RF Toolbox

For Use with MATLAB®

- Computation
- Visualization
- Programming

User's Guide

Version 2

The MathWorks

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RF Toolbox User's Guide

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Contents

1 Getting Started

2 Modeling an RF Component

3 Exporting Verilog-A Models

4 RF Tool: An RF Analysis GUI

5 Functions — By Category

B Examples

Index

1

Getting Started

What Is the RF Toolbox?

The RF Toolbox extends MATLAB® with objects and functions for modeling RF circuits consisting of:

- Components such as RF filters, transmission lines, amplifiers, and mixers.
- Networks of interconnected components, such as cascaded, parallel, series, or hybrid networks.

Note To use the RF Toolbox, you must have MATLAB installed.

You use objects from the RF Toolbox to represent the components of your RF network. The toolbox provides several types of component representations using network parameters (S, Y, Z, ABCD, H, and T format) and physical properties.

You integrate the components to represent your RF network and analyze the network at specified frequencies.

You then perform one or more of the following tasks:

- Visualize network data using plots and Smith charts.
- Compute the transfer function and impulse response of a circuit.
- Export a Verilog-A description of a component or network for use in a time-domain circuit simulator.

All RF Toolbox features are accessible and executable interactively from the MATLAB prompt or programmatically using M-code scripts.

The RF Toolbox provides access to a subset of the command-line functionality through a graphical user interface, RF Tool. Using RF Tool, you can perform the following tasks:

- Design, analyze, and visualize RF components and networks.
- Export circuits to the MATLAB workspace, or to a file for use with RF Toolbox functions and other circuit objects.

A validated model of an RF circuit can provide an executable specification for verification in a system-level simulation.

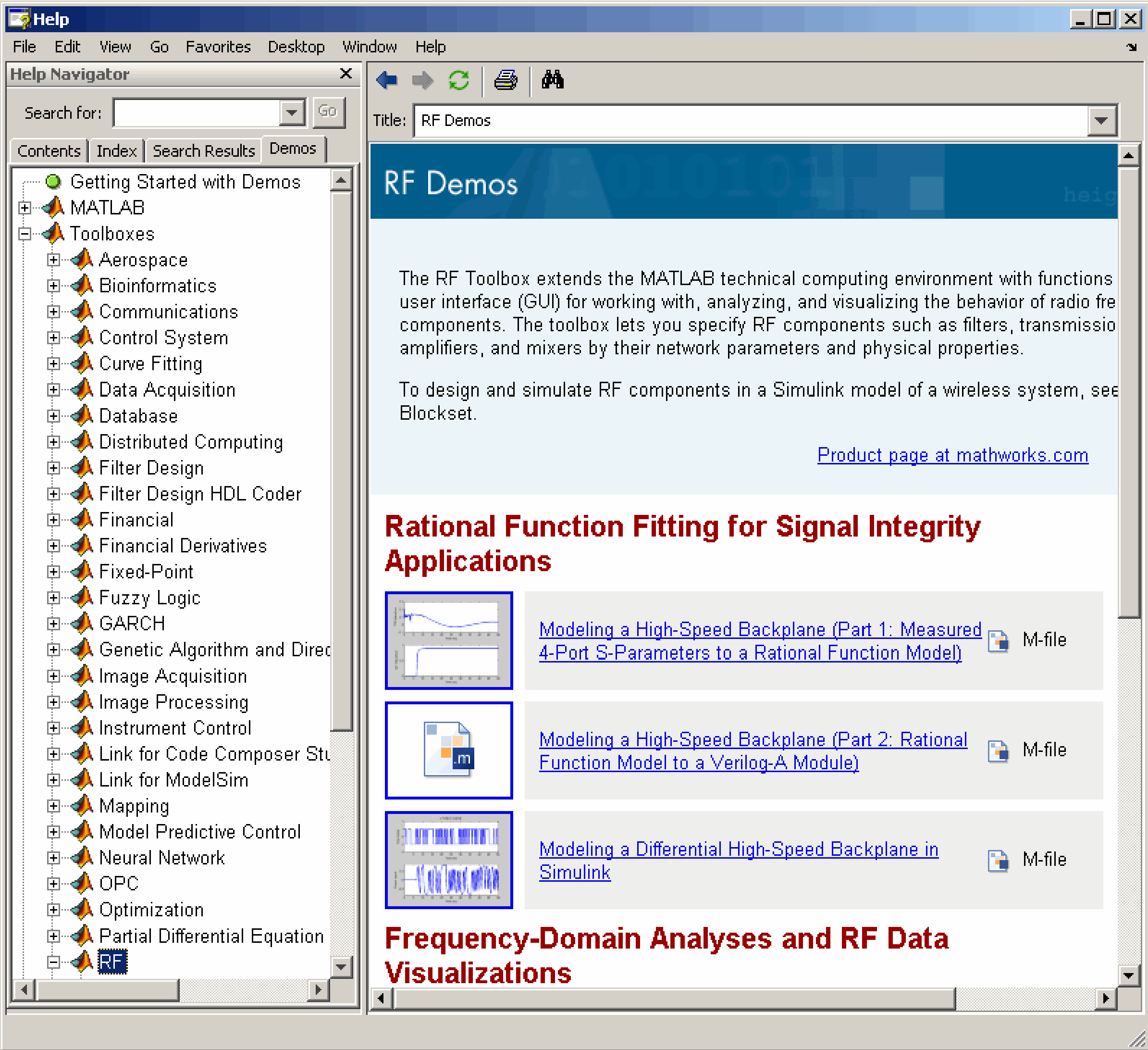
Related Products

The MathWorks provides several products that are especially relevant to the kinds of tasks you can perform with the RF Toolbox. The following table summarizes the related products and describes how they complement the features of the RF Toolbox.

Product	Description
Communications Blockset	Simulink blocks for time-domain simulation of modulation and demodulation of a wireless communications signal.
Communications Toolbox	MATLAB functions for signal modulation and demodulation.
Filter Design Toolbox	MATLAB functions for filtering the modulated communication signal.
RF Blockset	Time-domain simulation of RF components in Simulink.
Signal Processing Toolbox	MATLAB functions for filtering the modulated communication signal.
Signal Processing Blockset	Simulink blocks for time-domain simulation of for filtering the modulated communication signal.

Product Demos

You can find interactive RF Toolbox demos in the MATLAB Help browser.



To locate and open an RF Toolbox demo:

1 Type `demos` at the MATLAB prompt to open the Help browser to the **Demos** tab.

2 Select **Toolboxes > RF** in the **Demos** tab to see a list of demo categories.

3 Select a model, and click **Run in the Command Window** in the upper-right corner of the demo window to run the demo.

RF Objects

The RF Toolbox uses objects to represent RF components and networks. The following table summarizes the types of objects that are available in the RF Toolbox and describes the uses of each one.

Object Type	Name	Description
RF Data Objects	`rfdata`	Stores data for use by other RF objects or for plotting and network parameter conversion.
RF Circuit Objects	`rfckt`	Represents RF components and networks using network parameters and physical properties for frequency-domain simulation.
RF Model Objects	`rfmodel`	Represents RF components and networks mathematically for computing time-domain behavior and exporting models.

Every object has predefined fields called *properties*. The properties define the characteristics of the object. Each property associated with an object is assigned a value. Every object has a set of functions, or *methods* of the object, that act on that object.

You can construct any RF object from the command line using the object's constructor function, as described in "Creating RF Objects" on page 2-2.

You can set the values of many properties from the command line by specifying or importing object data, or you can accept the default values. For more information on object properties, see "Specifying or Importing Component Data" on page 2-5.

Note The RF Toolbox also provides a graphical interface for creating and analyzing circuit objects. For more information, see Chapter 4, "RF Tool: An RF Analysis GUI".

This section contains the following topics:

RF Data Objects

The RF Toolbox uses data (`rfdata`) objects to store:

- Component data created from files or from information that you specify in the MATLAB workspace.
- Analyzed data from a frequency-domain simulation of a circuit object.

You can perform basic tasks, such as plotting and network parameter conversion, on the data stored in these objects. However, data objects are primarily used to store data for use by other RF objects.

This section contains the following topics:

Types of Data

The RF Toolbox uses RF data objects to store one or more of the following types of data:

- Network parameters
- Spot noise
- Noise figure
- Third-order intercept point (IP3)
- Power out versus power in

Available Data Objects

For a list of the available `rfdata` object constructor functions and a description of the data the corresponding objects store, see Data Objects. For more information on data objects, see the `rfdata` reference page.

RF Circuit Objects

The RF Toolbox uses circuit (`rfckt`) objects to represent the following components:

- Circuit components such as amplifiers, transmission lines, and ladder filters
- RLC network components
- Networks of RF components

The RF Toolbox represents each type of component and network with a different object. You use these objects to analyze components and networks in the frequency domain.

This section contains the following topics:

Components Versus Networks

You define component behavior using network parameters and physical properties.

To specify an individual RF component:

1. Construct a circuit object to represent the component.
2. Specify or import component data.

You define network behavior by specifying the components that make up the network. These components can be either individual components (such as amplifiers and transmission lines) or other networks.

To specify an RF network:

1. Build circuit objects to represent the network components.
2. Construct a circuit object to represent the network.

> **Note** This object defines how to connect the network components. The network is empty until you specify the components that it contains.

3. Specify, as a property of the object that represents the network, a list of components that make up the network.

These procedures are illustrated by example in "Example — Modeling a Cascaded RF Network" on page 1-15.

Available Components and Networks

To create circuit objects that represent components, you use constructors whose names describe the components. To create circuit objects that represent networks, you use constructors whose names describe how the components are connected together.

For a list of the available `rfckt` object constructors and a description of the components or networks the corresponding objects represent, see Circuit Objects. For more information on circuit objects, see the `rfckt` reference page.

RF Model Objects

The RF Toolbox uses model (`rfmodel`) objects to represent components and measured data mathematically for computing time-domain information such as impulse response. Each type of model object uses a different mathematical model to represent the component.

RF model objects provide a high-level component representation for use after you perform detailed analysis using RF circuit objects. Use RF model objects to:

- Compute time-domain figures of merit for RF components
- Export Verilog-A models of RF components

For a list of the available `rfmodel` object constructor functions and a description of the model the corresponding objects use, see Model Objects. For more information on model objects, see the `rfmodel` reference page.

Help for Objects

The RF Toolbox provides convenient access to information about available objects and their methods from the MATLAB prompt.

Note The words *method* and *function* are used interchangeably to refer to methods in the rest of this user's guide.

For help in using objects, see Chapter 2, "Modeling an RF Component".

This section contains the following topics:

- "Lists of Objects and Methods" on page 1-12
- "Method Descriptions" on page 1-12

- "Object and Property Descriptions" on page 1-12

Lists of Objects and Methods

Type `help` *`objecttype`* or `doc` *`objecttype`* at the MATLAB prompt to get a list of objects and methods of a particular type. Here, *`objecttype`* is the type of object, i.e. `rfckt`, `rfdata`, or `rfmodel`.

Method Descriptions

There are two ways to get detailed descriptions of the methods for circuit (`rfckt`), data (`rfdata`), and model (`rfmodel`) objects:

- At the MATLAB prompt, type `doc` *`methodname`*.

  For example, type `doc analyze` to view a detailed description of the `analyze` method.

  Note If more than one product has a method or function by that name, MATLAB returns a list from which you can choose.

- At the MATLAB prompt, type `help` *`objecttype/methodname`*, where *`methodname`* is the name of the method.

  For example, type `help rfckt/analyze` to view a detailed description of the `analyze` method as it pertains to `rfckt` objects.

Object and Property Descriptions

At the MATLAB prompt, type `help` *`objecttype`* or `doc` *`objecttype`*, where *`objecttype`* is the type of object, i.e. `rfckt`, `rfdata`, or `rfmodel`. The result is a list of objects and methods of a particular type.

Type `doc` *`objecttype.objectname`* or `help` *`objecttype.objectname`* at the MATLAB prompt to get detailed information about a specific object and its properties.

For example, type `doc rfckt.amplifier` or `help rfckt.amplifier` to view detailed information about the `rfckt.amplifier` object.

RF Toolbox Workflow

When you analyze an RF circuit using the RF Toolbox, your workflow might include the following tasks:

1 Create RF circuit objects to represent the components of your RF network.

See "Creating RF Objects" on page 2-2.

2 Define component data by

- Specifying network parameters or physical properties (see "Setting Property Values" on page 2-5).
- Importing data from an industry-standard Touchstone file, a MathWorks AMP file, or the MATLAB workspace (see "Importing Property Values from Data Files" on page 2-8).

3 Integrate components to form a cascade, hybrid, parallel, or series network.

See "Constructing Networks of Specified Components" on page 2-7.

4 Analyze the network in the frequency domain.

See "Analyzing Networks in the Frequency Domain" on page 2-17.

5 Generate plots to gain insight into network behavior.

The following plots and charts are available in the RF Toolbox:

- Rectangular plots
- Polar plots
- Smith charts
- Budget plots (for cascaded S-parameters)

See "Visualizing Component and Network Data" on page 2-18.

6 Compute the network transfer function.

See "Computing the Network Transfer Function" on page 2-20.

7 Create an RF model object that describes the transfer function analytically.

See “Fitting a Model Object to Circuit Object Data” on page 2-20.

8 Plot the impulse response.

See “Computing and Plotting the Impulse Response” on page 2-21.

9 Export a Verilog-A description of the network.

See Chapter 3, “Exporting Verilog-A Models”.

Example — Modeling a Cascaded RF Network

In this example, you use the RF Toolbox command-line interface to model the gain and noise figure of a cascaded network. You analyze the network in the frequency domain and plot the results.

Note To learn how to use RF Tool to perform these tasks, see “Example — Modeling an RF Network Using RF Tool” on page 4-30.

The network that you use in this example consists of an amplifier and two transmission lines. The RF Toolbox represents RF components and RF networks using RF circuit objects. You learn how to create and manipulate these objects to analyze the cascaded amplifier network.

This example illustrates how to perform the following tasks:

- “Creating RF Components” on page 1-15
- “Specifying Component Data” on page 1-15
- “Validating RF Components” on page 1-16
- “Building and Simulating the Network” on page 1-18
- “Analyzing Simulation Results” on page 1-19

Creating RF Components

Type the following set of commands at the MATLAB prompt to create three circuit (`rfckt`) objects with the default property values. These circuit objects represent the two transmission lines and the amplifier:

```
FirstCkt = rfckt.txline;
SecondCkt = rfckt.amplifier;
ThirdCkt = rfckt.txline;
```

Specifying Component Data

In this part of the example, you specify the following component properties:

- “Transmission Line Properties” on page 1-16

- "Amplifier Properties" on page 1-16

Transmission Line Properties

1. Type the following command at the MATLAB prompt to change the line length of the first transmission line, `FirstCkt`, to `0.001`:

   ```
   set(FirstCkt,'LineLength',0.001)
   ```

2. Type the following command at the MATLAB prompt to change the line length of the second transmission line, `ThirdCkt`, to `0.025` and to change the phase velocity to `2.0e8`:

   ```
   set(ThirdCkt,'LineLength',0.025,'PV',2.0e8)
   ```

Amplifier Properties

1. Type the following command at the MATLAB prompt to import network parameters, noise data, and power data from the `default.amp` file into the amplifier, `SecondCkt`:

   ```
   read(SecondCkt, 'default.amp');
   ```

2. Type the following command at the MATLAB prompt to change the interpolation method of the amplifier, `SecondCkt`, to `cubic`:

   ```
   set(SecondCkt,'IntpType','cubic')
   ```

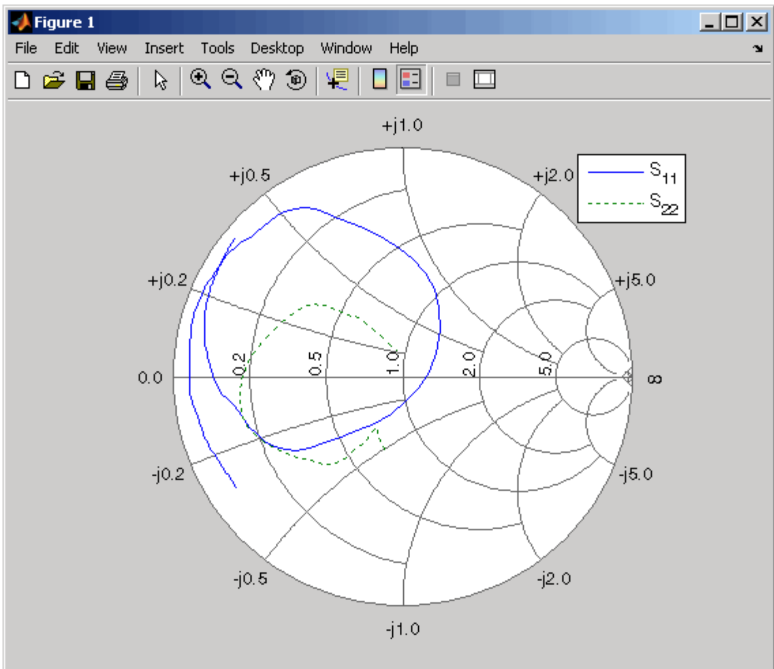
   The `IntpType` property tells the RF Toolbox how to interpolate the network parameters, noise data, and power data when you analyze the amplifier at frequencies other than those specified in the file.

Validating RF Components

In this part of the example, you plot the network parameters and power data (output power versus input power) to validate the behavior of the amplifier.

1 Type the following set of commands at the MATLAB prompt to use the `smith` command to plot the original S11 and S22 parameters of the amplifier (`SecondCkt`) on a Z Smith chart:

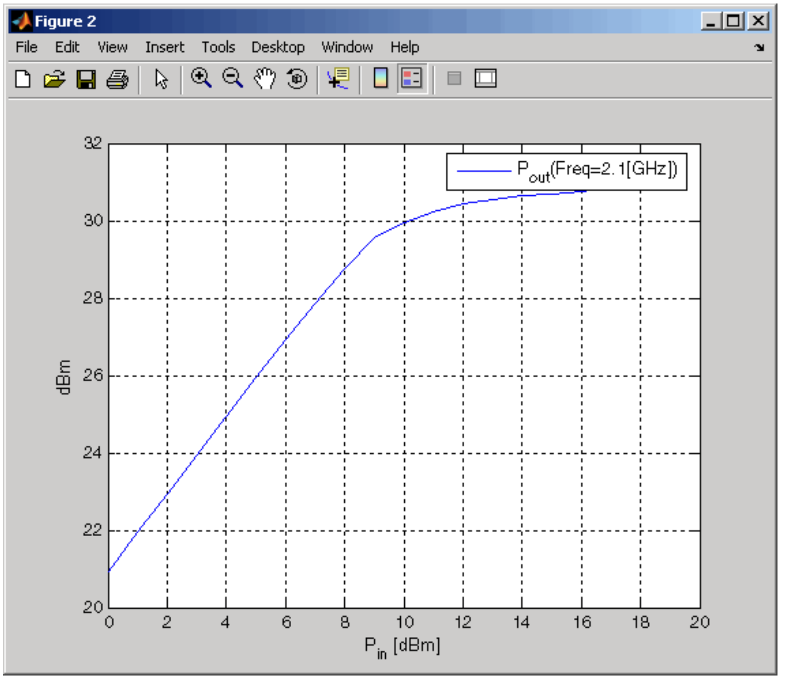
```
lineseries1 = smith(SecondCkt,'S11','S22');
set(lineseries1(1), 'LineStyle','-', 'LineWidth', 1);
set(lineseries1(2), 'LineStyle',':', 'LineWidth', 1);
legend show
```



Note The plot shows the S-parameters over the frequency range for which network data is specified in the `default.amp` file — from 1 GHz to 2.9 GHz.

2 Type the following set of commands at the MATLAB prompt to use the RF Toolbox `plot` command to plot the amplifier (`SecondCkt`) output power (P_{out}) as a function of input power (P_{in}), both in decibels referenced to one milliwatt (dBm), on an X-Y plane plot:

```
figure
plot(SecondCkt,'Pout','dBm');
legend show
```



Note The plot shows the power data at 2.1 GHz because this frequency is the one for which power data is specified in the `default.amp` file.

Building and Simulating the Network

In this part of the example, you create a circuit object to represent the cascaded amplifier and analyze the object in the frequency domain.

1 Type the following command at the MATLAB prompt to cascade the three circuit objects to form a new cascaded circuit object, `CascadedCkt`:

```
CascadedCkt = rfckt.cascade('Ckts',{FirstCkt,SecondCkt,...
              ThirdCkt});
```

2 Type the following set of commands at the MATLAB prompt to define the range of frequencies over which to analyze the cascaded circuit, and then run the analysis:

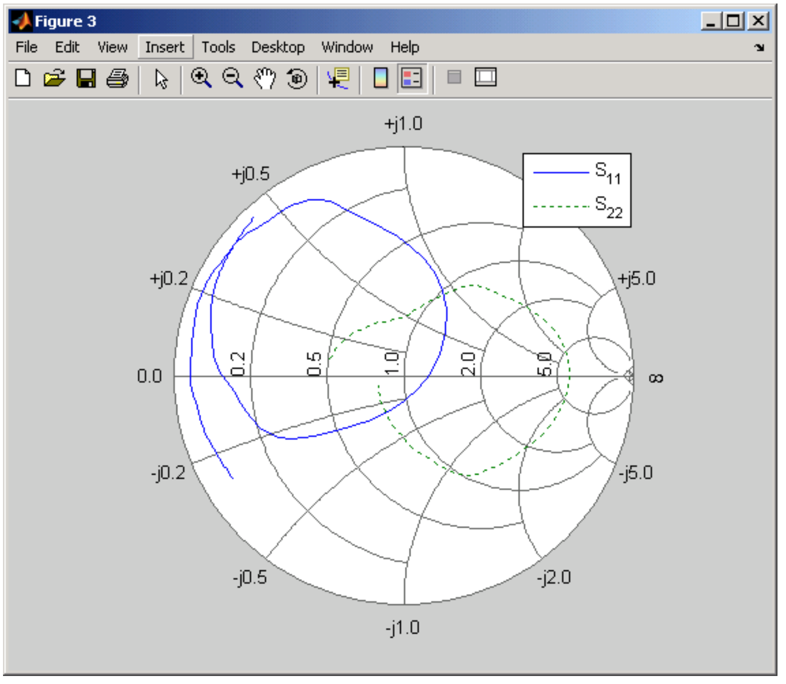
```
f = [1.0e9:1e7:2.9e9];
analyze(CascadedCkt,f);
```

Analyzing Simulation Results

In this part of the example, you analyze the results of the simulation by plotting data for the circuit object that represents the cascaded amplifier network.

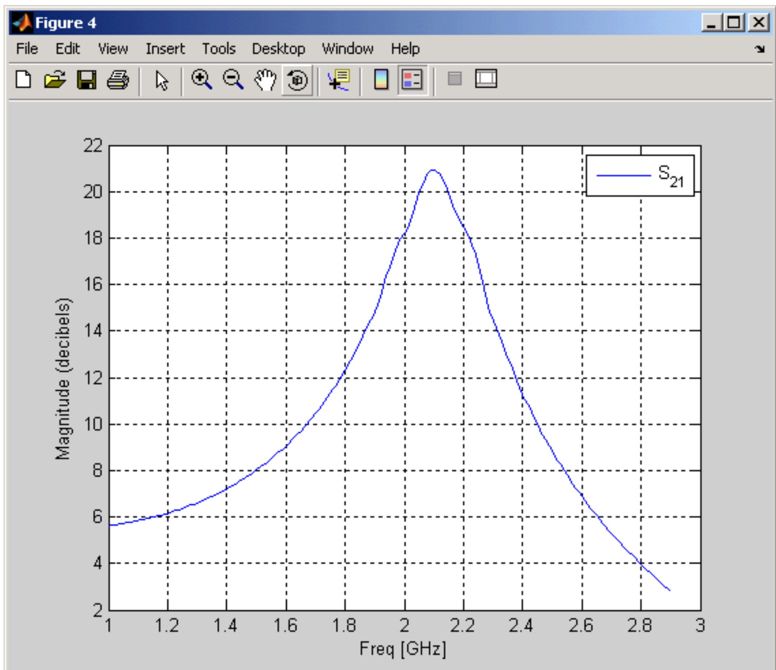
1 Type the following set of commands at the MATLAB prompt to use the `smith` command to plot the S11 and S22 parameters of the cascaded amplifier network on a Z Smith chart:

```
figure
lineseries2 = smith(CascadedCkt,'S11','S22','z');
set(lineseries2(1),'LineStyle','-','LineWidth',1);
set(lineseries2(2),'LineStyle',':','LineWidth',1);
legend show
```



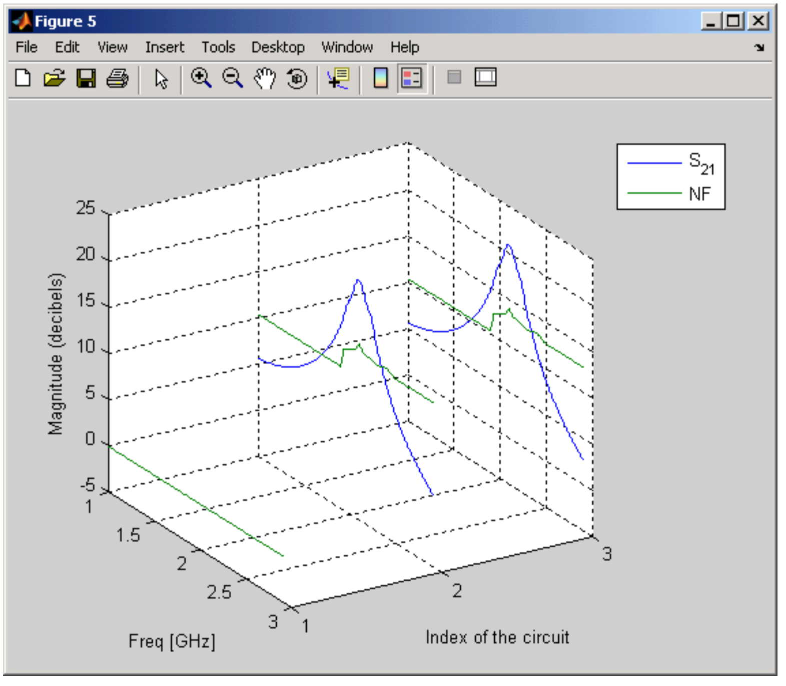
2 Type the following set of commands at the MATLAB prompt to use the `plot` command to plot the S21 parameter of the cascaded network, which represents the network gain, on an X-Y plane:

```
figure
plot(CascadedCkt,'S21','dB');
legend show
```



3 Type the following set of commands at the MATLAB prompt to use the plot command to create a budget plot of the S21 parameter and the noise figure of the amplifier network:

```
figure
plot(CascadedCkt,'budget', 'S21','NF');
legend show
```



The budget plot shows parameters as a function of frequency by circuit index. Components are indexed based on their position in the network. In this example:

- Circuit index one corresponds to FirstCkt.
- Circuit index two corresponds to SecondCkt.
- Circuit index three corresponds to ThirdCkt.

The curve for each index represents the contributions of the RF components up to and including the component at that index.

Example — Using a Rational Function Model to Analyze a Transmission Line

In this example, you use the RF Toolbox command-line interface to model the impulse response of a parallel plate transmission line. You analyze the network in the frequency domain, compute and plot the impulse response of the network, and export a Verilog-A model of the transmission line for use in system-level simulations.

This example illustrates how to perform the following tasks:

- "Building and Simulating the Transmission Line" on page 1-23
- "Computing the Transmission Line Transfer Function and Impulse Response" on page 1-23
- "Exporting a Verilog-A Model" on page 1-28

Building and Simulating the Transmission Line

1 Type the following command at the MATLAB prompt to create a circuit (`rfckt`) object to represent the transmission line, which is 0.1 meters long and 0.05 meters wide:

```
tline = rfckt.parallelplate('LineLength',0.1,'Width',0.05);
```

2 Type the following set of commands at the MATLAB prompt to define the range of frequencies over which to analyze the transmission line and then run the analysis:

```
f = [1.0e9:1e7:2.9e9];
analyze(tline,f);
```

Computing the Transmission Line Transfer Function and Impulse Response

This part of the example illustrates how to perform the following tasks:

- "Calculating the Transfer Function" on page 1-24
- "Fitting and Validating the Transfer Function Model" on page 1-24

- "Computing and Plotting the Impulse Response" on page 1-27

Calculating the Transfer Function

1 Type the following command at the MATLAB prompt to extract the computed S-parameter values and the corresponding frequency values for the transmission line:

```
[S_Params, Freq] = extract(tline,'S_Parameters');
```

2 Type the following command at the MATLAB prompt to compute the transfer function from the frequency response data using the `s2tf` function:

```
TrFunc = s2tf(S_Params);
```

Fitting and Validating the Transfer Function Model

In this part of the example, you fit a rational function model to the transfer function. The RF Toolbox stores the fitting results in an `rfmodel` object. You use the RF Toolbox `freqresp` function to validate the fit of the rational function model.

1 Type the following command at the MATLAB prompt to fit a rational function to the computed data and store the result in an `rfmodel` object:

```
RationalFunc = rationalfit(Freq,TrFunc)
```

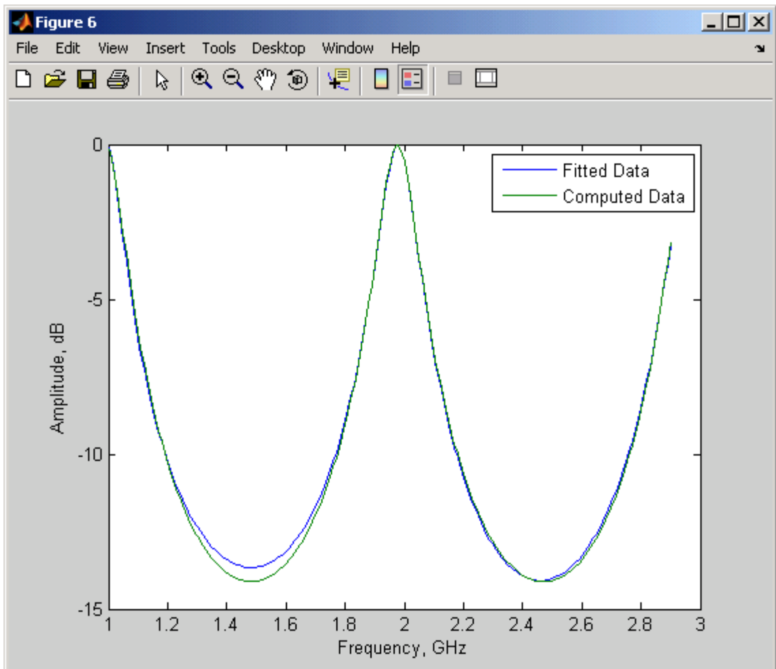
2 Type the following command at the MATLAB prompt to compute the frequency response of the fitted model data:

```
[fresp,freq]=freqresp(RationalFunc,Freq);
```

3 Type the following set of commands at the MATLAB prompt to plot the amplitude of the frequency response of the fitted model data and that of the computed data:

```
figure
plot(freq/1e9,db(fresp),freq/1e9,db(TrFunc));
xlabel('Frequency, GHz')
ylabel('Amplitude, dB')
legend('Fitted Model Data','Computed Data')
```

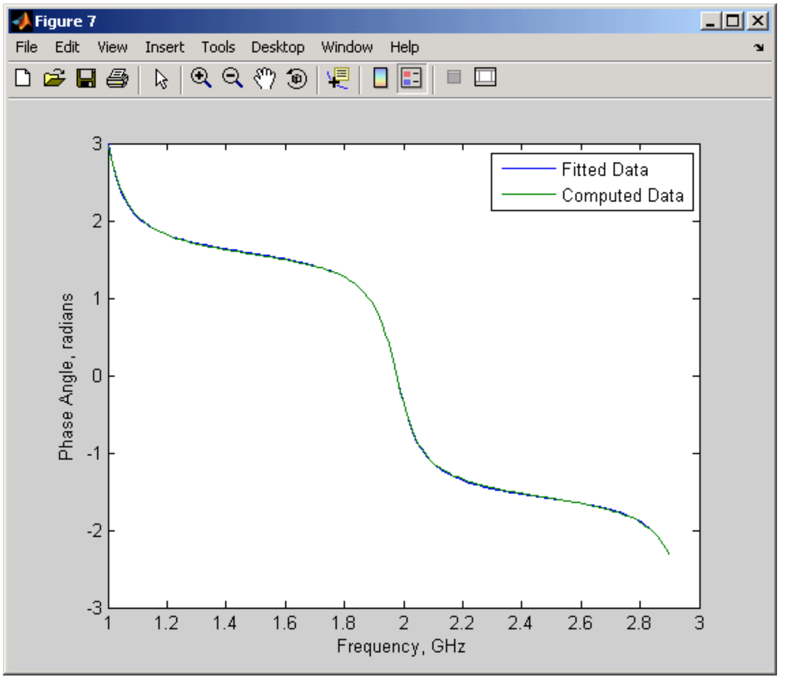
Note The amplitude of the model data is very close to the amplitude of the computed data. You can control the tradeoff between model accuracy and model complexity by specifying the optional tolerance argument, `tol`, to the `rationalfit` function, as described in "Representing a Circuit Object with a Model Object" on page 3-5.



4 Type the following set of commands at the MATLAB prompt to plot the phase angle of the frequency response of the fitted model data and that of the computed data:

```
figure
plot(freq/1e9,unwrap(angle(fresp)),freq/1e9,unwrap(angle(TrFunc)));
xlabel('Frequency, GHz')
ylabel('Phase Angle, radians')
legend('Fitted Data','Computed Data')
```

Note The phase angle of the model data is very close to the phase angle of the computed data.



Computing and Plotting the Impulse Response

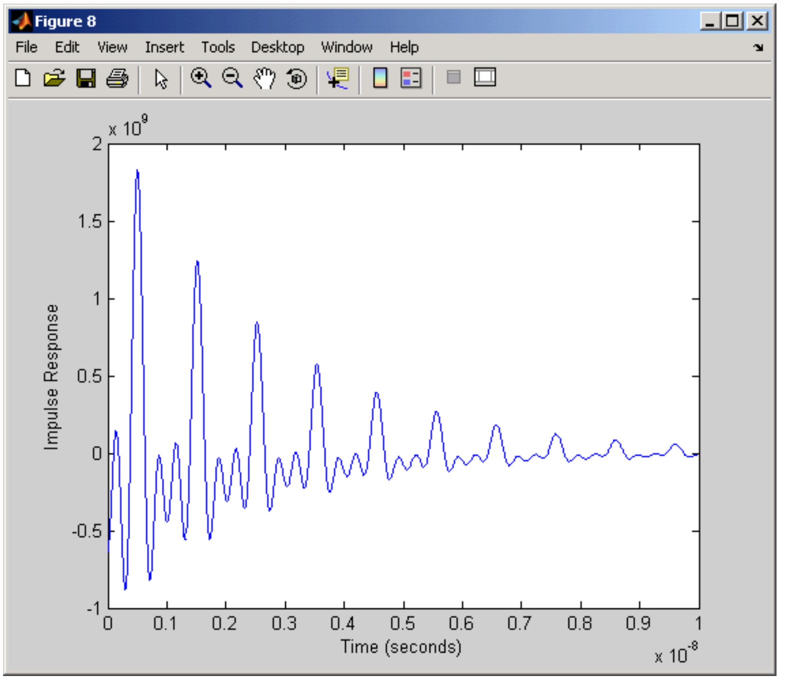
In this part of the example, you compute and plot the impulse response of the transmission line.

1. Type the following set of commands at the MATLAB prompt to compute the impulse response, `iresp`, of the fitted model data at a vector of time samples, `t`, every 1e-12 seconds for 1000 time points:

   ```
   sampletime=1e-12;
   numberofsamples=1e4;
   [iresp,t]=impulse(RationalFunc,sampletime,numberofsamples);
   ```

2. Type the following set of commands at the MATLAB prompt to plot the impulse response of the fitted model data:

   ```
   figure
   plot(t,iresp);
   xlabel('Time (seconds)')
   ylabel('Impulse Response')
   ```



Exporting a Verilog-A Model

In this part of the example, you export a Verilog-A model of the transmission line. You can use this model in other simulation tools for detailed time-domain analysis and system simulations.

The following code illustrates how to use the `writeva` function to write a Verilog-A module for `RationalFunc` to the file `tline.va`. The module has one input, `tline_in`, and one output, `tline_out`. The function returns a `status` of `True`, if the operation is successful, and `False` if it is unsuccessful.

```
status = writeva(RationalFunc,'tline','tline_in','tline_out')
```

For more information on the `writeva` function and its arguments, see the `writeva` reference page. For more information on Verilog-A models, see Chapter 3, "Exporting Verilog-A Models".

