mapped; default = 1 (cond)
Cond2 (for Layout Option) layer to which cond2 is mapped; default = 2 (cond2)

Range of Usage
Er ≥ 1.0
B > 0
T ≥ 0

Notes/Equations/References
1. SSUB sets up stripline substrate parameters for one or more stripline components. Either an SSUB or SSUBO is required for all stripline components. For offset center conductor layers, use SSUBO.
2. Gold conductivity is $4.1 \times 10^7$ S/m. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^7$.

3. The parameters Cond1 and Cond2 control the mask layers on which the conductors are drawn. These are layout-only parameters and are not used by the simulator.

In the case of SBCLIN and SOCLIN, the component parameter P1Layer identifies the virtual layer (cond1 or cond2) that the conductor associated with pin 1 is drawn on. All other stripline components have a Layer parameter that identifies the virtual layer (cond1 or cond2) on which the conductor is drawn.

The virtual layer referred to by P1Layer or Layer (cond1 or cond2) is mapped to an actual mask layer by the Cond1 or Cond2 parameter of the appropriate SSUB or SSUBO.
Stripline Components

SSUBO (Offset Stripline Substrate)

Symbol

Illustration

Parameters

Er = relative dielectric constant
Mur = relative permeability
S = inter-layer (conductor) spacing, in specified units
B = ground plane spacing, in specified units
T = conductor thickness, in specified units
Cond = conductor conductivity
TanD = dielectric loss tangent
Cond1 = (for Layout Option) layer to which cond1 is mapped; default = 1 (cond)
Cond2 = (for Layout Option) layer to which cond2 is mapped; default = 2 (cond2)

Range of Usage

Er ≥ 1.0
S ≥ 0
B > 0
T ≥ 0
S > 0.9 × B

Notes/Equations/References

1. This item specifies stripline substrate with two conductor layers located symmetrically between ground planes. It can also be used for specifying
stripline substrate with an offset center conductor layer. The only difference between SSUB and SSUBO is that spacing parameter S is added to SSUBO to support the offset conductor. SSUBO with S=0 is the same as SSUB.

2. A stripline Subst parameter can either refer to an SSUB or an SSUBO. From a simulation viewpoint, reference to SSUBO is meaningful only for the SBCLIN, SOCLIN, SLINO, SLIN, SLOC, SLEF, and SLSC, because the intrinsic models for these components support offset conductor configuration. For all other stripline components, a reference to SSUBO is effectively the same as a reference to SSUB because the spacing parameter of SSUBO is ignored.

3. An SSUBO or an SSUB is required for all stripline components.

4. Cond1 and Cond2 control the mask layers on which the conductors are drawn. These are layout-only parameters and are not used by the simulator.

5. Gold conductivity is $4.1 \times 10^7$ S/m. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^7$.

6. In the case of SBCLIN and SOCLIN, the parameter P1Layer identifies the virtual layer (cond1 or cond2) that the conductor associated with pin 1 is drawn on. All other stripline components have a Layer parameter that identifies the virtual layer (cond1 or cond2) on which the conductor is drawn.

7. The virtual layer referred to by P1Layer or Layer (cond1 or cond2) is mapped to an actual mask layer by the Cond1 or Cond2 parameter of the appropriate SSUB or SSUBO.
Stripline Components

**STEE (Stripline T-Junction)**

**Parameters**
- Subst = substrate instance name
- W1 = conductor width at pin 1, in specified units
- W2 = conductor width at pin 2, in specified units
- W3 = conductor width at pin 3, in specified units
- Temp = physical temperature, in °C
- Layer = (for Layout option) conductor layer number: cond1, cond2

**Range of Usage**

\[0.1 \leq \frac{Z_{01}}{Z_{03}} \leq 2.0\]

where

- \(Z_{01}\) = characteristic impedance of line connected to pin 1
- \(Z_{03}\) = characteristic impedance of line connected to pin 3

**Notes/Equations/References**

1. The frequency-domain analytical model is a frequency dependent, lumped component model developed for Agilent by William J. Getsinger. The model is
based on the waveguide E-plane parallel-plate model analyzed by J. Schwinger and published in Marcuvitz's book, Waveguide Handbook. Based on the work of Oliner, the waveguide model is transformed into its dual stripline model. Conductor and dielectric losses are not included in the simulation.

2. If the Subst parameter refers to an SSUBO whose spacing parameter S has a non-zero value, the component is considered offset for layout and electromagnetic analysis purposes. For other types of analyses, the offset is ignored.

3. Model assumes $W_1 = W_2$. If $W_1 \neq W_2$, then the width is calculated as $\sqrt{W_1 \times W_2}$.

4. For time-domain analysis, the frequency-domain analytical model is used.


**Equivalent Circuit**
Stripline Components
Chapter 5: Suspended Substrate Components
SSCLIN (Suspended Substrate Coupled Lines)

Symbol

Illustration

Parameters
Subst = substrate instance name
W = line width, in specified units
S = line spacing, in specified units
L = line length, in specified units
Temp = physical temperature
W1 = (for Layout option) width of line that connects to pin 1
W2 = (for Layout option) width of line that connects to pin 2
W3 = (for Layout option) width of line that connects to pin 3
W4 = (for Layout option) width of line that connects to pin 4

Range of Usage
Er ≥ 1.3
Hu ≥ H
\( \frac{H}{100} \leq Hl \leq 100 \times H \)
\[
\frac{H}{50} \leq W \leq 50 \times H \\
\frac{H}{10} \leq S \leq 10 \times H
\]

where

- \(E_r\) = dielectric constant (from SSSUB)
- \(H\) = substrate thickness (from SSSUB)
- \(H_l\) = lower ground plane to substrate spacing (from SSSUB)
- \(H_u\) = upper ground plane to substrate spacing (from SSSUB)

**Range of Usage:**

1. The frequency-domain analytical model is a non-dispersive static and lossless model. Conductor thickness is ignored.

2. In generating a layout, adjacent transmission lines will be lined up with the inner edges of the conductor strips. If the connecting transmission lines are narrower than the coupled lines, they will be centered on the conductor strips.

3. \(W_1, W_2, W_3\) and \(W_4\) are layout-only parameters and do not affect the simulation results.

Suspended Substrate Components

**SSLIN (Suspended Substrate Line)**

**Symbol**

![SSLIN Symbol](image)

**Illustration**

![SSLIN Illustration](image)

**Parameters**

Subst = substrate instance name  
W = line width, in specified units  
L = line length, in specified units  
Temp = physical temperature

**Range of Usage**

\[
\begin{align*}
E_r & \geq 1.3 \\
H_u & \geq H \\
\frac{H}{100} & \leq H_l \leq 100 \times H \\
\frac{H}{50} & \leq W \leq 50 \times H
\end{align*}
\]

where  
\(E_r\) = dielectric constant (from SSSUB)  
\(H\) = substrate thickness (from SSSUB)  
\(H_l\) = lower ground plane to substrate spacing (from SSSUB)  
\(H_u\) = upper ground plane to substrate spacing (from SSSUB)

**Range of Usage:**

1. The frequency-domain analytical model is a non-dispersive static and lossless model. Conductor thickness is ignored.
Suspended Substrate Components

SSSUB (Suspended Substrate)

Symbol

Illustration

Parameters
None

Range of Usage
Er ≥ 1.3
Hu ≥ H
0.01 × H ≤ Hl ≤ 100 × H

Notes/Equations/References

1. SSSUB sets up substrate parameters for suspended substrate components and is required for all suspended substrates.

2. Cond1 controls the layer on which the Mask layer is drawn; it is a layout-only parameter and is not used by the simulator.
Chapter 6: Transmission Line Components
Transmission Line Components

**CLIN (Ideal Coupled Transmission Lines)**

**Symbol**

![Symbol Image]

**Parameters**
- \( Ze \) = even-mode characteristic impedance, in ohms
- \( Zo \) = odd-mode characteristic impedance, in ohms
- \( E \) = electrical length, in degrees
- \( F \) = reference frequency for electrical length, in hertz

**Range of Usage**

- \( Ze > 0 \)
- \( Ze > Zo \)
- \( Zo > 0 \)
- \( E \neq 0 \)
- \( F > 0 \)

**Notes/Equations/References**

1. Odd- and even-mode phase velocities are assumed equal.
2. This component has no default artwork associated with it.
CLINP (Lossy Coupled Transmission Lines)

Symbol

Parameters
Ze = even-mode characteristic impedance, in ohms
Zo = odd-mode characteristic impedance, in ohms
L = physical length, in specified units
Ke = even-mode effective dielectric constant
Ko = odd-mode effective dielectric constant
Ae = even-mode attenuation, in dB per unit meter
Ao = odd-mode attenuation, in dB per unit meter
Temp = physical temperature, in °C

Range of Usage
Ze > 0 Ze > Zo Zo > 0
Ke > 0 Ko > 0 Ae ≥ 0 Ao ≥ 0

Notes/Equations/References
1. This component has no default artwork associated with it.
Transmission Line Components

**COAX (Coaxial Cable)**

**Symbol**

![Coaxial Cable Symbol]

**Illustration**

![Coaxial Cable Diagram]

**Parameters**

- \( \text{Di} = \) diameter of inner conductor, in specified units
- \( \text{Do} = \) inner diameter of outer conductor, in specified units
- \( \text{L} = \) length, in specified units
- \( \text{Er} = \) dielectric constant of dielectric between inner and outer conductors
- \( \text{TanD} = \) dielectric loss tangent
- \( \text{Rho} = \) conductor resistivity (relative to copper)
- \( \text{Sigma} = \) dielectric conductivity
- \( \text{Temp} = \) physical temperature, in \( ^\circ \text{C} \)

**Range of Usage**

Dimensions must support only TEM mode.

\[ \text{TanD} \geq 0 \]
Rho ≥ 0
Er ≥ 1
Do > Di

Simulation frequency < \frac{190 \text{ GHz}}{\sqrt{Er} \times [Di(\text{mm}) + Do(\text{mm})]}

Notes/Equations/References

1. This component has no default artwork associated with it.
Transmission Line Components

**CoaxTee (Coaxial 3-Port T-Junction, Ideal, Lossless)**

**Symbol**

![CoaxTee Symbol](image)

**Parameters**

- \( Z \) = line characteristic impedance, in specified units (value type: real, var)
- \( L \) = length of all T-junction branches, in specified units (value type: real, var)
- \( K \) = effective dielectric constant (value type: real, var)

**Range of Usage**

- \( Z > 0 \)
- \( L \geq 0 \)
- \( K \geq 1.0 \)

**Notes/Equations/References**

None
RCLIN (Distributed R-C Network)

