

Fast Modeling of a Transmission Line Wilkinson Power Divider

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Introduction

Some conventional three-port power dividers are resistive power dividers and T-junction power dividers. Such dividers are either lossy or not matched to the system reference impedance at all ports. In addition, isolation between two coupled ports is not guaranteed. The Wilkinson power divider outperforms the lossless T-junction divider and the resistive divider and does not have the abovementioned issues. This example model simulates a Wilkinson power divider using the Transmission Line physics interface in 2D. This approach is very fast compared to solving Maxwell's equations in 3D. The results present the S-parameters from 1 GHz to 5 GHz and electric potential distribution along the transmission line.



Figure 1: A microstrip Wilkinson power divider is composed of a 100 W resistor and transmission lines with two impedance values.

Model Definition

The power divider geometry consists of three straight lines built with Bézier polygons and three curved lines created by circles. Transmission Line Equation features define the distributed parameter values for 50 Ω and 70.71 Ω microstrip lines and it also defines the parameter values for the 100 Ω resistor connecting two 70.71 Ω microstrip lines.

The transmission line parameters for a 50 Ω microstrip line built on a 20 mil substrate with permittivity $\varepsilon_r = 3.38$ and 1 oz copper can be calculated accurately from Ref. 2.

R	L	G	С
l2.4I Ω/m	272.9 nH/m	0 S/m	107.1 pF/m

TABLE I: CALCULATED TRANSMISSION LINE PARAMETERS OF A 50 Ω MICROSTRIP LINE.

The contribution of the distributed resistance to the insertion loss with the given substrate properties is less than 0.05 dB. To make the modeling steps simpler in this example, the approximated parameter values in Table 2 are used for a 50 Ω microstrip line.

R	L	G	С
0 Ω/m	250 nH/m	0 S/m	100 pF/m

TABLE 2: SIMPLIFIED TRANSMISSION LINE PARAMETERS OF A 50 Ω Microstrip line.

70.71 Ω microstrip line parameters are adjusted using the normalized impedance. The distributed inductance is proportionally scaled and the distributed capacitance is inversely scaled by the normalized impedance of the microstrip line. The distributed resistance for the 100 Ω resistor that connects two 70.71 Ω microstrip lines is scaled inversely by the length of the curvature where the resistor is placed.

In order to have a complete S-parameter report, port sweep option in the physics interface needs to be activated. When the port sweep is combined with a parametric sweep, this will excite ports one by one to generate a full S-parameter matrix plot.

Results and Discussion

In Figure 2 and Figure 3, the electric potential along the transmission lines are plotted. When port 3 ix excited, the input electric potential is not delivered to port 2 (Figure 2). Since the device is symmetric with regard to port 2 and 3, the isolation from port 2 to port 3 is also expected when port 2 is excited. This ensures two coupled ports (port 2 and port 3) are isolated from each other. When port 1 is excited, the input electric potential is split equally between port 2 and port 3 (Figure 3).

Figure 4 and Figure 5 show the computed S-parameter plots when port 1 and port 2 is excited, respectively. When the input power is equally split to two coupled ports, the received power level is -3 dB (S_{21} and S_{31}) in each coupled port at 3 GHz. The impedance matching (S_{11} and S_{22}) to the reference characteristic impedance 50 Ω and isolation (S_{23}) are below -50 dB at the center frequency.



Figure 2: Port 3 is isolated from port 2 when port 3 is excited.



Figure 3: The input voltage is distributed equally between port 2 and port 3 when port 1 is excited.

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Figure 4: The computed S-parameter plot when port 1 is excited.



Figure 5: The computed S-parameter plot when port 2 is excited.

References

1. D.M. Pozar, Microwave Engineering, John Wiley & Sons, 1998.

2. COMSOL Application Gallery, "*Transmission Line Parameter Calculator*", https://www.comsol.com/model/transmission-line-parameter-calculator-22351

Application Library path: RF_Module/Couplers_and_Power_Dividers/ transmission_line_wpd

Model Instructions

From the **File** menu, choose **New**.

NEW

In the New window, click 🙆 Model Wizard.

MODEL WIZARD

- I In the Model Wizard window, click **2D**.
- 2 In the Select Physics tree, select Radio Frequency>Transmission Line (tl).
- 3 Click Add.
- 4 Click 🔿 Study.
- 5 In the Select Study tree, select General Studies>Frequency Domain.
- 6 Click 🗹 Done.