Modeling an RF Component

Creating RF Objects

You create an RF object by performing one of the following tasks:

- "Constructing a New Object" on page 2-2
- "Copying an Existing Object" on page 2-3

Constructing a New Object

You can create any `rfdata`, `rfckt` or `rfmodel` object by calling the object constructor. You can create an rfmodel object by fitting a rational function to passive component data.

This section contains the following topics:

- "Calling the Object Constructor" on page 2-2
- "Fitting a Rational Function to Passive Component Data" on page 2-3

Calling the Object Constructor

To create a new RF object, you call the object constructor:

```
h = ObjectConstructorName
```

where `h` is the handle to the new object and `ObjectConstructorName` is the name of the object constructor. This creates an object with default property values.

For a summary the available object constructors, see "RF Objects" on page 1-7.

The following code illustrates how to call the object constructor to create a microstrip transmission line object with default property values. The output `t1` is the handle of the newly created transmission line object.

```
t1 = rfckt.microstrip
```

The RF Toolbox lists the properties of the transmission line you created along with the associated default property values.

```
t1 =
           Name: 'Microstrip Transmission Line'
          nPort: 2
 AnalyzedResult: []
     LineLength: 0.0100
       StubMode: 'None'
    Termination: 'None'
          Width: 6.0000e-004
         Height: 6.3500e-004
      Thickness: 5.0000e-006
       EpsilonR: 9.8000
      SigmaCond: Inf
    LossTangent: 0
```

The `rfckt.microstrip` reference page describes these properties in detail.

Fitting a Rational Function to Passive Component Data

You can create a model object by fitting a rational function to passive component data. You use this approach to create a model object that represents one of the following using a rational function:

- A circuit object that you created and analyzed.
- Data that you imported from a file.

For more information, see "Fitting a Model Object to Circuit Object Data" on page 2-20.

Copying an Existing Object

You can create a new object with the same property values as an existing object by using the `copy` function to copy the existing object. This function is useful if you have an object that is similar to one you want to create.

For example,

```
t2 = copy(t1);
```

creates a new object which has the same property values as the microstrip transmission line object with handle `h`.

You can later change specific property values for this copy. For information on modifying object properties, see "Specifying or Importing Component Data" on page 2-5.

Note The syntax `t2 = t1` copies only the object handle and does not create a new object.

Specifying or Importing Component Data

Object properties specify the behavior of an object. To learn about properties that are specific to a particular type of circuit, data, or model object, see the reference page for that type of object.

Note The `rfckt`, `rfdata`, `rfmodel` and reference pages list the available types of circuit and data objects and provide links to their reference pages.

This section contains the following topics:

Setting Property Values

You can specify object property values when you construct an object or you can modify the property values of an existing object.

This section contains the following topics:

Specifying Property Values at Construction

To set a property when you construct an object, include a comma-separated list of one or more property/value pairs in the argument list of the object construction command. A property/value pair consists of the arguments

```
PropertyName,PropertyValue
```

where

- `PropertyName` is a string specifying the property name. The name is case-insensitive. In addition, you need only type enough letters to uniquely identify the property name. For example, `'st'` is sufficient to refer to the `StubMode` property.
- `PropertyValue` is the value to assign to the property.

Include as many property names in the argument list as there are properties you want to set. Any property values that you do not set retain their default values. The circuit and data object reference pages list the valid values as well as the default value for each property.

This section contains examples of how to perform the following tasks:

- "Constructing Components with Specified Properties" on page 2-6
- "Constructing Networks of Specified Components" on page 2-7

Constructing Components with Specified Properties. The following code creates a coaxial transmission line circuit object to represent a coaxial transmission line that is 0.05 meters long. Notice that the RF Toolbox lists the available properties and their values.

```
t1 = rfckt.coaxial('LineLength',0.05)

t1 =

              Name: 'Coaxial Transmission Line'
             nPort: 2
    AnalyzedResult: []
        LineLength: 0.0500
          StubMode: 'None'
       Termination: 'None'
       OuterRadius: 0.0026
       InnerRadius: 7.2500e-004
               MuR: 1
          EpsilonR: 2.3000
         SigmaCond: Inf
         SigmaDiel: 0
```

Constructing Networks of Specified Components. To combine a set of RF components and existing networks to form an RF network, you create a network object with the `Ckts` property set to an array containing the handles of all the circuit objects in the network.

Suppose you have the following RF components:

```
t1 = rfckt.coaxial('LineLength',0.05);
a1 = rfckt.amplifier;
t2 = rfckt.coaxial('LineLength',0.1);
```

The following code creates a cascaded network of these components:

```
casc_network = rfckt.cascade('Ckts',{t1,a1,t2});
```

Changing Property Values of an Existing Object

There are two ways to change the properties of an existing object:

- Using the `set` command
- Using structure-like assignments called dot notation

This section discusses the first option. For details on the second option, see "Direct Property Referencing Using Dot Notation" on page 2-16.

To modify the properties of an existing object, use the `set` command with one or more property/value pairs in the argument list. The general syntax of the command is

```
set(h,'Property1',value1,'Property2',value2,...)
```

where

- `h` is the handle of the object.
- `'Property1',value1,'Property2',value2,...` is the list of property/value pairs.

For example, the following code creates a default coaxial transmission line object and changes it to a series stub with open termination.

```
t1 = rfckt.coaxial;
set(t1,'StubMode','series','Termination','open')
```

Note You can use the `set` command without specifying any property/value pairs to display a list of all properties you can set for a specific object. This example lists the properties you can set for the coaxial transmission line `t1`:

```
set(t1)

ans =
     LineLength: {}
       StubMode: {}
    Termination: {}
    OuterRadius: {}
    InnerRadius: {}
            MuR: {}
       EpsilonR: {}
      SigmaCond: {}
      SigmaDiel: {}
```

Importing Property Values from Data Files

The RF Toolbox lets you import industry-standard data files and MathWorks AMP files into specific objects. This import capability lets you simulate the behavior of measured components.

You can import the following file formats:

- Industry-standard file formats — Touchstone S2P, Y2P, Z2P, and H2P formats specify the network parameters and noise information for measured and simulated data.

  For more information on Touchstone files, see `www.vhdl.org/pub/ibis/connector/touchstone_spec11.pdf`.

- MathWorks amplifier (AMP) file format — Specifies amplifier network parameters, output power versus input power, noise data and third-order intercept point.

For more information about `.amp` files, see Appendix A, "AMP File Format".

This section contains the following topics:

- "Objects Used to Import Data from a File" on page 2-9
- "How to Import Data Files" on page 2-9

Objects Used to Import Data from a File

One data object and three circuit objects accept data from a file. The following table lists the objects and any corresponding data format each supports.

Object	Description	Supported Format(s)
`rfdata.data`	Data object containing network parameter data, noise figure, and third-order intercept point	Touchstone, AMP
`rfckt.amplifier`	Amplifier	Touchstone, AMP
`rfckt.mixer`	Mixer	Touchstone
`rfckt.datafile`	Generic passive component	Touchstone

How to Import Data Files

Use the RF Toolbox `read` function to import the following properties from data files:

- "Data Object Properties" on page 2-9
- "Circuit Object Properties" on page 2-10

Data Object Properties. To import file data into a data object at construction, use a `read` command of the form:

```
data_obj = read(rfdata_type,'filename');
```

where

- `data_obj` is the handle of the data object.
- *`rfdata_type`* is the type of data object in which to store the data, from the list of objects that accept file data shown in "Objects Used to Import Data from a File" on page 2-9.
- *`filename`* is the name of the file that contains the data.

For example,

```
data_obj = read(rfdata.data,'passive.s2p');
```

reads data from the file `passive.s2p` into an `rfdata.data` object.

You can also import file data into an existing data object. The following commands are equivalent to the previous command:

```
data_obj = rfdata.data;
read(data_obj,'passive.s2p');
```

Circuit Object Properties. To import file data into a circuit object at construction, use a `read` command of the form:

```
circuit_obj = read(rfckt_type,'filename');
```

where `circuit_obj` is the handle of the circuit object, *`rfckt_type`* is the type of circuit object into which to import the data, and *`filename`* is the name of the file that contains the data.

For example,

```
ckt_obj=read(rfckt.amplifier, 'default.amp');
```

imports data from the file `default.amp` into an `rfckt.amplifier` object.

You can also import file data into an existing circuit object. The following commands are equivalent to the previous command:

```
ckt_obj=rfckt.amplifier;
read(ckt_obj, 'default.amp');
```

Using Data Objects to Specify Circuit Properties

To specify a circuit object property using a data object, use the `set` command with the name of the data object as the value in the property/value pair.

For example, suppose you have the following `rfckt.amplifier` and `rfdata.nf` objects:

```
amp = rfckt.amplifier

f = 2.0e9;
nf = 13.3244;

nfdata = rfdata.nf('Freq',f,'Data',nf)
```

The following command uses the `rfdata.nf` data object to specify the `rfckt.amplifier` `NoiseData` property:

```
set(amp,'NoiseData',nfdata)
```

Example — Setting Circuit Object Properties Using Data Objects

In this example, you create a circuit object. Then, you create three data objects and use them to update the properties of the circuit object.

1 **Create an amplifier object.** This circuit object, `rfckt.amplifier`, has a network parameter, noise data, and nonlinear data properties. These properties control the frequency response of the amplifier, which is stored in the `AnalyzedResult` property. By default, all amplifier properties contain values from the `default.amp` file. The `NetworkData` property is an `rfdata.network` object that contains 50-ohm S-parameters. The `NoiseData` property is an `rfdata.noise` object that contains frequency-dependent spot noise data. The `NonlinearData` property is an `rfdata.power` object that contains output power and phase information.

```
amp = rfckt.amplifier
```

The toolbox displays the following output:

```
amp =

              Name: 'Amplifier'
             nPort: 2
    AnalyzedResult: [1x1 rfdata.data]
          IntpType: 'linear'
       NetworkData: [1x1 rfdata.network]
         NoiseData: [1x1 rfdata.noise]
     NonlinearData: [1x1 rfdata.power]
```

2 **Create a data object that stores network data.** Type the following set of commands at the MATLAB prompt to create an `rfdata.network` object that stores the 2-port Y-parameters at 2.08 GHz, 2.10 GHz, and 2.15 GHz. Later in this example, you use this data object to update the `NetworkData` property of the `rfckt.amplifier` object.

```
f = [2.08 2.10 2.15]*1.0e9;
y(:,:,1) = [-.0090-.0104i, .0013+.0018i; -.2947+.2961i, .0252+.0075i];
y(:,:,2) = [-.0086-.0047i, .0014+.0019i; -.3047+.3083i, .0251+.0086i];
y(:,:,3) = [-.0051+.0130i, .0017+.0020i; -.3335+.3861i, .0282+.0110i];

netdata = rfdata.network('Type','Y_PARAMETERS','Freq',f,'Data',y)
```

The toolbox displays the following output:

```
netdata =

    Name: 'Network parameters'
    Type: 'Y_PARAMETERS'
    Freq: [3x1 double]
    Data: [2x2x3 double]
      Z0: 50
```

3 **Create a data object that stores noise figure values.** Type the following set of commands at the MATLAB prompt to create a `rfdata.nf` object that contains noise figure values, in dB, at seven different frequencies. Later in this example, you use this data object to update the `NoiseData` property of the `rfckt.amplifier` object.

```
f = [1.93 2.06 2.08 2.10 2.15 2.30 2.40]*1.0e9;
nf = [12.4521 13.2466 13.6853 14.0612 13.4111 12.9499 13.3244];

nfdata = rfdata.nf('Freq',f,'Data',nf)
```

The toolbox displays the following output:

```
nfdata =

    Name: 'Noise figure'
    Freq: [7x1 double]
    Data: [7x1 double]
```

4 **Create a data object that stores output third-order intercept points.** Type the following command at the MATLAB prompt to create a `rfdata.ip3` object that contains an output third-order intercept point of 8.45 watts, at 2.1 GHz. Later in this example, you use this data object to update the `NonlinearData` property of the `rfckt.amplifier` object.

```
ip3data = rfdata.ip3('Type','OIP3','Freq',2.1e9,'Data',8.45)
```

The toolbox displays the following output:

```
ip3data =

    Name: '3rd order intercept'
    Type: 'OIP3'
    Freq: 2.1000e+009
    Data: 8.4500
```

5 **Update the properties of the amplifier object.** Type the following set of commands at the MATLAB prompt to update the `NetworkData`, `NoiseData`, and `NonlinearData` properties of the amplifier object with the data objects you created in the previous steps:

```
amp.NetworkData = netdata;
amp.NoiseData = nfdata;
amp.NonlinearData = ip3data;
```

Retrieving Property Values

You can retrieve one or more property values of an existing object using the `get` command.

This section contains the following topics:

- "Retrieving Specified Property Values" on page 2-14
- "Retrieving All Property Values" on page 2-15

Retrieving Specified Property Values

To retrieve specific property values for an object, use the `get` command with the following syntax:

```
PropertyValue=get(h,PropertyName)
```

where

- `PropertyValue` is the value assigned to the property.
- `h` is the handle of the object.
- `PropertyName` is a string specifying the property name.

For example, suppose you have the following coaxial transmission line:

```
h2 = rfckt.coaxial;
```

The following code retrieves the value of the inner radius and outer radius for the coaxial transmission line:

```
ir = get(h2,'InnerRadius')
or = get(h2,'OuterRadius')

ir =
  7.2500e-004

or =
    0.0026
```

Retrieving All Property Values

To display a list of properties associated with a specific object as well as their current values, use the `get` command without specifying a property name.

For example:

```
get(h2)
             Name: 'Coaxial Transmission Line'
            nPort: 2
   AnalyzedResult: []
       LineLength: 0.0100
         StubMode: 'None'
      Termination: 'None'
      OuterRadius: 0.0026
      InnerRadius: 7.2500e-004
              MuR: 1
         EpsilonR: 2.3000
        SigmaCond: Inf
        SigmaDiel: 0
```

Note This list includes read-only properties that do not appear when you type `set(h2)`. For a coaxial transmission line object, the read-only properties are `Name`, `nPort`, and `AnalyzedResult`. The `Name` and `nPort` properties are fixed by the RF Toolbox. The `AnalyzedResult` property value is calculated and set by the toolbox when you analyze the component at specified frequencies.

Direct Property Referencing Using Dot Notation

An alternative way to query for or modify property values is by structure-like referencing. The field names for RF objects are the property names, so you can retrieve or modify property values with the structure-like syntax

```
PropertyValue = rfobj.PropertyName % gets property value
rfobj.PropertyName = PropertyValue % sets property value
```

These commands are respectively equivalent to

```
PropertyValue = get(rfobj,'PropertyName')
set(rfobj,'PropertyName',PropertyValue)
```

For example, typing

```
ckt = rfckt.amplifier('IntpType','cubic');
ckt.IntpType
```

gives the value of the property `IntpType` for the circuit object `ckt`.

```
ans =
  cubic
```

Similarly,

```
ckt.IntpType = 'linear';
```

resets the interpolation method to linear.

You do not need to type the entire field name or use uppercase characters. You only need to type the minimum number of characters sufficient to identify the property name uniquely. Thus either of the commands

```
ckt.IntpType
ckt.in
```

produces

```
ans =
  cubic
```

Analyzing and Plotting RF Components

The RF Toolbox provides a variety of functions that act on objects. These functions are also referred to as *methods* because they are methods of the objects. The functions let you perform operations such as

- "Analyzing Networks in the Frequency Domain" on page 2-17
- "Visualizing Component and Network Data" on page 2-18
- "Computing and Plotting Time-Domain Specifications" on page 2-19

For a complete listing of the available functions, listed by category, see Chapter 5, "Functions — By Category".

Analyzing Networks in the Frequency Domain

The RF Toolbox lets you analyze RF components and networks in the frequency domain. You use the `analyze` function to analyze a circuit object over a specified set of frequencies.

For example, to analyze a coaxial transmission line from 1 GHz to 2.9 GHz in increments of 10 MHz:

```
ckt = rfckt.coaxial;
f = [1.0e9:1e7:2.9e9];
analyze(ckt,f);
```

Note For all circuits objects except those that contain data from a file, you must perform a frequency-domain analysis with the `analyze` function before visualizing component and network data. For circuits that contain data from a file, the RF Toolbox performs a frequency-domain analysis when you use the `read` function to import the data.

When you analyze a circuit object, the RF Toolbox computes the circuit network parameters, noise figure values, and output third-order intercept point (OIP3) values at the specified frequencies and stores the result of the analysis in the object's `AnalyzedResult` property.

For more information, see the `analyze` reference page or the circuit object reference page.

Visualizing Component and Network Data

The RF Toolbox provides variety of plots for analyzing the behavior of circuit objects that represent RF components and networks. The following table summarizes the available plots and charts, along with the function you use to create each one and a description of its contents.

Plot Type	Function	Plot Contents
X-Y Plane (Rectangular) Plot	`plot`	Parameters as a function of frequency, such as: • S-parameters • Noise figure • Voltage standing-wave ratio (VSWR) • OIP3
Budget Plot (3-D)	`plot`	Parameters as a function of frequency for each component in a cascade, where the curve for a given component represents the cumulative contribution of each RF component up to and including the parameter value of that component.

Plot Type	Function	Plot Contents
Polar Plot	polar	Magnitude and phase of S-parameters as a function of frequency.
Smith Chart	smith	Real and imaginary parts of S-parameters as a function of frequency, used for analyzing the reflections caused by impedance mismatch.

For each plot you create, you choose a parameter to plot and a format in which to plot the parameter. The plot format defines how the RF Toolbox displays the data on the plot. The available formats vary with the data you select to plot. The data you can plot depends on the type of plot you create.

Note You can use the `listparam` function to list the parameters of a specified circuit object that are available for plotting.

You can use the `listformat` function to list the available formats for a specified circuit object parameter.

For example, to plot the S11 parameter of the coaxial transmission line from the previous example on a rectangular plot:

```
plot(ckt,'S11')
```

See the individual function reference pages for more information on plotting circuit object data.

Computing and Plotting Time-Domain Specifications

The RF Toolbox lets you compute and plot time-domain characteristics for RF components.

This section contains the following topics:

Computing the Network Transfer Function

You use the `s2tf` function to convert two-port S-parameters to a transfer function. The function returns a vector of transfer function values that represent the normalized voltage gain of a two-port network.

The following code illustrates how to read file data into a passive circuit object, extract the two-port S-parameters from the object and compute the transfer function of the data at the frequencies for which the data is specified. `z0` is the reference impedance of the S-parameters, `zs` is the source impedance, and `zl` is the load impedance. See the `s2tf` reference page for more information on how these impedances are used to define the gain.

```
PassiveCkt = rfckt.passive('File','passive.s2p')
z0=50; zs=50; zl=50;
[SParams, Freq] = extract(PassiveCkt, 'S Parameters', z0);
TransFunc = s2tf(SParams, z0, zs, zl);
```

Fitting a Model Object to Circuit Object Data

You use the `rationalfit` function to fit a rational function to the transfer function of a passive component. The `rationalfit` function returns an `rfmodel` object that represents the transfer function analytically.

The following code illustrates how to use the `rationalfit` function to create an `rfmodel.rational` object that contains a rational function model of the transfer function that you created in the previous example.

```
RationalFunc = rationalfit(Freq, TransFunc)
```

To find out how many poles the RF Toolbox used to represent the data, look at the length of the `A` vector of the `RationalFunc` model object.

```
nPoles = length(RationalFunc.A)
```

Note The number of poles is important if you plan to use the RF model object to create a model for use in another simulator, because a large number of poles can increase simulation time. For information on how to represent a component accurately using a minimum number of poles, see "Representing a Circuit Object with a Model Object" on page 3-5.

See the `rationalfit` reference page for more information.

Use the `freqresp` function to compute the frequency response of the fitted data. To validate the model fit, plot the transfer function of the original data and the frequency response of the fitted data.

```
Resp = freqresp(RationalFunc, Freq);
plot(Freq, 20*log10(abs(TransFunc)), 'r', ...
    Freq, 20*log10(abs(Resp)), 'b--');
ylabel('Magnitude of H(s) (decibels)');
xlabel('Frequency (Hz)');
legend('Original', 'Fitting result');
title(['Rational fitting with ', int2str(nPoles), ' poles']);
```

Computing and Plotting the Impulse Response

You use the `impulse` function to compute the impulse response of the transfer function that `RationalFunc` represents.

The following code illustrates how to compute and plot the impulse response of `RationalFunc` at a vector of time samples, `Time`, every 1e-11 seconds for 4750 time points.

```
SampleTime = 1e-11;
TotalSamples = 4750;
StopTime = SampleTime*(TotalSamples-1);
[ImpResp, Time] = impulse(RationalFunc, SampleTime, TotalSamples);
plot(Time*1e9,ImpResp);
title('Fitting Impulse Response', 'fonts', 12);
ylabel('Impulse Response');
xlabel('Time (ns)');
```

For more information about computing the impulse response of a model object, see the `impulse` reference page.

Examples of Basic Operations with RF Objects

These examples show you how to perform some basic operations with RF objects:

- "Reading and Analyzing RF Data from a Touchstone Data File" on page 2-23
- "De-Embedding S-Parameters" on page 2-25
- "Impedance Matching" on page 2-30

Reading and Analyzing RF Data from a Touchstone Data File

In this example, you create an `rfdata.data` object by reading the S-parameters of a 2-port passive network stored in the Touchstone format data file, `passive.s2p`.

1. **Read S-parameter data from a data file.** Use the RF Toolbox `read` command to read the Touchstone data file, `passive.s2p`. This file contains 50-ohm S-parameters at frequencies ranging from 315 kHz to 6 GHz. The `read` command creates an `rfdata.data` object, `data`, and stores data from the file in the object's properties.

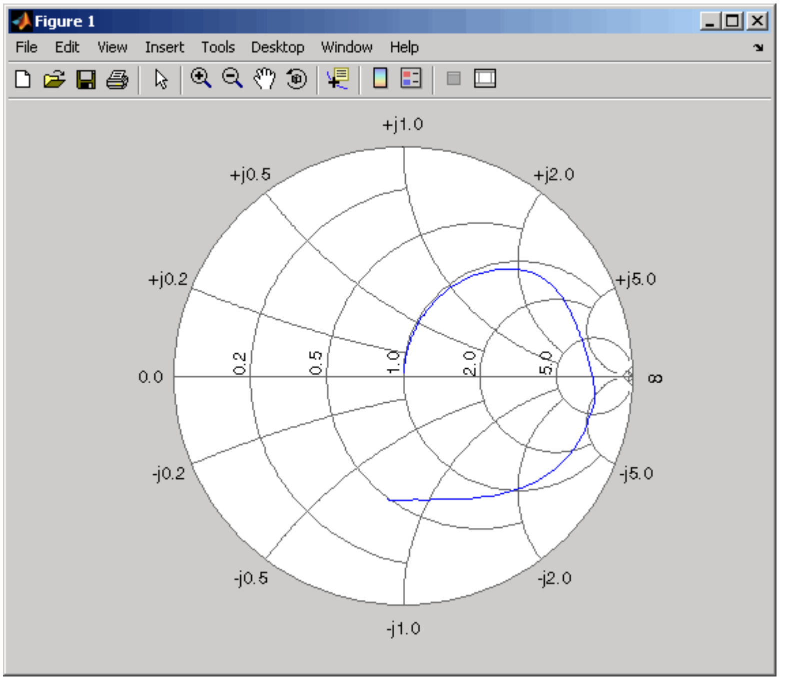
```
data = read(rfdata.data,'passive.s2p');
```

2. **Extract the network parameters from the data object.** Use the `extract` command to convert the 50-ohm S-parameters in the `rfdata.data` object, `data`, to 75-ohm S-parameters and save them in the variable `s_params`. You also use the command to extract the Y-parameters from the `rfdata.data` object and save them in the variable `y_params`.

```
freq = data.Freq;
s_params = extract(data,'S_PARAMETERS',75);
y_params = extract(data,'Y_PARAMETERS');
```

3 Plot the S11 parameters. Use the `smithchart` command to plot the 75-ohm S11 parameters on a Smith chart:

```
s11 = s_params(1,1,:);
smithchart(s11(:));
```



4 View the 75-ohm S-parameters and Y-parameters at 6 GHz. Type the following set of commands at the MATLAB prompt to display the four 75-ohm S-parameter values and the four Y-parameter values at 6 GHz.

```
f = freq(end)
s = s_params(:,:,end)
y = y_params(:,:,end)
```

The toolbox displays the following output:

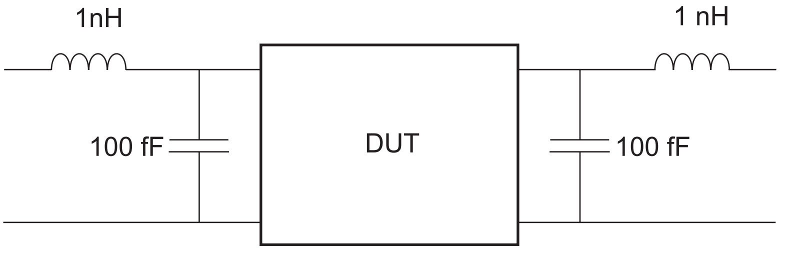
```
f =
  6.0000e+009

s =
  -0.0764 - 0.5401i   0.6087 - 0.3018i
   0.6094 - 0.3020i  -0.1211 - 0.5223i

y =
   0.0210 + 0.0252i  -0.0215 - 0.0184i
  -0.0215 - 0.0185i   0.0224 + 0.0266i
```

For more information, see the `rfdata.data`, `read`, and `extract` reference pages.

De-Embedding S-Parameters

The Touchstone data file `samplebjt2.s2p` contains S-parameter data collected from a bipolar transistor in a test fixture. The input of the fixture has a bond wire connected to a bond pad. The output of the fixture has a bond pad connected to a bond wire.

The configuration of the bipolar transistor, which is the device under test (DUT), and the fixture is shown in the following figure.



In this example, you remove the effects of the fixture and extract the S-parameters of the DUT.

1 **Create RF objects.** Create a data object for the measured S-parameters by reading the Touchstone data file samplebjt2.s2p. Then, create two more circuit objects, one each for the input pad and output pad.

```
measured_data = read(rfdata.data,'samplebjt2.s2p');
input_pad = rfckt.cascade('Ckts',...
      {rfckt.seriesrlc('L',1e-9), ...
      rfckt.shuntrlc('C',100e-15)});    % L=1 nH, C=100 fF
output_pad = rfckt.cascade('Ckts',...
      {rfckt.shuntrlc('C',100e-15),...
      rfckt.seriesrlc('L',1e-9)});     % L=1 nH, C=100 fF
```

2 **Analyze the input pad and output pad circuit objects.** Analyze the circuit objects at the frequencies at which the S-parameters are measured.

```
freq = measured_data.Freq;
analyze(input_pad,freq);
analyze(output_pad,freq);
```

3 **De-embed the S-parameters.** Extract the S-parameters of the DUT from the measured S-parameters by removing the effects of the input and output pads.

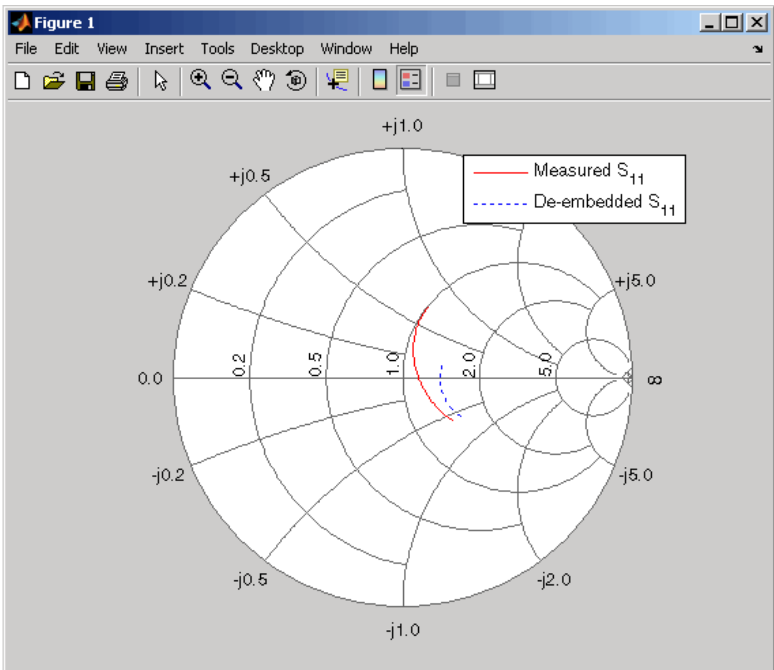
```
z0 = measured_data.Z0;

input_pad_sparams = extract(input_pad.AnalyzedResult,...
'S_Parameters',z0);
output_pad_sparams = extract(output_pad.AnalyzedResult,...
'S_Parameters',z0);

de_embedded_sparams =
deembedsparams(measured_data.S_Parameters,...
                      input_pad_sparams, output_pad_sparams);
```

4 **Create a data object for the de-embedded S-parameters.** In a later step, you use this data object to plot the de-embedded S-parameters.

```
de_embedded_data = rfdata.data('Z0',z0,...
                  'S_Parameters',de_embedded_sparams,...
                  'Freq',freq);
```

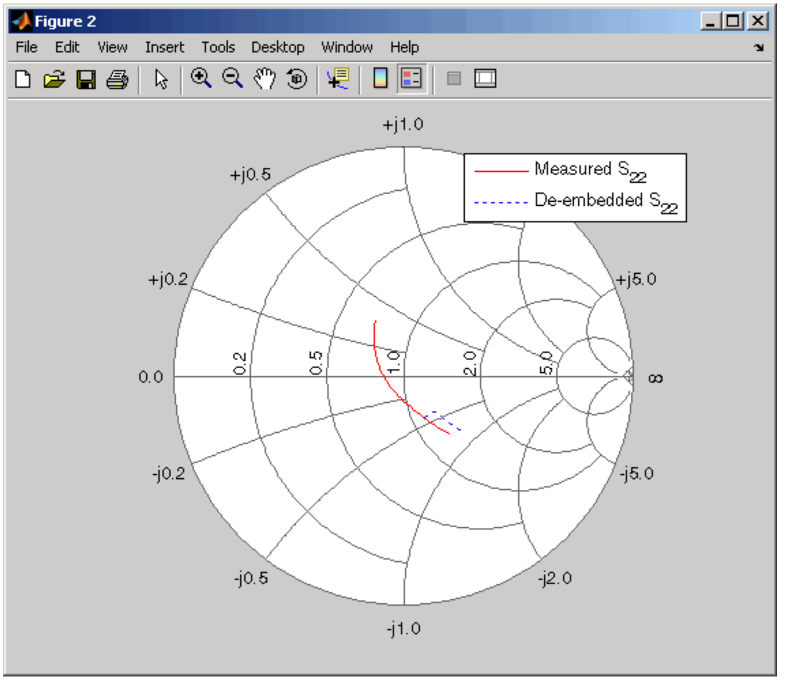
5 Plot the measured and de-embedded S11 parameters. Type the following set of commands at the MATLAB prompt to plot both the measured and the de-embedded S11 parameters on a Z Smith chart:

```
hold off;
h = smith(measured_data,'S11');
set(h, 'Color', [1 0 0]);
hold on
i = smith(de_embedded_data,'S11');
set(i,'Color', [0 0 1],'LineStyle',':');
l = legend;
legend(l, {'Measured S_{11}', 'De-embedded S_{11}'});
legend show;
```



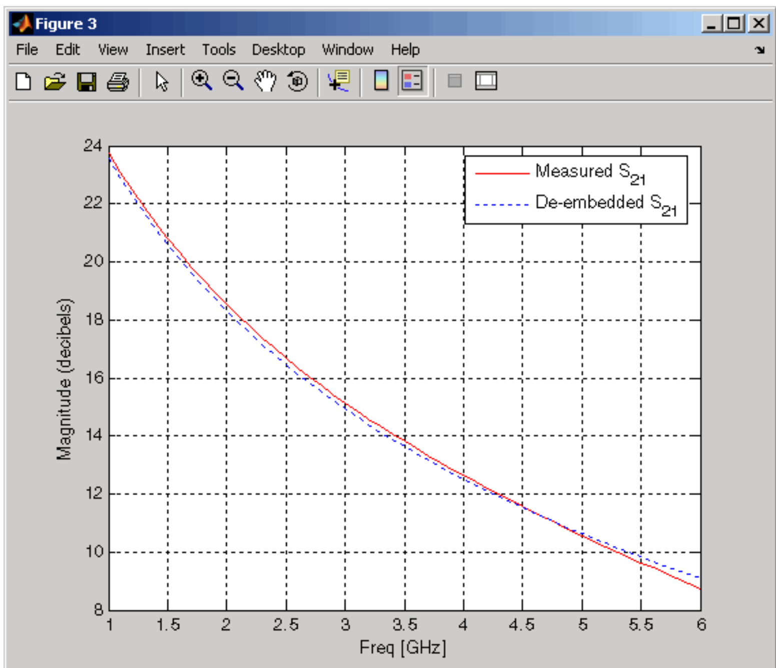
6 Plot the measured and de-embedded S22 parameters. Type the following set of commands at the MATLAB prompt to plot the measured and the de-embedded S22 parameters on a Z Smith chart:

```
figure;
hold off;
h = smith(measured_data,'S22');
set(h, 'Color', [1 0 0]);
hold on
i = smith(de_embedded_data,'S22');
set(i,'Color', [0 0 1],'LineStyle',':');
l = legend;
legend(l, {'Measured S_{22}', 'De-embedded S_{22}'});
legend show;
```



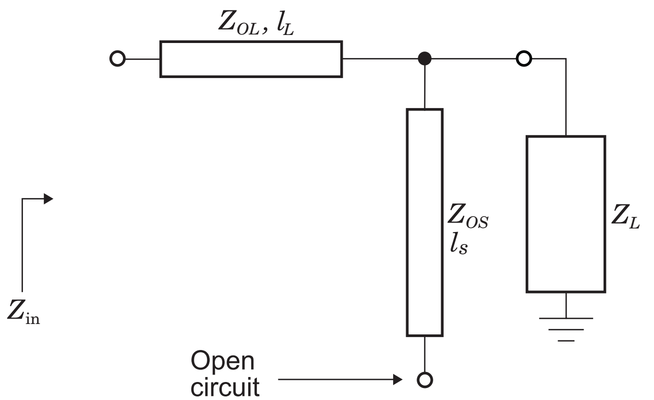
7 Plot the measured and de-embedded S21 parameters. Type the following set of commands at the MATLAB prompt to plot the measured and the de-embedded S21 parameters, in decibels, on an X-Y plane:

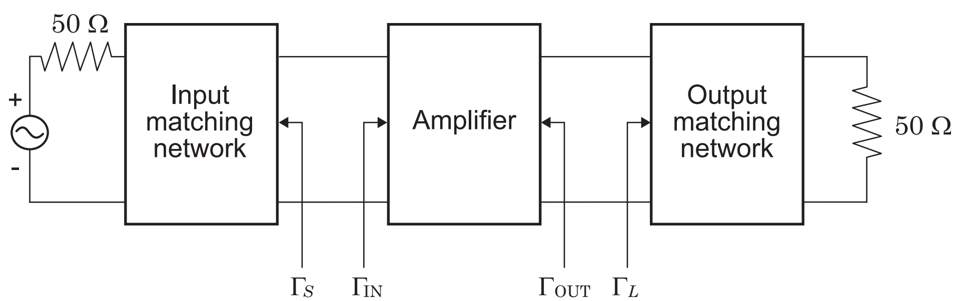
```
figure
hold off;
h = plot(measured_data,'S21', 'db');
set(h, 'Color', [1 0 0]);
hold on
i = plot(de_embedded_data,'S21','db');
set(i,'Color', [0 0 1],'LineStyle',':');
l = legend;
legend(l, {'Measured S_{21}', 'De-embedded S_{21}'});
legend show;
hold off;
```

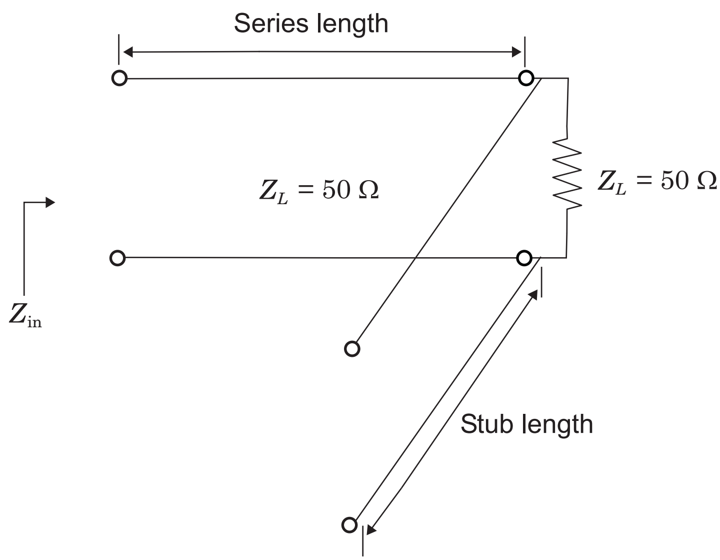


Impedance Matching

Input and output matching networks are an important part of amplifier design. In this example, you use a Smith chart to find the input and output matching networks that maximize the power delivered to a 50-ohm load. The single-stub network topology that consists of a series transmission line connected to a parallel combination of load and stub is shown in the following figure.