Symbol

Parameters

$R = \text{series resistance per meter}$

$C = \text{shunt capacitance per meter}$

$L = \text{length, in specified units}$

$\text{Temp} = \text{physical temperature, in } ^\circ\text{C}$

Range of Usage

N/A

Notes/Equations/References

1. Total series resistance $= R \times L$; total shunt capacitance $= C \times L$

2. This component has no default artwork associated with it.

Equivalent Circuit

For transient analysis, a simplified lumped model is used, as shown below.
Transmission Line Components

TLIN (Ideal 2-Terminal Transmission Line)

Symbol

Illustration

Parameters

Z = characteristic impedance, in ohms
E = electrical length, in degrees
F = reference frequency for electrical length, in hertz

Range of Usage

Z ≠ 0
F ≠ 0

Notes/Equations/References

1. This component has no default artwork associated with it.
TLIN4 (Ideal 4-Terminal Transmission Line)

Symbol

Parameters

- $Z =$ characteristic impedance, in ohms
- $E =$ electrical length, in degrees
- $F =$ reference frequency for electrical length, in hertz

Range of Usage

- $Z \neq 0$
- $F \neq 0$

Notes/Equations/References

1. This component has no default artwork associated with it.
Transmission Line Components

TLINP (2-Terminal Physical Transmission Line)

Symbol

![Illustration]

Parameters
- $Z = \text{characteristic impedance, in ohms}$
- $L = \text{physical length, in specified units}$
- $K = \text{effective dielectric constant}$
- $A = \text{attenuation, in dB per unit meter}$
- $F = \text{frequency for scaling attenuation, in hertz}$
- $\tan D = \text{dielectric loss tangent}$
- $\mu_r = \text{relative permeability}$
- $T = \text{permeability}$
- $\sigma = \text{dielectric conductivity}$
- $\text{Temp} = \text{physical temperature, in } ^\circ\text{C}$

Range of Usage
- $Z > 0 \quad K \geq 1 \quad A \geq 0 \quad F \geq 0$

Notes/Equations/References
1. The $A$ parameter specifies conductor loss only. To specify dielectric loss, specify a non-zero value for $\tan D$ (to specify a frequency-dependent dielectric loss) or $\sigma$ (to specify a constant dielectric loss).
2. Because conductor and dielectric losses can be specified separately, the component is not assumed to be distortionless. Therefore, the actual characteristic impedance of the line may be complex and frequency-dependent.
This may cause reflections in your circuit that would not occur if a distortionless approximation were made.

3. $A(f) = A$ (for $F = 0$)

$$A(f) = A(F) \times \sqrt{\frac{f}{F}} \quad (\text{for } F \neq 0)$$

where

- $f =$ simulation frequency
- $F =$ reference frequency

4. For time-domain analysis, the frequency-domain analytical model is used.

5. This component has no default artwork associated with it.
Transmission Line Components

TLINP4 (4-Terminal Physical Transmission Line)

Symbol

Parameters

\( Z \) = characteristic impedance, in ohms
\( L \) = physical length, in specified units
\( K \) = effective dielectric constant
\( A \) = attenuation, in dB per unit meter
\( F \) = frequency for scaling attenuation, in hertz
\( \text{TanD} \) = dielectric loss tangent
\( \mu_r \) = relative permeability
\( \text{TanM} \) = permeability
\( \Sigma \) = dielectric conductivity
\( \text{Temp} \) = physical temperature, in °C

Range of Usage

\( Z > 0 \quad K \geq 1 \quad A \geq 0 \quad F \geq 0 \)

Notes/Equations/References

1. The \( A \) parameter specifies conductor loss only. To specify dielectric loss, specify non-zero value for \( \text{TanD} \) (to specify a frequency-dependent dielectric loss) or \( \Sigma \) (to specify a constant dielectric loss).

2. Since conductor and dielectric losses can be specified separately, the component is not assumed to be distortionless. Therefore, the actual characteristic impedance of the line may be complex and frequency-dependent. This may cause reflections in your circuit that would not occur if a distortionless approximation were made.

3. \( A(f) = A \quad \text{for } F = 0 \)
\[ A(f) = A(F) \times \frac{F}{\sqrt{F}} \quad \text{(for } F \neq 0) \]

where

- \( f \) = simulation frequency
- \( F \) = reference frequency

4. For time-domain analysis, the frequency-domain analytical model is used.

5. This component has no default artwork associated with it.
Transmission Line Components

TLOC (Ideal Transmission Line Open-Circuited Stub)

Symbol

Illustration

Parameters
Z = characteristic impedance, in ohms
E = electrical length, in degrees
F = reference frequency for electrical length, in hertz

Range of Usage
Z ≠ 0
F ≠ 0

Notes/Equations/References
1. This component has no default artwork associated with it.
2. Port 2 should be connected to the system ground reference.
TLPOC (Physical Transmission Line Open-Circuited Stub)

Symbol

Illustration

Parameters

- \( Z \) = characteristic impedance, in ohms
- \( L \) = physical length, in specified units
- \( K \) = effective dielectric constant
- \( A \) = attenuation, in dB per unit meter
- \( F \) = frequency for scaling attenuation, in hertz
- \( \text{TanD} \) = dielectric loss tangent
- \( \text{Mur} \) = relative permeability
- \( \text{TanM} \) = permeability
- \( \Sigma \) = dielectric conductivity
- \( \text{Temp} \) = physical temperature, in °C

Range of Usage

- \( Z > 0 \)
- \( K \geq 1 \)
- \( A \geq 0 \)
- \( F \geq 0 \)

Notes/Equations/References

1. The \( A \) parameter specifies conductor loss only. To specify dielectric loss, specify non-zero value for \( \text{TanD} \) (to specify a frequency-dependent dielectric loss) or \( \Sigma \) (to specify a constant dielectric loss).

2. Since conductor and dielectric losses can be specified separately, the component is not assumed to be distortionless. Therefore, the actual characteristic
Transmission Line Components

... impedance of the line may be complex and frequency-dependent. This may cause reflections in your circuit that would not occur if a distortionless approximation were made.

3. \( A(f) = A \quad \text{for} \; F = 0 \)

\[ A(f) = A(F) \times \frac{f}{F} \quad \text{for} \; F \neq 0 \]

where

\( f = \) simulation frequency

\( F = \) reference frequency

4. For time-domain analysis, the frequency-domain analytical model is used.

5. This component has no default artwork associated with it.
TLPSC (Physical Transmission Line Short-Circuited Stub)

Symbol

Illustration

Parameters

Z = characteristic impedance, in ohms
L = physical length, in specified units
K = effective dielectric constant
A = attenuation, in dB per unit meter
F = frequency for scaling attenuation, in hertz
TanD = dielectric loss tangent
Mur = relative permeability
TanM = permeability
Sigma = dielectric conductivity
Temp = physical temperature, in °C

Range of Usage

Z > 0  K ≥ 1  A ≥ 0  F ≥ 0

Notes/Equations/References

1. The A parameter specifies conductor loss only. To specify dielectric loss, specify non-zero value for TanD (to specify a frequency-dependent dielectric loss) or Sigma (to specify a constant dielectric loss).
2. Because conductor and dielectric losses can be specified separately, the component is not assumed to be distortionless. Therefore, the actual characteristic impedance of the line may be complex and frequency-dependent. This may cause reflections in your circuit that would not occur if a distortionless approximation were made.

3. $A(f) = A \text{ (for } F = 0)$$

   $A(f) = A(F) \times \sqrt[\frac{F}{f}] \text{ (for } F \neq 0)$$

   where
   
   $f = \text{simulation frequency}$
   
   $F = \text{reference frequency}$

4. For time-domain analysis, the frequency-domain analytical model is used.

5. This component has no default artwork associated with it.
TLSC (Ideal Transmission Line Short-Circuited Stub)

Symbol

![Symbol Illustration](image)

Parameters

- $Z =$ characteristic impedance, in ohms
- $E =$ electrical length, in degrees
- $F =$ reference frequency for electrical length, in hertz

Range of Usage

- $Z \neq 0$
- $F \neq 0$

Notes/Equations/References

1. This component has no default artwork associated with it.
2. Port 2 should be connected to the system ground reference.
Chapter 7: Waveguide Components
Waveguide Components

**CPW (Coplanar Waveguide)**

**Symbol**

![Illustration of CPW](image)

**Parameters**

- **Subst** = substrate instance name
- **W** = center conductor width, in specified units
- **G** = gap (spacing) between center conductor and ground plane, in specified units
- **L** = center conductor length, in specified units
- **Temp** = physical temperature, in °C

**Range of Usage**

- \(0.125 \times W \leq G \leq 4.5 \times W\)
- \(W + 2G \leq 20 \times H\)
- **W > 0**
- **G > 0**

**Notes/Equations/References**

1. The frequency-domain analytical model for the coplanar waveguide was developed for Agilent by William J. Getsinger and is based on a conformal mapping technique. The resulting formulas for the characteristic line impedance and effective dielectric constant are virtually the same as those...
published by Ghione and Naldi. However, the formulas are extended to account for conductors of finite thickness, conductor losses and dielectric losses.

The thickness correction is based on a technique proposed by Cohn. The conductor losses are calculated using Wheeler's incremental inductance rule. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dispersion at high frequencies is not included in the model.

2. No lower ground plane is included.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Waveguide Components

**CPWCGAP (Coplanar Waveguide, Center-Conductor Gap)**

**Symbol**

![Symbol Image]

**Illustration**

![Illustration Image]

**Parameters**

Subst = substrate instance name

W = center conductor width, in specified units

G = gap (spacing) between center conductor and ground plane, in specified units

S = gap between end of center conductor and ground plane, in specified units

Temp = physical temperature, in °C

**Range of Usage**

W > 0

G > 0

W ≤ S ≤ 1.4 × W

**Notes/Equations/References**

1. The center conductor gap in coplanar waveguide is modeled as a static, lumped component circuit. More specifically, the network is a pi-network with capacitive coupling between the center conductors and fringing capacitance from the center conductors to ground. The value of the capacitances are calculated from formula developed by William Getsinger for Agilent. The formula is based on an analysis of an analogous twin-strip configuration of the coplanar discontinuity as proposed by Getsinger. Additionally, metallization thickness correction is applied.
2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Equivalent Circuit
Waveguide Components

CPWCPL2 (Coplanar Waveguide Coupler (2 Center Conductors))

Symbol

Illustration

Parameters
Subst = substrate instance name
W = center conductor width, in specified units
G = gap (spacing) between center conductor and ground plane, in specified units
S = gap between end of center conductor and ground plane, in specified units
L = center conductor length, in specified units
Temp = physical temperature, in °C

Range of Usage
W > 0
G > 0
S > 0

Notes/Equations/References
1. The frequency-domain analytical model for a 2-conductor coupler in coplanar waveguide was developed for Agilent by William J. Getsinger and is based on a conformal mapping technique. The resulting formulas for the even and odd-mode characteristic line impedances and effective dielectric constants include the effects of finite conductor thickness, conductor losses and dielectric losses.
The thickness correction is based on a technique proposed by Cohn. The conductor losses are calculated using Wheeler's incremental inductance rule. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dispersion at high frequencies is not included in the model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Waveguide Components

**CPWCPL4 (Coplanar Waveguide Coupler) 4 Center Conductors)**

**Symbol**

![Diagram of CPWCPL4](image)

**Illustration**

![Detailed Diagram of CPWCPL4](image)

**Parameters**

- **Subst** = substrate instance name
- **W** = width of outer center conductors, in specified units
- **G** = gap (spacing) between center conductors and ground plane, in specified units
- **S** = gap between outer and inner center conductors, in specified units
- **Wi** = width of inner center conductors, in specified units
- **Si** = gap between inner center conductors, in specified units
- **L** = center conductor length, in specified units
- **Temp** = physical temperature, in °C

**Range of Usage**

- **W > 0**
- **G > 0**
- **S > 0**
- **Wi > 0**
Notes/Equations/References

1. The frequency-domain analytical model for a 4-conductor coupler in coplanar waveguide was developed for Agilent by William J. Getsinger and is based on a conformal mapping technique. The resulting formulas for the even and odd-mode characteristic line impedances and effective dielectric constants include the effects of finite conductor thickness, conductor losses and dielectric losses.