GLOBAL DEFINITIONS

Parameters 1

- I In the Model Builder window, under Global Definitions click Parameters I.
- 2 In the Settings window for Parameters, locate the Parameters section.
- **3** In the table, enter the following settings:

Name	Expression	Value	Description
fO	3[GHz]	3E9 Hz	Center frequency
10	250[nH/m]	2.5E-7 H/m	Distributed inductance, 50[ohm] line

Name	Expression	Value	Description
c0	100[pF/m]	1E-10 F/m	Distributed capacitance, 50[ohm] line
z0	<pre>sqrt(10/c0)</pre>	50 Ω	Characteristic impedance
lda0_t	1/f0/sqrt(l0*c0)	0.066667 m	Wavelength, transmission line
11	10*sqrt(2)	3.5355E-7 H/m	Distributed inductance, 70.71[ohm] line
c1	cO/sqrt(2)	7.0711E-11 F/m	Distributed capacitance, 70.71[ohm] line
z1	sqrt(l1/c1)	70.711 Ω	Characteristic impedance
r0	lda0_t/(4*pi)* 360/350	0.0054567 m	Radius, 70.71[ohm] line

GEOMETRY I

- I In the Model Builder window, under Component I (compl) click Geometry I.
- 2 In the Settings window for Geometry, locate the Units section.
- 3 From the Length unit list, choose mm.

Line Segment I (IsI)

- I In the Geometry toolbar, click 🗱 More Primitives and choose Line Segment.
- 2 In the Settings window for Line Segment, locate the Starting Point section.
- 3 From the Specify list, choose Coordinates.
- 4 Locate the Endpoint section. From the Specify list, choose Coordinates.
- 5 Locate the Starting Point section. In the x text field, type -r0-5.
- 6 Locate the Endpoint section. In the x text field, type -r0.

Circle I (c1)

- I In the **Geometry** toolbar, click 🕑 **Circle**.
- 2 In the Settings window for Circle, locate the Object Type section.
- 3 From the Type list, choose Curve.
- 4 Locate the Size and Shape section. In the Radius text field, type r0.
- 5 In the Sector angle text field, type 350.

- 6 Locate the Rotation Angle section. In the Rotation text field, type 5.
- 7 Click 🔚 Build Selected.
- 8 Click the + Zoom Extents button in the Graphics toolbar.

Delete Entities I (dell)

- I In the Model Builder window, right-click Geometry I and choose Delete Entities.
- 2 On the object cl, select Boundaries 5 and 6 only.

It might be easier to select the boundaries by using the **Selection List** window. To open this window, in the **Home** toolbar click **Windows** and choose **Selection List**. (If you are running the cross-platform desktop, you find **Windows** in the main menu.)



Delete total four line entities.

Circular Arc 1 (cal)

- I In the Geometry toolbar, click 😕 More Primitives and choose Circular Arc.
- 2 In the Settings window for Circular Arc, locate the Radius section.
- **3** In the **Radius** text field, type r0.
- 4 Locate the Angles section. In the Start angle text field, type 355.
- 5 In the End angle text field, type 5.

Line Segment 2 (Is2)

- I In the Geometry toolbar, click 😕 More Primitives and choose Line Segment.
- 2 In the Settings window for Line Segment, locate the Starting Point section.
- 3 From the Specify list, choose Coordinates.
- 4 Locate the Endpoint section. From the Specify list, choose Coordinates.
- 5 Locate the Starting Point section. In the x text field, type r0*cos(5[deg]).
- 6 In the y text field, type r0*sin(5[deg]).
- 7 Locate the Endpoint section. In the x text field, type r0*2.
- 8 In the y text field, type r0.

Line Segment 3 (Is3)

- I In the Geometry toolbar, click 🗱 More Primitives and choose Line Segment.
- 2 In the Settings window for Line Segment, locate the Starting Point section.
- 3 From the Specify list, choose Coordinates.
- 4 Locate the Endpoint section. From the Specify list, choose Coordinates.
- 5 Locate the Starting Point section. In the x text field, type r0*cos(5[deg]).
- 6 In the y text field, type -r0*sin(5[deg]).
- 7 Locate the **Endpoint** section. In the **x** text field, type r0*2.
- **8** In the **y** text field, type r0.
- 9 Click 🟢 Build All Objects.



TRANSMISSION LINE (TL)

Lumped Port I

- I In the Model Builder window, under Component I (compl) right-click Transmission Line (tl) and choose Lumped Port.
- 2 Select Point 1 only.

Lumped Port 2

- I In the Physics toolbar, click 💮 Points and choose Lumped Port.
- 2 Select Point 8 only.

Lumped Port 3

- I In the Physics toolbar, click 💭 Points and choose Lumped Port.
- 2 Select Point 7 only.