You begin by finding the required transmission line lengths for the single-stub matching networks. Then, you cascade the matching networks with the amplifier and visualize the results.

1 **Create an amplifier object.** Create an amplifier object from the data in the file `samplebjt2.s2p`. Then, analyze the amplifier at the center frequency of 1.9 GHz and get its S-parameters. For later convenience, use the `deal` function to deal the various S-parameters into separate variables.

```
amp = rfckt.amplifier;
read(amp, 'samplebjt2.s2p');
analyze(amp, 1.9e9);
data = calculate(amp,'S11','S12','S21','S22','none');

[s11,s12,s21,s22] = deal(data{1},data{2},data{3},data{4});
```

2 **Check for amplifier stability.** For unconditional stability, K must be greater than 1 and the absolute value of delta must be less than 1. Use the following code to verify that the amplifier is stable:

```
delta = s11*s22-s12*s21;
K = (1-abs(s11)^2-abs(s22)^2+abs(delta)^2)/(2*abs(s12*s21))
```

```
abs_delta = abs(delta)
```

The toolbox displays the following output:

```
K =

    1.0599

abs_delta =

    0.6776
```

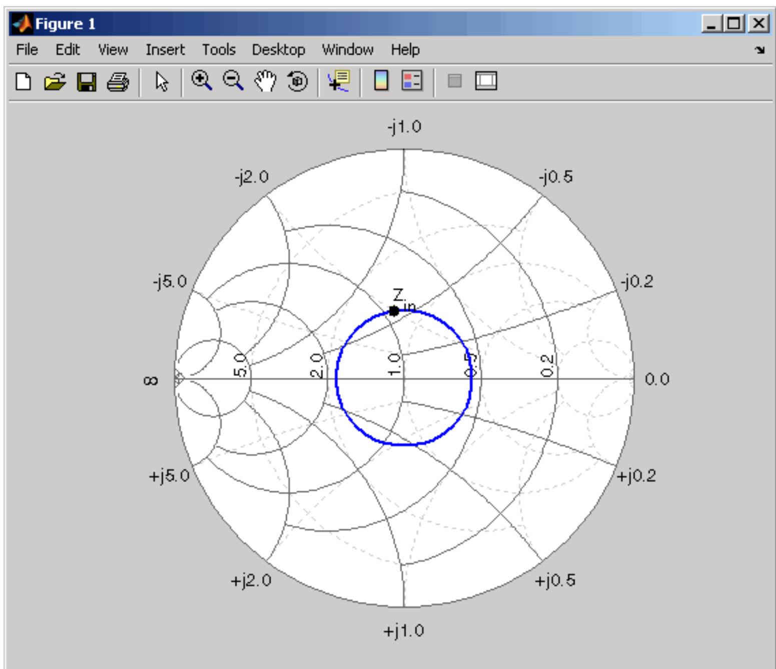
3 **Find the source and load reflection coefficients.** To design input and output matching networks, you must calculate the required source and load reflection coefficients that produce a simultaneous conjugate match. You can calculate the load reflection coefficient, `gammaL`, using the amplifier S-parameters.

```
B = 1+abs(s22)^2-abs(s11)^2-abs(delta)^2;
C = s22-delta*conj(s11);
gammaL = (B-sqrt(B^2-4*abs(C)^2))/2/C;
```

4 **Define the input standing wave ratio (SWR) circle associated with the load reflection coefficient.** The radius of this circle is given by the magnitude of the load reflection coefficient. You can use this radius (center is the origin) to calculate points on the SWR circle. Then, you plot the

desired input impedance point and the input SWR circle on a ZY Smith chart.

```
theta = 0:pi/50:2*pi;
xin = abs(gammaL)*cos(theta);
yin = abs(gammaL)*sin(theta);

[hls, hs] = smithchart;
set(hs,'Type','yz');
hold on
plot(xin,yin,'-',real(gammaL),imag(gammaL),'k.',...
    'LineWidth',2,'MarkerSize',20);
text(-0.05, 0.35, 'z_{in}',...
    'FontSize',12,'FontUnits','normalized');
```



5 Draw the constant conductance circle. To find the required susceptance to move the 50-ohm load admittance to the SWR circle, you must define the constant conductance circle. To define the circle, you calculate the normalized load impedance and the corresponding 50-ohm load admittance for the transmission lines.

```
zL = 50/50; %zL = 1
yL = 1/zL; %yL = 1
```

Next, you calculate the diameter and center of the circle using the conductance value.

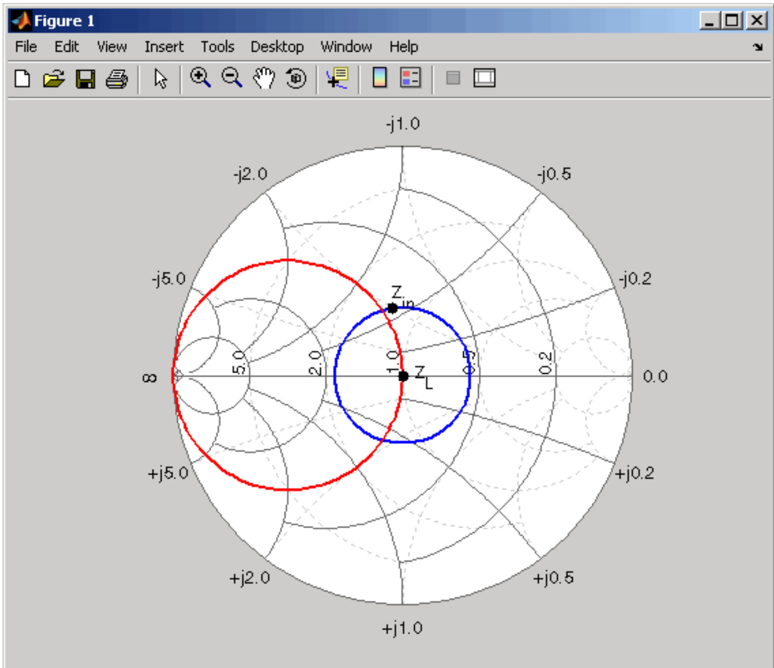
```
g  = real(yL); %g=1
d = -(g-1)/(g+1)+1; %d=1
C = -1+d/2; %C= 1/2
```

Then, you use the radius and center of the constant conductance circle to calculate points on the circle.

```
xg = d/2*cos(theta)+C;
yg = d/2*sin(theta);
```

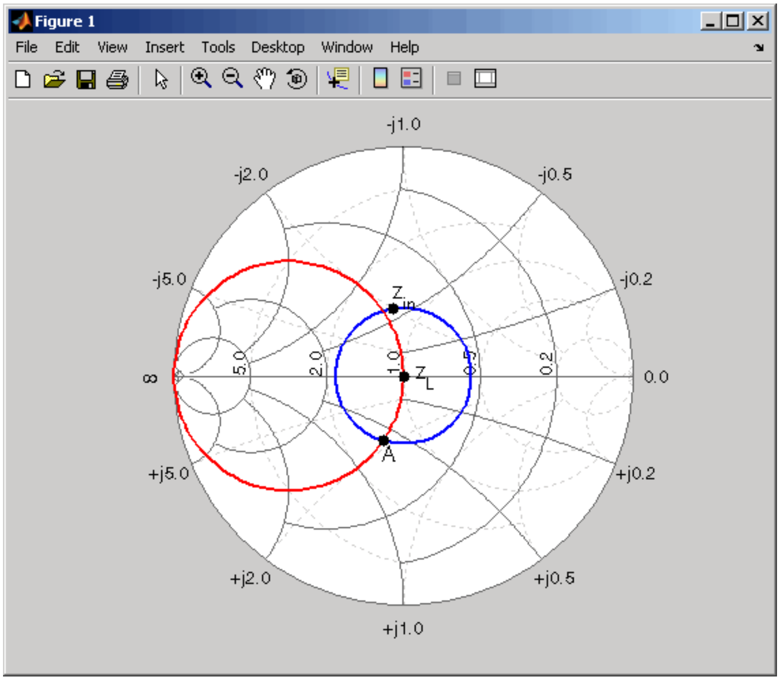
Finally, you plot and label the load impedance point along with the constant conductance circle associated with the load admittance on the Smith chart.

```
plot(xg, yg,'r',0,0,'k.','LineWidth',2,'MarkerSize',20);
text(0.05,0,'z_L','FontSize',12,'FontUnits','normalized');
```



6 Find the intersection points. After you draw the input SWR and constant conductance circles, you can find the points of intersection that correspond to the two possible solutions. Because only one solution is necessary, choose the lower-half intersection point, and designate this as the solution point A. Use the following code to plot and label this intersection point on the Smith chart using the reflection coefficient calculated from the admittance value:

```
yA = 1+0.62j;
gammaA = (1/yA-1)/(1/yA+1);
plot(real(gammaA),imag(gammaA),'k.','MarkerSize',20);
text(-0.09,-0.35,'A','FontSize',12,'FontUnits','normalized');
hold off
```



7 Calculate the required lengths. Based on the intersection point A, you can find the required lengths of the series transmission line and open-circuit stub. To find these lengths, first calculate the required susceptance value for the stub and its corresponding reflection coefficient.

```
jbSA = yA-yL;
gammaSA = (1/jbSA-1)/(1/jbSA+1);
```

Next, you can find the stub length by calculating the angle of rotation from the `y = 0` (open-circuit) point to the calculated susceptance point.

```
ang = -angle(gammaSA)*180/pi;
stubLengthA = ang/360/2
```

Finally, you find the required length of the series transmission line based on the angle of rotation from point `A` to `Zin`.

```
seriesAngleA = 360-(angle(gammaL)-angle(gammaA))*180/pi;
seriesLengthA = seriesAngleA/360/2
```

The toolbox displays the following output, which represents the required lengths (in terms of wavelength) for the transmission lines based on the intersection point A.

```
stubLengthA =
    0.0883

seriesLengthA =
    0.2147
```

Using a similar approach, you can verify that the line lengths for the input matching network are

```
stubLengthin = 0.0763;
seriesLengthin = 0.2266;
```

8 **Verify the design.** Build the circuit using microstrip transmission lines, with a characteristic impedance of 50 ohms, for the matching networks. To build the circuit, analyze a microstrip object at 1.9 GHz.

```
hstubOutput = rfckt.microstrip;
analyze(hstubOutput,1.9e9);
Z0 = get(hstubOutput,'z0')
```

The toolbox displays the following output:

```
Z0 =
   50.2561
```

Because this characteristic impedance is close to the desired impedance, you can use it for the design.

To appropriately set the required transmission line lengths in meters, you must analyze the microstrip to get a phase velocity value, which is necessary to calculate the wavelength.

```
phase_vel = get(hstubOutput,'PV');
```

Set the appropriate transmission line lengths for the two series microstrip transmission lines necessary for the input and output matching networks.

```
hseriesOutput = rfckt.microstrip(...
    'LineLength',phase_vel/1.9e9*seriesLengthA);
hseriesInput = rfckt.microstrip(...
    'LineLength',phase_vel/1.9e9*seriesLengthin);
```

Similarly, set the transmission line lengths and the stub mode for the two stubs necessary for the input and output matching networks.

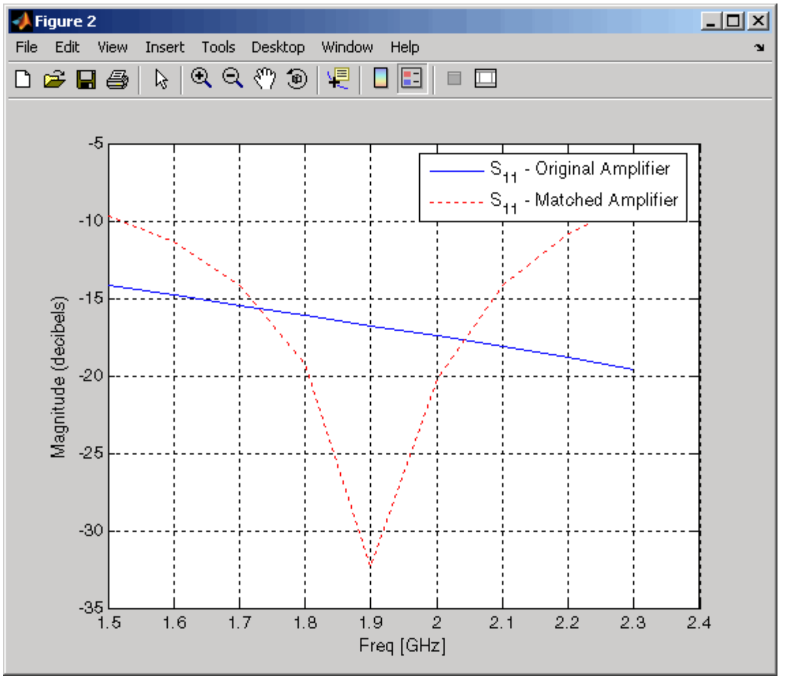
```
set(hstubOutput,'LineLength',phase_vel/1.9e9*stubLengthA,...
    'StubMode','shunt','Termination','open');
hstubInput = rfckt.microstrip(...
    'LineLength',phase_vel/2.1e9*stubLengthin,...
    'StubMode','shunt','Termination','open');
```

Then, cascade the circuit elements and analyze the amplifier with and without the matching networks over the frequency range of 1.5 to 2.3 GHz to visualize and compare the results.

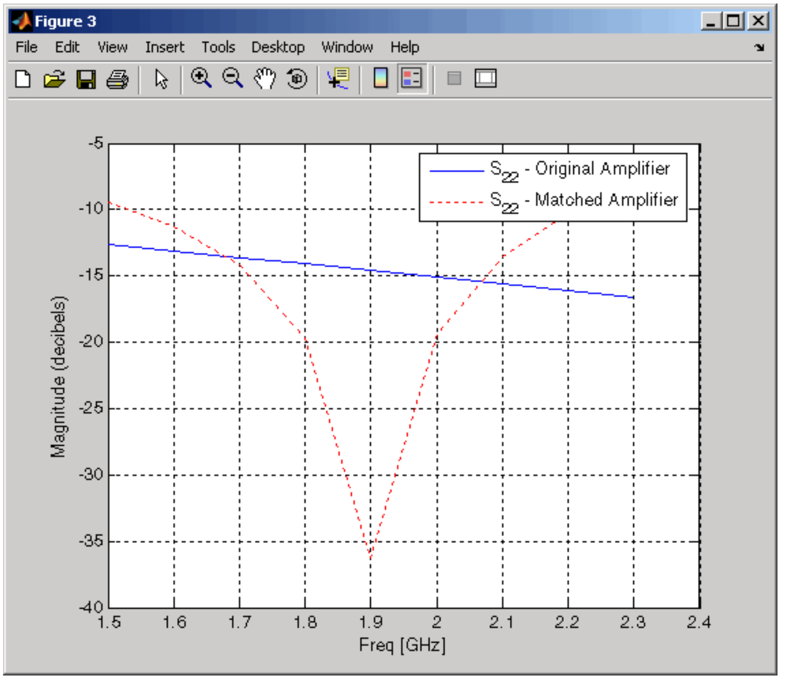
```
matched_amp = rfckt.cascade('Ckts',...
    {hstubInput,hseriesInput,amp,hseriesOutput,hstubOutput});
analyze(matched_amp,1.5e9:1e8:2.3e9);
analyze(amp,1.5e9:1e8:2.3e9);
```

To verify the simultaneous conjugate match at the input and output of the amplifier, plot S11 parameters and S22 parameters, in decibels, for both circuits:

```
figure
hls = zeros(1,2);
hls(1) = plot(amp,'S11','dB');
hold on;
hls(2) = plot(matched_amp,'S11','dB');
set(hls(2),'Color',[1 0 0],'LineStyle',':');
legend(hls,'S_{11} - Original Amplifier',...
    'S_{11} - Matched Amplifier');
```

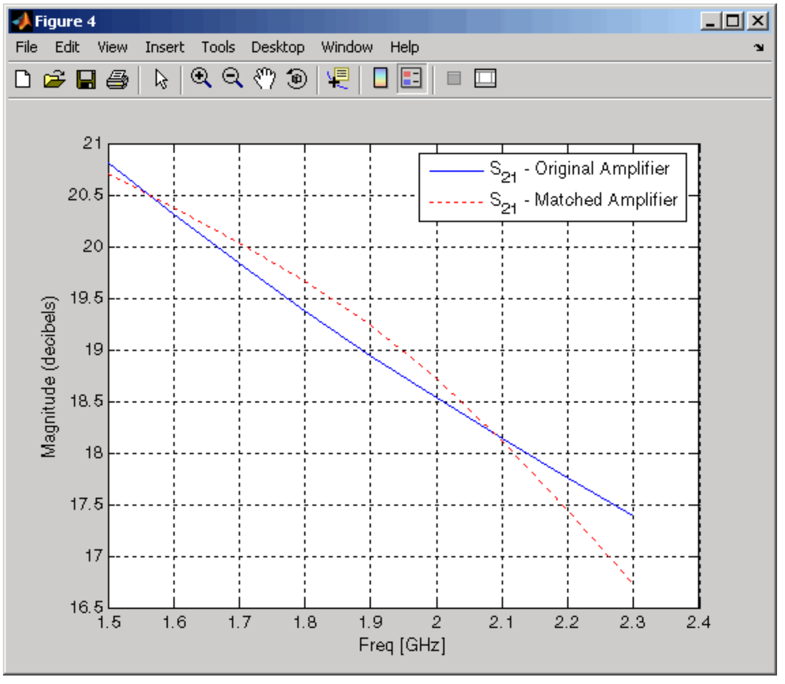


```
figure
hls(1) = plot(amp,'S22','dB');
hold on;
hls(2) = plot(matched_amp,'S22','dB');
set(hls(2),'Color',[1 0 0],'LineStyle',':');
legend(hls,'S_{22} - Original Amplifier',...
     'S_{22} - Matched Amplifier');
```



Finally, plot S21 parameters for both circuits:

```
figure
hls(1) = plot(amp,'S21','dB');
hold on;
hls(2) = plot(matched_amp,'S21','dB');
set(hls(2),'Color',[1 0 0],'LineStyle',':');
legend(hls,'S_{21} - Original Amplifier',...
     'S_{21} - Matched Amplifier');
hold off;
```



You can compare the matched amplifier results with the expected transducer gain (in dB). From the S21 parameters plot, you can see that the gain of the matched amplifier at 1.9 GHz is between 19 dB and 19.5 dB. The expected gain is given by the following equation:

```
Gt = 10*log10(abs(s21)/abs(s12)*(K-sqrt(K^2-1)))
```

The toolbox displays the following output:

```
Gt =
    19.2407
```

Thus, the matched amplifier's gain is very close to the expected transducer gain.

Exporting Verilog-A Models

Modeling RF Objects Using Verilog-A

Verilog-A is a language for modeling the high-level behavior of analog components and networks. Verilog-A describes components mathematically, for fast and accurate simulation.

The RF Toolbox lets you export a Verilog-A description of your circuit. You can create a Verilog-A model of any passive RF component or network and use it as a behavioral model for transient analysis in a third-party circuit simulator. This capability is useful in signal integrity engineering. For example, you can import the measured four-port S-parameters of a backplane into the RF Toolbox, export a Verilog-A model of the backplane to a circuit simulator, and use the model to determine the performance of your driver and receiver circuitry when they are communicating across the backplane.

This section contains the following topics:

Behavioral Modeling Using Verilog-A

The Verilog-A language is a high-level language that uses modules to describe the structure and behavior of analog systems and their components. A *module* is a programming building block that forms an executable specification of the system.

Verilog-A uses modules to capture high-level analog behavior of components and systems. Modules describe circuit behavior in terms of

- Input and output nets characterized by predefined Verilog-A disciplines that describe the attributes of the nets.
- Equations and module parameters that define the relationship between the input and output nets mathematically.

When you create a Verilog-A model of your circuit, the RF Toolbox writes a Verilog-A module that specifies circuit's input and output nets and the mathematical equations that describe how the circuit operates on the input to produce the output.

For more information on the Verilog-A language, see the Verilog-A Reference Manual.

Supported Verilog-A Models

The RF Toolbox lets you export a Verilog-A model of an `rfmodel` object. The RF Toolbox provides one `rfmodel` object, `rfmodel.rational`, that you can use to represent any RF component or network for export to Verilog-A.

The `rfmodel.rational` object represents components as rational functions in pole-residue form, as described in the `rfmodel.rational` reference page. This representation can include complex poles and residues, which occur in complex-conjugate pairs.

The RF Toolbox implements each `rfmodel.rational` object as a series of Laplace Transform S-domain filters in Verilog-A using the numerator-denominator form of the Laplace transform filter:

$$H(s) = \frac{\sum_{k=0}^{M} n_k s^k}{\sum_{k=0}^{N} d_k s^k}$$

where

- M is the order of the numerator polynomial.
- N is the order of the denominator polynomial.
- n_k is the coefficient of the k^{th} power of s in the numerator.
- d_k is the coefficient of the k^{th} power of s in the denominator.

The number of poles in the rational function is related to the number of Laplace transform filters in the Verilog-A module. However, there is not a one-to-one correspondence between the two. The difference arises because the RF Toolbox combines each pair of complex-conjugate poles and the corresponding residues in the rational function to form a Laplace transform numerator and denominator with real coefficients. The RF Toolbox converts the real poles of the rational function directly to a Laplace transform filter in numerator-denominator form.

How to Export a Verilog-A Model

To export a Verilog-A model of a component, you perform the following tasks:

- "Representing a Circuit Object with a Model Object" on page 3-5
- "Writing a Verilog-A Module" on page 3-7

An example of this export process appears in the RF Toolbox demo, "Modeling a High-Speed Backplane (Part 2: Rational Function Model to a Verilog-A Module".

Representing a Circuit Object with a Model Object

Before you can write a Verilog-A model of an RF circuit object, you need to create an `rfmodel.rational` object to represent the component.

There are two ways to create an RF model object:

- You can fit a rational function model to the component data using the `rationalfit` function.
- You can use the `rfmodel.rational` constructor to specify the pole-residue representation of the component directly.

This section discusses using a rational function model. For more information on using the constructor, see the `rfmodel.rational` reference page.

When you use the `rationalfit` function to create an `rfmodel.rational` object that represents an RF component, the arguments you specify affect how quickly the resulting Verilog-A model runs in a circuit simulator.

You can use the `rationalfit` function with only the two required arguments. The syntax is:

```
model_obj = rationalfit(freq,data)
```

where

- `model_obj` is a handle to the rational function model object.
- `data` is a vector that contains the data to fit.

- freq is a vector of frequency values that correspond to the data values.

For faster simulation, create a model object with the smallest number of poles required to accurately represent the component. Use the following arguments, which are described in detail in the rationalfit function reference page, to control the number of poles:

- delayfactor — controls the amount of delay used to fit the data. Specify a value that reflects the amount of delay in your data. Delay introduces a phase shift in the frequency domain that may require a large number of poles to fit using a rational function model. When you specify the delayfactor, the rationalfit function represents the delay as an exponential phase shift. This phase shift allows the function to fit the data using fewer poles.
- tol — the relative error-fitting tolerance, in decibels. Specify the largest acceptable tolerance for your application. Using tighter tolerance values may force the rationalfit function to add more poles to the model to achieve a better fit.

The syntax is:

```
model_obj = rationalfit(freq,data,tol,weight,delayfactor)
```

where weight is a vector that specifies the weighting of the fit at each frequency.

Note You can also specify the number of poles directly using the npoles argument. The model accuracy is not guaranteed with approach, so you should not specify npoles when accuracy is critical. For more information on the npoles argument, see the rationalfit reference page.

If you plan to integrate the Verilog-A module into a large design for simulation using detailed models, such as transistor-level circuit models, the simulation time consumed by a Verilog-A module may have a trivial impact on the overall simulation time. In this case, there is no reason to take the time to optimize the rational function model of the component.

For more information on the rationalfit function arguments, see the rationalfit reference page.

Writing a Verilog-A Module

You use the writeva function to create a Verilog-A module that describes the RF model object. This function writes the module to a specified file.

The following code illustrates how to write a Verilog-A module for the model object model_obj to the file obj1.va. The module has differential input nets, inp and inn, and differential output nets, outp and outn. The function returns a status of True if the operation is successful and False otherwise.

```
status = writeva(model_obj,'obj1',{'inp','inn'},{'outp','outn'})
```

The writeva reference page describes the function arguments in detail.

RF Tool: An RF Analysis GUI

Introduction to RF Tool

RF Tool is a GUI that provides a visual interface for creating and analyzing RF components and networks. You can use RF Tool as a convenient alternative to the command-line RF circuit design and analysis functions that come with the RF Toolbox.

RF Tool provides the ability to

- Create and import circuits.
- Set circuit parameters.
- Analyze circuits.
- Display circuit S-parameters in tabular form and on X-Y plots, polar plots, and Smith charts.
- Export circuit data to the MATLAB workspace and to data files.

This section contains the following topics:

Opening RF Tool

To open RF Tool, type the following at the MATLAB prompt:

```
rftool
```

For a description of the RF Tool GUI, see “RF Tool Window” on page 4-3. To learn how to create and import circuits, see “Creating and Importing Circuits” on page 4-6.

Note The work you do with this tool is organized into sessions. Each session is a collection of independent RF circuits, which can be RF components or RF networks. You can save sessions and then load them for later use. For more information, see "Working with Sessions" on page 4-27.

RF Tool Window

The RF Tool window consists of the following three panes:

- **RF Component List**

  Shows the components and networks in the session. The top-level node is the session.

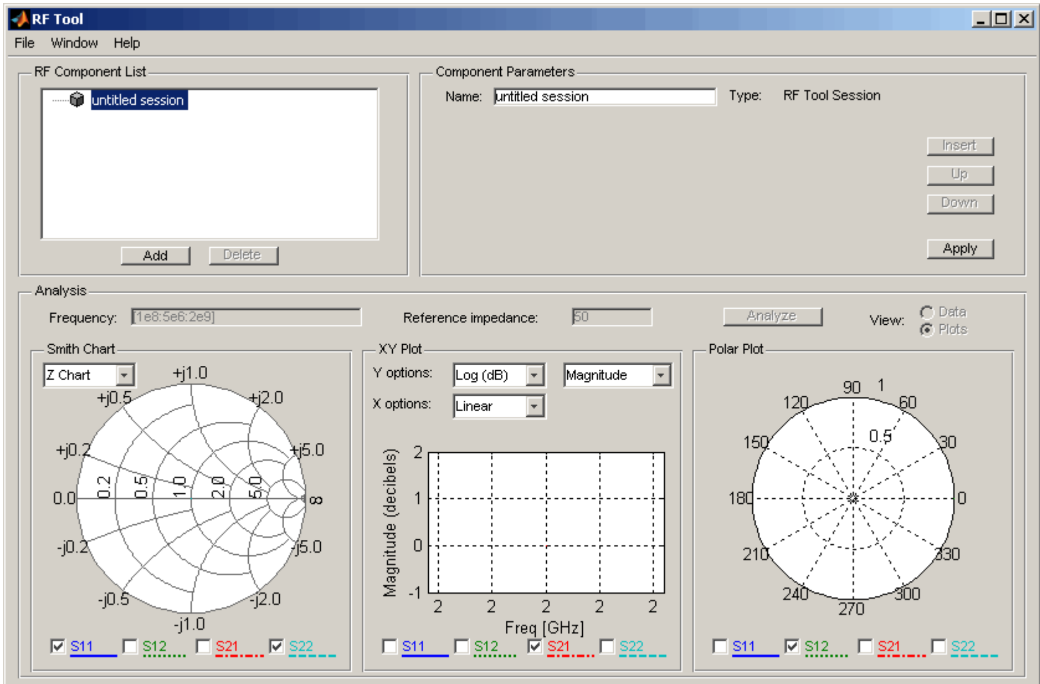
- **Component Parameters**

  Displays options and settings pertaining to the node you selected in the **RF Component List** pane.

- **Analysis**

  Displays options and settings pertaining to the circuit analysis and results display. After you analyze the circuit, this pane displays the analysis results and provides an interface for you to view the S-parameter data and modify the displayed plots.

The following figure shows the RF Tool window.



RF Tool Workflow

When you analyze a circuit using the RF Tool GUI, your workflow might include the following tasks:

1. Build the circuit by
   - Creating RF components and networks.
   - Importing components and networks from the MATLAB workspace or from a data file.

   See "Creating and Importing Circuits" on page 4-6.

2. Specify component data.

   See "Modifying Component Data" on page 4-19.

3. Analyze the circuit.

   See "Analyzing Circuits" on page 4-20.

4. Export the circuit to the MATLAB workspace or to a file.

   See "Exporting RF Objects" on page 4-23.

Getting Help

At any time, you can use the **Help** menu to access complete Help information on RF Tool, the RF Toolbox, and the RF Demos.

Creating and Importing Circuits

In RF Tool, you can create circuits that include RF components and RF networks. Networks can contain both components and other networks.

Note In the circuit object command line interface, you create networks by building components and then connecting them together to form a network. In contrast, you build networks in RF Tool by creating a network and then populating it with components.

This section contains the following topics:

- "Creating RF Components" on page 4-6
- "Creating RF Networks" on page 4-10
- "Importing RF Objects" on page 4-15

Creating RF Components

This section contains the following topics:

- "Available RF Components" on page 4-6
- "How to Add an RF Component to a Session" on page 4-8

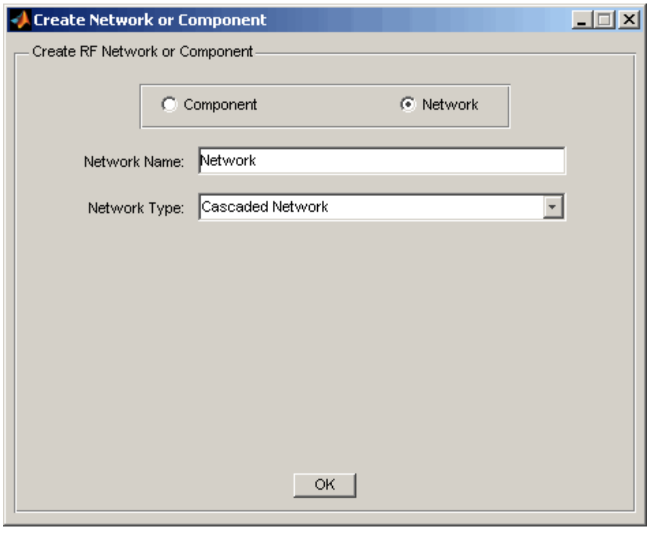
Available RF Components

The following table lists the RF components you can create using RF Tool and the corresponding RF Toolbox object.

RF Component	Corresponding RF Toolbox Object
Data File	`rfckt.datafile`
Delay Line	`rfckt.delay`
Coaxial Transmission Line	`rfckt.coaxial`
Coplanar Waveguide Transmission Line	`rfckt.cpw`
Microstrip Transmission Line	`rfckt.microstrip`
Parallel-Plate Transmission Line	`rfckt.parallelplate`
Transmission Line	`rfckt.txline`
Two-Wire Transmission Line	`rfckt.twowire`
Series RLC	`rfckt.seriesrlc`
Shunt RLC	`rfckt.shuntrlc`
LC Bandpass Pi	`rfckt.lcbandpasspi`
LC Bandpass Tee	`rfckt.lcbandpasstee`
LC Bandstop Pi	`rfckt.lcbandstoppi`
LC Bandstop Tee	`rfckt.lcbandstoptee`
LC Highpass Pi	`rfckt.lchighpasspi`
LC Highpass Tee	`rfckt.lchighpasstee`
LC Lowpass Pi	`rfckt.lclowpasspi`
LC Lowpass Tee	`rfckt.lclowpasstee`

How to Add an RF Component to a Session

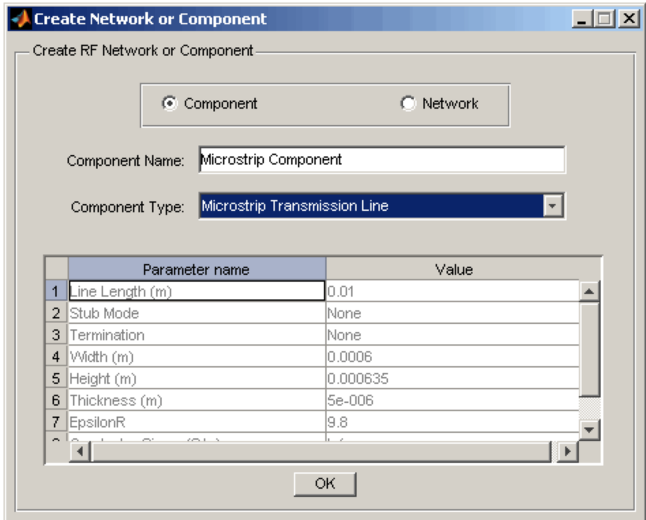
1 In the **RF Component List** pane, click **Add** to open the Create Network or Component dialog box.



2 In the Create Network or Component dialog box, select **Component**.

3 In the **Component Name** field, enter a name for the component. This name is used to identify the component in the **RF Component List** pane. For example, Microstrip Component.

4 From the **Component Type** menu, select the type of RF component you want to create. For example, `Microstrip Transmission Line`.



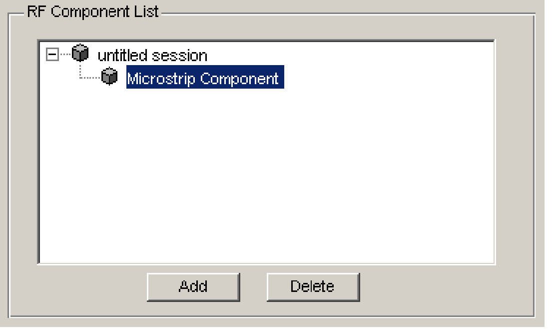
5 Adjust the parameter values as necessary.

Note You can accept the default values for some or all of the parameters and then change them later. For information on modifying the parameter values of an existing component, see "Modifying Component Data" on page 4-19.

---

6 Click **OK**.

RF Tool adds the component to your session.



Creating RF Networks

You create an RF network in RF Tool by adding a network to the session and then adding components to the network.

This section contains the following topics:

- "Available RF Networks" on page 4-10
- "Adding an RF Network to a Session" on page 4-11
- "Populating an RF Network" on page 4-13
- "Reordering Circuits Within a Network" on page 4-14

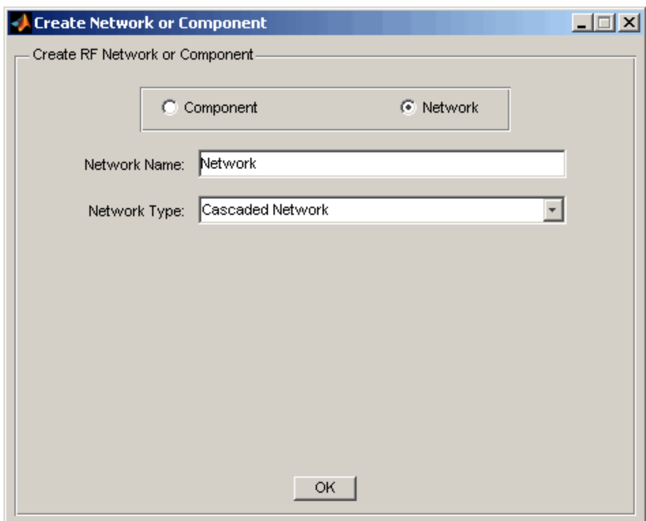
Available RF Networks

The following table lists the RF networks you can create using RF Tool.