The thickness correction is based on a technique proposed by Cohn. The conductor losses are calculated using Wheeler's incremental inductance rule. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dispersion at high frequencies is not included in the model.

2. Alternate center conductors are directly connected at ends of CPWCPL4 coupler.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Waveguide Components

**CPWEF (Coplanar Waveguide, Open-End Effect)**

*Symbol*

[Diagram of CPWEF symbol]

*Illustration*

[Diagram of CPWEF illustration]

*Parameters*

Subst = substrate instance name

W = center conductor width, in specified units

G = gap (spacing) between center conductor and ground plane, in specified units

L = center conductor length, in specified units

Temp = physical temperature, in °C

*Range of Usage*

W > 0

G > 0

W + 2 × G ≤ 20 × H

0.125 × W ≤ G ≤ 4.5 × W

where

H = substrate thickness (from associated CPWSUB)

*Notes/Equations/References*

1. The frequency-domain analytical model for the coplanar waveguide was developed for Agilent by William J. Getsinger and is based on a conformal
mapping technique. The resulting formulas for the characteristic line impedance and effective dielectric constant are virtually the same as those published by Ghione and Naldi. However, the formulas are extended to account for conductors of finite thickness, conductor losses and dielectric losses. The thickness correction is based on a technique proposed by Cohn.

The conductor losses are calculated using Wheeler's incremental inductance rule. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dispersion at high frequencies is not included in the model.

2. The end effect of the abruptly terminated line is modeled as a lumped capacitance to ground. The value of the capacitance is calculated from formula developed by William Getsinger for Agilent. The formula is based on an analysis of an analogous twin-strip configuration of the coplanar discontinuity as proposed by Getsinger.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Waveguide Components

CPWEGAP (Coplanar Waveguide, End Gap)

Symbol

Illustration

Parameters
Subst = substrate instance name
W = center conductor width, in specified units
G = gap (spacing) between center conductor and ground plane, in specified units
S = gap between end of center conductor and ground plane, in specified units
L = center conductor length, in specified units
Temp = physical temperature, in °C

Range of Usage
W > 0, G > 0
W ≤ S ≤ 1.4 × W
0.125 × W ≤ G ≤ 4.5 × W
W + 2 × G ≤ 20 × H
where
H = substrate thickness (from associated CPWSUB)
Notes/Equations/References

1. The frequency-domain analytical model for the coplanar waveguide was developed for Agilent by William J. Getsinger and is based on a conformal mapping technique. The resulting formulas for the characteristic line impedance and effective dielectric constant are virtually the same as those published by Ghione and Naldi. However, the formulas are extended to account for conductors of finite thickness, conductor losses and dielectric losses. The thickness correction is based on a technique proposed by Cohn. The conductor losses are calculated using Wheeler's incremental inductance rule. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dispersion at high frequencies is not included in the model.

2. The end effect of the abruptly terminated line is modeled as a lumped capacitance to ground. The value of the capacitance is calculated from formula developed by William Getsinger for Agilent. The formula is based on an analysis of an analogous twin-strip configuration of the coplanar discontinuity as proposed by Getsinger.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Waveguide Components

CPWG (Coplanar Waveguide with Lower Ground Plane)

Symbol

Illustration

Parameters
Subst = substrate instance name
W = center conductor width, in specified units
G = gap (spacing) between center conductor and ground plane, in specified units
L = center conductor length, in specified units
Temp = physical temperature, in °C

Range of Usage
0.125 \times W \leq G \leq 4.5 \times W
W + 2 \times G \leq 10 \times H
W > 0
G > 0

where
H = substrate thickness

Notes/Equations/References
1. The frequency-domain analytical model for the coplanar waveguide was developed for Agilent by William J. Getsinger and is based on a conformal
mapping technique. The resulting formulas for the characteristic line impedance and effective dielectric constant are virtually the same as those published by Ghione and Naldi. However, the formulas are extended to account for conductors of finite thickness, conductor losses and dielectric losses. The thickness correction is based on a technique proposed by Cohn. The conductor losses are calculated using Wheeler's incremental inductance rule. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dispersion at high frequencies is not included in the model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Waveguide Components

**CPWOC (Coplanar Waveguide, Open-Circuited Stub)**

**Symbol**

![Symbol](image)

**Illustration**

![Illustration](image)

**Parameters**

- **Subst** = substrate instance name
- **W** = center conductor width, in specified units
- **G** = gap (spacing) between center conductor and ground plane, in specified units
- **L** = center conductor length, in specified units
- **Temp** = physical temperature, in °C

**Range of Usage**

- **W** > 0
- **G** > 0
- \(0.125 \times W \leq G \leq 4.5 \times W\)
- \(W + 2 \times G \leq 20 \times H\)

where

- **H** = substrate thickness (from associated CPWSUB)

**Notes/Equations/References**

1. The frequency-domain analytical model for the coplanar waveguide was developed for Agilent by William J. Getsinger and is based on a conformal mapping technique. The resulting formulas for the characteristic line
impedance and effective dielectric constant are virtually the same as those published by Ghione and Naldi. However, the formulas are extended to account for conductors of finite thickness, conductor losses and dielectric losses. The thickness correction is based on a technique proposed by Cohn.

The conductor losses are calculated using Wheeler's incremental inductance rule. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dispersion at high frequencies is not included in the model. No end effects are included in the model.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Waveguide Components

CPWSC (Coplanar Waveguide, Short-Circuited Stub)

Symbol

Illustration

Parameters
Subst = substrate instance name
W = center conductor width, in specified units
G = gap (spacing) between center conductor and ground plane, in specified units
L = center conductor length, in specified units
Temp = physical temperature, in °C

Range of Usage
W > 0
G > 0
0.125 × W ≤ G ≤ 4.5 × W
W + 2 × G ≤ 20 × H

where
H = substrate thickness (from associated CPWSUB)

Notes/Equations/References
1. The frequency-domain analytical model for the coplanar waveguide was developed for Agilent by William J. Getsinger and is based on a conformal mapping technique. The resulting formulas for the characteristic line

7-18
impedance and effective dielectric constant are virtually the same as those published by Ghione and Naldi. However, the formulas are extended to account for conductors of finite thickness, conductor losses and dielectric losses. The thickness correction is based on a technique proposed by Cohn.

The conductor losses are calculated using Wheeler's incremental inductance rule. The attenuation formula provides a smooth transition from dc resistance to resistance due to skin effect at high frequencies. Dispersion at high frequencies is not included in the model.

2. The end effect of the abruptly terminated line is modeled as a lumped inductance to ground. The value of the inductance is calculated from formula developed by William Getsinger for Agilent. The formula is based on an analysis of an analogous twin-strip configuration of the coplanar discontinuity as proposed by Getsinger.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.


Waveguide Components

**CPWSUB (Coplanar Waveguide Substrate)**

**Symbol**

```
CPWSUB
```

**Parameters**

- **H** = substrate thickness, in specified units
- **Er** = relative dielectric constant
- **Mur** = relative permeability
- **Cond** = conductor conductivity
- **Hu** = cover height, in specified units
- **T** = conductor thickness, in specified units
- **TanD** = dielectric loss tangent
- **Rough** = conductor surface roughness, in specified units
- **Cond1** = (for Layout option) layer to which Cond is mapped; default=cond

**Range of Usage**

- **H** > 0
- **Er** ≥ 1.0
- **T** ≥ 0

**Notes/Equations/References**

1. CPWSUB is required for all coplanar waveguide components.
2. The substrate defined by this component does not have a lower ground plane.

3. Losses are accounted for when Rough > 0 and T > 0. The Rough parameter modifies the loss calculations.

4. Cond1 controls the layer on which the Mask layer is drawn; it is a Layout-only parameter and is not used by the simulator.
Waveguide Components

**RWG (Rectangular Waveguide)**

*Symbol*

![Illustration](image)

*Parameters*

- \(A\) = inside width of enclosure, in specified units
- \(B\) = inside height of enclosure, in specified units
- \(L\) = waveguide length, in specified units
- \(E_r\) = relative dielectric constant
- \(\rho\) = metal resistivity (relative to copper)
- \(\tan \delta\) = dielectric loss tangent
- \(\mu_r\) = relative permeability
- \(\tan \mu\) = permeability
- \(\sigma\) = dielectric conductivity
- \(\text{Temp}\) = physical temperature, in °C

*Range of Usage*

\(A > B\)

TE10 and evanescent (below cutoff) modes are supported.

**Notes/Equations/References**
1. The power-voltage definition of waveguide impedance is used in the frequency-domain analytical model.

2. Conductor losses can be specified using Rho or TanM or both. Dielectric loss can be specified using TanD or Sigma or both.

3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. If the values of A and B are such that $B > A$, then B is assumed to be the width, and A is assumed to be the height.

5. This component has no default artwork associated with it.

Waveguide Components

RWGINDF (Rectangular Waveguide Inductive Fin)

Symbol

Illustration

Parameters

A = inside width of enclosure, in specified units
B = inside height of enclosure, in specified units
L = length of the fin, in specified units
Er = relative dielectric constant
Rho = metal resistivity (relative to copper)
TanD = dielectric loss tangent
Mur = relative permeability
TanM = permeability
Sigma = dielectric conductivity
Temp = physical temperature, in °C

Range of Usage

0.02 ≤ L/A ≤ 1.1
B < A/2
TE10 mode only
Simulation frequency > FC

where
FC = cutoff frequency of waveguide

Notes/Equations/References

1. Strip is centered between sidewalls of waveguide. Strip contacts top and bottom of waveguide.

2. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

3. This component has no default artwork associated with it.
Waveguide Components

RWGT (Rectangular Waveguide Termination)

Symbol

Illustration

Parameters
A = inside width of enclosure, in specified units
B = inside height of enclosure, in specified units
Er = relative dielectric constant
Rho = metal resistivity (relative to copper)
TanD = dielectric loss tangent
Mur = relative permeability
TanM = permeability
Sigma = dielectric conductivity
Temp = physical temperature, in °C

Range of Usage
A > B
TE10 and evanescent (below cutoff) modes are supported.