Transmission Line Equation 1

Set parameter values for 50 Ω transmission lines. Since this is a default feature, the properties are applied to all line parts.

- I In the Model Builder window, click Transmission Line Equation I.
- 2 In the Settings window for Transmission Line Equation, locate the Transmission Line Equation section.

- **3** In the L text field, type 10.
- **4** In the *C* text field, type c0.

Transmission Line Equation 2

- I In the Physics toolbar, click Boundaries and choose Transmission Line Equation.
 - 9 8 7 6 5 4 3-2 1_ 0--1--2 -3⁻⁻ -5⁻⁻ -6⁻⁻ -7⁻⁻ -8 -9 -10 -8 6 4 | -2 0 Ļ 4 ۱ ۲ 10
- **2** Select Boundaries 4–7 only.

Set parameter values for 70.71 Ω transmission lines. This overrides the default properties in the selected boundaries.

- **3** In the Settings window for Transmission Line Equation, locate the Transmission Line Equation section.
- **4** In the *L* text field, type 11.
- **5** In the *C* text field, type c1.

Transmission Line Equation 3

I In the Physics toolbar, click — Boundaries and choose Transmission Line Equation.

2 Select Boundary 8 only.



3 In the **Geometry** toolbar, click **Measure**.

Check the Messages window to obtain the measured curvature length and use it to scale the distributed resistance. The transmission line with the adjusted resistance represents a 100 Ω resistor.

- **4** In the Settings window for Transmission Line Equation, locate the Transmission Line Equation section.
- **5** In the *R* text field, type 100/0.9524e-3.
- 6 In the *L* text field, type 0.
- 7 In the *C* text field, type 0.
- 8 In the Model Builder window, click Transmission Line (tl).
- 9 In the Settings window for Transmission Line, locate the Port Sweep Settings section.
- **IO** Select the **Use manual port sweep** check box.
- II Click **Configure Sweep Settings**. By clicking the **Configure Sweep Settings** button, all necessary port sweep settings such as sweep parameter and parametric study step will be automatically added. It is necessary to run the parametric sweep with port names to get a full S-parameter matrix.

STUDY I

- Step 1: Frequency Domain
- I In the Model Builder window, under Study I click Step I: Frequency Domain.
- 2 In the Settings window for Frequency Domain, locate the Study Settings section.
- 3 In the Frequencies text field, type range(1[GHz],0.02[GHz],5[GHz]).
- **4** In the **Home** toolbar, click **= Compute**.

RESULTS

- 2D Plot Group I
- I In the Settings window for 2D Plot Group, locate the Data section.
- 2 From the Parameter value (freq (GHz)) list, choose 3.

Line Graph

- I In the Model Builder window, expand the 2D Plot Group I node, then click Line Graph.
- 2 In the Settings window for Line, locate the Expression section.
- 3 In the Expression text field, type 20*log10(abs(V)).
- 4 Locate the Coloring and Style section. From the Color table list, choose Traffic.
- 5 In the 2D Plot Group I toolbar, click 💿 Plot.

The excited electric potential at port 3 is isolated from port 2. Compare with Figure 2.

2D Plot Group 1

- I In the Model Builder window, click 2D Plot Group I.
- 2 In the Settings window for 2D Plot Group, locate the Data section.
- 3 From the Parameter value (PortName) list, choose I.
- 4 In the 2D Plot Group I toolbar, click 💿 Plot.

When port 1 is excited, the resulting plot shows that the electric potential is distributed equally between port 2 and port 3 (Figure 3).

S-parameter (tl)

- I In the Model Builder window, click S-parameter (tl).
- 2 In the Settings window for ID Plot Group, locate the Data section.
- 3 From the Dataset list, choose Study I/Parametric Solutions I (sol2).
- 4 From the Parameter selection (PortName) list, choose From list.
- 5 In the Parameter values (PortName) list, select 1.
- 6 Locate the Axis section. Select the Manual axis limits check box.

- 7 In the **y minimum** text field, type -50.
- **8** In the **y maximum** text field, type **0**.
- 9 In the S-parameter (tl) toolbar, click 💿 Plot.

The reproduced plot shows the calculated S-parameters when port 1 is excited. See Figure 4.

S-parameter (tl) 1

- I Right-click S-parameter (tl) and choose Duplicate.
- 2 In the Settings window for ID Plot Group, locate the Data section.
- 3 In the Parameter values (PortName) list, select 2.
- 4 In the S-parameter (tl) I toolbar, click **I** Plot.

The S-parameters plot should look like Figure 5 when port 2 is excited.