RF Network	Corresponding RF Toolbox Object
Cascaded Network	`rfckt.cascade`
Series Connected Network	`rfckt.series`
Parallel Connected Network	`rfckt.parallel`
Hybrid Connected Network	`rfckt.hybrid`
Inverse Hybrid Connected Network	`rfckt.hybridg`

Adding an RF Network to a Session

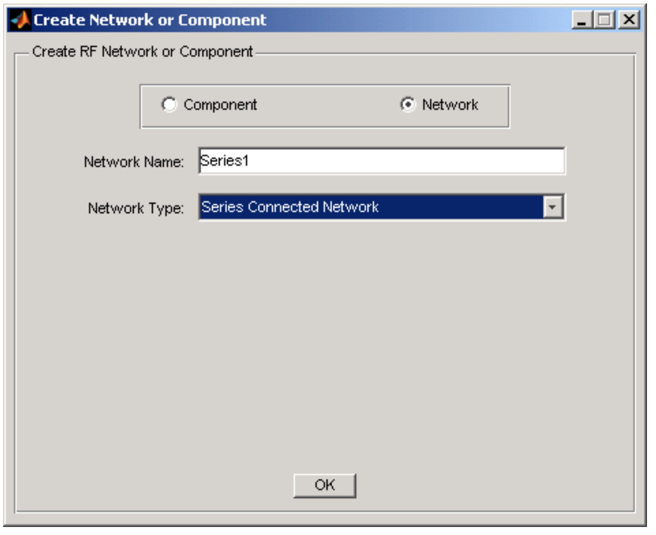
1 In the **RF Component List** pane, click **Add** to open the Create Network or Component dialog box.



2 In the Create Network or Component dialog box, select the **Network** option button.

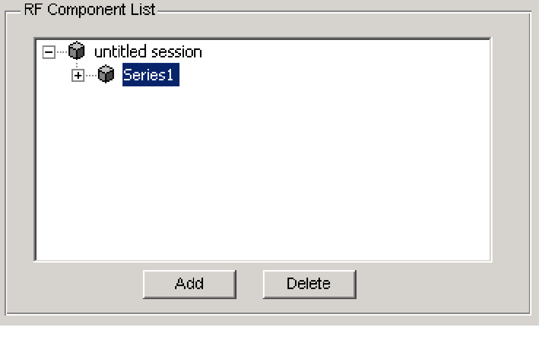
3 In the **Network Name** field, enter a name for the component. This name is used to identify the network in the **RF Component List** pane. For example, Series1.

4 From the **Network Type** menu, select the type of RF network you want to create. For example, `Series Connected Network`.



5 Click **OK**.

The RF Component List pane shows the new network.

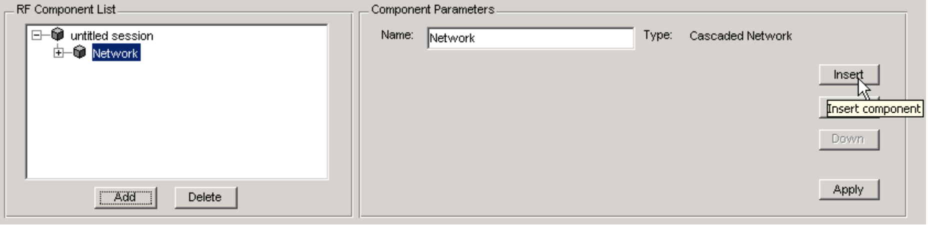


Populating an RF Network

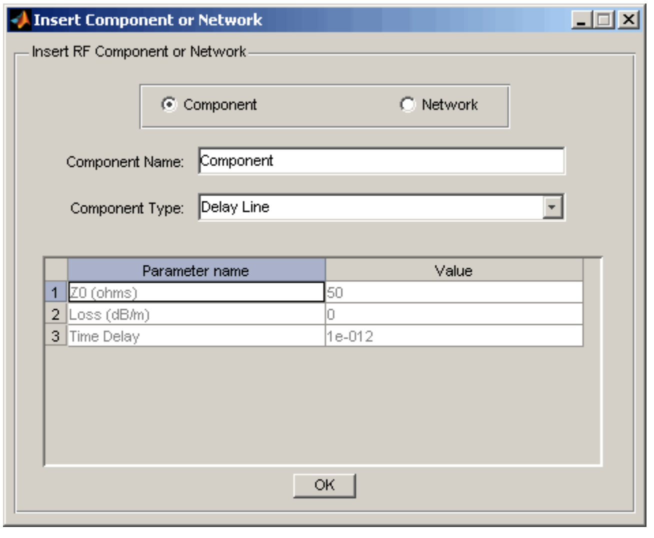
After you create a network using RF Tool, you must populate it with RF components and networks. You insert a component or network into a network in much the same way you add one to a session.

To populate an RF network:

1 In the **RF Component List** pane, select the network component you want to modify. Then, in the **Component Parameters** pane, click **Insert**.



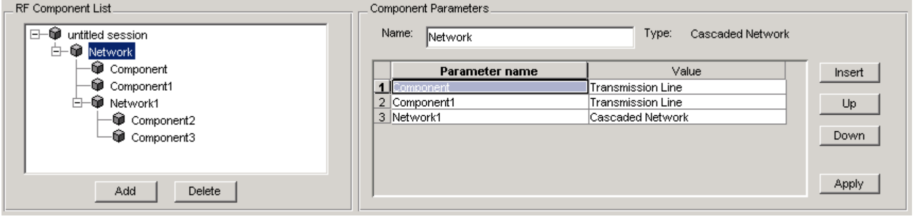
The Insert Component or Network dialog box appears.



2 Click **Component** or **Network** in the Insert Component or Network dialog box to add either a component or a network.

   Enter the component or network name, and select the appropriate type. If you are inserting a component, modify the parameter values as necessary. See “How to Add an RF Component to a Session” on page 4-8 or “Adding an RF Network to a Session” on page 4-11 for details.

As you insert components and networks into a network, they are reflected in the **RF Component List** and **Component Parameters** panes. The figure below shows an example of a cascaded network that contains two components and a network. The subnetwork, in turn, contains two components.



Reordering Circuits Within a Network

To change the order of the components and networks within a network:

1 In the **RF Component List** pane, select the network whose circuits you want to reorder.

2 In the **Component Parameters** pane, select the circuit whose position you want to change.

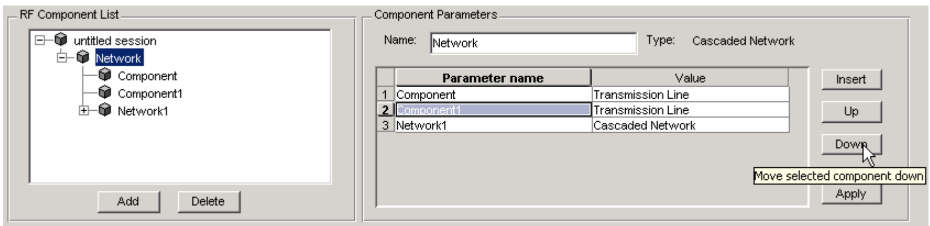
3 Click **Up** or **Down** until the circuit is where you want it.

To reverse the positions of `Component1` and `Network1` in the network shown in the following figure:

1 Select `Network` in the **RF Component List** pane.

2 Select `Component1` in the **Component Parameters** pane.

3 Click **Down** in the **Component Parameters** pane.



Importing RF Objects

RF Tool lets you import RF objects from your workspace and from files to the top level of your session. You can import the following types of objects:

- Complex component and network objects that you created in your workspace using RF Toolbox functions.
- Components and networks you exported into your workspace from another RF Tool session.

  For information on exporting components and networks from an RF Tool session, see "Exporting RF Objects" on page 4-23.

After you have imported an object, you can change its name and work with it as you would any other component or network.

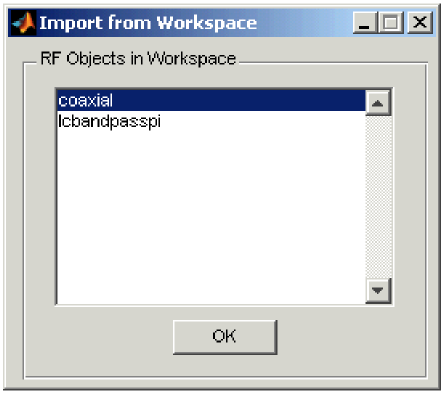
This section contains the following topics:

- "Importing from the Workspace" on page 4-16
- "Importing from a File into a Session" on page 4-16
- "Importing from a File into a Network" on page 4-18

Importing from the Workspace

To import RF circuit objects from the MATLAB workspace into your RF Tool session:

1 Select **Import From Workspace** from the **File** menu. The Import from Workspace dialog box appears. This dialog box lists the handles of all RF circuit (`rfckt`) objects in the workspace.



2 From the list of RF circuit objects, select the object you want to import, and click **OK**.

The object is added to your session with the same name as the object handle. If there is already a circuit by that name, RF Tool appends a numeral, starting with 1, to the new circuit name.

Importing from a File into a Session

You can import RF components from the following types of files into the top level of your session:

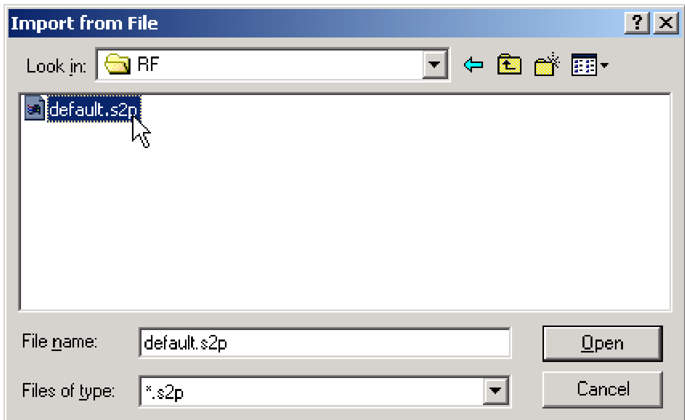
- S2P
- Y2P
- Z2P
- H2P

To import a component from one of these files:

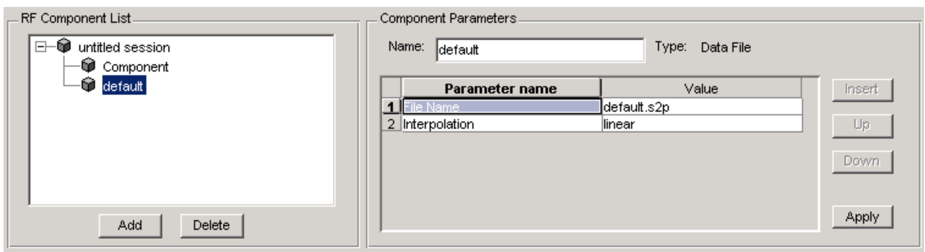
1 Select **Import From File** from the **File** menu. A file browser appears.

2 Select the file type you want to import.

3 Select the name of the file to import from the list of files in the browser.



4 Click **Open** to add the object to your session as a component.



The name of the component is the file name without the extension. If there is already a component by that name, RF Tool appends a numeral, starting with 1, to the new component name. The file name, including the extension, appears as the value of the component's `File Name` parameter. If the file is not on the MATLAB path, the value of the `File Name` parameter also contains the file path.

Importing from a File into a Network

You can import RF components from the following types of files into a network:

- S2P
- Y2P
- Z2P
- H2P

To import an RF component from a file into a network:

1. Insert a Data File component into the network.

   For more information on how add a component to a network, see "Populating an RF Network" on page 4-13.

2. Specify the name of the file from which to import the component in one of two ways:

   - Select the file name in the file name and type in the Import from File dialog box, and click **Open**.
   - Click **Cancel** to get out of the Import from File dialog box, and enter the file name in the **Value** field across from the **File Name** parameter in the Insert Component or Network dialog box.

"Example — Modeling an RF Network Using RF Tool" on page 4-30 shows this process.

Modifying Component Data

You can change the values of component parameters that you create and import. The component parameters in RF Tool correspond to the component properties that you specify in the command line.

To modify these values:

1. Select the component in the **RF Component List** pane.

2. In the **Component Parameters** pane, select the value you want to change, and enter the new value.

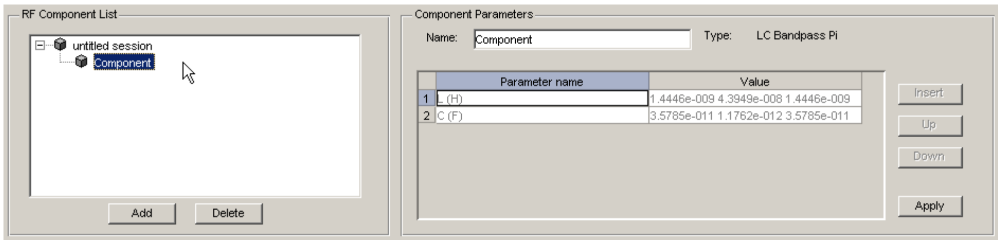
   Valid values for component parameters are listed on the corresponding RF Toolbox reference page. Use the links in “Available RF Components” on page 4-6 and “Available RF Networks” on page 4-10 to access these pages.

3. Click **Apply**.

Analyzing Circuits

After you add your circuits, you can analyze them with RF Tool:

1 Select the component or network you want to analyze in the **RF Component List** pane of RF Tool. For example, select the LC Bandpass Pi component, as shown in the following figure.



2 In the **Analysis** pane:

- Enter `[1e8:5e6:2e9]`, the analysis frequency range and step size in hertz, in the **Frequency** field.

  This value specifies an analysis from 0.1 GHz to 2 GHz in 5 MHz steps.

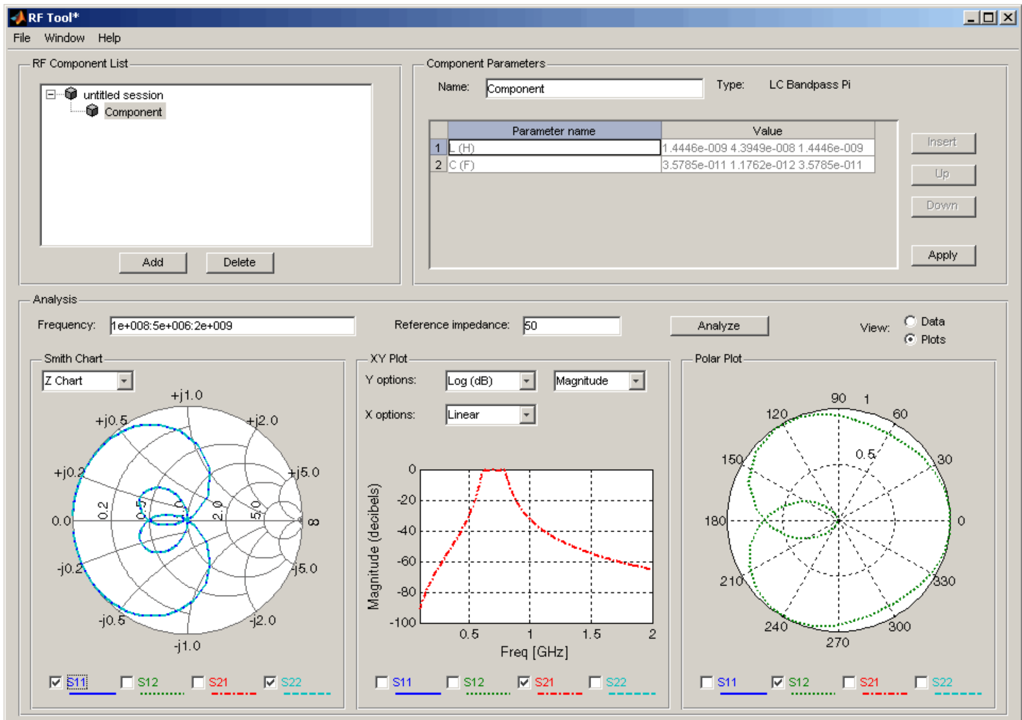
- Enter `50`, the reference impedance in ohms, in the **Reference impedance** field.

Note Alternately, you can specify the **Frequency** and **Reference impedance** values as MATLAB workspace variables or as valid MATLAB expressions.

---

3 Click **Analyze**.

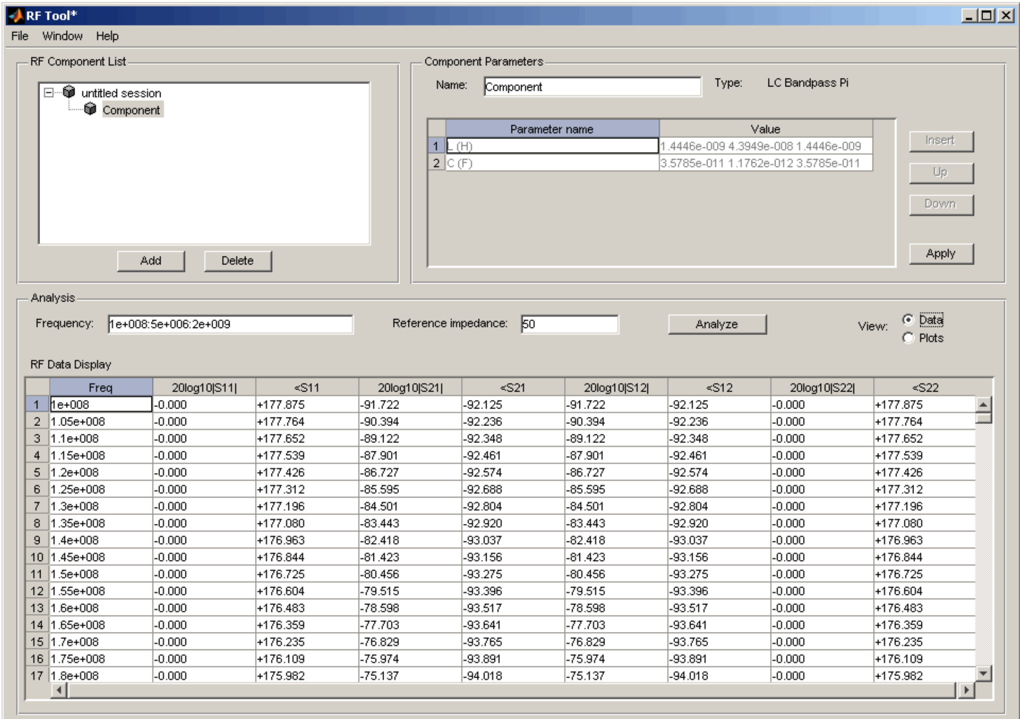
The **Analysis** pane displays Smith, XY, and polar plots of the analyzed circuit.



4 Select or deselect the S-parameter check boxes at the bottom of each plot to customize the parameters that the plot displays. Use the pull-downs at the top of each plot to customize the plot options.

The plots automatically update as you change the check box and pull-down options on the GUI.

5 Click **Data** in the upper-right corner of the **Analysis** pane to view the data in tabular form. The following figure shows the analysis data for the LC Bandpass Pi component at the frequencies and reference impedance shown in step 2.



Note The magnitude, in decibels, of S11 is listed in the 20log10[S11] column and the phase, in degrees, of S11 is listed in the <S11 column.

Exporting RF Objects

You can export RF components and networks that you create and refine in RF Tool to your MATLAB workspace or to files. You export circuits for the following reasons:

- To perform additional analysis using RF Toolbox functions that are not available in RF Tool.
- To incorporate them into larger RF systems.
- To import them into another session.

This section contains the following topics:

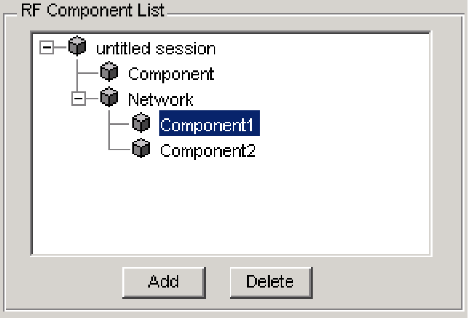
- “Exporting to the Workspace” on page 4-23
- “Exporting to a File” on page 4-24

Exporting to the Workspace

RF Tool enables you to export components and networks to the MATLAB workspace. In your workspace, you can use the resulting circuit (`rfckt`) object as you would any other RF circuit object.

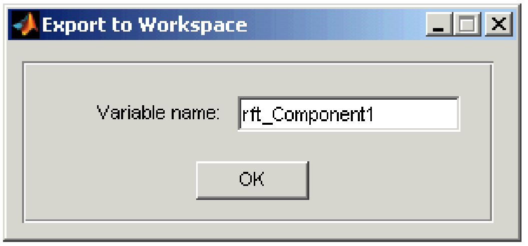
To export a component or network to the workspace:

1 Select the component or network to export in the **RF Component List** pane of RF Tool.

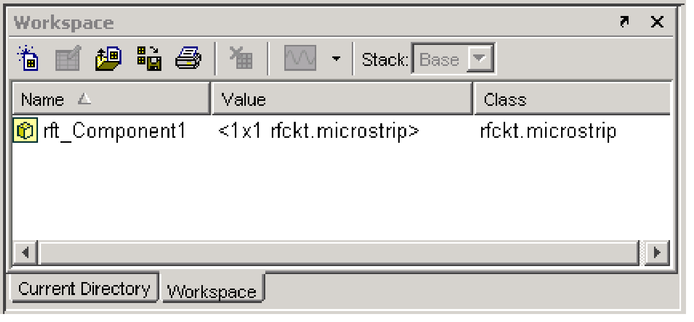


2 Select **Export to Workspace** from the **File** menu.

3 Enter a name for the exported object's handle in the **Variable name** field and click **OK**. The default name is the name of the component or network prefaced with the string `'rft_'`.



The component or network becomes accessible in the workspace via the specified object handle.



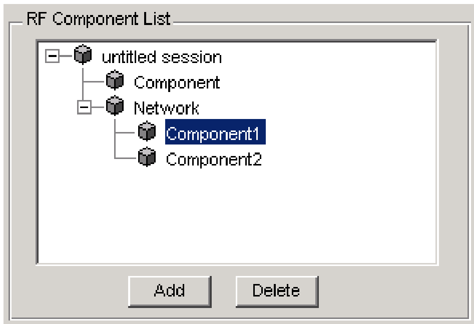
Exporting to a File

RF Tool lets you export components and networks to files in S2P format.

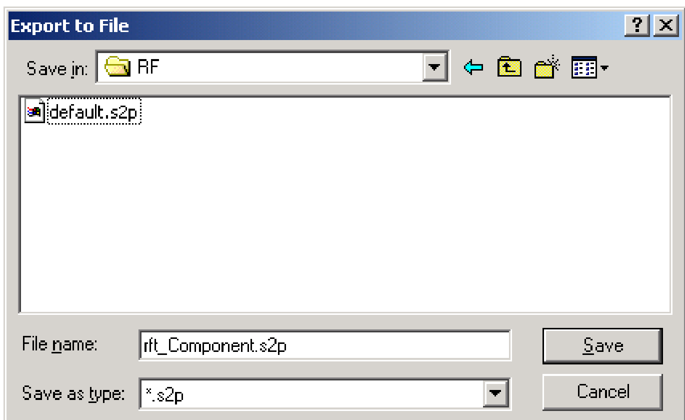
Note You must analyze a component or network in RF Tool before you can export it to a file. See "Analyzing Circuits" on page 4-20 for more information.

To export a component or network to a file:

1 Select the component or network to export in the **RF Component List** pane of RF Tool.



2 Select **Export To File** from the **File** menu to open the file browser.



3 Browse to the appropriate directory. Enter the name you want to give the file and click **Save**.

The default file name is the current name of the component or network prefaced with the string `'rft_'`. RF Tool also converts any characters that are not alphanumeric to underscores (_).

Managing Circuits and Sessions

This section contains the following topics:

- "Working with Circuits" on page 4-26
- "Working with Sessions" on page 4-27

Working with Circuits

In addition to building and specifying circuits, the RF Tool GUI allows you to perform the following tasks:

- "Deleting Circuits" on page 4-26
- "Renaming Circuits" on page 4-27

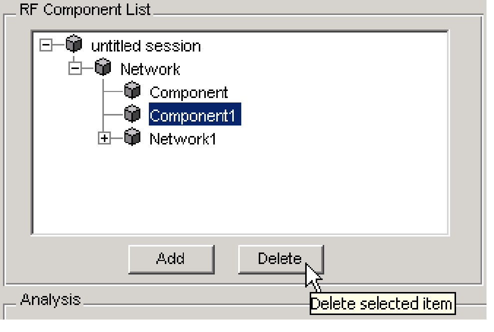
Deleting Circuits

To delete a circuit from your session:

1 Select the circuit in the **RF Component List** pane.

2 Click **Delete**.

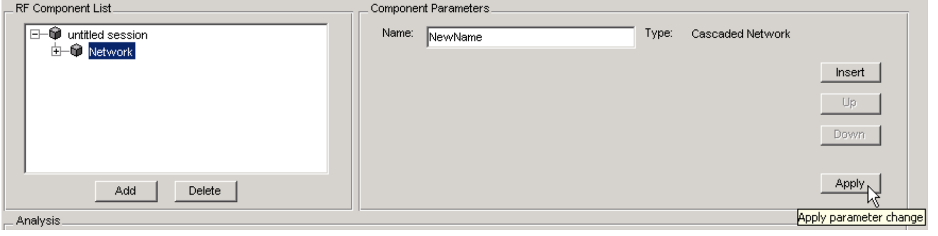
Note If the circuit you delete is a network, RF Tool deletes the network everything in the network.



Renaming Circuits

To rename a component or a network:

1. Select the component or network in the **RF Component List** pane.
2. Type the new name in the **Name** field of the **Component Parameters** pane.
3. Click **Apply**.



Working with Sessions

The work you do with RF Tool is organized into sessions. Each session is a collection of independent RF circuits, which can be RF components or RF networks.

This section contains the following topics:

- “Naming or Renaming a Session” on page 4-27
- “Saving a Session” on page 4-28
- “Opening an Existing Session” on page 4-29
- “Starting a New Session” on page 4-29

Naming or Renaming a Session

To name or rename an RF session:

1. Select the session, or top-level node, in the **RF Component List** pane. (The session is selected by default when you open the RF Tool GUI.)

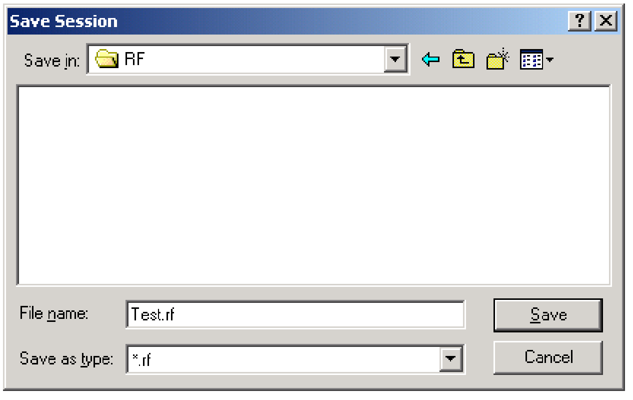
2 Type the desired name in the **Name** field of the **Component Parameters** pane.

3 Click **Apply**.

Saving a Session

To save your session, select **Save Session** or **Save Session As** from the **File** menu. The first time you save a session a browser opens, prompting you for a file name.

Note The default file name is the session name with any characters that are not alphanumeric converted to underscores (_). The name of the session itself is unchanged.

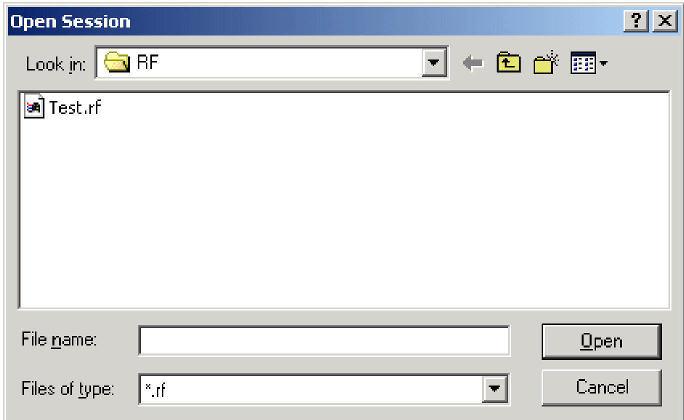


For example, to save your session as `Test.rf` in your current working directory, you would type `Test` in the **File name** field as shown above. RF Tool adds the `.rf` extension automatically to all RF Tool sessions you save.

If the name of your session is `gk's session`, the default file name is `gk_s_session.rf`.

Opening an Existing Session

You can load an existing session into RF Tool by selecting **Open Session** from the **File** menu. A browser enables you to select from your previously saved sessions.



Before opening the requested session, RF Tool prompts you to save your current session.

Starting a New Session

To start a new session, select **New Session** from the **File** menu. A new session opens in RF Tool. All its values are set to their defaults.

Before starting a new session, RF Tool prompts you to save your current session.

Example — Modeling an RF Network Using RF Tool

In this example, you model the gain and noise figure of a cascaded network and then analyze the network using the RF Toolbox graphical user interface, RF Tool.

The network used in this example consists of an amplifier and two transmission lines. Here, you learn how to create and analyze the network using RF Tool.

This example illustrates how to perform the following tasks:

- "Starting RF Tool" on page 4-30
- "Creating the Amplifier Network" on page 4-30
- "Populating the Amplifier Network" on page 4-33
- "Simulating the Amplifier Network" on page 4-37
- "Exporting the Network to the Workspace" on page 4-38

Starting RF Tool

Type the following command at the MATLAB prompt to open the RF Tool window:

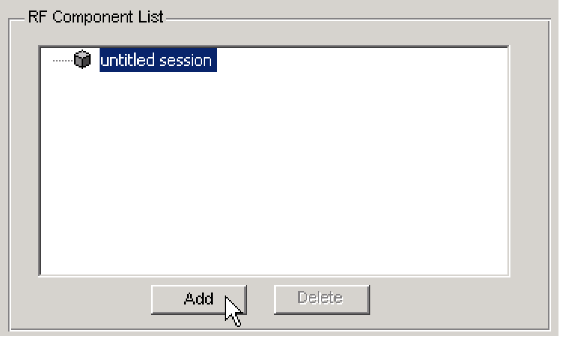
```
rftool
```

For more information about this GUI, see "RF Tool Window" on page 4-3.

Creating the Amplifier Network

In this part of the example, you create a network to connect the amplifier components in cascade.

1 In the **RF Component List** pane, click **Add**.



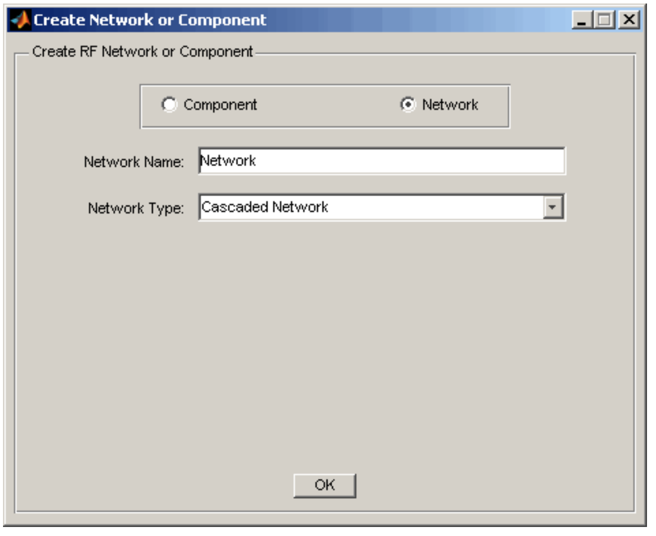
The Create Network or Component dialog box opens.

2 In the Create Network or Component dialog box:

- Select the **Network** option button.
- In the **Network Name** field, enter Amplifier Network.

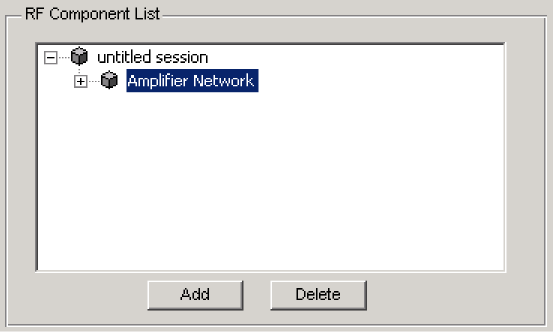
  This name is used to identify the network in the **RF Component List** pane.
- In the **Network Type** list, select `Cascaded Network`.

  A `Cascaded Network` means that when you add components to the network, the RF Toolbox connects them in cascade.



3 Click **OK** to add the cascaded network to the session.

The network now appears in the **RF Component List** pane.



Populating the Amplifier Network

This part of the example shows how to add the following components to the network:

- "Transmission Line 1" on page 4-33
- "Amplifier" on page 4-34
- "Transmission Line 2" on page 4-36

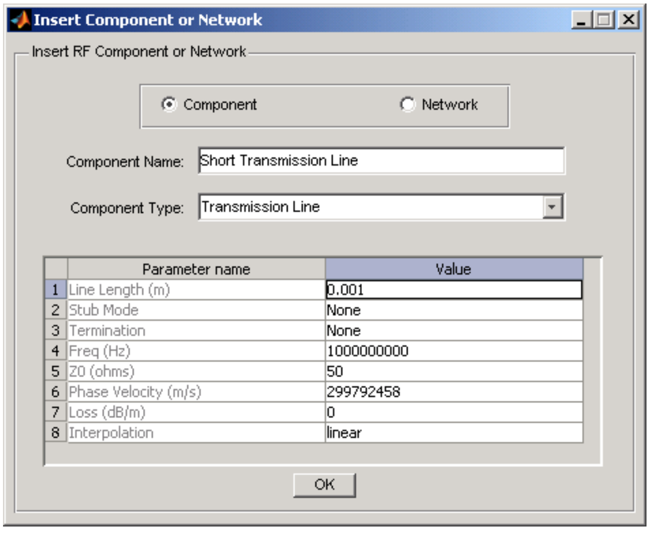
Transmission Line 1

1 In the **Component Parameters** pane, click **Insert** to open the Insert Component or Network dialog box.

2 In the Insert Component or Network dialog box:

- Select the **Component** option button.
- In the **Component Name** field, enter Short Transmission Line.

  This name is used to identify the component in the **RF Component List** pane.
- In the **Component Type** pull-down list, select `Transmission Line`.
- In the **Value** field across from the **Line Length (m)** parameter, enter `0.001`.



3 Click **OK** to add the transmission line to the network.

Amplifier

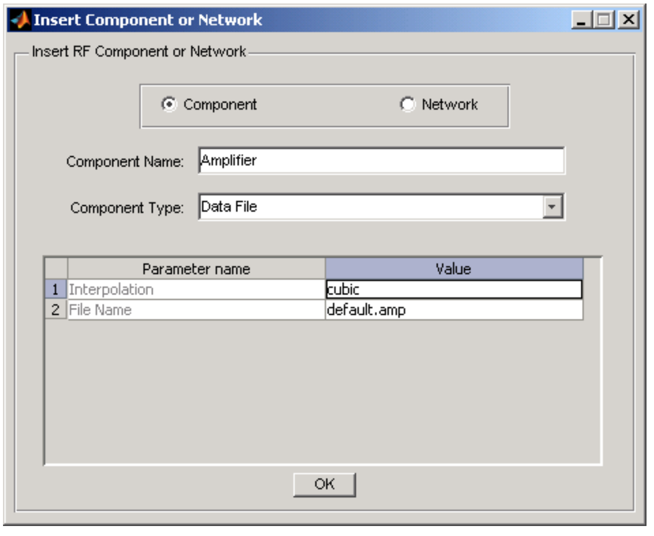
1 In the **Component Parameters** pane, click **Insert** to open the Insert Component or Network dialog box.

2 In the Insert Component or Network dialog box:

- Select the **Component** option button.
- In the **Component Name** field, enter Amplifier.

  This name is used to identify the component in the **RF Component List** pane.
- In the **Component Type** list, select `Data File`.
- In the Import from File dialog box that appears, click **Cancel** . You will specify the name of the file from which to import data in a later step.
- In the **Value** field across from the **Interpolation** parameter, enter `cubic`.

  This value tells the RF Toolbox to use cubic interpolation to determine the behavior of the amplifier at frequency values that are not specified explicitly in the data file.
- In the **Value** field across from the **File Name** parameter, enter `default.amp`.



3 Click **OK** to add the amplifier to the network.

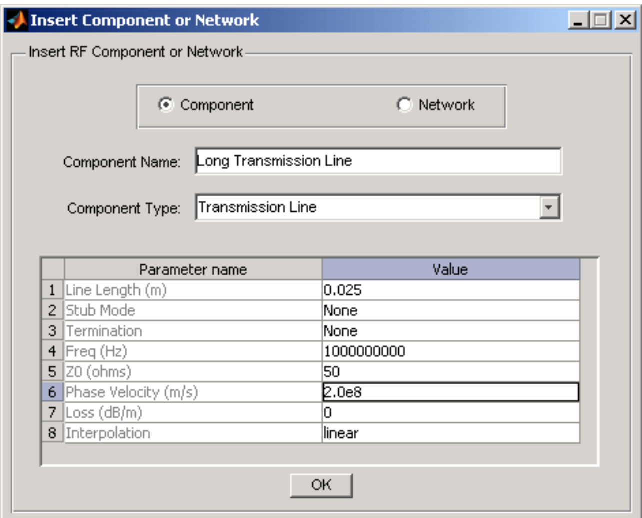
Transmission Line 2

1 In the **Component Parameters** pane, click **Insert** to open the Insert Component or Network dialog box.

2 In the Insert Component or Network dialog box, perform the following actions:

- Select the **Component** option button.
- In the **Component Name** field, enter Long Transmission Line.