Notes/Equations/References
1. The power-voltage definition of waveguide impedance is used in the frequency-domain analytical model.
2. Conductor losses can be specified using Rho or TanM or both. Dielectric loss can be specified using TanD or Sigma or both.
3. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

4. If the values of A and B are such that \( B > A \), then B is assumed to be the width, and A is assumed to be the height.

5. This component has no default artwork associated with it.


This chapter has parameters for the simulation control elements listed above. There are some unresolved xrefs in here—you will either want to remove the reference or update it when we know how to make external xrefs.
Waveguide Components
Chapter 8: Printed Circuit Board Components

PCB Model Basis and Limits

The printed circuit board line components available in this library are based on a quasi-static analysis in an enclosed region with stratified layers of a single dielectric. The dielectric layers and the metal enclosure are specified by PCBSubn (n=1, ..., 7) whereas the coupled lines are specified by PCLINn (n=1, ..., 10). There can be any combination of 1 to 10 conducting strips and 1 to 7 dielectric layers. In other words, for a given PCLINn, its conductors can be associated with any metal layers of a given PCBSubn.

All of the dielectric layers of a PCBSubn have the same dielectric constant. However, each dielectric layer can have a different thickness. There can be an air layer above the top-most dielectric or below the bottom-most dielectric. When an air layer exists, there may be a conductor pattern at the air-dielectric interface. The structure can be open or covered by a conducting shield at the top and at the bottom. The sidewalls are required.

Method of Analysis

The model is that of N coupled TEM transmission lines. Laplace's equation is solved in the plane transverse to the direction of propagation subject to appropriate boundary conditions at the conducting surfaces. Then the solution of Laplace's equation is used to formulate the indefinite admittance matrix for N-coupled TEM transmission lines. The solution of Laplace's equation is by means of finite differences.

The quasi-static solution makes these suitable for use at RF frequencies and for high-speed digital applications.

Because the analysis is quasi-static, the time required for analysis is improved. In contrast to a full-wave analysis, which is expected to be slow, a quasi-static analysis is expected to be relatively fast. Essentially all of the analysis time is required for the solution of the Laplace's equation.

The mesh size used in the finite difference solution of Laplace's equation is the single most important determinant of analysis time for a given structure. Use discretion.
when specifying the width of the enclosure (parameter \( W \) of PCSUBn) and the heights of the upper and lower conducting shields (\( H_u \) and \( H_l \) parameters of PCSUBn). Specifying large values for these parameters requires a large number of cells for the mesh resulting in longer simulation times. If sidewalls are not actually present then a rough guide is to use a spacing of 10 conductor widths to the sidewalls instead of specifying a large number for the width of enclosure.

**Assumptions and Limitations**

The conductor thickness is used solely for loss calculations. In the solution of Laplace's equation the conductors are assumed to have zero thickness. Conductor losses are effectively ignored if the thickness is set to zero or if \( \rho \) is set to 0. Conductor losses include both dc and skin effect calculations.

The dielectric loss is accounted for by non-zero dielectric conductivity, \( \sigma \). Provision for a frequency-dependent loss tangent component has been made by specification of the \( \tan \delta \) parameter, but is not used in the present implementation.

In principle, the aspect ratio (conductor width to dielectric thickness or horizontal spacing between conductors) is unrestricted. In reality, the problem size (and, therefore, computation time) increases greatly for aspect ratios less than 0.1 or greater than 10. It is highly recommended to keep the aspect ratio within this range.

**References**

PCBEND (PCB Bend (Arbitrary Angle/Miter))

Symbol

Illustration

“SMALL” MITERS
\[ M < M_s \]
\[ M = \frac{X}{D} \]
\[ M_s = \sin^2 \left( \frac{\text{Angle}}{2} \right) \]

“LARGE” MITERS
\[ M \geq M_s \]

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1,2, ..., 7)
W = conductor width, in specified units
CLayer = conductor layer number
Angle = angle of bend, in degrees
M = miter fraction
Temp = physical temperature, in °C

Range of Usage

W > 0
1 ≤ CLayer ≤ Nlayers + 1
Printed Circuit Board Components

\[-90 \leq \text{Angle} \leq 90, \text{ degrees}\]

where

N\text{layers} = \text{number of layers specified by PCSUBi (i=1, 2, ..., 7)}

Notes/Equations/References

1. This component is modeled as an ideal short-circuit between pins 1 and 2. It is provided mainly to facilitate interconnections between PCB lines oriented at different angles in layout.

2. The value of CL\text{ayer} and the value of the associated PCSUB parameters H\text{u} and H\text{l} must be compatible so as to not short out the CL\text{ayer} to the upper or lower ground plane. For example, it is invalid for CL\text{ayer}=1 if H\text{u}=0 or for CL\text{ayer}=i+1 (for PCSUBi, i=1, 2, ..., 7) if H\text{l}=0.

3. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUB\text{i} substrate, the lower surface of dielectric layer #i is conductor layer #(2+i).

4. In layout, a positive value for Angle draws a counterclockwise bend from pin 1 to 2; a negative value for Angle draws a clockwise bend.

5. Layout artwork requires placing a PCSUB\text{i}(i=1, 2, ..., 7) prior to placing the component directly in the Layout window.
PCCORN (Printed Circuit Corner)

Symbol

Parameters

- Subst = printed circuit substrate name (PCSUBi, i=1, 2, ..., 7)
- W = conductor width, in specified units
- CLayer = conductor layer number
- Temp = physical temperature, in °C

Range of Usage

- W > 0
- 1 ≤ CLayer ≤ Nlayers + 1

where

- Nlayers = number of layers specified by PCSUBi (i=1, 2, ..., 7)

Notes/Equations/References

1. This component is treated as an ideal connection between pins 1 and 2, and is provided mainly to facilitate interconnections between PCB lines in layout.

2. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=1+1 (for PCSUBi, i=1, 2, ..., 7) if Hl=0.

3. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer (#2+i).

4. Layout artwork requires placing a PCSUBi(i=1, 2, ..., 7) prior to placing the component directly in the Layout window.
PCCROS Printed Circuit Cross-Junction

Symbol

Illustration

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1, 2, ..., 7)
W1 = width at pin 1, in specified units
W2 = width at pin 2, in specified units
W3 = width at pin 3, in specified units
W4 = width at pin 4, in specified units
CLayer = conductor layer number
Temp = physical temperature, in °C

Range of Usage

W1 > 0, W2 > 0, W3 > 0, W4 > 0
1 ≤ CLayer ≤ Nlayers + 1

where

Nlayers = number of layers specified by PCSUBi (i=1, 2, ..., 7)
Notes/Equations/References

1. This component is treated as an ideal connection between pins 1, 2, 3, and 4, and has been provided mainly to facilitate interconnections among PCB lines in layout.

2. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1, 2, ..., 7) if Hl=0.

3. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #i is conductor layer #(2+i).

4. Layout artwork requires placing a PCSUBi (i=1, 2, ..., 7) prior to placing the component directly in the Layout window.
PCCURVE (PCB Curve)

Symbol

Illustration

Parameters
Subst = printed circuit substrate name (PCSUBi, i=1,2, ..., 7)
W  = conductor width, in specified units
CLayer = conductor layer number
Angle  = angle subtended by the bend, in degrees
Radius  = radius (measured to center of conductor), in specified units
Temp  = physical temperature, in °C

Range of Usage
W > 0
1 ≤ CLayer ≤ Nlayers+1
-180 ≤ Angle ≤ 180, degrees
Radius ≥ W/2
where
Notes/Equations/References

1. This component is modeled as PCLIN1, assuming a single straight line of length \( \text{Radius} \times \text{Angle} \), where Angle is in radians. The single line is assumed to be located halfway between and parallel to the sidewalls. The distance between the sidewalls is given as part of the PCSUBi specification.

2. The distance between the sidewalls is typically the width of the metal enclosure around the PC board. If the metal enclosure is absent, width of the PC board itself can be specified and treated as the distance between the sidewalls. Note, however, that the simulation time increases rapidly as the sidewall distance increases. If the effect of the sidewalks is not important, it is highly recommended to set it to approximately 10 times the line width for this component.

3. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as not to short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1,2, ..., 7) if Hl=0.

4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer \#1) is conductor layer \#1; the lower surface of the dielectric layer \#1 (which could also be the upper surface of the dielectric layer \#2) is conductor layer \#2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer \#i is conductor layer \((2+1)\).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

6. This component has been provided mainly to facilitate interconnections between PCB lines oriented at different angles in layout.

7. In layout, a positive value for Angle specifies a counterclockwise curvature; a negative value specifies a clockwise curvature.

8. Layout artwork requires placing a PCSUBi (i=1, 2, ..., 7) prior to placing the component directly in the Layout window.
Printed Circuit Board Components

**PCILC (Printed Circuit Inter-layer Connection)**

**Symbol**

![Symbol](attachment:image.png)

**Parameters**

- **Subst** = printed circuit substrate name (PCSUB\(i\), \(i=1,2, \ldots, 7\))
- **D** = diameter of via hole, in specified units
- **CLayer1** = conductor layer number at pin 1
- **CLayer2** = conductor layer number at pin 2
- **Temp** = physical temperature, in °C
- **Ang** = (for Layout Option) angle of orientation at pin 2, in degrees
- **W1** = (for Layout Option) width of square pad or diameter of circular pad on layer **CLayer1**, in specified units
- **W2** = (for Layout Option) width of square pad or diameter of circular pad on layer **CLayer2**, in specified units
- **Type** = (for Layout Option) type of via pad, square or circular

**Range of Usage**

\[1 \leq CLayer1, CLayer2 \leq Nlayers + 1\]

where

- **Nlayers** = number of layers specified by PCSUB\(i\) \((i=1,2, \ldots, 7)\)

**Notes/Equations/References**

1. This component is modeled as an ideal connection between pin 1 and pin 2 and has been provided mainly to facilitate interconnections between PCB components placed on different conductor layers in layout.

2. The value of **CLayer** and the value of the associated PCSUB parameters **Hu** and **Hl** must be compatible so as to not short out the **CLayer** to the upper or lower ground plane. For example, it is invalid for **CLayer** = 1 if **Hu** = 0 or for **CLayer** = \(i + 1\) (for PCSUB\(i\), \(i=1,2, \ldots, 7\)) if **Hl** = 0.

3. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of...
the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #i is conductor layer #(2+i).