  This name is used to identify the component in the **RF Component List** pane.
- In the **Component Type** list, select `Transmission Line`.
- In the **Value** field across from the **Line Length (m)** parameter, enter `0.025`.
- In the **Value** field across from the **Phase Velocity (m/s)** parameter, enter `2.0e8`.



3 Click **OK** to add the transmission line to the network.

Simulating the Amplifier Network

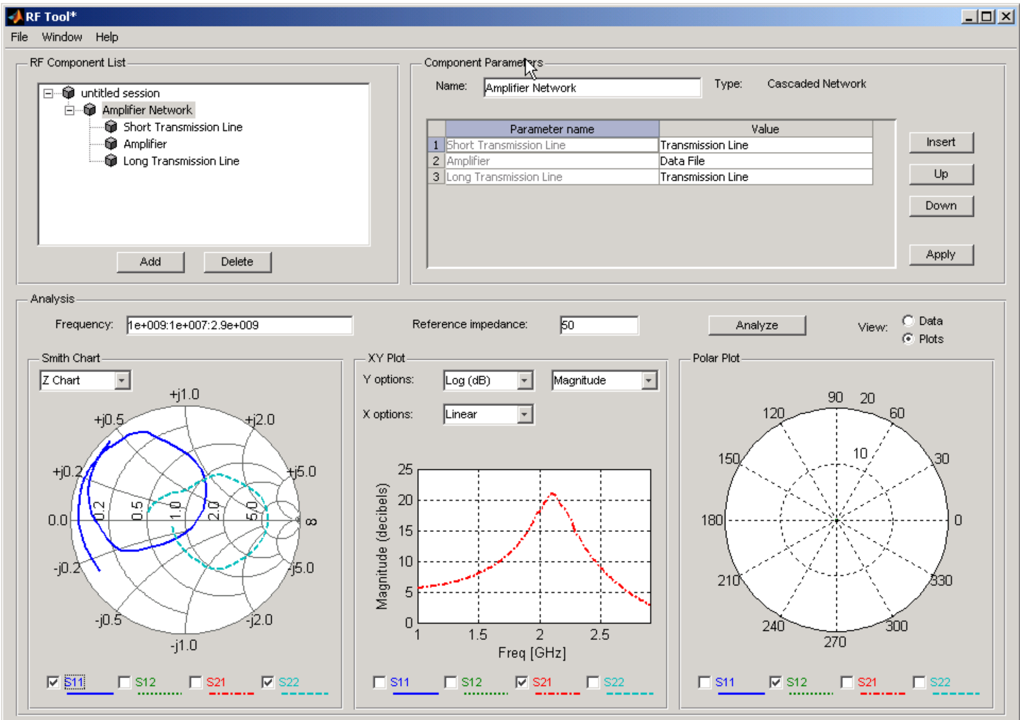
In this part of the example, you specify the range of frequencies over which to analyze the amplifier network and then run the analysis.

1 In the **Analysis** pane, change the **Frequency** entry to `[1.0e9:1e7:2.9e9]`.

   This value specifies an analysis from 1 GHz to 2.9 GHz by 10 MHz.

In the **Analysis** pane, click **Analyze** to simulate the network at the specified frequencies.

RF Tool displays Smith, XY, and polar plots of the analyzed circuit.



You can modify the plots by

- Selecting and deselecting the S-parameter check boxes at the bottom of each plot to customize the parameters that the plot displays.
- Using the pull-downs at the top of each plot to customize the plot options.

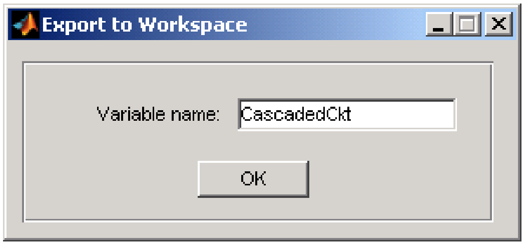
Exporting the Network to the Workspace

RF Tool lets you export components and networks to the workspace as circuit objects so you can use the RF Toolbox functions to perform additional analysis. This part of the example shows how to export the amplifier network to the workspace.

1 In the RF Tool window, select **File > Export to Workspace**.

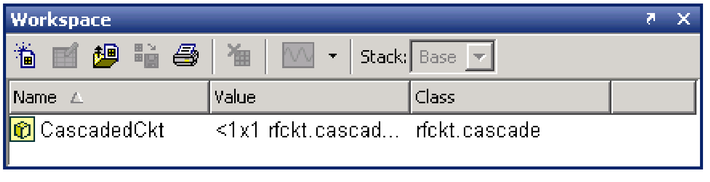
2 In the **Variable name** field, enter `CascadedCkt`.

   This name is the exported object's handle.



3 Click **OK**.

   The RF Toolbox exports the amplifier network to an `rfckt.cascade` object, with the specified object handle, in the MATLAB workspace.



Functions — By Category

Circuit Objects

`rfckt`	Construct RF circuit object
`rfckt.amplifier`	Construct amplifier object
`rfckt.cascade`	Construct cascaded network object
`rfckt.coaxial`	Construct coaxial transmission line object
`rfckt.cpw`	Construct coplanar waveguide transmission line object

`rfckt.datafile`	Construct circuit object from data file
`rfckt.delay`	Construct delay line object
`rfckt.hybrid`	Construct hybrid connected network object
`rfckt.hybridg`	Construct inverse hybrid connected network object
`rfckt.lcbandpasspi`	Construct LC bandpass pi network object
`rfckt.lcbandpasstee`	Construct LC bandpass tee network object
`rfckt.lcbandstoppi`	Construct LC bandstop pi network object
`rfckt.lcbandstoptee`	Construct LC bandstop tee network object
`rfckt.lchighpasspi`	Construct LC highpass pi network object
`rfckt.lchighpasstee`	Construct LC highpass tee network object
`rfckt.lclowpasspi`	Construct LC lowpass pi network object
`rfckt.lclowpasstee`	Construct LC lowpass tee filter object
`rfckt.microstrip`	Construct microstrip transmission line object
`rfckt.mixer`	Construct 2-port object representing mixer and its local oscillator
`rfckt.parallel`	Construct parallel connected network object
`rfckt.parallelplate`	Construct parallel-plate transmission line object
`rfckt.passive`	Construct passive network object

`rfckt.rlcgline`	Construct RLCG transmission line object
`rfckt.series`	Construct series connected network object
`rfckt.seriesrlc`	Construct series RLC network object
`rfckt.shuntrlc`	Construct shunt RLC network object
`rfckt.twowire`	Construct 2-wire transmission line object
`rfckt.txline`	Construct transmission line object

Data Objects

`rfdata`	Construct RF data object
`rfdata.data`	Store result of circuit object analysis
`rfdata.ip3`	Store frequency-dependent, third-order intercept points for amplifiers or mixers
`rfdata.network`	Store frequency-dependent network parameters
`rfdata.nf`	Store frequency-dependent noise figure data for amplifiers or mixers
`rfdata.noise`	Store frequency-dependent spot noise data for amplifiers or mixers
`rfdata.power`	Store output power and phase information for amplifiers or mixers

Model Objects

`rfmodel`	Construct RF model object
`rfmodel.rational`	Construct rational function model object

Calculations

`analyze`	Analyze circuit object in frequency domain
`calculate`	Calculate specified parameters for circuit object
`deembedsparams`	De-embed S-parameters from cascaded network
`freqresp`	Calculate frequency response of model object
`gammain`	Calculate input reflection coefficient of 2-port network
`gammaout`	Calculate output reflection coefficient of 2-port network
`impulse`	Calculate impulse response for model object
`rationalfit`	Fit rational function to broadband data
`stabilityk`	Calculate stability factor *K* of 2-port network
`stabilitymu`	Calculate stability factor, mu, of 2-port network
`vswr`	Calculate VSWR at given reflection coefficient gamma

Data Visualization

plot	Plot specified circuit object parameters on X-Y plane
polar	Plot specified circuit object parameters on polar coordinates
smith	Plot specified circuit object parameters on Smith chart
smithchart	Plot complex vector on Smith chart

Utility Functions

copy	Copy circuit or data object
extract	Array of network parameters from data object
getdata	Data object containing analyzed result of specified circuit object
getz0	Characteristic impedance of transmission line object
listformat	List valid formats for specified circuit object parameter
listparam	List valid parameters for specified circuit object

Data I/O

`read`	Read RF data from file to new or existing circuit or data object
`write`	Write RF data from circuit or data object to file
`writeva`	Write Verilog-A description of RF model object

Network Parameter Conversion

`abcd2h`	Convert ABCD-parameters to hybrid h-parameters
`abcd2s`	Convert ABCD-parameters to S-parameters
`abcd2y`	Convert ABCD-parameters to Y-parameters
`abcd2z`	Convert ABCD-parameters to Z-parameters
`g2h`	Convert hybrid g-parameters to hybrid h-parameters
`h2abcd`	Convert hybrid h-parameters to ABCD-parameters
`h2g`	Convert hybrid h-parameters to hybrid g-parameters
`h2s`	Convert hybrid h-parameters to S-parameters
`h2y`	Convert hybrid h-parameters to Y-parameters
`h2z`	Convert hybrid h-parameters to Z-parameters

`s2abcd`	Convert S-parameters to ABCD-parameters
`s2h`	Convert S-parameters to hybrid h-parameters
`s2s`	Convert S-parameters to S-parameters with different impedance
`s2scc`	Convert 4-port, single-ended S-parameters to 2-port, common mode S-parameters (S_{cc})
`s2scd`	Convert 4-port, single-ended S-parameters to 2-port, cross mode S-parameters (S_{cd})
`s2sdc`	Convert 4-port, single-ended S-parameters to 2-port, cross mode S-parameters (S_{dc})
`s2sdd`	Convert 4-port, single-ended S-parameters to 2-port, differential mode S-parameters (S_{dd})
`s2t`	Convert S-parameters to T-parameters
`s2tf`	Convert 2-port S-parameters to transfer function
`s2y`	Convert S-parameters to Y-parameters
`s2z`	Convert S-parameters to Z-parameters
`t2s`	Convert T-parameters to S-parameters
`y2abcd`	Convert Y-parameters to ABCD-parameters
`y2h`	Convert Y-parameters to hybrid h-parameters

`y2s`	Convert Y-parameters to S-parameters
`y2z`	Convert Y-parameters to Z-parameters
`z2abcd`	Convert Z-parameters to ABCD-parameters
`z2h`	Convert Z-parameters to hybrid h-parameters
`z2s`	Convert Z-parameters to S-parameters
`z2y`	Convert Z-parameters to Y-parameters

Graphical User Interface

`rftool`	Open RF Analysis Tool (RF Tool)

Functions — Alphabetical List

abcd2h

Purpose Convert ABCD-parameters to hybrid h-parameters

Syntax

```
h_params = abcd2h(abcd_params)
```

Description

`h_params = abcd2h(abcd_params)` converts the ABCD-parameters `abcd_params` into the hybrid parameters `h_params`. The `abcd_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port ABCD-parameters. `h_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port hybrid h-parameters.

See Also

`abcd2s`	RF Toolbox
`abcd2y`	RF Toolbox
`abcd2z`	RF Toolbox
`h2abcd`	RF Toolbox
`s2h`	RF Toolbox
`y2h`	RF Toolbox
`z2h`	RF Toolbox

Purpose Convert ABCD-parameters to S-parameters

Syntax

```
s_params = abcd2h(abcd_params,z0)
```

Description

`s_params = abcd2h(abcd_params,z0)` converts the ABCD-parameters `abcd_params` into the scattering parameters `s_params`. The `abcd_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port ABCD-parameters. `z0` is the reference impedance; its default is 50 ohms. `s_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters.

See Also

`abcd2h`	RF Toolbox
`abcd2y`	RF Toolbox
`abcd2z`	RF Toolbox
`s2abcd`	RF Toolbox
`s2h`	RF Toolbox
`y2h`	RF Toolbox
`z2h`	RF Toolbox

Purpose

Convert ABCD-parameters to Y-parameters

Syntax

```
y_params = abcd2y(abcd_params)
```

Description

`y_params = abcd2y(abcd_params)` converts the ABCD-parameters `abcd_params` into the admittance parameters `y_params`. The `abcd_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port ABCD-parameters. `y_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port Y-parameters.

See Also

`abcd2h`	RF Toolbox
`abcd2s`	RF Toolbox
`abcd2z`	RF Toolbox
`h2y`	RF Toolbox
`s2y`	RF Toolbox
`y2abcd`	RF Toolbox
`z2y`	RF Toolbox

Purpose

Convert ABCD-parameters to Z-parameters

Syntax

```
z_params = abcd2z(abcd_params)
```

Description

`z_params = abcd2z(abcd_params)` converts the ABCD-parameters `abcd_params` into the impedance parameters `z_params`. The `abcd_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port ABCD-parameters. `z_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port Z-parameters.

See Also

`abcd2h`	RF Toolbox
`abcd2s`	RF Toolbox
`abcd2y`	RF Toolbox
`h2y`	RF Toolbox
`y2abcd`	RF Toolbox
`z2abcd`	RF Toolbox

analyze

Purpose

Analyze circuit object in frequency domain

Syntax

```
analyze(h,freq)
analyze(h,freq,zl,zs,zo)
```

Description

`analyze(h,freq)` calculates the circuit network parameters and noise figure values at the specified frequencies. `h` is the handle of the circuit object to be analyzed. `freq` is a vector of frequencies, specified in Hz, at which the circuit is analyzed.

`analyze(h,freq,zl,zs,zo)` calculates the circuit network parameters and noise figure for the specified frequencies. The arguments `zl`, `zs`, and `zo` are optional. These arguments represent the circuit load, circuit source, and reference impedances of the S-parameters, respectively. The default value of all these arguments is 50 ohms.

Analysis of Circuit Objects

For most circuit objects, the `AnalyzedResult` property is empty until the `analyze` function is applied to the circuit object. However, these four circuit objects are the exception to this rule: `rfckt.datafile`, `rfckt.passive`, `rfckt.amplifier`, and `rfckt.mixer`.

By default, the `AnalyzedResult` property of `rfckt.datafile` objects contains the S-parameters, noise figure, and OIP3 values that are calculated over the network parameter frequencies in the `passive.s2p` data file.

By default, the `AnalyzedResult` property of `rfckt.passive` objects contains the S-parameters, noise figure, and OIP3 values that are the result of analyzing the values stored in the `passive.s2p` file at the frequencies stored in this file. These frequency values are also stored in the `NetworkData` property.

By default, the `AnalyzedResult` property of `rfckt.amplifier` objects contains the S-parameters, noise figure, and OIP3 values that are the result of analyzing the values stored in the `default.amp` file at the frequencies stored in this file. These frequency values are also stored in the `NetworkData` property.

By default, the `AnalyzedResult` property of `rfckt.mixer` objects contains the S-parameters, noise figure, and OIP3 values that are the result of analyzing the values stored in the `default.s2p` file at the frequencies stored in this file. These frequency values are also stored in the `NetworkData` property.

See Also

`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`smith`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`write`	RF Toolbox

calculate

Purpose

Calculate specified parameters for circuit object

Syntax

```
[data,params] = calculate(h,'parameter1',..., 'parametern',
'format')
```

Description

`[data,params,freq] = calculate(h,'parameter1',...,'parametern', 'format')` calculates the specified network parameters for the object `h` and returns them in the `n`-element cell array `data`. The input `h` is the handle of a circuit object. `parameter1,...`, `parametern` are the network parameters to be calculated. `format` is the format of the output `data`. Specify `format` as `'none'` to return the network parameters unchanged.

`params` is an n-element cell array containing the names, as strings, of the parameters in `data`. `freq` is a vector of frequencies at which the network parameters are known.

Note Before calling `calculate`, you must use the `analyze` function to perform a frequency domain analysis for the circuit object.

For example, `[data,params,freq] = calculate(h,'S11','S22','dB')` returns the S11 and S22 parameters in decibel format for the circuit object `h`.

Use the `listparam` and `listformat` functions to get lists of valid network parameters for a circuit object and the valid formats for a particular parameter.

Examples

Analyze a general transmission line, `trl`, with the default characteristic impedance of 50 ohms, phase velocity of 299792458 meters per second, and line length of 0.01 meters for frequencies of 1.0 GHz to 3.0 GHz. Then calculate S11 and S22 parameters in decibels.

```
trl = rfckt.txline;
f = [1e9:1.0e7:3e9];
analyze(trl,f);
[data,params,freq] = calculate(trl,'S11','S22','dB')
```

```
data =
    [201x1 double]    [201x1 double]
params =
    'S_{11}'    'S_{22}'

freq = 1.0e+009 *

    1.0000
    1.0100
    1.0200
  ...
```

Note that the params output is formatted so you can use it as a plot legend. The first few elements of data{1} look like

```
ans =

 1.0e+003 *

   -6.4661
   -0.3372
   -0.3432
   -0.3432
   -0.3432
  ...
```

See Also

analyze	RF Toolbox
getz0	RF Toolbox
listformat	RF Toolbox
listparam	RF Toolbox
plot	RF Toolbox
polar	RF Toolbox

`smith`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`write`	RF Toolbox

Purpose

Copy circuit or data object

Syntax

```
h2 = copy(h)
```

Description

`h2 = copy(h)` returns a copy of the circuit or data object `h`.

Note The syntax `h2 = h` copies only the object handle and does not create a new object.

See Also

`analyze`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox

deembedsparams

Purpose

De-embed S-parameters from cascaded network

Syntax

```
s2_params = deembedsparams(s_params,s1_params,s3_params)
```

Description

`s2_params = deembedsparams(s_params,s1_params,s3_params)` derives the `s2_params` from the cascaded S-parameters `s_params`, by removing the effects of `s1_params`, and `s3_params`.

Each of the input networks must be a 2-port network described by a 2-by-2-by-`m` array of S-parameters. All networks must have the same reference impedance. `s_params` must contains the S-parameters of the cascaded network of `s1_params`, `s2_params`, and `s3_params`.

`s2_params` is a 2-by-2-by-`m` array. It contains the de-embedded S-parameters.

See Also

`rfckt.cascade`	RF Toolbox
`s2t`	RF Toolbox
`t2s`	RF Toolbox

Purpose

Array of network parameters from data object

Syntax

```
[outmatrix, freq] = extract(h,outtype,z0)
```

Description

`[outmatrix, freq] = extract(h,outtype,z0)` extracts the network parameters of `outtype` from an `rfckt`, `rfdata.data` or `rfdata.network` object, `h`, and returns them in `outmatrix`. `freq` is a vector of frequencies that correspond to the network parameters.

`outtype` can be one of these case-insensitive strings `'ABCD_parameters'`, `'S_parameters'`, `'Y_parameters'`, `'Z_parameters'`, `'H_parameters'`, `'G_parameters'`, or `'T_parameters'`. `z0` is the reference impedance for the S-parameters. The default is 50 ohms.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`smith`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`write`	RF Toolbox

freqresp

Purpose

Calculate frequency response of model object

Syntax

```
[resp,outfreq] = freqresp(h,infreq)
```

Description

`[resp,outfreq] = freqresp(h,infreq)` computes the frequency response, `resp`, of the `rfmodel` object, `h`, at the frequencies specified by `freq`.

The input `h` is the handle of a model object, and `infreq` is a positive vector of frequencies, in Hz, over which the frequency response is calculated.

The output argument `outfreq` is a vector that contains the same frequencies as the input frequency vector, in order of increasing frequency. The frequency response, `resp`, is a vector of impulse response values corresponding to these frequencies. It is computed using the analytical form of the rational function

$$resp = \left(\sum_{k=1}^{n} \frac{C_k}{s - A_k} + D \right) e^{-s^*Delay}, \quad s = j2\pi^* freq$$

where `A`, `C`, `D`, and `Delay` are properties of the `rfmodel` object, `h`.

Examples

The following example shows you how to compute the frequency response of the data stored in the file `default.s2p` by reading it into an `rfdata` object, fitting a rational function model to the data, and using the `freqresp` function to compute the frequency response of the model.

```
orig_data=read(rfdata.data,'default.s2p')
freq=orig_data.Freq;
data=orig_data.S_Parameters(2,1,:);
fit_data=rationalfit(freq,data)

[resp,freq]=freqresp(fit_data,freq);

plot(freq/1e9,db(resp));
figure
```

```
plot(freq/1e9,unwrap(angle(resp)));
```

See Also

`impulse`	RF Toolbox
`rationalfit`	RF Toolbox
`rfmodel`	RF Toolbox
`rfmodel.rational`	RF Toolbox
`write`	RF Toolbox

Purpose Convert hybrid g-parameters to hybrid h-parameters

Syntax

```
h_params = g2h(g_params,z0)
```

Description

`h_params = g2h(g_params)` converts the hybrid g-parameters `g_params` into the hybrid h-parameters `h_params`. The `g_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port g-parameters. `h_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port h-parameters.

See Also

`h2g` RF Toolbox

Purpose

Calculate input reflection coefficient of 2-port network

Syntax

```
result = gammain(s_params,z0,zl)
```

Description

`result = gammain(s_params,z0,zl)` calculates the input reflection coefficient of a 2-port network as

$$\Gamma_{In} = S_{11} + \frac{(S_{12} * S_{21}) * \Gamma_L}{1 - S_{22} * \Gamma_L}$$

where

$$\Gamma_L = \frac{Z_l - Z_0}{Z_l + Z_0}$$

`s_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters. `z0` is the reference impedance Z_0; its default is 50 ohms. `zl` is the load impedance Z_l; its default is also 50 ohms. `result` is an `m`-element complex vector.

See Also

`gammaout` RF Toolbox

gammaout

Purpose

Calculate output reflection coefficient of 2-port network

Syntax

`result = gammaout(s_params,z0,zs)`

Description

`result = gammaout(s_params,z0,zs)` calculates the output reflection coefficient of a 2-port network as

$$\text{GammaOut} = S_{22} + \frac{(S_{12}*S_{21})*\text{GammaS}}{1 - S_{11}*\text{GammaS}}$$

where

$$\text{GammaS} = \frac{\text{zs} - \text{z0}}{\text{zs} + \text{z0}}$$

`s_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters. `z0` is the reference impedance; its default is 50 ohms. `zs` is the source impedance; its default is also 50 ohms. `result` is an `m`-element complex vector.

See Also

`gammain` RF Toolbox

Purpose

Data object containing analyzed result of specified circuit object

Syntax

```
hd = getdata(h)
```

Description

`hd = getdata(h)` returns a handle `hd` to the `rfdata.data` object containing the analysis data, if any, for circuit (`rfckt`) object `h`. If the circuit object `h` has not been analyzed, i.e., there is no analysis data, `getdata` displays an error message.

Note For all circuit objects except those of type `rfckt.amplifier`, `rfckt.datafile`, and `rfckt.mixer`, before calling `getdata`, you must use the `analyze` function to perform a frequency domain analysis for the circuit (`rfckt`) object. When you create an object of type `rfckt.amplifier`, `rfckt.datafile`, or `rfckt.mixer`, by reading data from a file, the RF Toolbox automatically creates an `rfdata.data` object and stores data from the file as properties of the data object. You can use the `getdata` function, without first calling `analyze`, to retrieve the handle of this data object.

See Also

`rfckt`	RF Toolbox
`rfdata`	RF Toolbox

getz0

Purpose

Characteristic impedance of transmission line object

Syntax

```
z0 = getz0(h)
```

Description

`z0 = getz0(h)` returns a scalar or vector, `z0`, that represents the characteristic impedance(s) of circuit object `h`. The object `h` can be `rfckt.txline`, `rfckt.rlcgline`, `rfckt.twowire`, `rfckt.parallelplate`, `rfckt.coaxial`, `rfckt.microstrip`, or `rfckt.cpw`.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Convert hybrid h-parameters to ABCD-parameters

Syntax

```
abcd_params = h2abcd(h_params)
```

Description

`abcd_params = h2abcd(h_params)` converts the hybrid parameters `h_params` into the ABCD-parameters `abcd_params`. The `h_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port hybrid h-parameters. `abcd_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port ABCD-parameters.

See Also

`abcd2h`	RF Toolbox
`h2s`	RF Toolbox
`h2y`	RF Toolbox
`h2z`	RF Toolbox
`s2abcd`	RF Toolbox
`y2abcd`	RF Toolbox
`z2abcd`	RF Toolbox

h2g

Purpose

Convert hybrid h-parameters to hybrid g-parameters

Syntax

```
g_params = h2g(h_params,z0)
```

Description

`g_params = h2g(h_params)` converts the hybrid parameters `h_params` into the hybrid g-parameters `g_params`. The `h_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port h-parameters. `g_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port g-parameters.

See Also

`g2h`	RF Toolbox
`h2abcd`	RF Toolbox
`h2s`	RF Toolbox
`h2y`	RF Toolbox
`h2z`	RF Toolbox

Purpose

Convert hybrid h-parameters to S-parameters

Syntax

```
s_params = h2s(h_params,z0)
```

Description

`s_params = h2s(h_params,z0)` converts the hybrid parameters `h_params` into the scattering parameters `s_params`. The `h_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port hybrid h-parameters. `z0` is the reference impedance; its default is 50 ohms. `s_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters.

See Also

`abcd2s`	RF Toolbox
`h2abcd`	RF Toolbox
`h2y`	RF Toolbox
`h2z`	RF Toolbox
`y2s`	RF Toolbox
`z2s`	RF Toolbox

h2y

Purpose

Convert hybrid h-parameters to Y-parameters

Syntax

```
y_params = h2y(h_params,z0)
```

Description

`y_params = h2y(h_params)` converts the hybrid parameters `h_params` into the admittance parameters `y_params`. The `h_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port hybrid h-parameters. `y_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port Y-parameters.

See Also

`abcd2z`	RF Toolbox
`h2abcd`	RF Toolbox
`h2s`	RF Toolbox
`h2y`	RF Toolbox
`s2z`	RF Toolbox
`y2z`	RF Toolbox
`z2h`	RF Toolbox

Purpose

Convert hybrid h-parameters to Z-parameters

Syntax

```
z_params = h2z(h_params)
```

Description

`z_params = h2z(h_params)` converts the hybrid parameters `h_params` into the impedance parameters `z_params`. The `h_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port hybrid h-parameters. `z_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port Z-parameters.

See Also

`abcd2z`	RF Toolbox
`h2abcd`	RF Toolbox
`h2s`	RF Toolbox
`h2y`	RF Toolbox
`s2z`	RF Toolbox
`y2z`	RF Toolbox
`z2h`	RF Toolbox

Purpose

Calculate impulse response for model object

Syntax

```
[resp,t] = impulse(h,ts,n)
```

Description

`[resp,t] = impulse(h,ts,n)` computes the impulse response, `resp`, of the `rfmodel` object, `h`, over the time period specified by `ts` and `n`.

The input `h` is the handle of a model object. `ts` is a positive scalar value that specifies the sample time of the computed impulse response, and `n` is a positive integer that specifies the total number of samples in the response.

The vector of time samples of the impulse response, `t`, is computed from the inputs as `t = [0,ts,2*ts,...,(n-1)*ts]`. The impulse response, `resp`, is an `n`-element vector of impulse response values corresponding to these times. It is computed using the analytical form of the rational function

$$resp = \sum_{k=1}^{n} C_k e^{A_k(t-Delay)} u(t - Delay) + D\delta(t - Delay)$$

where `A`, `C`, `D`, and `Delay` are properties of the `rfmodel` object, `h`.

Examples

The following example shows you how to compute the impulse response of the data stored in the file `default.s2p` by fitting a rational function model to the data and using the `impulse` function to compute the impulse response of the model.

```
orig_data=read(rfdata.data,'default.s2p')
freq=orig_data.Freq;
data=orig_data.S_Parameters(2,1,:);
fit_data=rationalfit(freq,data)

[resp,t]=impulse(fit_data,1e-12,1e4);

plot(t,resp);
```

See Also

`freqresp`	RF Toolbox
`rationalfit`	RF Toolbox
`rfmodel`	RF Toolbox
`rfmodel.rational`	RF Toolbox
`write`	RF Toolbox

listformat

Purpose

List valid formats for specified circuit object parameter

Syntax

```
list = listformat(h,'parameter')
```

Description

`list = listformat(h,'parameter')` lists the allowable formats for the specified network parameter. The first listed format is the default format for the specified parameter.

In these lists, `'Abs'` and `'Mag'` are the same as `'Magnitude (linear)'`, and `'Angle'` is the same as `'Angle (degrees)'`.

Use the `listparam` function to get the valid parameters of a circuit object.

Note Before calling `listformat`, you must use the `analyze` function to perform a frequency domain analysis for the circuit object.

Examples

```
trl = rfckt.txline;
f = [1e9:1.0e7:3e9];
analyze(trl,f);
list = listformat(trl,'S11')

list =
    'dB'
    'Magnitude (decibels)'
    'Abs'
    'Mag'
    'Magnitude (linear)'
    'Angle'
    'Angle (degrees)'
    'Angle (radians)'
    'Real'
    'Imag'
    'Imaginary'
```

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

listparam

Purpose

List valid parameters for specified circuit object

Syntax

`list = listparam(h)`

Description

`list = listparam(h)` lists the valid parameters for the specified circuit object h.

Note Before calling `listparam`, you must use the `analyze` function to perform a frequency domain analysis for the circuit object.

Examples

The following example show you how to list the parameters for a transmission line object.

```
trl = rfckt.txline;
f = [1e9:1.0e7:3e9];
analyze(trl,f);
list = listparam(trl)

list =
    'S11'
    'S12'
    'S21'
    'S22'
    'GAMMAIn'
    'GAMMAOut'
    'VSWRIn'
    'VSWROut'
    'OIP3'
    'NF'
```

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox

`getz0`	RF Toolbox
`listformat`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Plot specified circuit object parameters on X-Y plane

Syntax

```
lineseries = plot(h,parameter)
lineseries = plot(h,parameter1,...,parametern)
lineseries = plot(h,parameter1,...,parametern,format)
lineseries = plot(h,'budget',...)
```

Description

`lineseries = plot(h,parameter)` plots the specified `parameter` on an X-Y plane in the default format. `h` is the handle of a circuit (`rfckt`) object.

Type `listparam(h)` to get a list of valid parameters for a circuit object, `h`. Type `listformat(h,parameter)` to see the legitimate formats for a specified `parameter`. The first listed format is the default for the specified parameter.

`The plot` function returns a column vector of handles to `lineseries` objects, one handle per line. This is the same as the output returned by the MATLAB `plot` function.

`lineseries = plot(h,parameter1,...,parametern)` plots the network parameters `parameter1,...,` `parametern` from the object `h` on an X-Y plane.

`lineseries = plot(h,parameter1,...,parametern,format)` plots the network parameters `parameter1,...,` `parametern` in the specified `format`. `format` is the format of the data to be plotted, e.g. `'Magnitude (decibels)'`.

`lineseries = plot(h,'budget',...)` plots budget data for the network parameters `parameter1,...,` `parametern` from the `rfckt.cascade` object `h`.

Use the Property Editor (`propertyeditor`) or the MATLAB `set` function to change `lineseries properties`. The reference pages for MATLAB functions such as `figure`, `axes`, and `text` also list available properties and provide links to more complete property descriptions.

Note For all circuit objects except those that contain data from a data file, you must perform a frequency domain analysis with the `analyze` function before calling `plot`.

Note Use the MATLAB `plot` function to plot network parameters that are specified as vector data and are not part of a circuit (`rfckt`) object or data (`rfdata`) object.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

polar

Purpose

Plot specified circuit object parameters on polar coordinates

Syntax

```
lineseries = polar(h,parameter1,...,parametern,format)
```

Description

`lineseries = polar(h,parameter1,...,parametern,format)` plots the parameters `parameter1,...`, `parametern` from the object `h` on polar coordinates. `h` is the handle of a circuit (`rfckt`) object. `format` is the format of the data to be plotted, e.g., `'Magnitude (decibels)'`.

`polar` returns a column vector of handles to `lineseries` objects, one handle per line. This is the same as the output returned by the MATLAB `polar` function.

Use the Property Editor (`propertyeditor`) or the MATLAB `set` function to change the `lineseries properties`. The reference pages for MATLAB functions such as `figure`, `axes`, and `text` list available properties and provide links to more complete descriptions.

Type `listparam(h)` to get a list of valid parameters for a circuit object `h`. Type `listformat(h,parameter)` to see the legitimate formats for a specified `parameter`.

Note For all circuit objects except those that contain data from a data file, you must use the `analyze` function to perform a frequency domain analysis before calling `polar`.

Note Use the MATLAB `polar` function to plot parameters that are not part of a circuit (`rfckt`) object, but are specified as vector data.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox

`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Fit rational function to broadband data

Syntax

```
h = rationalfit(freq,data)
h = rationalfit(freq,data,tol,weight,delayfactor,diszero,
   npoles)
```

Description

`h = rationalfit(freq,data)` fits a rational function model of the form

$$F(s) = \left(\sum_{k=1}^{n} \frac{C_k}{s - A_k} + D\right) e^{-s*Delay}, \quad s = j2\pi * freq$$

to the complex vector of passive values in `data` over the corresponding frequency values in the positive vector `freq`. The function returns a handle to the rational function model object, `h`, whose properties, `A`, `C`, `D`, and `Delay`, are shown in the preceding equation.

`h = rationalfit(freq,data,tol,weight,delayfactor,diszero,npoles)` fits a rational function to the data using the optional arguments `tol`, `weight`, `delayfactor`, `diszero`, and `npoles` that control the data fitting.

`tol` is a scalar that specifies the relative error-fitting tolerance, in decibels. The relative error of the fit is computed as $\text{relerror} = \frac{\text{norm}(\text{abs}(data - fitdata))}{\text{norm}(\text{abs}(data))}$, where `fitdata` is a vector containing the dependent values of the fit data. The default tolerance is -10 dB. If the model does not fit the original data to within the specified tolerance, a warning message appears.

`weight` is a vector that specifies the weighting of the fit at each frequency. You can increase the weight at a particular frequency to improve the model fitting at that frequency. The length of `weight` must be equal to the length of `freq`. The default is [].

`delayfactor` is a scaling factor between 0 and 1 that controls the amount of delay used to fit the data. The `Delay` used to fit the model to the data is `delayfactor` times the ratio of the phase difference of the data across the specified frequencies to the difference between the maximum and minimum frequencies. The default value is 0. This value guarantees that no fitting accuracy is lost due to overestimating the delay. However, you may be able to fit the data accurately with a lower-order model (i.e., a model with fewer poles) by increasing `delayfactor`.

`diszero` is a Boolean value that specifies whether the constant term `D` in the equation above is zero or nonzero. A value of 1 indicates that `D` is zero. A value of 0 indicates that `D` is nonzero. The default value of 1 is appropriate for almost every set of data. However, if you are having trouble fitting the data after adjusting the other control arguments, you should change the value of `diszero`.

`npoles` is an even integer or a two-element vector `[M,N]` of even integers.

- If `npoles` is an integer, it specifies the number of poles (`k` in the previous equation) to use to fit the rational function to the data.
- If `npoles` is a vector, it specifies a range of values of the number of poles, `k`, to use in trying to fit the data. `rationalfit` first tries to fit the data using `M` poles. If the fit error using `M` poles is greater than `tol`, `rationalfit` increases the number of poles in the fit until the error is less than `tol` or the number of poles reaches `N`.

Specifying `npoles` can speed up the fitting process because `rationalfit` does not spend time trying to fit a model with an unreasonably small number of poles to the data. As a rule of thumb, you should specify a value of `npoles` greater than or equal to twice the number of peaks that can be readily observed by plotting the data in the frequency domain. The default is [4, MAX], where MAX is either one quarter the number of frequency samples or 256, whichever is smaller.

To see how well the model fits the original data, use the `freqresp` function to compute the frequency response of the model. Then, plot the original data and the frequency response of the rational function model. See the `freqresp` reference page or the examples in the next section for more information.

Examples

The following example shows how to fit a rational function model to data from the `passive.s2p` file and how to generate plots that compare the frequency response of the original data to that of the fit data.

```
orig_data = read(rfdata.data,'passive.s2p')
freq = orig_data.Freq;
data = orig_data.S_Parameters(1,1,:);
fit_data = rationalfit(freq,data)
[resp,freq] = freqresp(fit_data,freq);

plot(orig_data,'S11','dB');
hold on
plot(freq/1e9,db(resp));

figure

plot(orig_data,'S11','Angle (radians)');
hold on
plot(freq/1e9,unwrap(angle(resp)));
```

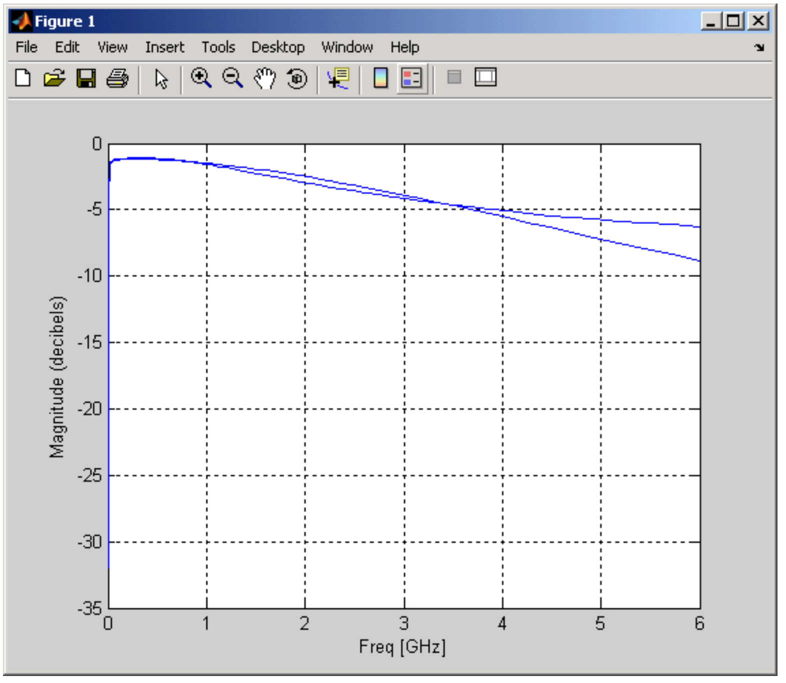
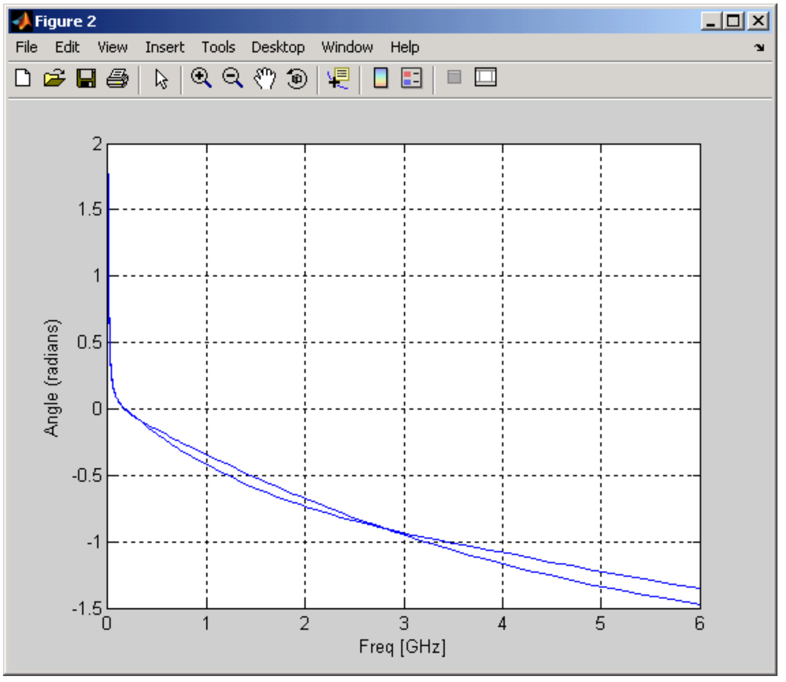


Figure 1
File Edit View Insert Tools Desktop Window Help
Magnitude (decibels)
0
-5
-10
-15
-20
-25
-30
-35
0
1
2
3
4
5
6
Freq [GHz]



References

B. Gustavsen and A. Semlyen, "Rational approximation of frequency domain responses by vector fitting," IEEE Trans. Power Delivery, Vol. 14, No. 3, pp. 1052–1061, July 1999.

R. Zeng and J. Sinsky, "Modified Rational Function Modeling Technique for High Speed Circuits," IEEE MTT-S Int. Microwave Symp. Dig., San Francisco, CA, June 11–16, 2006.

See Also

`freqresp`	RF Toolbox
`impulse`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox

`rfmodel`	RF Toolbox
`s2tf`	RF Toolbox
`write`	RF Toolbox

Purpose Read RF data from file to new or existing circuit or data object

Syntax

```
h = read(h)
h = read(h,filename)
h = read(rfckt.datafile,filename)
h = read(rfckt.passive,filename)
h = read(rfckt.amplifier,filename)
h = read(rfckt.mixer,filename)
h = read(rfdata.data,filename)
```

Description

`h = read(h)` prompts you to select a `.snp`, `.ynp`, `.znp`, `.hnp`, or `.amp` file, where `n` is the number of ports. `read` then updates `h` with data from the file you select. Here, `h` can be a circuit or data object. For information about the `.amp` format, see Appendix A, "AMP File Format" .

`h = read(h,filename)` updates `h` with data from the specified file. Here, `h` can be a circuit or data object. `filename` is a string, representing the filename of a `.snp`, `.ynp`, `.znp`, `.hnp`, or `.amp` file. The filename must include the file extension.

`h = read(rfckt.datafile,filename)` creates an `rfckt.datafile` object `h`, reads the RF data from the specified file, and stores it in `h`.

`h = read(rfckt.passive,filename)` creates an `rfckt.passive` object `h`, reads the RF data from the specified file, and stores it in `h`.

`h = read(rfckt.amplifier,filename)` creates an `rfckt.amplifier` object `h`, reads the RF data from the specified file, and stores it in `h`.

`h = read(rfckt.mixer,filename)` creates an `rfckt.mixer` object `h`, reads the RF data from the specified file, and stores it in `h`.

`h = read(rfdata.data,filename)` creates an `rfdata.data` object `h`, reads the RF data from the specified file, and stores it in `h`.

References

EIA/IBIS Open Forum, "Touchstone File Format Specification," Rev. 1.1, 2002 (`http://www.vhdl.org/pub/ibis/connector/touchstone_spec11.pdf`).

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

restore

Purpose

Restore data to original frequencies

Syntax

```
h = restore(h)
```

Description

`h = restore(h)` restores data in `h` to the original frequencies of `NetworkData` for plotting. Here, `h` can be `rfckt.datafile`, `rfckt.passive`, `rfckt.amplifier`, or `rfckt.mixer`.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose Construct RF circuit object

Syntax

```
h = rfckt.component('Property1',value1,...)
```

Description

`h = rfckt.component('Property1',value1,...)` returns a circuit object, `h`, of type *`component`*. See the individual `rfckt` component reference pages for information about a specific circuit object and its properties. See Chapter 2, "Modeling an RF Component" for additional information.

Objects

The `component` for an `rfckt` object specifies the type of RF circuit object. The following table lists the available RF circuit objects.

rfckt.*component*	**Description**
`rfckt.amplifier`	Amplifier, described by an `rfdata` object
`rfckt.cascade`	Cascaded network, described by the list of components and networks that comprise it
`rfckt.coaxial`	Coaxial transmission line, described by dimensions and electrical characteristics
`rfckt.cpw`	Coplanar waveguide transmission line, described by dimensions and electrical characteristics
`rfckt.datafile`	General circuit, described by a data file
`rfckt.delay`	Delay line, described by loss and delay
`rfckt.hybrid`	Hybrid connected network, described by the list of components and networks that comprise it

rfckt.*component*	**Description**
`rfckt.hybridg`	Inverse hybrid connected network, described by the list of components and networks that comprise it
`rfckt.lcbandpasspi`	LC bandpass pi network, described by LC values
`rfckt.lcbandpasstee`	LC bandpass tee network, described by LC values
`rfckt.lcbandstoppi`	LC bandstop pi network, described by LC values
`rfckt.lcbandstoptee`	LC bandstop tee network, described by LC values
`rfckt.lchighpasspi`	LC highpass pi network, described by LC values
`rfckt.lchighpasstee`	LC highpass tee network, described by LC values
`rfckt.lclowpasspi`	LC lowpass pi network, described by LC values
`rfckt.lclowpasstee`	LC lowpass tee network, described by LC values
`rfckt.microstrip`	Microstrip transmission line, described by dimensions and electrical characteristics
`rfckt.mixer`	Mixer, described by an `rfdata` object
`rfckt.parallel`	Parallel connected network , described by the list of components and networks that comprise it

rfckt.*component*	Description
`rfckt.parallelplate`	Parallel-plate transmission line, described by dimensions and electrical characteristics
`rfckt.rlcgline`	RLCG transmission line, described by RLCG values
`rfckt.series`	Series connected network, described by the list of components and networks that comprise it
`rfckt.seriesrlc`	Series RLC network, described by RLC values
`rfckt.shuntrlc`	Shunt RLC network, described by RLC values
`rfckt.twowire`	Two-wire transmission line, described by dimensions and electrical characteristics
`rfckt.txline`	General transmission line, described by dimensions and electrical characteristics

Functions

The following table lists the functions that act on circuit objects, the types of objects on which each can act, and the purpose of each function. These functions are also referred to as *methods*.

Function	Types of Objects	Purpose
`analyze`	All circuit objects	Analyze a circuit object in the frequency domain.

Function	Types of Objects	Purpose
`calculate`	All circuit objects	Calculate specified parameters for a circuit object.
`copy`	All circuit objects	Copy a circuit or data object.
`extract`	All circuit objects	Extract specified network parameters from a circuit or data object and return the result in an array.
`getdata`	All circuit objects	Get data object containing analyzed result of a specified circuit object.
`getz0`	`rfckt.txline`, `rfckt.rlcgline`, `rfckt.twowire`, `rfckt.parallelplate`, `rfckt.coaxial`, `rfdata.microstrip`, `rfckt.cpw`	Get characteristic impedance of a transmission line.
`listformat`	All circuit objects	List valid formats for a specified circuit object parameter.
`listparam`	All circuit objects	List valid parameters for a specified circuit object.
`plot`	All circuit objects	Plot the specified circuit object parameters on an X-Y plane.

Function	Types of Objects	Purpose
`polar`	All circuit objects	Plot the specified circuit object parameters on polar coordinates.
`read`	`rfckt.datafile`, `rfckt.passive`, `rfckt.amplifier`, `rfckt.mixer`	Read RF data from a file to a new or existing circuit object.
`restore`	`rfckt.datafile`, `rfckt.passive`, `rfckt.amplifier`, `rfckt.mixer`	Restore data to original frequencies of `NetworkData` for plotting.
`smith`	All circuit objects	Plot the specified circuit object parameters on a Smith chart.
`write`	All circuit objects	Write RF data from a circuit object to a file.

Properties

Properties vary for each type of component. See the individual component reference pages for information about properties.

Viewing Object Properties

You can use `get` to view an `rfckt` object's properties. To see a specific property of an object `h`, use

```
get(h,'PropertyName')
```

To see all properties for an object `h`, use

```
get(h)
```

Changing Object Properties

To see the properties of an object `h` whose values you can change use

```
set(h)
```

To change specific properties of object `h`, use

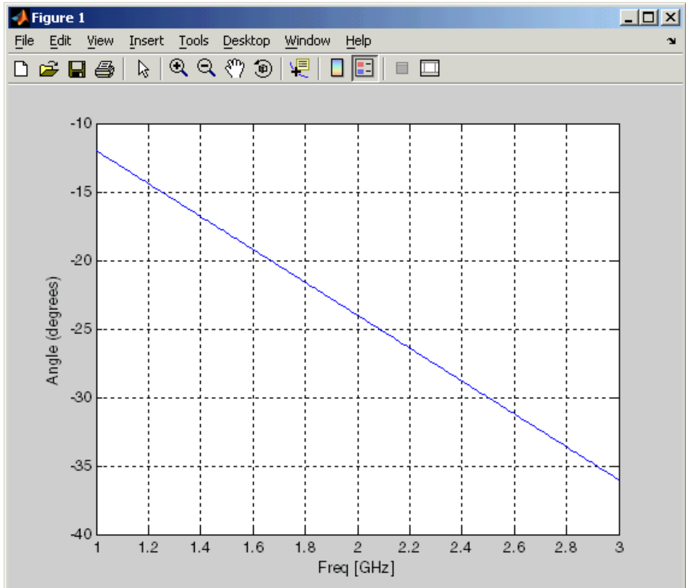
```
set(h,'PropertyName1',value1,'PropertyName2',value2,...)
```

Note You must use single quotation marks around the property name.

Examples

Construct a general transmission line, `trl`, with the default characteristic impedance of 50 ohms, phase velocity of 299792458 meters per second, and line length of 0.01 meters. Then perform frequency domain analysis from 1.0 GHz to 3.0 GHz. Plot the resulting S21 network parameters, using the `'angle'` format, on the X-Y plane.

```
trl = rfckt.txline;
f = [1e9:1.0e7:3e9];     % Simulation frequencies
analyze(trl,f);          % Do frequency domain analysis
figure
plot(trl,'s21','angle'); % Plot magnitude of S21
```



You can also use other RF Toolbox functions such as `polar` and `smith` to visualize results.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`copy`	RF Toolbox
`getdata`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox

`rfdata`	RF Toolbox
`smith`	RF Toolbox

Purpose Construct amplifier object

Syntax

```
h = rfckt.amplifier
h = rfckt.amplifier('Property1',value1,'Property2',value2,...)
```

Description `h = rfckt.amplifier` returns an amplifier circuit object whose properties all have their default values.

`h = rfckt.amplifier('Property1',value1,'Property2',value2,...)` returns a circuit object, `h`, based on the specified properties. Properties you do not specify retain their default values.

Use the `read` method to read the amplifier data from a Touchstone or AMP data file. See Appendix A, "AMP File Format" for information about the `.amp` format.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis After you create the `rfckt.amplifier` circuit object, use the `analyze` function to calculate the S-parameters, output third-order intercept point, and noise figure at the specified frequencies. For `rfckt.amplifier` objects, `freq` must be nonnegative.

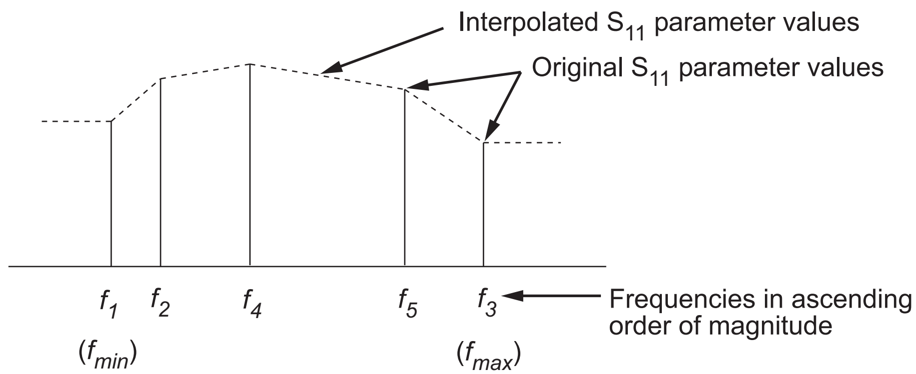
```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

If the `'NetworkData'` property of your `rfckt.amplifier` object contains network Y- or Z-parameters, the `analyze` function first converts the parameters to S-parameters. Using the interpolation method you specify with the `'IntpType'` property, the `analyze` function interpolates the S-parameter values to determine the S-parameters at the specified frequencies.

Specifically, the analyze function orders the S-parameters according to the ascending order of their frequencies, f_n. It then interpolates the S-parameters, using the MATLAB interp1 function. For example, the curve in the following diagram illustrates the result of interpolating the S11 parameters at five different frequencies.



You can specify the interpolation method as Cubic, Linear (default), or Spline. For more information, see "One-Dimensional Interpolation" and the interp1 reference page in the MATLAB documentation.

As shown in the diagram above, the analyze function uses the parameter values at f_{min}, the minimum input frequency, for all frequencies smaller than f_{min}. It uses the parameters values at f_{max}, the maximum input frequency, for all frequencies greater than f_{max}. In both cases, the results may not be accurate.

OIP3

The analyze function uses the data stored in the 'NonlinearData' property of the rfckt.amplifier object to calculate OIP3.

Noise Figure

The analyze function uses the data stored in the 'NoiseData' property of the rfckt.amplifier object to calculate the noise figure.

Properties

This table lists properties associated with `rfckt.amplifier` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the amplifier object.	Handle. Default is `[1-by-1 rfdata.data]`.
`IntpType`	Interpolation method.	`'Linear'` (default), `'Spline'`, or `'Cubic'`
`Name`	Object name (read only).	String. `'Amplifier'`
`NetworkData`	`rfdata.network` object.	The default network parameters are taken from the `'default.amp'` data file.
`NoiseData`	Scalar noise figure in dB, `rfdata.noise` object or `rfdata.nf` object.	The default noise data values are taken from the `'default.amp'` data file and stored in an `rfdata.noise` object.
`NonlinearData`	Scalar OIP3 in dBm, `rfdata.power` object or `rfdata.ip3` object.	The default data values are taken from the `'default.amp'` data file and stored in an `rfdata.power` object.
`nPort`	Number of ports (read only).	Integer. The value is always 2.

References

EIA/IBIS Open Forum, "Touchstone File Format Specification," Rev. 1.1, 2002 (`http://www.vhdl.org/pub/ibis/connector/touchstone_spec11.pdf`).

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.datafile`	RF Toolbox
`rfckt.mixer`	RF Toolbox
`rfckt.passive`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct cascaded network object

Syntax

```
h = rfckt.cascade
h = rfckt.cascade('Property1',value1,'Property2',value2,...)
```

Description

`h = rfckt.cascade` returns a cascaded network object whose properties all have their default values.

`h = rfckt.cascade('Property1',value1,'Property2',value2,...)` returns a cascaded network object, `h`, based on the specified properties. Use the `'Ckts'` property to specify the `rfckt` objects to be cascaded. Properties you do not specify retain their default values.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `cascade` network object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.cascade` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

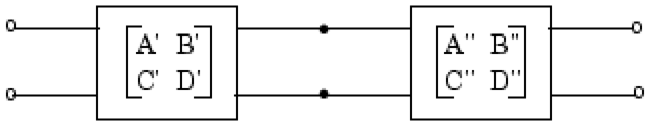
The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

The `analyze` function first calculates the ABCD-parameters of the cascaded network. It starts by converting each component network's parameters to an ABCD-parameters matrix. The figure shows a cascaded network consisting of two 2-port networks, each represented by its ABCD matrix.

The `analyze` function then calculates the ABCD-parameter matrix for the cascaded network by calculating the product of the ABCD matrices of the individual networks.

The figure shows a cascaded network consisting of two 2-port networks, each represented by its ABCD-parameters.



The following equation illustrates calculations of the ABCD-parameters for two 2-port networks.

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix} \begin{bmatrix} A'' & B'' \\ C'' & D'' \end{bmatrix}$$

Finally, `analyze` converts the ABCD-parameters of the cascaded network to S-parameters at the frequencies specified in the `analyze` input argument `freq`.

OIP3

The `analyze` function calculates the output power at the third-order intercept point (OIP3) for an N-element cascade using the following equation

$$OIP_3 = \frac{1}{\frac{1}{OIP_{3,N}} + \frac{1}{(G_N \cdot OIP_{3,N-1})} + \ldots + \frac{1}{(G_N \cdot G_{N-1} \cdot \ldots \cdot G_2 \cdot OIP_{3,1})}}$$

where G_n is the gain of the nth element of the cascade and $OIP_{3,n}$ is the OIP3 of the nth element.

Noise Figure

The `analyze` function calculates the noise figure for an N-element cascade using the following equation

$$NF = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 \cdot G_2} + \ldots + \frac{NF_N - 1}{G_1 \cdot G_2 \cdot \ldots \cdot G_{N-1}}$$

where G_n is the gain of the nth element of the cascade and NF_n is the noise figure of the nth element.

Properties

This table lists properties associated with `rfckt.cascade` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the cascaded network object.	Handle. Default is `[]`.
`Ckts`	Cell array containing all circuit objects in the network, in order from source to load. All circuits must be 2-port.	Handles to `rfckt` objects. Default is `{}`.
`Name`	Object name (read only).	String. `'Cascaded Network'`
`nPort`	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox

`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.hybrid`	RF Toolbox
`rfckt.hybridg`	RF Toolbox
`rfckt.parallel`	RF Toolbox
`rfckt.series`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct coaxial transmission line object

Syntax

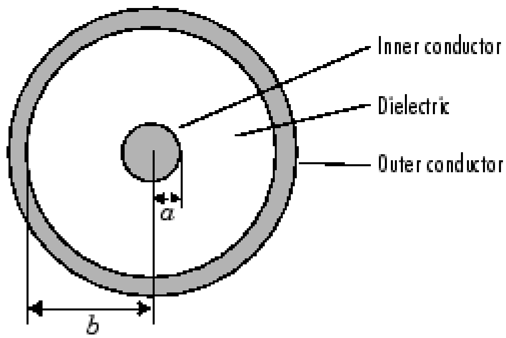
```
h = rfckt.coaxial('Property1',value1,'Property2',value2,...)
h = rfckt.coaxial
```

Description

`h = rfckt.coaxial('Property1',value1,'Property2',value2,...)` returns a coaxial transmission line object, `h`, with the specified properties. Properties you do not specify retain their default values.

`h = rfckt.coaxial` returns a coaxial transmission line object whose properties all have their default values.

A coaxial transmission line is shown here in cross-section. Its physical characteristics include the radius of the inner conductor of the coaxial transmission line a, and the radius of the outer conductor b.



Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `coaxial` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.coaxial` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

A coaxial transmission line object enables you to model the transmission line as a stub or as a stubless line.

Stubless Transmission Line

If you model the transmission line as a stubless line, the `analyze` function calculates the S-parameters for the specified frequencies, based on the physical length of the transmission line, *D*, and the complex propagation constant, *k*.

$$S_{11} = 0$$

$$S_{12} = e^{-kD}$$

$$S_{21} = e^{-kD}$$

$$S_{22} = 0$$

k is a vector whose elements correspond to the elements of the input vector `freq`. *k* can be expressed in terms of the resistance (*R*), inductance (*L*), conductance (*G*), and capacitance (*C*) per unit length (meters) as

$$k = k_r + jk_i = \sqrt{(R + j2\pi fL)(G + j2\pi fC)}$$

where *f* is the frequency range specified in the `analyze` input argument `freq`, and

$$R = \frac{1}{2\pi\sigma_{cond}\delta}\left(\frac{1}{a}+\frac{1}{b}\right)$$

$$L = \frac{\mu}{2\pi}\ln(b/a)$$

$$G = \frac{2\pi\sigma_{diel}}{\ln(b/a)}$$

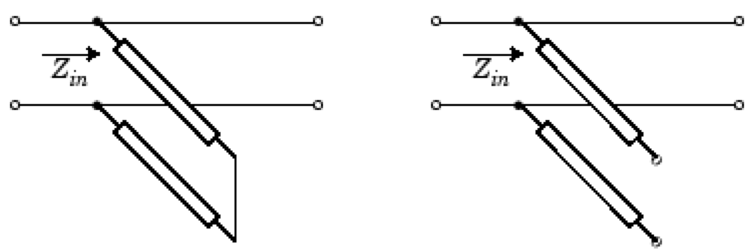
$$C = \frac{2\pi\varepsilon}{\ln(b/a)}$$

In these equations, σ_{cond} is the conductivity in the conductor and σ_{diel} is the conductivity in the dielectric. μ is the relative permeability of the dielectric, ε is its permittivity as derived from the EpsilonR property, and skin depth δ is calculated as $1/\sqrt{\pi f \mu \sigma_{cond}}$.

Shunt and Series Stubs

If you model the transmission line as a shunt or series stub, the analyze function first calculates the ABCD-parameters at the specified frequencies. It then uses the abcd2s function to convert the ABCD-parameters to S-parameters.

When you set the StubMode property to 'Shunt', the 2-port network consists of a stub transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the shunt circuit. The ABCD-parameters for the shunt stub are calculated as

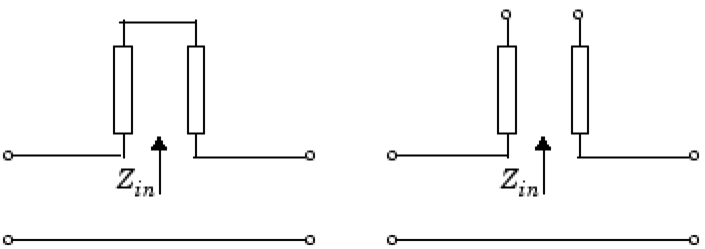
$A = 1$

$B = 0$

$C = 1/Z_{in}$

$D = 1$

When you set the StubMode property to 'Series', the 2-port network consists of a series transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the series circuit. The ABCD-parameters for the series stub are calculated as

$A = 1$

$B = Z_{in}$

$C = 0$

$D = 1$

Properties

This table lists properties useful to rfckt.coaxial objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the coaxial transmission line object.	Handle. Default is [].
EpsilonR	Relative permittivity of the dielectric expressed as the ratio of the permittivity of the dielectric to permittivity in free space ε_0.	Default is 2.3.
Inner Radius	Radius of the inner conductor.	Meters. Default is 7.25e-4.
LineLength	Physical length of the transmission line.	Meters. Default is 0.01.
Loss	Reduction in strength of the signal as it travels over the transmission line. Read-only; set by the analyze function.	Decibels per meter. Default is [].
MuR	Relative permeability of the dielectric expressed as the ratio of the permeability of the dielectric to permeability in free space μ_0.	Default is 1.

Property	Description	Units, Values
`Name`	Object name (read only).	String. `'Coaxial Transmission Line'`
`nPort`	Number of ports (read only).	Integer. The value is always `2`.
`Outer Radius`	Radius of the outer conductor.	Meters. Default is `0.0026`.
`PV`	Phase velocity. Propagation velocity of a uniform plane wave on the transmission line. Read-only; set by the `analyze` function.	Meters per second. Default is `[]`.
`SigmaCond`	Conductivity in the conductor.	Siemens per meter (S/m). Default is `Inf`.
`SigmaDiel`	Conductivity in the dielectric.	Siemens per meter (S/m). Default is `0`.
`StubMode`	Type of stub.	String. `'None'` (default), `'Series'`, or `'Shunt'`
`Termination`	Stub termination for stub models `Shunt` and `Series`.	String. `'None'` (default), `'Open'`, or `'Short'`. Use `'None'` when `StubMode` is `'None'`.
`Z0`	Characteristic impedance. Read-only; set by the `analyze` function.	Ohms. Default is `[]`.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.cpw`	RF Toolbox
`rfckt.microstrip`	RF Toolbox
`rfckt.parallelplate`	RF Toolbox
`rfckt.rlcgline`	RF Toolbox
`rfckt.twowire`	RF Toolbox
`rfckt.txline`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.cpw

Purpose

Construct coplanar waveguide transmission line object

Syntax

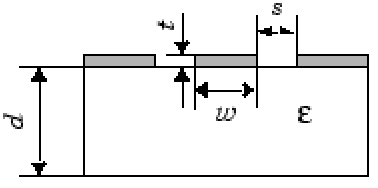
```
h = rfckt.cpw('Property1',value1,'Property2',value2,...)
h = rfckt.cpw
```

Description

`h = rfckt.cpw('Property1',value1,'Property2',value2,...)` returns a coplanar waveguide transmission line object, `h`, with the specified properties. Properties you do not specify retain their default values.

`h = rfckt.cpw` returns a coplanar waveguide transmission line object whose properties all have their default values.

A coplanar waveguide transmission line is shown here in cross-section. Its physical characteristics include the conductor width (w), the conductor thickness (t), the slot width (s), the substrate height (d), and the permittivity constant (ε).



Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `rfckt.cpw` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.cpw` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

A coplanar waveguide transmission line object enables you to model the transmission line as a stub or as a stubless line.

Stubless Transmission Line

If you model the transmission line as a stubless line, the `analyze` function calculates the S-parameters for the specified frequencies, based on the physical length of the transmission line, D, and the complex propagation constant, k.

$$S_{11} = 0$$

$$S_{12} = e^{-kD}$$

$$S_{21} = e^{-kD}$$

$$S_{22} = 0$$

$k = \alpha_a + i\beta$, where α_a is the attenuation coefficient and β is the wave number. The attenuation coefficient α_a is related to the loss, α, by

$$\alpha_a = -\ln 10^{-\frac{\alpha}{20}}$$

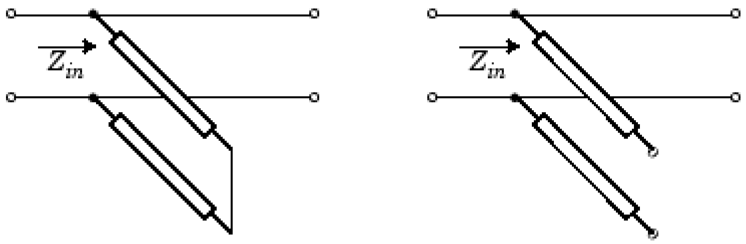
where α is the reduction in signal strength, in dB, per unit length. α combines both conductor loss and dielectric loss and is derived from the `rfckt.cpw` object properties.

The `analyze` function normalizes the S-parameters to 50 ohms. This is the default reference impedance of the `rfdata.data` object that the `analyze` function creates.

Shunt and Series Stubs

If you model the transmission line as a shunt or series stub, the `analyze` function first calculates the ABCD-parameters at the specified frequencies. It then uses the `abcd2s` function to convert the ABCD-parameters to S-parameters.

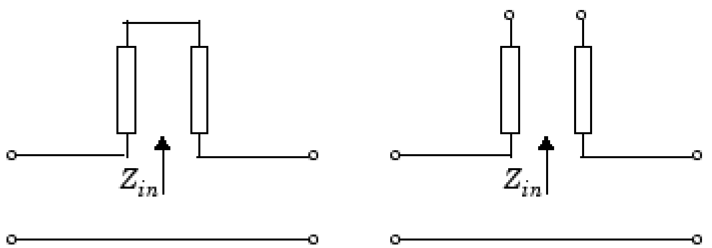
When you set the StubMode property to 'Shunt', the 2-port network consists of a stub transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the shunt circuit. The ABCD-parameters for the shunt stub are calculated as

$$A = 1$$
$$B = 0$$
$$C = 1/Z_{in}$$
$$D = 1$$

When you set the StubMode property to 'Series', the 2-port network consists of a series transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the series circuit. The ABCD-parameters for the series stub are calculated as

$$A = 1$$
$$B = Z_{in}$$
$$C = 0$$
$$D = 1$$

Properties

This table lists properties useful to rfckt.cpw objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the coaxial transmission line object.	Handle. Default is [].
ConductorWidth	Physical width of the conductor.	Meters. Default is 0.6e-4.
EpsilonR	Relative permittivity of the dielectric expressed as the ratio of the permittivity of the dielectric to permittivity in free space ε_0.	Default is 9.8.
Height	Thickness of the dielectric on which the conductor resides.	Meters. Default is 0.635e-4.
LineLength	Physical length of the transmission line.	Meters. Default is 0.01.

Property	Description	Units, Values
`Loss`	Reduction in strength of the signal as it travels over the transmission line. Read-only; set by the `analyze` function.	Decibels per meter. Default is `[]`.
`LossTangent`	Loss angle tangent of the dielectric.	Default is `0`.
`Name`	Object name (read only).	String. `'Coplanar Waveguide Transmission Line'`
`nPort`	Number of ports (read only).	Integer. The value is always `2`.
`PV`	Phase velocity. Propagation velocity of a uniform plane wave on the transmission line. Read-only; set by the `analyze` function.	Meters per second. Default is `[]`.
`SigmaCond`	Conductivity in the conductor.	Siemens per meter (S/m). Default is `Inf`.
`SlotWidth`	Physical width of the slot.	Meters. Default is `0.2e-4`.
`StubMode`	Type of stub.	String. `'None'` (default), `'Series'`, or `'Shunt'`

Property	Description	Units, Values
Termination	Termination for stub modes 'Shunt' and 'Series'.	String. 'None' (default), 'Open', or 'Short'. Use 'None' when StubMode is 'None'.
Thickness	Physical thickness of the conductor.	Meters. Default is 0.005e-6.
Z0	Characteristic impedance. Read-only; set by the analyze function.	Ohms. Default is [].

References

Gupta, K. C., Ramesh Garg, Inder Bahl, and Prakash Bhartia, *Microstrip Lines and Slotlines*, 2nd Edition, Artech House, Inc., Norwood, MA, 1996.

See Also

analyze	RF Toolbox
calculate	RF Toolbox
getz0	RF Toolbox
listformat	RF Toolbox
listparam	RF Toolbox
plot	RF Toolbox
polar	RF Toolbox
rfckt	RF Toolbox
rfckt.coaxial	RF Toolbox
rfckt.microstrip	RF Toolbox
rfckt.parallelplate	RF Toolbox

`rfckt.rlcgline`	RF Toolbox
`rfckt.twowire`	RF Toolbox
`rfckt.txline`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct circuit object from data file

Syntax

```
h = rfckt.datafile('Property1',value1,'Property2',value2,...)
h = rfckt.datafile
```

Description

`h = rfckt.datafile('Property1',value1,'Property2',value2,...)` returns a circuit object, `h`, based on the specified properties. Use the `'File'` property to specify a source `.snp`, `.ynp`, `.znp`, `.hnp`, or `.amp` file that describes an `n`-port circuit. Properties you do not specify retain their default values. See Appendix A, "AMP File Format" for information about the `.amp` format.

`h = rfckt.datafile` returns a circuit object whose properties all have their default values.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `datafile` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.datafile` objects, `freq` must be nonnegative.

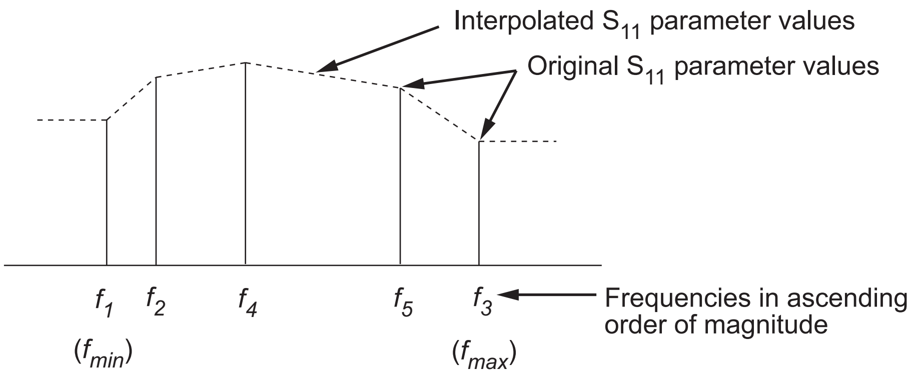
```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

If the file you specify with the `'File'` property contains network Y- or Z-parameters, `analyze` first converts these parameters, as they exist in the `rfckt.datafile` object, to S-parameters. Using the interpolation method you specify with the `'IntpType'` property, `analyze` interpolates the S-parameters to determine the S-parameters at the specified frequencies.

Specifically, `analyze` orders the S-parameters according to the ascending order of their frequencies, f_n. It then interpolates the S-parameters, using the MATLAB `interp1` function. For example, the curve in the following diagram illustrates the result of interpolating the S11 parameters at five different frequencies.



You can specify the interpolation method as `cubic`, `linear` (default), or `spline`. For more information, see "One-Dimensional Interpolation" and the `interp1` reference page in the MATLAB documentation.

As shown in the diagram above, `analyze` uses the parameter values at f_{min}, the minimum input frequency, for all frequencies smaller than f_{min}. It uses the parameters values at f_{max}, the maximum input frequency, for all frequencies greater than f_{max}. In both cases, the results may not be accurate.

Properties

This table lists properties useful to `rfckt.datafile` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the circuit object.	Handle. Default is [1x1 rfdata.data]
File	.snp, .ynp, .znp, or .hnp file describing a circuit, where n is the number of ports.	String. Default is 'passive.s2p'.
IntpType	Interpolation method.	'linear' (default), 'spline', or 'cubic'
Name	Object name (read only).	String. 'Data File'
nPort	Number of ports.	Integer. Default is 2.

References

EIA/IBIS Open Forum, “Touchstone File Format Specification,” Rev. 1.1, 2002 (http://www.vhdl.org/pub/ibis/connector/touchstone_spec11.pdf).

See Also

analyze	RF Toolbox
calculate	RF Toolbox
listformat	RF Toolbox
listparam	RF Toolbox
plot	RF Toolbox
polar	RF Toolbox
read	RF Toolbox
restore	RF Toolbox
rfckt	RF Toolbox

`rfckt.amplifier`	RF Toolbox
`rfckt.mixer`	RF Toolbox
`rfckt.passive`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose Construct delay line object

Syntax

```
h = rfckt.delay('Property1',value1,'Property2',value2,...)
h = rfckt.delay
```

Description

`h = rfckt.delay('Property1',value1,'Property2',value2,...)` returns a delay line object, `h`, based on the specified properties. Properties you do not specify retain their default values.