4. Type specifies the type of the via pad. Type=square draws a square pad on layers CLayer1 and CLayer2; Type=circular draws a circular pad on layers CLayer1 and CLayer2.

5. Layout artwork requires placing a PCSUBi (i=1, 2, ..., 7) prior to placing the component directly in the Layout window.
PCLIN1 (1 Printed Circuit Line)

Symbol

Illustration

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1,2, ..., 7)

W = width of line, in specified units

S1 = distance from line to left wall, in specified units

CLayer1 = conductor layer number
(value type: integer)

L = length of line, in specified units

Temp = physical temperature, in °C

Range of Usage

W > 0

S1 > 0

1 ≤ CLayer1 ≤ Nlayers+1

where

Nlayers = number of layers specified by PCSUBi (i=1,2, ..., 7)

Notes/Equations/References

1. The 2-layer illustration shown is only an example. PCSUBi has between 1 and 7 dielectric layers, and any conductor can be placed above or below any dielectric layer. Conductors can overlap if desired.
2. The frequency-domain analytical model for this component is a non-dispersive static model developed by Agilent. Refer to the section “PCB Model Basis and Limits” on page 8-1 at the beginning of this chapter.

3. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1,2, ..., 7) if Hl=0.

4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #i is conductor layer #(2+i).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
Printed Circuit Board Components

PCLIN2 (2 Printed Circuit Coupled Lines)

Symbol

![Symbol Image]

Illustration

![Illustration Image]

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1,2, ..., 7)

W1 = width of line #1, in specified units

S1 = distance from line #1 to left wall, in specified units

CLayer1 = conductor layer number - line #1 (value type: integer)

W2 = width of line #2, in specified units

S2 = distance from line #2 to left wall, in specified units

CLayer2 = conductor layer number - line #2 (value type: integer)

L = length of the lines, in specified units

Temp = physical temperature, in °C

Range of Usage

W1 > 0, W2 > 0

S1 > 0, S2 > 0

1 ≤ CLayer1 ≤ Nlayers+1

1 ≤ CLayer2 ≤ Nlayers+1

where
Notes/Equations/References

1. The 2-layer illustration shown is only an example. PCSUBi has between 1 and 7 dielectric layers, and any conductor can be placed above or below any dielectric layer. Conductors can overlap if desired.

2. The frequency-domain analytical model for this component is a non-dispersive static model developed by Agilent. Refer to the section “PCB model basis and limits” at the beginning of this chapter.

3. The value of CLayer and the value of the associated PCSUB parameters H\text{u} and H\text{l} must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if H\text{u}=0 or for CLayer=i+1 (for PCSUBi, i=1,2, ..., 7) if H\text{l}=0.

4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+1).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
Printed Circuit Board Components

**PCLIN3 (3 Printed Circuit Coupled Lines)**

**Symbol**

![Symbol of PCLIN3](image)

**Illustration**

![Illustration of PCLIN3](image)

**Parameters**

Subst = printed circuit substrate name (PCSUBi, i=1,2, ... , 7)

W1 = width of line #1, in specified units

S1 = distance from line #1 to left wall, in specified units

CLayer1 = conductor layer number - line #1 (value type: integer)

W2 = width of line #2, in specified units

S2 = distance from line #2 to left wall, in specified units

CLayer2 = conductor layer number - line #2 (value type: integer)

W3 = width of line #3, in specified units

S3 = distance from line #3 to left wall, in specified units

CLayer3 = conductor layer number - line #3 (value type: integer)

L = length of the lines, in specified units

Temp = physical temperature, in °C
Range of Usage
W1 > 0, W2 > 0, W3 > 0
S1 > 0, S2 > 0, S3 > 0
1 ≤ CLayer1 ≤ Nlayers + 1
1 ≤ CLayer2 ≤ Nlayers + 1
1 ≤ CLayer3 ≤ Nlayers + 1
where
Nlayers = number of layers specified by PCSUBi (i=1,2, ..., 7)

Notes/Equations/References
1. The 2-layer illustration shown is only an example. PCSUBi has between 1 and 7
dielectric layers, and any conductor can be placed above or below any dielectric
layer. Conductors can overlap if desired.
2. The frequency-domain analytical model for this component is a non-dispersive
static model developed by Agilent. Refer to the section “PCB Model Basis and
Limits” on page 8-1 at the beginning of this chapter.
3. The value of CLayer and the value of the associated PCSUB parameters Hu and
Hl must be compatible so as to not short out the CLayer to the upper or lower
ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1
(for PCSUBi, i=1,2, ..., 7) if Hl=0.
4. Conductor layers are numbered as follows: the upper surface of the top
dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of
the dielectric layer #1 (which could also be the upper surface of the dielectric
layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower
surface of dielectric layer #i is conductor layer #(2+i).
5. For time-domain analysis, an impulse response obtained from the
frequency-domain analytical model is used.
PCLIN4 (4 Printed Circuit Coupled Lines)

Symbol

Illustration

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1,2, ..., 7)

W1 = width of line #1, in specified units

S1 = distance from line #1 to left wall, in specified units

CLayer1 = conductor layer number - line #1 (value type: integer)

W2 = width of line #2, in specified units

S2 = distance from line #2 to left wall, in specified units

CLayer2 = conductor layer number - line #2 (value type: integer)

W3 = width of line #3, in specified units

S3 = distance from line #3 to left wall, in specified units

CLayer3 = conductor layer number - line #3 (value type: integer)

W4 = width of line #4, in specified units

S4 = distance from line #4 to left wall, in specified units
CLayer4 = conductor layer number - line #4 (value type: integer)
L = length of the lines, in specified units
Temp = physical temperature, in °C

Range of Usage
W1 > 0,  W2 > 0,  W3 > 0,  W4 > 0
S1 > 0,  S2 > 0,  S3 > 0,  S4 > 0
1 ≤ CLayer1 ≤ Nlayers+1
1 ≤ CLayer2 ≤ Nlayers+1
1 ≤ CLayer3 ≤ Nlayers+1
1 ≤ CLayer4 ≤ Nlayers+1

where
Nlayers = number of layers specified by PCSUBi (i=1,2, ..., 7)

Notes/Equations/References
1. The 2-layer illustration shown is only an example. The PCSUBi has between 1 and 7 dielectric layers, and any conductor can be placed above or below any dielectric layer. Conductors can overlap if desired.
2. The frequency-domain analytical model for this component is a non-dispersive static model developed by Agilent. Refer to the section “PCB Model Basis and Limits” on page 8-1 at the beginning of this chapter.
3. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1,2, ..., 7) if Hl=0.
4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #1 is conductor layer #(2+1).
5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
PCLIN5 (5 Printed Circuit Coupled Lines)

Symbol

Illustration

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1, 2, ... , 7)
W1 = width of line #1, in specified units
S1 = distance from line #1 to left wall, in specified units
CLayer1 = conductor layer number - line #1 (value type: integer)
W2 = width of line #2, in specified units
S2 = distance from line #2 to left wall, in specified units
CLayer2 = conductor layer number - line #2 (value type: integer)
W3 = width of line #3, in specified units
S3 = distance from line #3 to left wall, in specified units
CLayer3 = conductor layer number - line #3 (value type: integer)
W4 = width of line #4, in specified units
S4 = distance from line #4 to left wall, in specified units
CLayer4 = conductor layer number - line #4 (value type: integer)
W5 = width of line #5, in specified units
S5 = distance from line #5 to left wall, in specified units
CLayer5 = conductor layer number - line #5 (value type: integer)
S4 = distance from line #4 to left wall, in specified units
CLayer4 = conductor layer number - line #4 (value type: integer)
W5 = width of line #5, in specified units
S5 = distance from line #5 to left wall, in specified units
CLayer5 = conductor layer number - line #5 (value type: integer)
L = length of the lines, in specified units
Temp = physical temperature, in °C

Range of Usage
W1 > 0, W2 > 0, W3 > 0, W4 > 0, W5 > 0
S1 > 0, S2 > 0, S3 > 0, S4 > 0, S5 > 0
1 ≤ CLayer1 ≤ Nlayers+1
1 ≤ CLayer2 ≤ Nlayers+1
1 ≤ CLayer3 ≤ Nlayers+1
1 ≤ CLayer4 ≤ Nlayers+1
1 ≤ CLayer5 ≤ Nlayers+1
where
Nlayers = number of layers specified by PCSUBi (i=1, 2, ... , 7)

Notes/Equations/References
1. The 2-layer illustration shown is only an example. PCSUBi has between 1 and 7
dielectric layers, and any conductor can be placed above or below any dielectric
layer. Conductors can overlap if desired.
2. The frequency-domain analytical model for this component is a non-dispersive
static model developed by Agilent. Refer to the section “PCB Model Basis and
Limits” on page 8-1 at the beginning of this chapter.
3. The value of CLayer and the value of the associated PCSUB parameters Hu and
Hl must be compatible so as to not short out the CLayer to the upper or lower
ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1
(for PCSUBi, i=1,2, ... , 7) if Hl=0.
4. Conductor layers are numbered as follows: the upper surface of the top
dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of
Printed Circuit Board Components

the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #i is conductor layer #(2+i).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
PCLIN6 (6 Printed Circuit Coupled Lines)

Symbol

Illustration

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1, 2, ..., 7)
W1 = width of line #1, in specified units
S1 = distance from line #1 to left wall, in specified units
CLayer1 = conductor layer number - line #1 (value type: integer)
W2 = width of line #2, in specified units
S2 = distance from line #2 to left wall, in specified units
CLayer2 = conductor layer number - line #2 (value type: integer)
W3 = width of line #3, in specified units
S3 = distance from line #3 to left wall, in specified units
CLayer3, CLayer4 = 2
CLayer5, CLayer6 = 1
CLayer1, CLayer2 = 3
Pin 1 (Pin 8 far side)
Pin 2 (Pin 7 far side)
Pin 3 (Pin 10 far side)
Pin 4 (Pin 9 far side)
Pin 5 (Pin 8 far side)
Pin 6 (Pin 7 far side)
Pin 7 (Pin 11 far side)
Pin 8 (Pin 12 far side)
Printed Circuit Board Components

$CLayer3 =$ conductor layer number - line #3 (value type: integer)
$W4 =$ width of line #4, in specified units
$S4 =$ distance from line #4 to left wall, in specified units
$CLayer4 =$ conductor layer number - line #4 (value type: integer)
$W5 =$ width of line #5, in specified units
$S5 =$ distance from line #5 to left wall, in specified units
$CLayer5 =$ conductor layer number - line #5 (value type: integer)
$W6 =$ width of line #6, in specified units
$S6 =$ distance from line #6 to left wall, in specified units
$CLayer6 =$ conductor layer number - line #6 (value type: integer)
$L =$ length of the lines, in specified units
$Temp =$ physical temperature, in °C

**Range of Usage**

$W1 > 0$, $W2 > 0$, $W3 > 0$, $W4 > 0$, $W5 > 0$, $W6 > 0$

$S1 > 0$, $S2 > 0$, $S3 > 0$, $S4 > 0$, $S5 > 0$, $S6 > 0$

$1 \leq CLayer1 \leq Nlayers+1$

$1 \leq CLayer2 \leq Nlayers+1$

$1 \leq CLayer3 \leq Nlayers+1$

$1 \leq CLayer4 \leq Nlayers+1$

$1 \leq CLayer5 \leq Nlayers+1$

$1 \leq CLayer6 \leq Nlayers+1$

where

$Nlayers =$ number of layers specified by PCSUBi ($i=1, 2, \ldots, 7$)

**Notes/Equations/References**

1. The 2-layer illustration shown is only an example. PCSUBi has between 1 and 7 dielectric layers, and any conductor can be placed above or below any dielectric layer. Conductors can overlap if desired.
2. The frequency-domain analytical model for this component is a non-dispersive static model developed by Agilent. Refer to the section “PCB Model Basis and Limits” on page 8-1 at the beginning of this chapter.

3. The value of CLayer and the value of the associated PCSUB parameters Hu and HI must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1,2, ..., 7) if HI=0.

4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #i is conductor layer #(2+i).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
Printed Circuit Board Components

**PCLIN7 (7 Printed Circuit Coupled Lines)**

**Symbol**

![Symbol Diagram]

**Illustration**

![Illustration Diagram]

**Parameters**

- **Subst** = printed circuit substrate name (PCSUBi, i=1, 2, ..., 7)
- **W1** = width of line #1, in specified units
- **S1** = distance from line #1 to left wall, in specified units
- **CLayer1, CLayer2, CLayer7** = 3
- **CLayer3, CLayer4** = 2
- **CLayer5, CLayer6** = 1
- **Pin 1 (Pin 14 far side)**
- **Pin 2 (Pin 13 far side)**
- **Pin 3 (Pin 12 far side)**
- **Pin 4 (Pin 11 far side)**
- **Pin 5 (Pin 10 far side)**
- **Pin 6 (Pin 9 far side)**
- **Pin 7 (Pin 8 far side)**

**W2, W3, W4, W5, W6, W7**

**S1, S2, S3, S4, S5, S6, S7**
CLayer2 = conductor layer number - line #2 (value type: integer)
W3 = width of line #3, in specified units
S3 = distance from line #3 to left wall, in specified units
CLayer3 = conductor layer number - line #3 (value type: integer)
W4 = width of line #4, in specified units
S4 = distance from line #4 to left wall, in specified units
CLayer4 = conductor layer number - line #4 (value type: integer)
W5 = width of line #5, in specified units
S5 = distance from line #5 to left wall, in specified units
CLayer5 = conductor layer number - line #5 (value type: integer)
W6 = width of line #6, in specified units
S6 = distance from line #6 to left wall, in specified units
CLayer6 = conductor layer number - line #6 (value type: integer)
W7 = width of line #7, in specified units
S7 = distance from line #7 to left wall, in specified units
CLayer7 = conductor layer number - line #7 (value type: integer)
L = length of the lines, in specified units
Temp = physical temperature, in °C

Range of Usage
W1 > 0, W2 > 0, W3 > 0, W4 > 0, W5 > 0, W6 > 0, W7 > 0
S1 > 0, S2 > 0, S3 > 0, S4 > 0, S5 > 0, S6 > 0, S7 > 0
1 ≤ CLayer1 ≤ Nlayers + 1
1 ≤ CLayer2 ≤ Nlayers + 1
1 ≤ CLayer3 ≤ Nlayers + 1
1 ≤ CLayer4 ≤ Nlayers + 1
1 ≤ CLayer5 ≤ Nlayers + 1
1 ≤ CLayer6 ≤ Nlayers + 1
Printed Circuit Board Components

\[ 1 \leq \text{CLayer}_7 \leq \text{Nlayers}+1 \]

where

\[ \text{Nlayers} = \text{number of layers specified by PCSUB}_i \ (i=1, 2, \ldots, 7) \]

Notes/Equations/References

1. The 2-layer illustration shown is only an example. PCSUBi has between 1 and 7 dielectric layers, and any conductor can be placed above or below any dielectric layer. Conductors can overlap if desired.

2. The frequency-domain analytical model for this component is a non-dispersive static model developed by Agilent. Refer to the section “PCB Model Basis and Limits” on page 8-1 at the beginning of this chapter.

3. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1, 2, ... , 7) if Hl=0.

4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+i).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
PCLIN8 (8 Printed Circuit Coupled Lines)

Symbol

Illustration

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1,2, ..., 7)

W1 = width of line #1, in specified units

S1 = distance from line #1 to left wall, in specified units

CLayer1 = conductor layer number - line #1 (value type: integer)
Printed Circuit Board Components

\[ W_2 = \text{width of line } #2, \text{ in specified units} \]
\[ S_2 = \text{distance from line } #2 \text{ to left wall, in specified units} \]
\[ \text{CLayer}_2 = \text{conductor layer number - line } #2 \text{ (value type: integer)} \]
\[ W_3 = \text{width of line } #3, \text{ in specified units} \]
\[ S_3 = \text{distance from line } #3 \text{ to left wall, in specified units} \]
\[ \text{CLayer}_3 = \text{conductor layer number - line } #3 \text{ (value type: integer)} \]
\[ W_4 = \text{width of line } #4, \text{ in specified units} \]
\[ S_4 = \text{distance from line } #4 \text{ to left wall, in specified units} \]
\[ \text{CLayer}_4 = \text{conductor layer number - line } #4 \text{ (value type: integer)} \]
\[ W_5 = \text{width of line } #5, \text{ in specified units} \]
\[ S_5 = \text{distance from line } #5 \text{ to left wall, in specified units} \]
\[ \text{CLayer}_5 = \text{conductor layer number - line } #5 \text{ (value type: integer)} \]
\[ W_6 = \text{width of line } #6, \text{ in specified units} \]
\[ S_6 = \text{distance from line } #6 \text{ to left wall, in specified units} \]
\[ \text{CLayer}_6 = \text{conductor layer number - line } #6 \text{ (value type: integer)} \]
\[ W_7 = \text{width of line } #7, \text{ in specified units} \]
\[ S_7 = \text{distance from line } #7 \text{ to left wall, in specified units} \]
\[ \text{CLayer}_7 = \text{conductor layer number - line } #7 \text{ (value type: integer)} \]
\[ W_8 = \text{width of line } #8, \text{ in specified units} \]
\[ S_8 = \text{distance from line } #8 \text{ to left wall, in specified units} \]
\[ \text{CLayer}_8 = \text{conductor layer number - line } #8 \text{ (value type: integer)} \]
\[ L = \text{length of the lines, in specified units} \]
\[ \text{Temp} = \text{physical temperature, in } ^\circ \text{C} \]

**Range of Usage**

\[ W_i > 0 \text{ for } i = 1, \ldots, 8 \]
\[ S_i > 0 \text{ for } i = 1, \ldots, 8 \]
\[ 1 \leq \text{CLayer}_1 \leq N_{\text{layers}} + 1 \]
1 ≤ CLayer2 ≤ Nlayers+1  
1 ≤ CLayer3 ≤ Nlayers+1  
1 ≤ CLayer4 ≤ Nlayers+1  
1 ≤ CLayer5 ≤ Nlayers+1  
1 ≤ CLayer6 ≤ Nlayers+1  
1 ≤ CLayer7 ≤ Nlayers+1  
1 ≤ CLayer8 ≤ Nlayers+1  

where  

Nlayers = number of layers specified by PCSUBi (i=1, 2, ..., 7)

Notes/Equations/References

1. The 2-layer illustration shown is only an example. PCSUBi has between 1 and 7 dielectric layers, and any conductor can be placed above or below any dielectric layer. Conductors can overlap if desired.

2. The frequency-domain analytical model for this component is a non-dispersive static model developed by Agilent. Refer to the section “PCB Model Basis and Limits” on page 8-1 at the beginning of this chapter.

3. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1, 2, ..., 7) if Hl=0.

4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #i is conductor layer #(2+i).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
Printed Circuit Board Components

PCLIN9 (9 Printed Circuit Coupled Lines)

Symbol

Parameters

Subst = printed circuit substrate name (PCSUBi, i=1, 2, ..., 7)

W1 = width of line #1, in specified units
S1 = distance from line #1 to left wall, in specified units
CLayer1 = conductor layer number - line #1 (value type: integer)
W2 = width of line #2, in specified units
S2 = distance from line #2 to left wall, in specified units
CLayer2 = conductor layer number - line #2 (value type: integer)
W3 = width of line #3, in specified units
S3 = distance from line #3 to left wall, in specified units
CLayer3 = conductor layer number - line #3 (value type: integer)
W4 = width of line #4, in specified units
S4 = distance from line #4 to left wall, in specified units
CLayer4 = conductor layer number - line #4 (value type: integer)
W5 = width of line #5, in specified units
S5 = distance from line #5 to left wall, in specified units
CLayer5 = conductor layer number - line #5 (value type: integer)
W6 = width of line #6, in specified units
S6 = distance from line #6 to left wall, in specified units
CLayer6 = conductor layer number - line #6 (value type: integer)
W7 = width of line #7, in specified units
S7 = distance from line #7 to left wall, in specified units
CLayer7 = conductor layer number - line #7 (value type: integer)
W8 = width of line #8, in specified units
S8 = distance from line #8 to left wall, in specified units
CLayer8 = conductor layer number - line #8 (value type: integer)
W9 = width of line #9, in specified units
S9 = distance from line #9 to left wall, in specified units
CLayer9 = conductor layer number - line #9 (value type: integer)
L = length of the lines, in specified units
Temp = physical temperature, in °C

**Range of Usage**

\[ W_i > 0 \text{ for } i = 1, \ldots, 9 \]
\[ S_i > 0 \text{ for } i = 1, \ldots, 9 \]

\[ 1 \leq \text{Layer}_1 \leq \text{Nlayers}+1 \]
\[ 1 \leq \text{Layer}_2 \leq \text{Nlayers}+1 \]
\[ 1 \leq \text{Layer}_3 \leq \text{Nlayers}+1 \]
\[ 1 \leq \text{Layer}_4 \leq \text{Nlayers}+1 \]
\[ 1 \leq \text{Layer}_5 \leq \text{Nlayers}+1 \]
\[ 1 \leq \text{Layer}_6 \leq \text{Nlayers}+1 \]
\[ 1 \leq \text{Layer}_7 \leq \text{Nlayers}+1 \]
\[ 1 \leq \text{Layer}_8 \leq \text{Nlayers}+1 \]
\[ 1 \leq \text{Layer}_9 \leq \text{Nlayers}+1 \]

where

\[ \text{Nlayers} = \text{number of layers specified by PCSUB}_i (i=1, 2, \ldots, 7) \]

**Notes/Equations/References**

1. The 2-layer illustration shown is only an example. PCSUB has between 1 and 7 dielectric layers, and any conductor can be placed above or below any dielectric layer. Conductors can overlap if desired.