`h = rfckt.delay` returns a delay line object whose properties all have their default values.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `delay` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.delay` objects, the elements of the vector `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

The delay line object enables you to model time delay which can be lossy or lossless. It is treated as a 2-port linear network.

The `analyze` function calculates the S-parameters for the specified frequencies, based on the values of the delay line's `loss`, α, and time delay, D.

$$S_{11} = 0$$
$$S_{12} = e^{-p}$$
$$S_{21} = e^{-p}$$
$$S_{22} = 0$$

where $p = \alpha_a + i\beta$, and α_a is the attenuation coefficient and β is the wave number. The attenuation coefficient α_a is related to the loss, α, by

$$\alpha_a = -\ln 10^{-\frac{\alpha}{20}}$$

and the wave number β is related to the time delay, *D*, by

$$\beta = 2\pi f D$$

where *f* is the frequency range specified in the `analyze` input argument `freq`.

Properties

This table lists properties useful to `rfckt.delay` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the delay line object.	Handle. Default is `[]`.
`Loss`	Reduction in strength of the signal as it travels over the delay line.	Decibels. Must be positive. Default is `0`.
`Name`	Object name (read only).	String. `'Delay'`

Property	Description	Units, Values
nPort	Number of ports (read only).	Integer. The value is always 2.
TimeDelay	Time delay.	Seconds. Default is 1.0000e-012.
Z0	Characteristic impedance.	Ohms. Default is 50.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

analyze	RF Toolbox
calculate	RF Toolbox
getz0	RF Toolbox
listformat	RF Toolbox
listparam	RF Toolbox
plot	RF Toolbox
polar	RF Toolbox
rfckt	RF Toolbox
rfckt.rlcgline	RF Toolbox
rfckt.txline	RF Toolbox
rfdata	RF Toolbox
smith	RF Toolbox
write	RF Toolbox

Purpose

Construct hybrid connected network object

Syntax

```
h = rfckt.hybrid('Property1',value1,'Property2',value2,...)
h = rfckt.hybrid
```

Description

`h = rfckt.hybrid('Property1',value1,'Property2',value2,...)` returns a hybrid connected network object, `h`, based on the specified properties. Use the `'Ckts'` property to specify the `rfckt` objects to be connected. Properties you do not specify retain their default values.

`h = rfckt.hybrid` returns a hybrid connected network object whose properties all have their default values.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

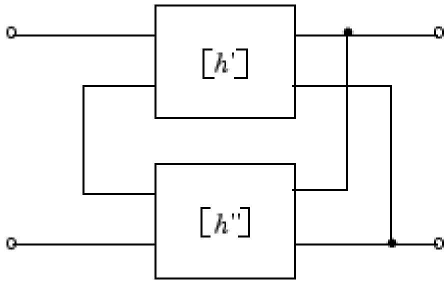
After you create the `hybrid` network object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.hybrid` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

The `analyze` function first calculates the h matrix of the hybrid network. It starts by converting each component network's parameters to an h matrix. The figure shows a hybrid connected network consisting of two 2-port networks, each represented by its h matrix.



where $[h'] = \begin{bmatrix} h_{11}' & h_{12}' \\ h_{21}' & h_{22}' \end{bmatrix}$ and $[h''] = \begin{bmatrix} h_{11}'' & h_{12}'' \\ h_{21}'' & h_{22}'' \end{bmatrix}$

The `analyze` function then calculates the *h* matrix for the hybrid network by calculating the sum of the *h* matrices of the individual networks. The following equation illustrates the calculations for two 2-port networks.

$$[h] = \begin{bmatrix} h_{11}' + h_{11}'' & h_{12}' + h_{12}'' \\ h_{21}' + h_{21}'' & h_{22}' + h_{22}'' \end{bmatrix}$$

Finally, `analyze` converts the *h* matrix of the hybrid network to S-parameters at the frequencies specified in the `analyze` input argument `freq`.

Properties

This table lists properties useful to `rfckt.hybrid` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the hybrid connected network object.	Handle. Default is `[]`.
`Ckts`	Cell array containing all circuit objects in the network, in order from source to load. All circuits must be 2-port.	Handles to `rfckt` objects. Default is `{}`.
`Name`	Object name (read only).	String. `'Hybrid Connected Network'`
`nPort`	Number of ports (read only).	Integer. The value is always `2`.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.cascade`	RF Toolbox

`rfckt.hybridg`	RF Toolbox
`rfckt.parallel`	RF Toolbox
`rfckt.series`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.hybridg

Purpose

Construct inverse hybrid connected network object

Syntax

```
h = rfckt.hybridg('Property1',value1,'Property2',value2,...)
h = rfckt.hybridg
```

Description

`h = rfckt.hybridg('Property1',value1,'Property2',value2,...)` returns an inverse hybrid connected network object, `h`, based on the specified properties. Use the `'Ckts'` property to specify the `rfckt` objects to be connected. Properties you do not specify retain their default values.

`h = rfckt.hybridg` returns an inverse hybrid connected network object whose properties all have their default values.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

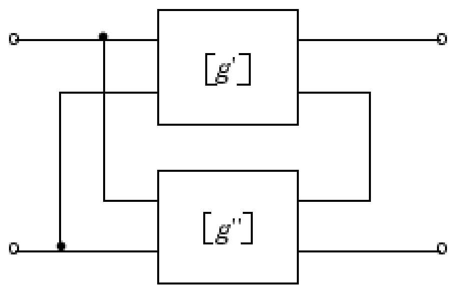
After you create the inverse `hybrid` network object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.hybridg` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

The `analyze` function first calculates the g matrix of the inverse hybrid network. It starts by converting each component network's parameters to a g matrix. The figure shows an inverse hybrid connected network consisting of two 2-port networks, each represented by its g matrix.



where $[g'] = \begin{bmatrix} g_{11}' & g_{12}' \\ g_{21}' & g_{22}' \end{bmatrix}$ and $[g''] = \begin{bmatrix} g_{11}'' & g_{12}'' \\ g_{21}'' & g_{22}'' \end{bmatrix}$

The `analyze` function then calculates the *g* matrix for the inverse hybrid network by calculating the sum of the *g* matrices of the individual networks. The following equation illustrates the calculations for two 2-port networks.

$$[g] = \begin{bmatrix} g_{11}' + g_{11}'' & g_{12}' + g_{12}'' \\ g_{21}' + g_{21}'' & g_{22}' + g_{22}'' \end{bmatrix}$$

Finally, `analyze` converts the *g* matrix of the inverse hybrid network to S-parameters at the frequencies specified in the `analyze` input argument `freq`.

Properties

This table lists properties useful to `rfckt.hybridg` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the inverse hybrid connected network object.	Handle. Default is `[]`.
`Ckts`	Cell array containing all circuit objects in the network, in order from source to load. All circuits must be 2 port.	Handles to `rfckt` objects. Default is `{}`.
`Name`	Object name (read only).	String. `'Hybrid G Connected Network'`
`nPort`	Number of ports (read only).	Integer. The value is always 2.

References

Davis, Artice M., *Linear Circuit Analysis*, PWS Publishing Company, 1998.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox

`rfckt.cascade`	RF Toolbox
`rfckt.hybrid`	RF Toolbox
`rfckt.parallel`	RF Toolbox
`rfckt.series`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.lcbandpasspi

Purpose

Construct LC bandpass pi network object

Syntax

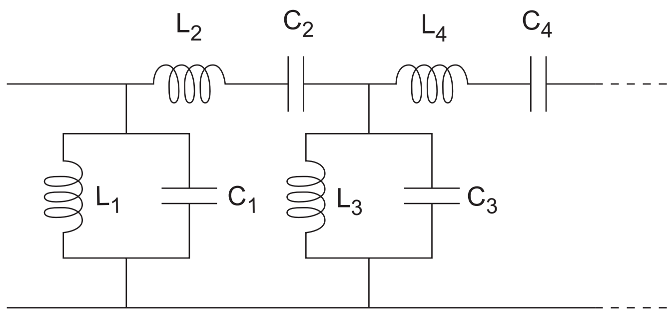
```
h = rfckt.lcbandpasspi('Property1',value1,'Property2',value2,...)
h = rfckt.lcbandpasspi
```

Description

`h = rfckt.lcbandpasspi('Property1',value1,'Property2',value2,...)` returns an LC bandpass pi network object, `h`, based on the specified properties. Properties you do not specify retain their default values.

`h = rfckt.lcbandpasspi` returns an LC bandpass pi network object whose properties all have their default values.

The LC bandpass pi network object is a 2-port network as shown in the circuit diagram below.



Where [L_1, L_2, L_3, L_4, ...] is the value of the `'L'` property, and [C_1, C_2, C_3, C_4, ...] is the value of the `'C'` property.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the lcbandpasspi circuit object, use the analyze function to calculate the S-parameters and noise figure at specified frequencies. For rfckt.lcbandpasspi objects, freq must be strictly positive.

```
analyze(h,freq)
```

The analyze function stores the results of the analysis in the AnalyzedResult property of the circuit object.

Network Parameters

For each inductor and capacitor pair in the network, the analyze function first calculates the ABCD-parameters for each frequency in the input vector, freq. For each series pair, A = 1, B = Z, C = 0, and D = 1, where Z is the impedance of the series pair. For each shunt pair, A = 1, B = 0, C = Y, and D = 1, where Y is the admittance of the shunt pair.

The analyze function cascades the ABCD-parameters for each series and shunt pair, then converts the cascaded parameters to S-parameters using the abcd2s function.

Properties

This table lists properties useful to rfckt.lcbandpasspi objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the LC bandpass pi network object.	Handle. Default is [].

Property	Description	Units, Values
C	Vector containing the capacitances, in order from source to load, of all capacitors in the network. Its length must be equal to the length of the vector you provide for 'L'. All values must be strictly positive.	Farads. Default is [0.3579e-10, 0.0118e-10, 0.3579e-10].
L	Vector containing the inductances, in order from source to load, of all inductors in the network. The inductance vector must contain at least three elements. All values must be strictly positive.	Henrys. Default is [0.0144e-7, 0.4395e-7, 0.0144e-7].
Name	Object name (read only).	String. 'LC Bandpass Pi'
nPort	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

Zverev, Anatol I., *Handbook of Filter Synthesis*, John Wiley & Sons, 1967.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.lcbandpasstee`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.lcbandpasstee

Purpose

Construct LC bandpass tee network object

Syntax

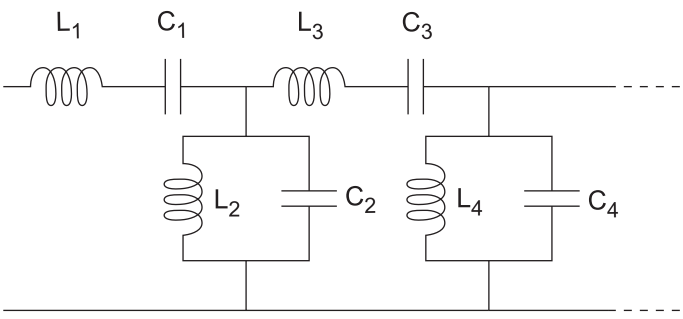
```
h = rfckt.lcbandpasstee('Property1',value1,'Property2',value2,...)
h = rfckt.lcbandpasstee
```

Description

`h = rfckt.lcbandpasstee('Property1',value1,'Property2',value2,...)` returns an LC bandpass tee network object, `h`, based on the specified properties. Properties you do not specify retain their default values.

`h = rfckt.lcbandpasstee` returns an LC bandpass tee network object whose properties all have their default values.

The LC bandpass tee network object is a 2-port network as shown in the circuit diagram below.



Where [L_1, L_2, L_3, L_4, ...] is the value of the `'L'` property, and [C_1, C_2, C_3, C_4, ...] is the value of the `'C'` property.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `lcbandpasstee` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.lcbandpasstee` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

For each inductor and capacitor pair in the network, the `analyze` function first calculates the ABCD-parameters for each frequency in the input vector, `freq`. For each series pair, A = 1, B = Z, C = 0, and D = 1, where Z is the impedance of the series pair. For each shunt pair, A = 1, B = 0, C = Y, and D = 1, where Y is the admittance of the shunt pair.

The `analyze` function cascades the ABCD-parameters for each series and shunt pair, then converts the cascaded parameters to S-parameters using the `abcd2s` function.

Properties

This table lists properties useful to `rfckt.lcbandpasstee` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the LC bandpass tee network object.	Handle. Default is `[]`.

Property	Description	Units, Values
`C`	Vector containing the capacitances, in order from source to load, of all capacitors in the network. Its length must be equal to the length of the vector you provide for `'L'`. All values must be strictly positive.	Farads. Default is `[0.0186e-10, 0.1716e-10, 0.0186e-10]`.
`L`	Vector containing the inductances, in order from source to load, of all inductors in the network. The inductance vector must contain at least three elements. All values must be strictly positive.	Henrys. Default is `[0.2781e-7, 0.0301e-7, 0.2781e-7]`.
`Name`	Object name (read only).	String. `'LC Bandpass Tee'`
`nPort`	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

Zverev, Anatol I., *Handbook of Filter Synthesis*, John Wiley & Sons, 1967.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.lcbandpasspi`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.lcbandstoppi

Purpose

Construct LC bandstop pi network object

Syntax

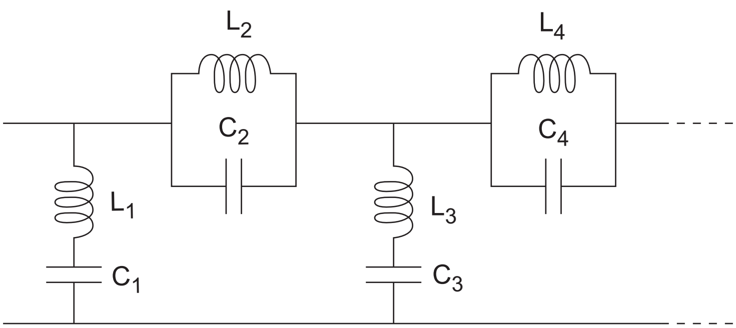
```
h = rfckt.lcbandstoppi('Property1',value1,'Property2',value2,...)
h = rfckt.lcbandstoppi
```

Description

`h = rfckt.lcbandstoppi('Property1',value1,'Property2',value2,...)` returns an LC bandstop pi network object, `h`, based on the specified properties. Properties you do not specify retain their default values.

`h = rfckt.lcbandstoppi` returns an LC bandstop pi network object whose properties all have their default values.

The LC bandstop pi network object is a 2-port network as shown in the circuit diagram below.



Where [L_1, L_2, L_3, L_4, ...] is the value of the `'L'` property, and [C_1, C_2, C_3, C_4, ...] is the value of the `'C'` property.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the lcbandstoppi circuit object, use the analyze function to calculate the S-parameters and noise figure at specified frequencies. For rfckt.lcbandstoppi objects, freq must be strictly positive.

```
analyze(h,freq)
```

The analyze function stores the results of the analysis in the AnalyzedResult property of the circuit object.

Network Parameters

For each inductor and capacitor pair in the network, the analyze function first calculates the ABCD-parameters for each frequency in the input vector, freq. For each series pair, A = 1, B = Z, C = 0, and D = 1, where Z is the impedance of the series pair. For each shunt pair, A = 1, B = 0, C = Y, and D = 1, where Y is the admittance of the shunt pair.

The analyze function cascades the ABCD-parameters for each series and shunt pair, then converts the cascaded parameters to S-parameters using the abcd2s function.

Properties

This table lists properties useful to rfckt.lcbandstoppi objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the LC bandstop pi network object.	Handle. Default is [].

Property	Description	Units, Values
C	Vector containing the capacitances, in order from source to load, of all capacitors in the network. Its length must be equal to the length of the vector you provide for 'L'. All values must be strictly positive.	Farads. Default is [0.0184e-10, 0.2287e-10, 0.0184e-10].
L	Vector containing the inductances, in order from source to load, of all inductors in the network. The inductance vector must contain at least three elements. All values must be strictly positive.	Henrys. Default is [0.2809e-7, 0.0226e-7, 0.2809e-7].
Name	Object name (read only).	String. 'LC Bandstop Pi'
nPort	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

Zverev, Anatol I., *Handbook of Filter Synthesis*, John Wiley & Sons, 1967.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.lcbandstoptee`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct LC bandstop tee network object

Syntax

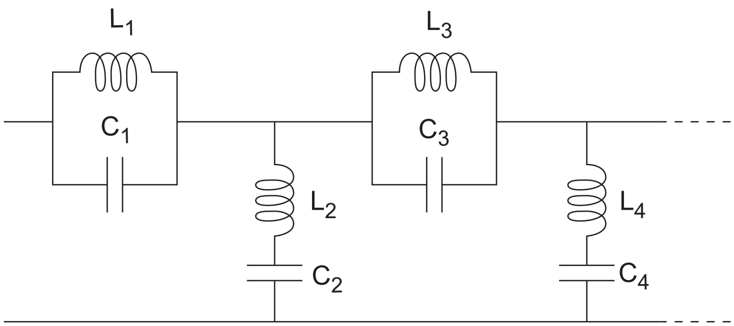
```
h = rfckt.lcbandstoptee('Property1',value1,'Property2',value2,...)
h = rfckt.lcbandstoptee
```

Description

`h = rfckt.lcbandstoptee('Property1',value1,'Property2',value2,...)` returns an LC bandstop tee network object, `h`, based on the specified properties. Properties you do not specify retain their default values.

`h = rfckt.lcbandstoptee` returns an LC bandstop tee network object whose properties all have their default values.

The LC bandstop tee network object is a 2-port network as shown in the circuit diagram below.



Where [L_1, L_2, L_3, L_4, ...] is the value of the `'L'` property, and [C_1, C_2, C_3, C_4, ...] is the value of the `'C'` property.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the lcbandstoptee circuit object, use the analyze function to calculate the S-parameters and noise figure at specified frequencies. For rfckt.lcbandstoptee objects, freq must be strictly positive.

```
analyze(h,freq)
```

The analyze function stores the results of the analysis in the AnalyzedResult property of the circuit object.

Network Parameters

For each inductor and capacitor pair in the network, the analyze function first calculates the ABCD-parameters for each frequency in the input vector, freq. For each series pair, A = 1, B = Z, C = 0, and D = 1, where Z is the impedance of the series pair. For each shunt pair, A = 1, B = 0, C = Y, and D = 1, where Y is the admittance of the shunt pair.

The analyze function cascades the ABCD-parameters for each series and shunt pair, then converts the cascaded parameters to S-parameters using the abcd2s function.

Properties

This table lists properties useful to rfckt.lcbandstoptee objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the LC bandstop tee network object	Handle. Default is [].

Property	Description	Units, Values
`C`	Vector containing the capacitances, in order from source to load, of all capacitors in the network. Its length must be equal to the length of the vector you provide for `'L'`. All values must be strictly positive.	Farads. Default is `[0.1852e-10, 0.0105e-10, 0.1852e-10]`.
`L`	Vector containing the inductances, in order from source to load, of all inductors in the network. The inductance vector must contain at least three elements. All values must be strictly positive.	Henrys. Default is `[0.0279e-7, 0.4932e-7, 0.0279e-7]`.
`Name`	Object name (read only)	String. `'LC Bandstop Tee'`
`nPort`	Number of ports (read only)	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

Zverev, Anatol I., *Handbook of Filter Synthesis*, John Wiley & Sons, 1967.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.lcbandstoppi`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.lchighpasspi

Purpose Construct LC highpass pi network object

Syntax

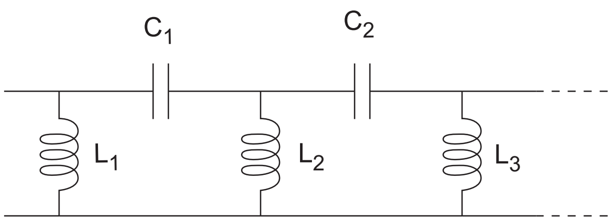
```
h = rfckt.lchighpasspi('Property1',value1,'Property2',value2,...)
h = rfckt.lchighpasspi
```

Description

`h = rfckt.lchighpasspi('Property1',value1,'Property2',value2,...)` returns an LC highpass pi network object, `h`, based on the specified properties. Properties you do not specify retain their default values.

`h = rfckt.lchighpasspi` returns an LC highpass pi network object whose properties all have their default values.

The LC highpass pi network object is a 2-port network as shown in the circuit diagram below.



Where [L_1, L_2, L_3, ...] is the value of the `'L'` property, and [C_1, C_2, ...] is the value of the `'C'` property.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `lchighpasspi` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.lchighpasspi` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The analyze function stores the results of the analysis in the AnalyzedResult property of the circuit object.

Network Parameters

For each inductor and capacitor in the network, the analyze function first calculates the ABCD-parameters for each frequency in the input vector, freq. For each series element, A = 1, B = Z, C = 0, and D = 1, where Z is the impedance of the series element. For each shunt element, A = 1, B = 0, C = Y, and D = 1, where Y is the admittance of the shunt element.

The analyze function cascades the ABCD-parameters for each circuit element, then converts the cascaded parameters to S-parameters using the abcd2s function.

Properties

This table lists properties useful to rfckt.lchighpasspi objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the LC highpass pi network object.	Handle. Default is [].
L	Vector containing the inductances, in order from source to load, of all inductors in the network. The inductance vector must contain at least two elements. All values must be strictly positive.	Henrys. Default is [2.2363e-9].

Property	Description	Units, Values
C	Vector containing the capacitances, in order from source to load, of all capacitors in the network. Its length must be equal to or one less than the length of the vector you provide for 'L'. All values must be strictly positive.	Farads. Default is [0.1188e-5, 0.1188e-5].
Name	Object name (read only).	String. 'LC Highpass Pi'
nPort	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

Zverev, Anatol I., *Handbook of Filter Synthesis*, John Wiley & Sons, 1967.

See Also

analyze	RF Toolbox
calculate	RF Toolbox
listformat	RF Toolbox
listparam	RF Toolbox
plot	RF Toolbox
polar	RF Toolbox
rfckt	RF Toolbox

`rfckt.lchighpasstee`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.lchighpasstee

Purpose

Construct LC highpass tee network object

Syntax

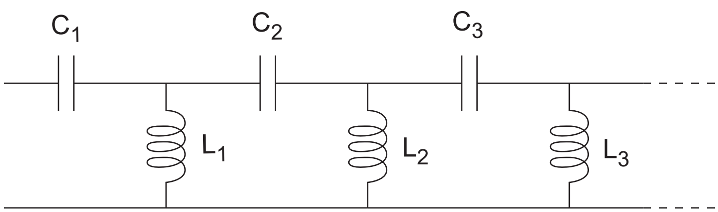
```
h = rfckt.lchighpasstee('Property1',value1,'Property2',value2,...)
h = rfckt.lchighpasstee
```

Description

`h = rfckt.lchighpasstee('Property1',value1,'Property2',value2,...)` returns an LC highpass tee network object, `h`, with the specified properties. Properties you do not specify retain their default values.

`h = rfckt.lchighpasstee` returns an LC highpass tee network object whose properties all have their default values.

The LC highpass tee network object is a 2-port network as shown in the circuit diagram below.



Where [L_1, L_2, L_3, ...] is the value of the `'L'` property, and [C_1, C_2, C_3, ...] is the value of the `'C'` property.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `lchighpasstee` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.lchighpasstee` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

For each inductor and capacitor in the network, the `analyze` function first calculates the ABCD-parameters for each frequency in the input vector, `freq`. For each series element, A = 1, B = Z, C = 0, and D = 1, where Z is the impedance of the series element. For each shunt element, A = 1, B = 0, C = Y, and D = 1, where Y is the admittance of the shunt element.

The `analyze` function cascades the ABCD-parameters for each circuit element, then converts the cascaded parameters to S-parameters using the `abcd2s` function.

Properties

This table lists properties useful to `rfckt.lchighpasstee` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the LC highpass tee network object.	Handle. Default is `[]`.

Property	Description	Units, Values
`C`	Vector containing the capacitances, in order from source to load, of all capacitors in the network. The capacitance vector must contain at least two elements. Its length must be equal to or one greater than the length of the vector you provide for `'L'`. All values must be strictly positive.	Farads. Default is `[0.4752e-9, 0.4752e-9]`.
`L`	Vector containing the inductances, in order from source to load, of all inductors in the network. All values must be strictly positive. The vector cannot be empty.	Henrys. Default is `[5.5907e-6]`.
`Name`	Object name (read only).	String. `'LC Highpass Tee'`
`nPort`	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

Zverev, Anatol I., *Handbook of Filter Synthesis*, John Wiley & Sons, 1967.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.lchighpasspi`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.lclowpasspi

Purpose Construct LC lowpass pi network object

Syntax

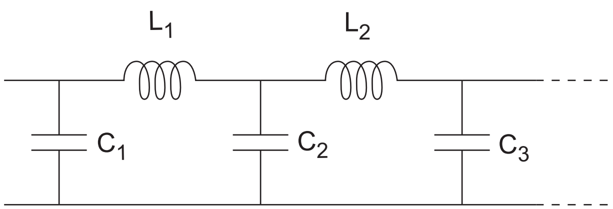
```
h = rfckt.lclowpasspi('Property1',value1,'Property2',value2,...)
h = rfckt.lclowpasspi
```

Description

`h = rfckt.lclowpasspi('Property1',value1,'Property2',value2,...)` returns an LC lowpass pi network object, `h`, based on the specified properties. Properties you do not specify retain their default values.

`h = rfckt.lclowpasspi` returns an LC lowpass pi network object whose properties all have their default values.

The LC lowpass pi network object is a 2-port network as shown in the circuit diagram below.



Where [L_1, L_2, ...] is the value of the `'L'` property, and [C_1, C_2, C_3, ...] is the value of the `'C'` property.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `lclowpasspi` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.lclowpasspi` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

For each inductor and capacitor in the network, the `analyze` function first calculates the ABCD-parameters for each frequency in the input vector, `freq`. For each series element, A = 1, B = Z, C = 0, and D = 1, where Z is the impedance of the series element. For each shunt element, A = 1, B = 0, C = Y, and D = 1, where Y is the admittance of the shunt element.

The `analyze` function cascades the ABCD-parameters for each circuit element, then converts the cascaded parameters to S-parameters using the `abcd2s` function.

Properties

This table lists properties useful to `rfckt.lclowpasspi` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the LC lowpass pi network object.	Handle. Default is `[]`.

Property	Description	Units, Values
C	Vector containing the capacitances, in order from source to load, of all capacitors in the network. The capacitance vector must contain at least two elements. Its length must be equal to or one greater than the length of the vector you provide for 'L'. All values must be strictly positive.	Farads. Default is [0.5330e-8, 0.5330e-8].
L	Vector containing the inductances, in order from source to load, of all inductors in the network. All values must be strictly positive. The vector cannot be empty.	Henrys. Default is [2.8318e-6].
Name	Object name (read only).	String. 'LC Lowpass Pi'
nPort	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

Zverev, Anatol I., *Handbook of Filter Synthesis*, John Wiley & Sons, 1967.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.lclowpasstee`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.lclowpasstee

Purpose Construct LC lowpass tee filter object

Syntax

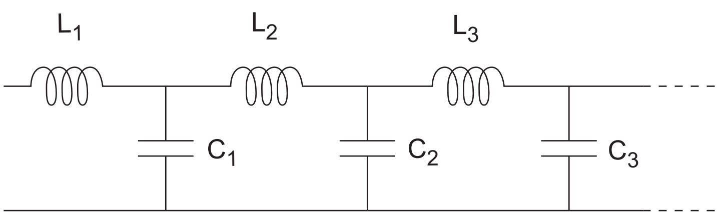
```
h = rfckt.lclowpasstee
h = rfckt.lclowpasstee('Property1',value1,'Property2',value2,...)
```

Description

`h = rfckt.lclowpasstee` returns an LC lowpass tee filter object whose properties all have their default values.

`h = rfckt.lclowpasstee('Property1',value1,'Property2',value2,...)` returns an LC lowpass tee filter object, `h`, based on the specified properties. Properties you do not specify retain their default values.

The LC lowpass tee network object is a 2-port network as shown in the circuit diagram below.



Where [L_1, L_2, L_3, ...] is the value of the `'L'` property, and [C_1, C_2, C_3, ...] is the value of the `'C'` property.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `lclowpasstee` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.lclowpasstee` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

For each inductor and capacitor in the network, the `analyze` function first calculates the ABCD-parameters for each frequency in the input vector, `freq`. For each series element, A = 1, B = Z, C = 0, and D = 1, where Z is the impedance of the series element. For each shunt element, A = 1, B = 0, C = Y, and D = 1, where Y is the admittance of the shunt element.

The `analyze` function cascades the ABCD-parameters for each circuit element, then converts the cascaded parameters to S-parameters using the `abcd2s` function.

Properties

This table lists properties associated with `rfckt.lclowpasstee` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the LC lowpass tee network object.	Handle. Default is `[]`.

Property	Description	Units, Values
`C`	Vector containing the capacitances, in order from source to load, of all capacitors in the network. Its length must be equal to or one less than the length of the vector you provide for `'L'`. All values must be strictly positive.	Farads. Default is `[1.1327e-9]`.
`L`	Vector containing the inductances, in order from source to load, of all inductors in the network. The inductance vector must contain at least two elements. All values must be strictly positive.	Henrys. Default is `[0.1332e-4, 0.1332e-4]`.
`Name`	Object name (read only).	String. `'LC Lowpass Tee'`
`nPort`	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

Zverev, Anatol I., *Handbook of Filter Synthesis*, John Wiley & Sons, 1967.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.lclowpasspi`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct microstrip transmission line object

Syntax

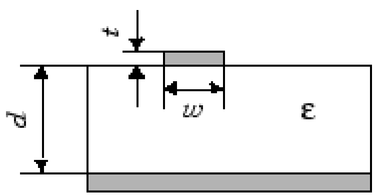
```
h = rfckt.microstrip('Property1',value1,'Property2',value2,...)
h = rfckt.microstrip
```

Description

`h = rfckt.microstrip('Property1',value1,'Property2',value2,...)` returns a microstrip transmission line object, `h`, with the specified properties. Properties you do not specify retain their default values.

`h = rfckt.microstrip` returns a microstrip transmission line object whose properties all have their default values.

A microstrip transmission line is shown here in cross-section. Its physical characteristics include the microstrip width (w), the microstrip thickness (t), the substrate height (d), and the relative permittivity constant (ε).



Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `microstrip` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.microstrip` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

A microstrip transmission line object enables you to model the transmission line as a stub or as a stubless line.

Stubless Transmission Line

If you model the transmission line as a stubless line, the `analyze` function calculates the S-parameters for the specified frequencies, based on the physical length of the transmission line, D, and the complex propagation constant, k.

$$S_{11} = 0$$

$$S_{12} = e^{-kD}$$

$$S_{21} = e^{-kD}$$

$$S_{22} = 0$$

$k = \alpha_a + i\beta$, where α_a is the attenuation coefficient and β is the wave number. The attenuation coefficient α_a is related to the loss, α, by

$$\alpha_a = -\ln 10^{-\frac{\alpha}{20}}$$

where α is the reduction in signal strength, in dB, per unit length. α combines both conductor loss and dielectric loss and is derived from the `rfckt.microstrip` object properties.

The wave number β is related to the phase velocity, V_P, by

$$\beta = \frac{2\pi f}{V_p}$$

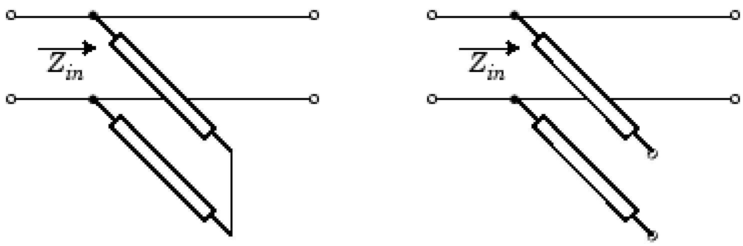
$V_P = c/\sqrt{\varepsilon_{eff}}$ where ε_{eff} is the frequency dependent effective dielectric constant. f is the frequency range specified in the `analyze` input argument `freq`. V_P and ε_{eff} are derived from the `rfckt.microstrip` object properties.

The phase velocity V_P is also known as the wave propagation velocity.

Shunt and Series Stubs

If you model the transmission line as a shunt or series stub, the `analyze` function first calculates the ABCD-parameters at the specified frequencies. It then uses the `abcd2s` function to convert the ABCD-parameters to S-parameters.

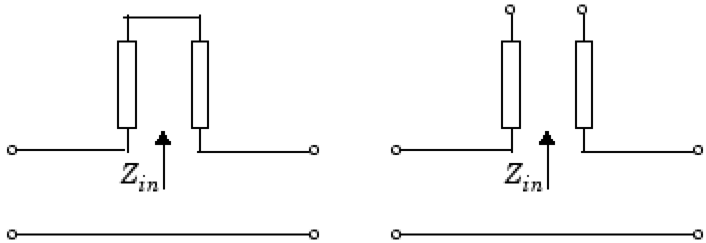
When you set the `StubMode` property to `'Shunt'`, the 2-port network consists of a stub transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the shunt circuit. The ABCD-parameters for the shunt stub are calculated as

$$A = 1$$
$$B = 0$$
$$C = 1/Z_{in}$$
$$D = 1$$

When you set the `StubMode` property to `'Series'`, the 2-port network consists of a series transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the series circuit. The ABCD-parameters for the series stub are calculated as

$$A = 1$$
$$B = Z_{in}$$
$$C = 0$$
$$D = 1$$

Properties

This table lists properties useful to `rfckt.microstrip` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the microstrip transmission line object.	Handle. Default is `[]`.
`EpsilonR`	Relative permittivity of the dielectric expressed as the ratio of the permittivity of the dielectric to permittivity in free space ε_0.	Default is `9.8`.

Property	Description	Units, Values
Height	Thickness of the dielectric on which the microstrip resides.	Meters. Default is 6.35e-4.
LineLength	Physical length of the transmission line.	Meters. Default is 0.01.
Loss	Reduction in strength of the signal as it travels over the transmission line. Read-only; set by the analyze function.	Decibels per meter. Default is [].
LossTangent	Loss angle tangent of the dielectric.	Default is 0.
Name	Object name (read only).	String. 'Microstrip Transmission Line'
nPort	Number of ports (read only).	Integer. The value is always 2.
PV	Phase velocity. Propagation velocity of a uniform plane wave on the transmission line. Read-only; set by the analyze function.	Meters per second. Default is [].
SigmaCond	Conductivity in the conductor.	Siemens per meter (S/m). Default is Inf.
StubMode	Type of stub.	String. 'None' (default), 'Series', or 'Shunt'

Property	Description	Units, Values
`Termination`	Termination for stub modes `'Shunt'` and `'Series'`.	String. `'None'` (default), `'Open'`, or `'Short'`. Use `'None'` when `StubMode` is `'None'`.
`Thickness`	Physical thickness of the microstrip.	Meters. Default is `5.0e-6`.
`Width`	Physical width of the parallel-plate.	Meters. Default is `6.0e-4`.
`Z0`	Characteristic impedance. Read-only; set by the `analyze` function.	Ohms. Default is `[]`.

References

Gupta, K.C., G. Ramesh, I. Bahl, and P. Bhartia, *Microstrip Lines and Slotlines*, Second Edition, Artech House, pp. 102-109, 1996.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.coaxial`	RF Toolbox
`rfckt.cpw`	RF Toolbox

`rfckt.parallelplate`	RF Toolbox
`rfckt.rlcgline`	RF Toolbox
`rfckt.twowire`	RF Toolbox
`rfckt.txline`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct 2-port object representing mixer and its local oscillator

Syntax

```
h = rfckt.mixer
h = rfckt.mixer('Property1',value1,'Property2',value2,...)
```

Description

`h = rfckt.mixer` returns a circuit object, `h`, whose properties are set to their default values.

`h = rfckt.mixer('Property1',value1,'Property2',value2,...)` returns a circuit object, `h`, that represents a mixer and its local oscillator (LO) with 2 ports (RF and IF). Properties you do not specify retain their default values.

Use the `read` method to read the mixer data from a Touchstone or AMP data file. See Appendix A, "AMP File Format" for information about the `.amp` format.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `rfckt.mixer` circuit object, use the `analyze` function to calculate the S-parameters, output third-order intercept point, and noise figure at specified frequencies. For `rfckt.mixer` objects, `freq` must be nonnegative.