2. The frequency-domain analytical model for this component is a non-dispersive static model developed by Agilent. Refer to the section “PCB Model Basis and Limits” on page 8-1 at the beginning of this chapter.

3. The value of Layer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the Layer to the upper or lower ground plane. For example, it is invalid for Layer=1 if Hu=0 or for Layer=i+1 (for PCSUB, i=1, 2, ..., 7) if Hl=0.

4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric
layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #i is conductor layer #(i+2).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
Printed Circuit Board Components

**PCLIN10 (10 Printed Circuit Coupled Lines)**

**Symbol**

![Symbol Diagram]

**Illustration**

![Illustration Diagram]
**Parameters**

Subst = printed circuit substrate name (PCSUBi, i=1,2, ... , 7)

W1 = width of line #1, in specified units

S1 = distance from line #1 to left wall, in specified units

CLayer1 = conductor layer number - line #1 (value type: integer)

W2 = width of line #2, in specified units

S2 = distance from line #2 to left wall, in specified units

CLayer2 = conductor layer number - line #2 (value type: integer)

W3 = width of line #3, in specified units

S3 = distance from line #3 to left wall, in specified units

CLayer3 = conductor layer number - line #3 (value type: integer)

W4 = width of line #4, in specified units

S4 = distance from line #4 to left wall, in specified units

CLayer4 = conductor layer number - line #4 (value type: integer)

W5 = width of line #5, in specified units

S5 = distance from line #5 to left wall, in specified units

CLayer5 = conductor layer number - line #5 (value type: integer)

W6 = width of line #6, in specified units

S6 = distance from line #6 to left wall, in specified units

CLayer6 = conductor layer number - line #6 (value type: integer)

W7 = width of line #7, in specified units

S7 = distance from line #7 to left wall, in specified units

CLayer7 = conductor layer number - line #7 (value type: integer)

W8 = width of line #8, in specified units

S8 = distance from line #8 to left wall, in specified units

CLayer8 = conductor layer number - line #8 (value type: integer)

W9 = width of line #9, in specified units
Printed Circuit Board Components

$S_9 =$ distance from line #9 to left wall, in specified units
$CLayer_9 =$ conductor layer number - line #9 (value type: integer)
$W_{10} =$ width of line #10, in specified units
$S_{10} =$ distance from line #10 to left wall, in specified units
$CLayer_{10} =$ conductor layer number - line #10 (value type: integer)
$L =$ length of the lines, in specified units
$Temp =$ physical temperature, in °C

**Range of Usage**

$W_i > 0$ for $i = 1, \ldots, 10$
$S_i > 0$ for $i = 1, \ldots, 10$

$1 \leq CLayer_1 \leq Nlayers+1$
$1 \leq CLayer_2 \leq Nlayers+1$
$1 \leq CLayer_3 \leq Nlayers+1$
$1 \leq CLayer_4 \leq Nlayers+1$
$1 \leq CLayer_5 \leq Nlayers+1$
$1 \leq CLayer_6 \leq Nlayers+1$
$1 \leq CLayer_7 \leq Nlayers+1$
$1 \leq CLayer_8 \leq Nlayers+1$
$1 \leq CLayer_9 \leq Nlayers+1$
$1 \leq CLayer_{10} \leq Nlayers+1$

where

$Nlayers =$ number of layers specified by PCSUBi ($i=1,2, \ldots, 7$)

**Notes/Equations/References**

1. The 2-layer illustration shown is only an example. PCSUBi has between 1 and 7 dielectric layers, and any conductor can be placed above or below any dielectric layer. Conductors can overlap if desired.
2. The frequency-domain analytical model for this component is a non-dispersive static model developed by Agilent. Refer to the section “PCB Model Basis and Limits” on page 8-1 at the beginning of this chapter.

3. The value of $\text{CLayer}$ and the value of the associated PCSUB parameters $H_u$ and $H_l$ must be compatible so as to not short out the $\text{CLayer}$ to the upper or lower ground plane. For example, it is invalid for $\text{CLayer}=1$ if $H_u=0$ or for $\text{CLayer}=i+1$ (for PCSUB$i$, $i=1, 2, \ldots, 7$) if $H_l=0$.

4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUB$i$ substrate, the lower surface of dielectric layer # is conductor layer #(2+i).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.
Printed Circuit Board Components

**PCSTEP (PCB Symmetric Steps)**

**Symbol**

![Symbol Illustration]

**Parameters**
- **Subst** = printed circuit substrate name (PCSUBi, i=1,2, ..., 7)
- **W1** = width at pin 1, in specified units
- **W2** = width at pin 2, in specified units
- **CLayer** = conductor layer number (value type: integer)
- **Temp** = physical temperature, in °C

**Range of Usage**
- **W1, W2 > 0**
- **1 ≤ CLayer ≤ Nlayers+1**
- where
  - **Nlayers** = number of layers specified by PCSUBi (i=1,2, ..., 7)

**Notes/Equations/References**

1. This component is modeled as an ideal short circuit between pins 1 and 2 and is provided mainly to facilitate interconnections between PCB lines of different width in layout.

2. The value of **CLayer** and the value of the associated PCSUB parameters **Hu** and **Hl** must be compatible so as to not short out the **CLayer** to the upper or lower
ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1, 2, ... , 7) if Hl=0.

3. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer #i is conductor layer #(2+i).

4. To turn off noise contribution, set Temp to $-273.15^\circ C$.

5. Layout artwork requires placing a PCSUBi (i=1, 2, ... , 7) prior to placing the component directly in the Layout window.
Printed Circuit Board Components

**PCSUB1 (1-Layer Printed Circuit Substrate)**

**Symbol**

![PCSub1 Symbol]

**Illustration**

![Illustration of PCB](image)

**Parameters**

- **H1** = thickness of dielectric layer #1, in specified units
- **Er** = dielectric constant
- **Cond** = conductor conductivity
- **Hu** = upper ground plane spacing, in specified units
- **Hl** = lower ground plane spacing, in specified units
- **T** = metal thickness, in specified units
- **W** = distance between sidewalls, in specified units
- **Sigma** = dielectric conductivity, in Siemens per meter

**Range of Usage**

- **H1 > 0, Er ≥ 0, Sigma ≥ 0**
- **T ≥ 0, Hu ≥ 0, Hl ≥ 0, W > 0**
Notes/Equations/References

1. Refer to the section “Assumptions and Limitations” on page 8-2 at the beginning of this chapter for important information.

2. A PCSUBi (i=1,2, ..., 7) is required for all PCB components.

3. PCSUBi specifies a multi-layered dielectric substrate with the number of dielectric layers=i. The dielectric constant of all the layers is the same but the thickness of each layer can be different. The structure is enclosed by metal sidewalls. The top and bottom metal enclosures are optional.

4. Gold conductivity is $4.1 \times 10^7$ S/m. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^7$.

5. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+i).
**Printed Circuit Board Components**

**PCSUB2 (2-Layer Printed Circuit Substrate)**

**Symbol**

![PCSub2 Symbol]

**Illustration**

![Illustration of PCSUB2]

**Parameters**

- $H_1 =$ thickness of dielectric layer #1, in specified units
- $H_2 =$ thickness of dielectric layer #2, in specified units
- $E_r =$ dielectric constant
- Cond = conductor conductivity
- $\sigma =$ dielectric conductivity, in Siemens per meter
- $T =$ metal thickness, in specified units
- $H_u =$ upper ground plane spacing, in specified units
- $H_l =$ lower ground plane spacing, in specified units
- $W =$ distance between sidewalls, in specified units

**Range of Usage**

$H_i > 0$ for $i = 1, 2$, $E_r \geq 0$, $\sigma \geq 0$

$T \geq 0$, $H_u \geq 0$, $H_l \geq 0$, $W > 0$
Notes/Equations/References

1. Refer to the section “Assumptions and Limitations” on page 8-2 at the beginning of this chapter for important information.

2. A PCSUBi (i=1,2, ..., 7) is required for all PCB components.

3. PCSUBi specifies a multi-layered dielectric substrate with the number of dielectric layers= i. The dielectric constant of all the layers is the same but the thickness of each layer can be different. The structure is enclosed by metal sidewalls. The top and bottom metal enclosures are optional.

4. Gold conductivity is 4.1×10⁷ S/m. Rough modifies loss calculations. Conductivity for copper is 5.8×10⁷.

5. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+1).
Printed Circuit Board Components

**PC SUB3 (3-Layer Printed Circuit Substrate)**

Symbol

![PC SUB3 Symbol](image)

Illustration

![Illustration of PC SUB3](image)

Parameters

- $H_1 =$ thickness of dielectric layer #1, in specified units
- $H_2 =$ thickness of dielectric layer #2, in specified units
- $H_3 =$ thickness of dielectric layer #3, in specified units
- $E_r =$ dielectric constant
- $C_{on} =$ conductor conductivity
- $T =$ metal thickness, in specified units
- $H_u =$ upper ground plane spacing, in specified units
- $H_l =$ lower ground plane spacing, in specified units
- $W =$ distance between sidewalls, in specified units
- $\sigma =$ dielectric conductivity, in Siemens per meter

**Range of Usage**

- $H_i > 0$ for $i = 1, ..., 3$, $E_r \geq 0$, $\sigma \geq 0$
- $T \geq 0$, $H_u \geq 0$, $H_l \geq 0$, $W \geq 0$
Notes/Equations/References

1. Refer to the section “Assumptions and Limitations” on page 8-2 at the beginning of this chapter for important information.

2. A PCSUBi (i=1,2, ..., 7) is required for all PCB components.

3. PCSUBi specifies a multi-layered dielectric substrate with the number of dielectric layers=i. The dielectric constant of all the layers is the same but the thickness of each layer can be different. The structure is enclosed by metal sidewalls. The top and bottom metal enclosures are optional.

4. Gold conductivity is \(4.1 \times 10^7\) S/m. Rough modifies loss calculations. Conductivity for copper is \(5.8 \times 10^7\).

5. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+1).
Printed Circuit Board Components

PCSUB4 (4-Layer Printed Circuit Substrate)

Symbol

![Diagram of PCSUB4](image)

Illustration

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hu</td>
<td></td>
<td>Upper ground plane spacing</td>
</tr>
<tr>
<td>H1</td>
<td></td>
<td>Thickness of dielectric layer #1</td>
</tr>
<tr>
<td>H2</td>
<td></td>
<td>Thickness of dielectric layer #2</td>
</tr>
<tr>
<td>H3</td>
<td></td>
<td>Thickness of dielectric layer #3</td>
</tr>
<tr>
<td>H4</td>
<td></td>
<td>Thickness of dielectric layer #4</td>
</tr>
<tr>
<td>Hl</td>
<td></td>
<td>Lower ground plane spacing</td>
</tr>
</tbody>
</table>

Parameters

- $H_i$ = thickness of dielectric layer #i, in specified units
- $H_1 > 0$ for $i = 1, ..., 4$
- $E_r \geq 0$
- $\Sigma \geq 0$
- $W$ = distance between sidewalls, in specified units

Range of Usage

- $H_i > 0$ for $i = 1, ..., 4$
- $E_r \geq 0$
- $\Sigma \geq 0$
$T \geq 0$, $H_u \geq 0$, $H_l \geq 0$, $W > 0$

**Notes/Equations/References**

1. Refer to the section “Assumptions and Limitations” on page 8-2 at the beginning of this chapter for important information.

2. A PCSUB$\text{i}$ ($i=1, 2, \ldots, 7$) is required for all PCB components.

3. PCSUB$i$ specifies a multi-layered dielectric substrate with the number of dielectric layers=$i$. The dielectric constant of all the layers is the same but the thickness of each layer can be different. The structure is enclosed by metal sidewalls. The top and bottom metal enclosures are optional.

4. Gold conductivity is $4.1 \times 10^7$ S/m. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^7$.

5. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer $#1$) is conductor layer $#1$; the lower surface of the dielectric layer $#1$ (which could also be the upper surface of the dielectric layer $#2$) is conductor layer $#2$; etc. When using a PCSUB$i$ substrate, the lower surface of dielectric layer $#i$ is conductor layer $#(2+1)$. 
Printed Circuit Board Components

PCSUB5 (5-Layer Printed Circuit Substrate)

Symbol

Illustration

<table>
<thead>
<tr>
<th>Hu</th>
<th>H1</th>
<th>H2</th>
<th>H3</th>
<th>H4</th>
<th>H5</th>
<th>Hl</th>
</tr>
</thead>
<tbody>
<tr>
<td>ε = ε₀</td>
<td>ε = ε₀ × Er</td>
<td>ε = ε₀ × Er</td>
<td>ε = ε₀ × Er</td>
<td>ε = ε₀ × Er</td>
<td>ε = ε₀ × Er</td>
<td>ε = ε₀</td>
</tr>
</tbody>
</table>

Parameters

H₁ = thickness of dielectric layer #1, in specified units
H₂ = thickness of dielectric layer #2, in specified units
H₃ = thickness of dielectric layer #3, in specified units
H₄ = thickness of dielectric layer #4, in specified units
H₅ = thickness of dielectric layer #5, in specified units
Er = dielectric constant
Cond = conductor conductivity
Hu = upper ground plane spacing, in specified units
Hl = lower ground plane spacing, in specified units
T = metal thickness, in specified units
W = distance between sidewalls, in specified units
Sigma = dielectric conductivity, in Siemens per meter

8-50 PCB Model Basis and Limits
Range of Usage

\[ H_i > 0 \text{ for } H_i = 1, \ldots, 5, \quad E_r \geq 0, \]
\[ \Sigma \geq 0, \quad T \geq 0, \quad H_u \geq 0, \quad H_l \geq 0, \quad W > 0 \]

Notes/Equations/References

1. Refer to the section “Assumptions and Limitations” on page 8-2 at the beginning of this chapter for important information.

2. A PCSUB\(i\) (\(i=1, 2, \ldots, 7\)) is required for all PCB components.

3. PCSUB\(i\) specifies a multi-layered dielectric substrate with the number of dielectric layers=i. The dielectric constant of all the layers is the same but the thickness of each layer can be different. The structure is enclosed by metal sidewalls. The top and bottom metal enclosures are optional.

4. Gold conductivity is 4.1\( \times 10^7 \) S/m. Rough modifies loss calculations. Conductivity for copper is 5.8\( \times 10^7 \).

5. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer \#1) is conductor #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUB\(i\) substrate, the lower surface of dielectric layer # is conductor layer \(#2+i\).
Printed Circuit Board Components

PCSUB6 (6-Layer Printed Circuit Substrate)

Symbol

Illustration

Parameters
None

Range of Usage
Hi > 0 for Hi = 1, ..., 6, Er ≥ 0,
Sigma ≥ 0, T ≥ 0, Hu ≥ 0, Hl ≥ 0, W > 0

Notes/Equations/References
1. Refer to the section “Assumptions and Limitations” on page 8-2 at the beginning of this chapter for important information.
2. A PCSUBi (i=1,2, ..., 7) is required for all PCB components.
3. PCSUBi specifies a multi-layered dielectric substrate with the number of dielectric layers=i. The dielectric constant of all the layers is the same but the thickness of each layer can be different. The structure is enclosed by metal sidewalls. The top and bottom metal enclosures are optional.
4. Gold conductivity is $4.1 \times 10^7$ S/m. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^7$.

5. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+1).
Printed Circuit Board Components

**PCSUB7 (7-Layer Printed Circuit Substrate)**

**Symbol**

![PCSub7](image)

**Illustration**

Hi > 0 for Hi = 1, ..., 7, Er ≥ 0,
Sigma ≥ 0, T ≥ 0, Hu ≥ 0, Hl ≥ 0, W > 0

**Parameters**

None

**Range of Usage**

Hi > 0 for Hi = 1, ..., 7, Er ≥ 0,
Sigma ≥ 0, T ≥ 0, Hu ≥ 0, Hl ≥ 0, W > 0

**Notes/Equations/References**

1. Refer to the section “Assumptions and Limitations” on page 8-2 at the beginning of this chapter for important information.

2. A PCSUBi (i=1,2, ..., 7) is required for all PCB components.

3. PCSUBi specifies a multi-layered dielectric substrate with the number of dielectric layers=i. The dielectric constant of all the layers is the same but the thickness of each layer can be different. The structure is enclosed by metal sidewalls. The top and bottom metal enclosures are optional.
4. Gold conductivity is $4.1 \times 10^7$ S/m. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^7$.

5. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+1).
### PCTAPER (PC Tapered Line)

**Symbol**

![Symbol Image]

**Illustration**

![Illustration Image]

**Parameters**

- **Subst** = printed circuit substrate name (PCSUBi, i=1, 2, ..., 7)
- **W1** = width at pin 1, in specified units
- **W2** = width at pin 2, in specified units
- **CLayer** = conductor layer number (value type: integer)
- **L** = length of line, in specified units
- **Temp** = physical temperature, in °C

**Range of Usage**

- **W1, W2 > 0**
- **1 ≤ CLayer ≤ Nlayers + 1**

where

- **Nlayers** = number of layers specified by PCSUBi (i=1, 2, ..., 7)

**Notes/Equations/References**

1. This component is modeled as PCLIN1. Width of the line is assumed to be \((W_1 + W_2)/2\). The single line is assumed to be located halfway between and parallel to the sidewalls. The distance between the sidewalls is given as a part of the PCSUBi parameter \(W\).

2. The distance between the sidewalls is typically the width of the metal enclosure around the PC board. If the metal enclosure is absent, width of the PC board...
itself can be specified and treated as the distance between the sidewalls. Note, however, that the simulation time increases rapidly as the sidewall distance increases. If the effect of the sidewalls is not important, it is highly recommended to set it to approximately 10 times the line width for this component.

3. This component is provided mainly to facilitate interconnection between PCB lines of different widths in layout.

4. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1,2,..., 7) if Hl=0.

5. Gold conductivity is $4.1 \times 10^7$ S/m. Rough modifies loss calculations. Conductivity for copper is $5.8 \times 10^7$.

6. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+1).

7. To turn off noise contribution, set Temp to $-273.15^\circ C$. 
Printed Circuit Board Components

**PCTEE (Printed Circuit T-Junction)**

**Symbol**

![Symbol](image)

**Illustration**

![Illustration](image)

**Parameters**

Subst = printed circuit substrate name (PCSUBi, i=1, 2, ..., 7)

W1 = width at pin 1, in specified units

W2 = width at pin 2, in specified units

W3 = width at pin 3, in specified units

CLayer = conductor layer number (value type: integer)

Temp = physical temperature, in °C

**Range of Usage**

Wi > 0 for Wi = 1, ..., 3

1 ≤ CLayer ≤ Nlayers + 1

where

Nlayers = number of layers specified by PCSUBi (i=1, 2, ..., 7)

**Notes/Equations/References**

1. This component is treated as an ideal connection between pins 1, 2, and 3, and has been provided mainly to facilitate interconnections between PCB lines oriented at different angles in layout.
2. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1,2,..., 7) if Hl=0.

3. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+i).

4. To turn off noise contribution, set Temp to $-273.15^\circ C$.

5. Layout artwork requires placing a PCSUBi ($i=1, 2, ..., 7$) prior to placing the component directly in the Layout window.
Printed Circuit Board Components

**PCTTRACE (Single PCB Line (Trace))**

**Symbol**

![Symbol](image)

**Parameters**

- **Subst** = printed circuit substrate name (PCSUBi, i=1,2,...,7)
- **W** = width of line, in specified units
- **CLayer** = conductor layer number (value type: integer)
- **L** = length of line, in specified units
- **Temp** = physical temperature, in °C

**Range of Usage**

- **W** > 0
- \(1 \leq CLayer \leq Nlayers + 1\)

where

- \(Nlayers\) = number of layers specified by PCSUBi (i=1,2,...,7)

**Notes/Equations/References**

1. This component is modeled as PCLIN1. The single line is assumed to be located halfway between and parallel to the sidewalls. The distance between the sidewalls is given as a part of the PCSUBi parameter W.

2. The distance between the sidewalls is typically the width of the metal enclosure around the PC board. If the metal enclosure is absent, width of the PC board itself can be specified and treated as the distance between the sidewalls. Note, however, that the simulation time increases rapidly as the sidewall distance increases. If the effect of the sidewalls is not important, it is highly recommended to set it to approximately 10 times the line width for this component.

3. The value of CLayer and the value of the associated PCSUB parameters Hu and Hl must be compatible so as to not short out the CLayer to the upper or lower ground plane. For example, it is invalid for CLayer=1 if Hu=0 or for CLayer=i+1 (for PCSUBi, i=1,2,...,7) if Hl=0.
4. Conductor layers are numbered as follows: the upper surface of the top dielectric layer (or dielectric layer #1) is conductor layer #1; the lower surface of the dielectric layer #1 (which could also be the upper surface of the dielectric layer #2) is conductor layer #2; etc. When using a PCSUBi substrate, the lower surface of dielectric layer # is conductor layer #(2+1).

5. For time-domain analysis, an impulse response obtained from the frequency-domain analytical model is used.

6. To turn off noise contribution, set Temp to $-273.15^\circ C$.

7. This component is provided mainly to facilitate interconnections between PCB lines in layout.

8. Layout artwork requires placing a PCSUBi(i=1,2, ... , 7) prior to placing the component directly in the Layout window.
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