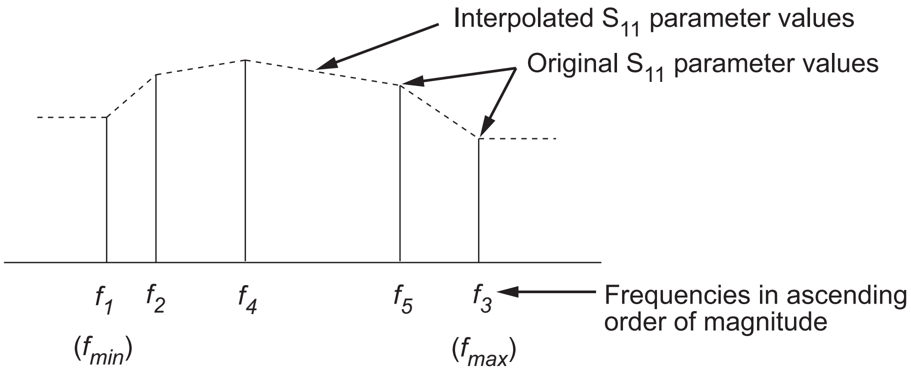
```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

If the `'NetworkData'` property of your `rfckt.mixer` object contains network Y- or Z-parameters, the `analyze` function first converts the parameters to S-parameters. Using the interpolation method you specify with the `'IntpType'` property, the `analyze` function interpolates the S-parameter values to determine the S-parameters at the specified frequencies.

Specifically, the `analyze` function orders the S-parameters according to the ascending order of their frequencies, f_n. It then interpolates the S-parameters, using the MATLAB `interp1` function. For example, the curve in the following diagram illustrates the result of interpolating the S11 parameters at five different frequencies.



You can specify the interpolation method as `cubic`, `linear` (default), or `spline`. For more information, see “One-Dimensional Interpolation” and the `interp1` reference page in the MATLAB documentation.

As shown in the diagram above, the `analyze` function uses the parameter values at f_{min}, the minimum input frequency, for all frequencies smaller than f_{min}. It uses the parameters values at f_{max}, the maximum input frequency, for all frequencies greater than f_{max}. In both cases, the results may not be accurate.

OIP3

The `analyze` function uses the data stored in the `'NonlinearData'` property of the `rfckt.mixer` object to calculate OIP3.

Noise Figure

The `analyze` function uses the data stored in the `'NoiseData'` property of the `rfckt.mixer` object to calculate the noise figure.

Properties

This table lists properties associated with `rfckt.mixer` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the mixer object.	Handle. Default is`[1-by-1 rfdata.data]`.
`FLO`	Local oscillator frequency. For `MixerType = 'Downconverter'`, $f_{out} = f_{in} - f_{lo}$. For `MixerType = 'Upconverter'`, $f_{out} = f_{in} + f_{lo}$.	Hertz. Default is `1.0e+9`.
`FreqOffset`	Vector specifying the frequency offset for the phase noise level.	Hertz. Default is `[]`.
`IntpType`	Interpolation method.	String.`'Linear'` (default), `'Spline'`, or `'Cubic'`
`MixerType`	Type of mixer.	String.`'Downconverter'` (default) or `'Upconverter'`
`Name`	Object name (read only).	String. `'Mixer'`
`NetworkData`	`rfdata.network` object.	The default network parameters are taken from the `'default.amp'` data file.

Property	Description	Units, Values
NoiseData	Scalar noise figure in dB, rfdata.noise object, or rfdata.nf object.	The default noise data values are taken from the 'default.s2p' data file and stored in an rfdata.noise object.
NonlinearData	Scalar OIP3 in dBm, rfdata.power object, or rfdata.ip3 object.	The default is Inf.
nPort	Number of ports (read only).	Integer. The value is always 2.
PhaseNoiseLevel	Vector specifying the phase noise level.	dBc/Hz. Default is [].

References

EIA/IBIS Open Forum, "Touchstone File Format Specification," Rev. 1.1, 2002 (http://www.vhdl.org/pub/ibis/connector/touchstone_spec11.pdf).

See Also

analyze	RF Toolbox
calculate	RF Toolbox
listformat	RF Toolbox
listparam	RF Toolbox
plot	RF Toolbox
polar	RF Toolbox
read	RF Toolbox
restore	RF Toolbox
rfckt	RF Toolbox
rfckt.amplifier	RF Toolbox

`rfckt.datafile`	RF Toolbox
`rfckt.passive`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct parallel connected network object

Syntax

```
h = rfckt.parallel('Property1',value1,'Property2',value2,...)
h = rfckt.parallel
```

Description

`h = rfckt.parallel('Property1',value1,'Property2',value2,...)` returns a parallel connected network object, `h`, based on the specified properties. Use the `'Ckts'` property to specify the 2-port `rfckt` objects to be connected. Properties you do not specify retain their default values.

`h = rfckt.parallel` returns a parallel connected network object whose properties all have their default values.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

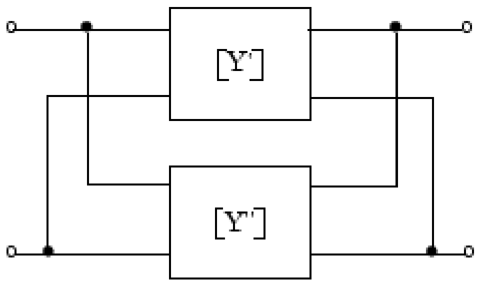
After you create the `parallel` network object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.parallel` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

The `analyze` function first calculates the admittance matrix of the parallel connected network. It starts by converting each component network's parameters to an admittance matrix. The figure shows a parallel connected network consisting of two 2-port networks, each represented by its admittance matrix.



where $[Y'] = \begin{bmatrix} Y_{11}' & Y_{12}' \\ Y_{21}' & Y_{22}' \end{bmatrix}$ and $[Y''] = \begin{bmatrix} Y_{11}'' & Y_{12}'' \\ Y_{21}'' & Y_{22}'' \end{bmatrix}$

The `analyze` function then calculates the admittance matrix for the parallel network by calculating the sum of the individual admittances. The following equation illustrates the calculations for two 2-port circuits.

$$[Y] = [Y'] + [Y''] = \begin{bmatrix} Y_{11}' + Y_{11}'' & Y_{12}' + Y_{12}'' \\ Y_{21}' + Y_{21}'' & Y_{22}' + Y_{22}'' \end{bmatrix}$$

Finally, `analyze` converts the admittance matrix of the parallel network to S-parameters at the frequencies specified in the `analyze` input argument `freq`.

Properties

This table lists properties useful to `rfckt.parallel` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the parallel connected network object.	Handle. Default is `[]`.
`Ckts`	Cell array containing all circuit objects in the network, in order from source to load. All circuits must be 2 port.	Handles to `rfckt` objects. Default is `{}`.
`Name`	Object name (read only).	String. `'Parallel Connected Network'`
`nPort`	Number of ports (read only).	Integer. The value is always `2`.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.cascade`	RF Toolbox

`rfckt.hybrid`	RF Toolbox
`rfckt.hybridg`	RF Toolbox
`rfckt.series`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.parallelplate

Purpose

Construct parallel-plate transmission line object

Syntax

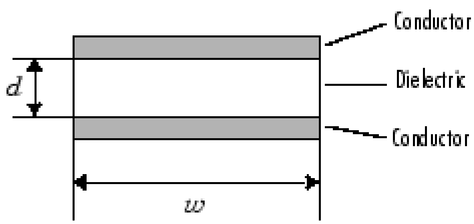
```
h = rfckt.parallelplate('Property1',value1,'Property2',value2,...)
h = rfckt.parallelplate
```

Description

`h = rfckt.parallelplate('Property1',value1,'Property2',value2,...)` returns a parallel-plate transmission line object, `h`, with the specified properties. Properties you do not specify retain their default values.

`h = rfckt.parallelplate` returns a parallel-plate transmission line object whose properties all have their default values.

A parallel-plate transmission line is shown here in cross-section. Its physical characteristics include the plate width w and the plate separation d.



Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `parallelplate` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.parallelplate` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

A parallel-plate transmission line object enables you to model the transmission line as a stub or as a stubless line.

Stubless Transmission Line

If you model the transmission line as a stubless line, the `analyze` function calculates the S-parameters for the specified frequencies, based on the physical length of the transmission line, *D*, and the complex propagation constant, *k*.

$$S_{11} = 0$$

$$S_{12} = e^{-kD}$$

$$S_{21} = e^{-kD}$$

$$S_{22} = 0$$

k is a vector whose elements correspond to the elements of the input vector `freq`. *k* can be expressed in terms of the resistance (*R*), inductance (*L*), conductance (*G*), and capacitance (*C*) per unit length (meters) as

$$k = k_r + jk_i = \sqrt{(R + j2\pi fL)(G + j2\pi fC)}$$

where *f* is the frequency range specified in the `analyze` input argument `freq`, and

$$R = \frac{2}{w \sigma_{cond} \delta}$$

$$L = \mu \frac{d}{w}$$

$$G = \sigma_{diel} \frac{w}{d}$$

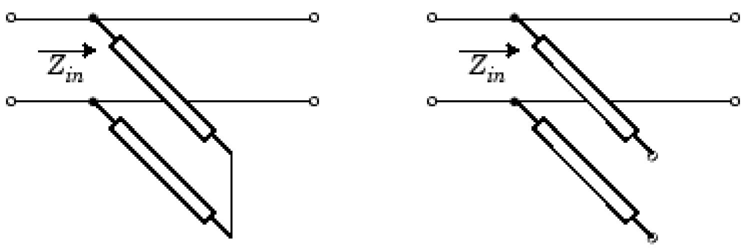
$$C = \varepsilon \frac{w}{d}$$

In these equations, σ_{cond} is the conductivity in the conductor and σ_{diel} is the conductivity in the dielectric. μ is the relative permeability of the dielectric, ε is its permittivity as derived from the `EpsilonR` property, and skin depth δ is calculated as $1/\sqrt{\pi f \mu \sigma_{cond}}$.

Shunt and Series Stubs

If you model the transmission line as a shunt or series stub, the `analyze` function first calculates the ABCD-parameters at the specified frequencies. It then uses the `abcd2s` function to convert the ABCD-parameters to S-parameters.

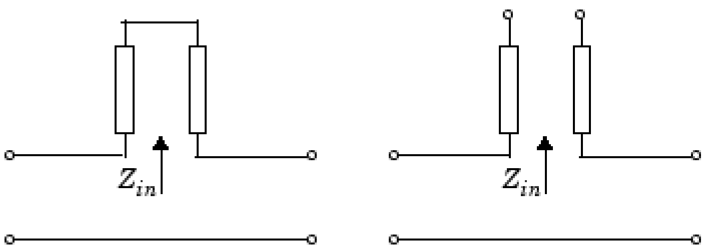
When you set the `StubMode` property to `'Shunt'`, the 2-port network consists of a stub transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the shunt circuit. The ABCD-parameters for the shunt stub are calculated as

$$A = 1$$
$$B = 0$$
$$C = 1/Z_{in}$$
$$D = 1$$

When you set the StubMode property to 'Series', the 2-port network consists of a series transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the series circuit. The ABCD-parameters for the series stub are calculated as

$$A = 1$$
$$B = Z_{in}$$
$$C = 0$$
$$D = 1$$

Properties

This table lists properties useful to rfckt.parallelplate objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the parallel-plate transmission line object.	Handle. Default is [].
EpsilonR	Relative permittivity of the dielectric expressed as the ratio of the permittivity of the dielectric to permittivity in free space ε_0.	Default is 2.3.
LineLength	Physical length of the transmission line.	Meters. Default is 0.01.
Loss	Reduction in strength of the signal as it travels over the transmission line. Read-only; set by the analyze function.	Decibels per meter. Default is [].
MuR	Relative permeability of the dielectric expressed as the ratio of the permeability of the dielectric to permeability in free space μ_0.	Default is 1.
Name	Object name (read only).	String. 'Parallel-Plate Transmission Line'

Property	Description	Units, Values
nPort	Number of ports (read only).	Integer. The value is always 2.
PV	Phase velocity. Propagation velocity of a uniform plane wave on the transmission line. Read-only; set by the analyze function.	Meters per second. Default is [].
Separation	Thickness of the dielectric separating the plates.	Meters. Default is 1.0e-3.
SigmaCond	Conductivity in the conductor.	Siemens per meter (S/m). Default is Inf.
SigmaDiel	Conductivity in the dielectric.	Siemens per meter (S/m). Default is 0.
StubMode	Type of stub.	String. 'None' (default), 'Series', or 'Shunt'
Termination	Termination for stub modes 'Shunt' and 'Series'.	String. 'None' (default), 'Open', or 'Short'. Use 'None' when StubMode is 'None'.
Width	Physical width of the parallel-plate transmission line.	Meters. Default is .005.
Z0	Characteristic impedance. Read-only; set by the analyze function.	Ohms. Default is [].

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.coaxial`	RF Toolbox
`rfckt.cpw`	RF Toolbox
`rfckt.microstrip`	RF Toolbox
`rfckt.rlcgline`	RF Toolbox
`rfckt.twowire`	RF Toolbox
`rfckt.txline`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose Construct passive network object

Syntax

```
h = rfckt.passive('Property1',value1,'Property2',value2,...)
```

Description

`h = rfckt.passive('Property1',value1,'Property2',value2,...)` returns a passive circuit object, `h`, based on the specified properties. The properties include:

```
Name: 'Data File' (read only)
nPort: 2 (read only)
AnalyzedResult: Analyzed result (read only)
IntpType: 'Linear', 'Cubic' or 'Spline'
NetworkData: [1x1 rfdata.network]
```

`NetworkData` is an `rfdata.network` object. The default is the network parameters from `passive.s2p` data file.

Use the `read` method to read the passive network parameters from a Touchstone data file.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.amplifier`	RF Toolbox

`rfckt.datafile`	RF Toolbox
`rfckt.mixer`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct RLCG transmission line object

Syntax

```
h = rfckt.rlcgline('Property1',value1,'Property2',value2, ...)
```

Description

`h = rfckt.rlcgline('Property1',value1,'Property2',value2, ...)` returns an RLCG transmission line object, `h`, based on the specified properties.

After you create the `rlcgline` circuit object, you can use the `analyze` function to calculate the network parameters and noise figure at the frequencies you pass into the `analyze` function. This function uses the interpolation method you specified in the `IntpType` property to find the R, L, C, and G values at these frequencies. Then, it calculates the characteristic impedance, Z0, phase velocity, PV, and loss using these interpolated values. For more information, see "Circuit Analysis" on page 6-172.

Properties

This table lists properties associated with `rfckt.rlcgline` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the RLCG transmission line object.	Handle. Default is `[]`.
`C`	Vector of capacitance per length values that correspond to the frequencies stored in the `Freq` property.	Farads/meter
`Freq`	Vector of positive frequency values.	Hertz. Default is `[]`.

Property	Description	Units, Values
G	Vector of conductance per length values that correspond to the frequencies stored in the Freq property.	Siemens/meter
IntpType	Interpolation method.	'linear' (default), 'spline', or 'cubic'
L	Vector of inductance per length values that correspond to the frequencies stored in the Freq property.	Henries/meter
LineLength	Scalar that represents the length of the transmission line.	Meters. Default is 0.01.
Name	Object name (read only).	String. 'RLCG Transmission Line'
nPort	Number of ports (read only).	Integer. The value is always 2.
R	Vector of resistance per length values that correspond to the frequencies stored in the Freq property.	Ohms/meter

Property	Description	Units, Values
StubMode	Type of stub.	String. 'None' (default), 'Series', or 'Shunt'
Termination	Termination for stub modes 'Shunt' and 'Series'.	String. 'None' (default), 'Open', or 'Short'. Use 'None' when StubMode is 'None'.

See Also

analyze	RF Toolbox
calculate	RF Toolbox
getz0	RF Toolbox
listformat	RF Toolbox
listparam	RF Toolbox
plot	RF Toolbox
polar	RF Toolbox
rfckt	RF Toolbox
rfckt.coaxial	RF Toolbox
rfckt.cpw	RF Toolbox
rfckt.microstrip	RF Toolbox
rfckt.parallelplate	RF Toolbox
rfckt.twowire	RF Toolbox
rfckt.txline	RF Toolbox
rfdata	RF Toolbox

`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct series connected network object

Syntax

```
h = rfckt.series('Property1',value1,'Property2',value2,...)
h = rfckt.series
```

Description

`h = rfckt.series('Property1',value1,'Property2',value2,...)` returns a series connected network object, `h`, based on the specified properties. Use the `'Ckts'` property to specify the 2-port `rfckt` objects to be connected. Properties you do not specify retain their default values.

`h = rfckt.series` returns a series connected network object whose properties all have their default values.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

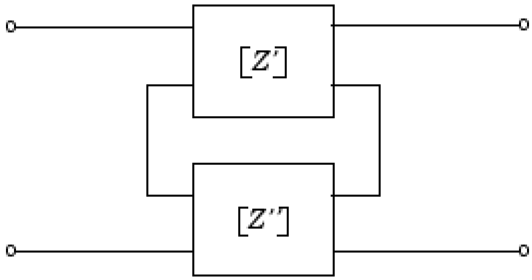
After you create the `series` network object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.series` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

The `analyze` function first calculates the impedance matrix of the series connected network. It starts by converting each component network's parameters to an impedance matrix. The figure shows a series connected network consisting of two 2-port networks, each represented by its impedance matrix.



where $[Z'] = \begin{bmatrix} Z_{11}' & Z_{12}' \\ Z_{21}' & Z_{22}' \end{bmatrix}$ and $[Z''] = \begin{bmatrix} Z_{11}'' & Z_{12}'' \\ Z_{21}'' & Z_{22}'' \end{bmatrix}$

The `analyze` function then calculates the impedance matrix for the series network by calculating the sum of the individual impedances. The following equation illustrates the calculations for two 2-port circuits.

$$[Z] = [Z'] + [Z''] = \begin{bmatrix} Z_{11}' + Z_{11}'' & Z_{12}' + Z_{12}'' \\ Z_{21}' + Z_{21}'' & Z_{22}' + Z_{22}'' \end{bmatrix}$$

Finally, `analyze` converts the impedance matrix of the series network to S-parameters at the frequencies specified in the analyze input argument `freq`.

Properties

This table lists properties useful to `rfckt.series` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the series connected network object.	Handle. Default is `[]`.
`Ckts`	Cell array containing all circuit objects in the network, in order from source to load. All circuits must be 2 port.	Handles to `rfckt` objects. Default is `{}`.
`Name`	Object name (read only).	String. `'Series Connected Network'`
`nPort`	Number of ports (read only).	Integer. The value is always 2.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.cascade`	RF Toolbox

`rfckt.hybrid`	RF Toolbox
`rfckt.hybridg`	RF Toolbox
`rfckt.parallel`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

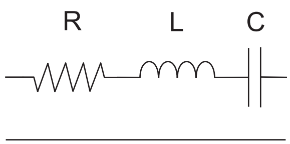
Construct series RLC network object

Syntax

```
h = rfckt.seriesrlc('R',Rvalue,'L',Lvalue,'C',Cvalue)
h = rfckt.seriesrlc
```

Description

The series RLC network object is a 2-port network as shown in the circuit diagram below.



`h = rfckt.seriesrlc('R',Rvalue,'L',Lvalue,'C',Cvalue)` returns a series RLC network object, `h`, based on the specified resistance (R), inductance (L), and capacitance (C) values. Properties you do not specify retain their default values, allowing you to specify a network of a single resistor, inductor, or capacitor.

`h = rfckt.seriesrlc` returns a series RLC network object whose properties all have their default values. This is equivalent to a pass-through 2-port network, i.e., the resistor, inductor, and capacitor are each replaced by a short circuit.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `seriesrlc` circuit object, use the `analyze` function to calculate the S-parameters and noise correlation matrix at specified frequencies. For `rfckt.seriesrlc` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The analyze function stores the results of the analysis in the AnalyzedResult property of the circuit object.

Network Parameters

The analyze function first calculates the ABCD-parameters for the circuit, then converts the ABCD-parameters to S-parameters using the abcd2s function. For this circuit, A = 1, B = Z, C = 0, and D = 1, where

$$Z = \frac{-LC\omega^2 + jRC\omega + 1}{jC\omega}$$

where $\omega = 2\pi f$.

Properties

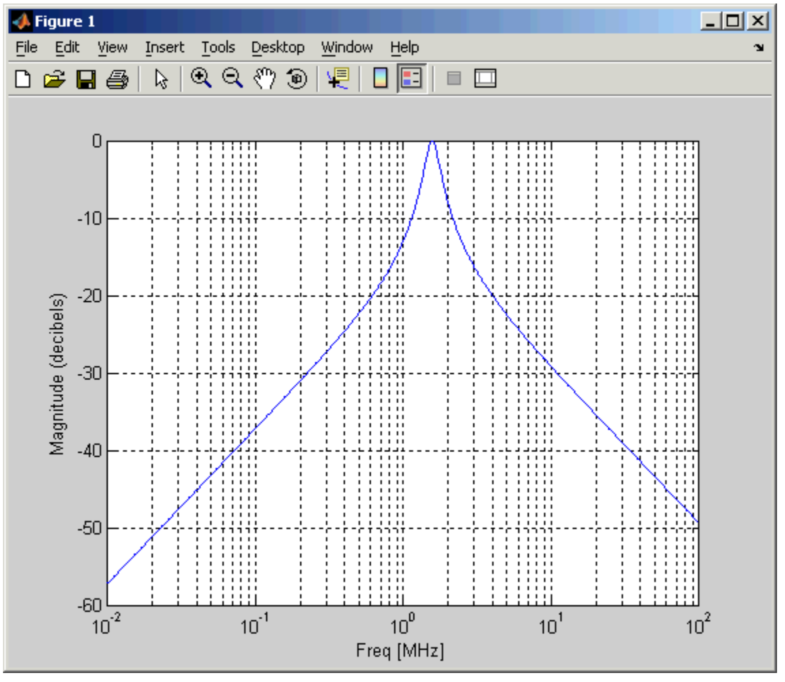
This table lists properties useful to rfckt.seriesrlc objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the series RLC network object.	Handle. Default is [].
C	Scalar value for the capacitance.	Farads. Default is Inf.
L	Scalar value for the inductance.	Henries. Default is 0.
Name	Object name (read only).	String, 'Series RLC'.
nPort	Number of ports (read only).	Integer. The value is always 2.
R	Scalar value for the resistance.	Ohms. Default is 0.

Examples

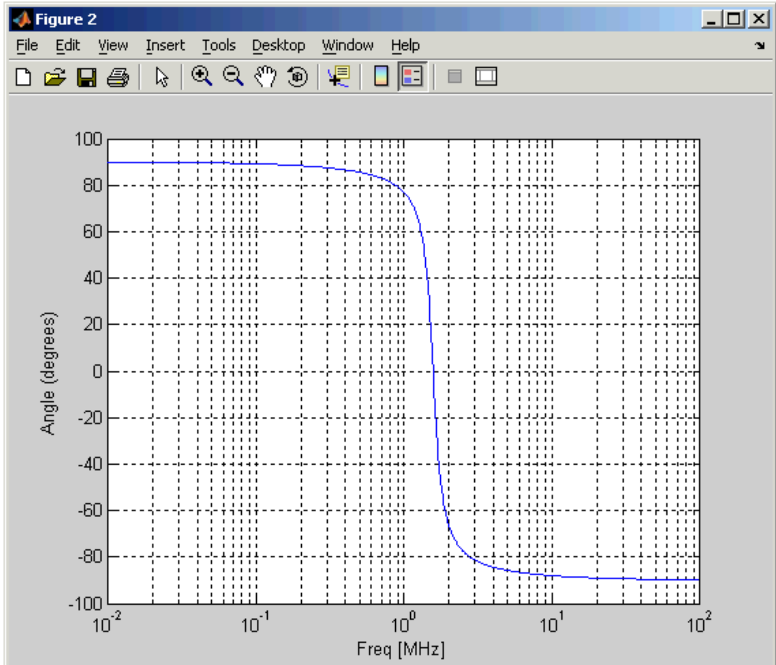
This example creates a series LC resonator and examines its frequency response. It first creates the circuit object then uses the analyze function to calculate its frequency response. Finally, it plots the results - first, the magnitude in decibels (dB).

```
h = rfckt.seriesrlc('L',4.7e-5,'C',2.2e-10);
analyze(h,logspace(4,8,1000));
plot(h,'s21','dB')
set(gca,'Xscale','log')
```



The example then plots the phase, in degrees

```
figure
plot(h,'s21','angle')
set(gca,'Xscale','log')
```



References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox

`rfckt.shuntrlc`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.shuntrlc

Purpose

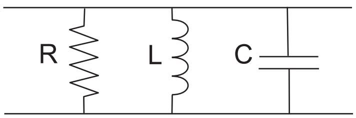
Construct shunt RLC network object

Syntax

```
h = rfckt.shuntrlc('R',Rvalue,'L',Lvalue,'C',Cvalue)
h = rfckt.shuntrlc
```

Description

The shunt RLC network object is a 2-port network as shown in the circuit diagram below.



`h = rfckt.shuntrlc('R',Rvalue,'L',Lvalue,'C',Cvalue)` returns a shunt RLC network object, `h`, based on the specified resistance (R), inductance (L), and capacitance (C) values. Properties you do not specify retain their default values, allowing you to specify a network of a single resistor, inductor, or capacitor.

`h = rfckt.shuntrlc` returns a shunt RLC network object whose properties all have their default values. This is equivalent to a pass-through 2-port network, i.e., the resistor, inductor, and capacitor are each replaced by an open circuit.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `shuntrlc` circuit object, use the `analyze` function to calculate the S-parameters and noise correlation matrix at specified frequencies. For `rfckt.shuntrlc` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

The `analyze` function first calculates the ABCD-parameters for the circuit, then converts the ABCD-parameters to S-parameters using the `abcd2s` function. For this circuit, A = 1, B = 0, C = Y, and D = 1, where

$$Y = \frac{-LC\omega^2 + j(L/R)\omega + 1}{jL\omega}$$

and $\omega = 2\omega f$.

Properties

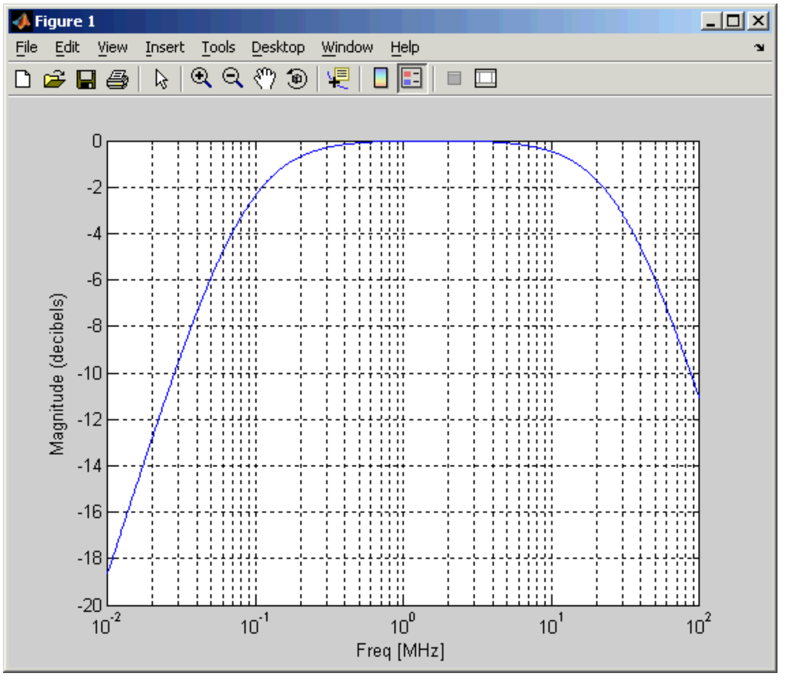
This table lists properties useful to `rfckt.shuntrlc` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`AnalyzedResult`	`rfdata.data` object that contains the result of applying the `analyze` function to the shunt RLC network object.	Handle. Default is [ ].
`C`	Scalar value for the capacitance.	Farads. Default is `0`.
`L`	Scalar value for the inductance.	Henries. Default is `Inf`.
`Name`	Object name (read only).	String. `'Shunt RLC'`.
`nPort`	Number of ports (read only).	Integer. The value is always `2`.
`R`	Scalar value for the resistance.	Ohms. Default is `Inf`.

Examples

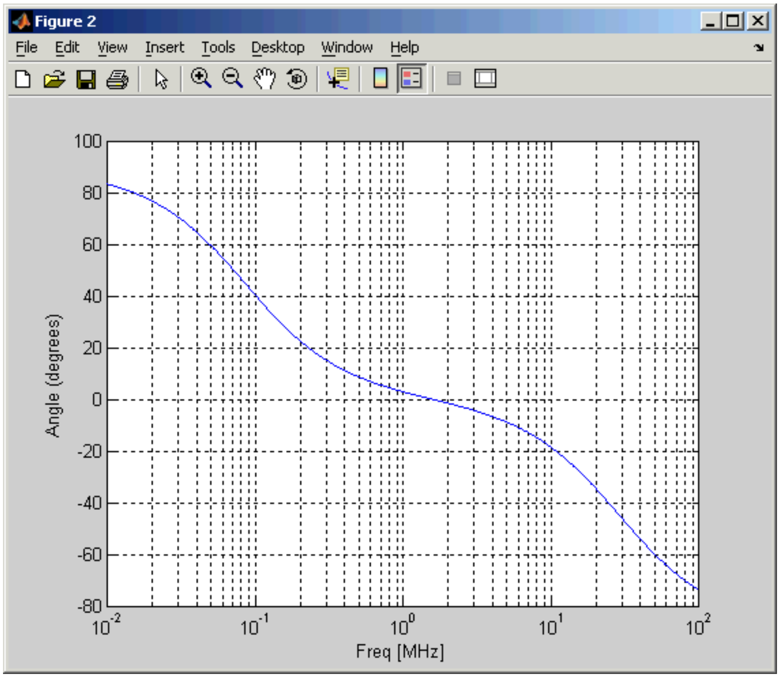
This example creates a shunt LC resonator and examines its frequency response. It first creates the circuit object then uses the `analyze` function to calculate its frequency response. Finally, it plots the results - first, the magnitude in decibels (dB).

```
h = rfckt.shuntrlc('L',4.7e-5,'C',2.2e-10);
analyze(h,logspace(4,8,1000));
plot(h,'s21','dB')
set(gca,'Xscale','log')
```



The example then plots the phase, in degrees

```
figure
plot(h,'s21','angle')
set(gca,'Xscale','log')
```



References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox

`rfckt.seriesrlc`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct 2-wire transmission line object

Syntax

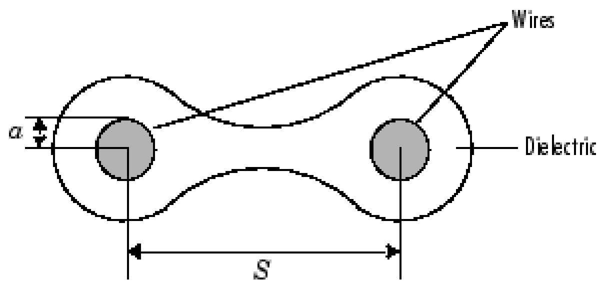
```
h = rfckt.twowire('Property1',value1,'Property2',value2,...)
h = rfckt.twowire
```

Description

`h = rfckt.twowire('Property1',value1,'Property2',value2,...)` returns a 2-wire transmission line object, `h`, with the specified properties. Properties you do not specify retain their default values.

`h = rfckt.twowire` returns a 2-wire transmission line object whose properties all have their default values.

A 2-wire transmission line is shown here in cross-section. Its physical characteristics include the radius of the wires a, and the separation or physical distance between the wire centers S.



Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `twowire` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.twowire` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

A 2-wire transmission line object enables you to model the transmission line as a stub or as a stubless line.

Stubless Transmission Line

If you model the transmission line as a stubless line, the `analyze` function calculates the S-parameters for the specified frequencies, based on the physical length of the transmission line, D, and the complex propagation constant, k.

$$S_{11} = 0$$

$$S_{12} = e^{-kD}$$

$$S_{21} = e^{-kD}$$

$$S_{22} = 0$$

k is a vector whose elements correspond to the elements of the input vector `freq`. k can be expressed in terms of the resistance (R), inductance (L), conductance (G), and capacitance (C) per unit length (meters) as

$$k = k_r + jk_i = \sqrt{(R + j2\pi fL)(G + j2\pi fC)}$$

where f is the frequency range specified in the `analyze` input argument `freq`, and

$$R = \frac{1}{\pi a \sigma_{cond} \delta}$$

$$L = \frac{\mu}{\pi} \operatorname{acosh}\left(\frac{D}{2a}\right)$$

$$G = \frac{\pi \sigma_{diel}}{\operatorname{acosh}(D/(2a))}$$

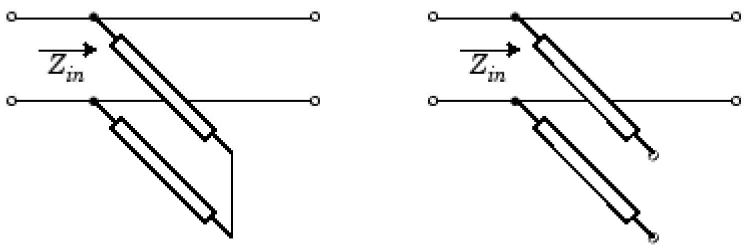
$$C = \frac{\pi \varepsilon}{\operatorname{acosh}(D/(2a))}$$

In these equations, σ_{cond} is the conductivity in the conductor and σ_{diel} is the conductivity in the dielectric. μ is the relative permeability of the dielectric, ε is its permittivity as derived from the `EpsilonR` property, and skin depth δ is calculated as $1/\sqrt{\pi f \mu \sigma_{cond}}$.

Shunt and Series Stubs

If you model the transmission line as a shunt or series stub, the `analyze` function first calculates the ABCD-parameters at the specified frequencies. It then uses the `abcd2s` function to convert the ABCD-parameters to S-parameters.

When you set the `StubMode` property to `'Shunt'`, the 2-port network consists of a stub transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the shunt circuit. The ABCD-parameters for the shunt stub are calculated as

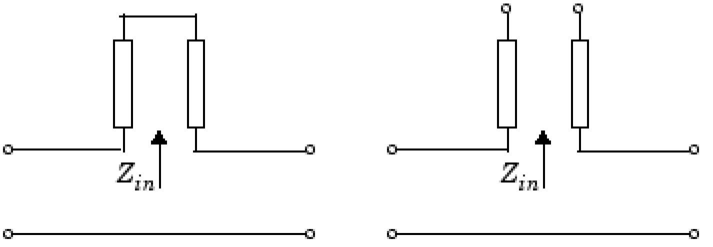
$A = 1$

$B = 0$

$C = 1/Z_{in}$

$D = 1$

When you set the StubMode property to 'Series', the 2-port network consists of a series transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the series circuit. The ABCD-parameters for the series stub are calculated as

$A = 1$

$B = Z_{in}$

$C = 0$

$D = 1$

Properties

This table lists properties useful to rfckt.twowire objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the 2-wire transmission line object.	Handle. Default is [].
EpsilonR	Relative permittivity of the dielectric expressed as the ratio of the permittivity of the dielectric to permittivity in free space ε_0.	Default is 2.3.
LineLength	Physical length of the transmission line.	Meters. Default is 0.01.
Loss	Reduction in strength of the signal as it travels over the transmission line. Read-only; set by the analyze function.	Decibels per meter. Default is [].
MuR	Relative permeability of the dielectric expressed as the ratio of the permeability of the dielectric to permeability in free space μ_0.	Default is 1.
Name	Object name (read only).	String. 'Two-Wire Transmission Line'

Property	Description	Units, Values
nPort	Number of ports (read only).	Integer. The value is always 2.
PV	Phase velocity. Propagation velocity of a uniform plane wave on the transmission line. Read-only; set by the analyze function.	Meters per second. Default is [].
Radius	Radius of the conducting wires.	Meters. Default is 6.7e-4.
Separation	Physical distance between the wires.	Meters. Default is 0.0016.
SigmaCond	Conductivity in conductor.	Siemens per meter (S/m). Default is Inf.
SigmaDiel	Conductivity in dielectric.	Siemens per meter (S/m). Default is 0.
StubMode	Type of stub.	String. 'None' (default), 'Series', or 'Shunt'
Termination	Termination for stub modes 'Shunt' and 'Series'.	String. 'None' (default), 'Open', or 'Short'. Use 'None' when StubMode is 'None'.
Z0	Characteristic impedance. Read-only; set by the analyze function.	Ohms. Default is [].

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.coaxial`	RF Toolbox
`rfckt.cpw`	RF Toolbox
`rfckt.microstrip`	RF Toolbox
`rfckt.parallelplate`	RF Toolbox
`rfckt.rlcgline`	RF Toolbox
`rfckt.txline`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

rfckt.txline

Purpose

Construct transmission line object

Syntax

```
h = rfckt.txline
h = rfckt.txline('Property1',value1,'Property2',value2,...)
```

Description

`h = rfckt.txline` returns a transmission line object whose properties are set to their default values.

`h = rfckt.txline('Property1',value1,'Property2',value2,...)` returns a transmission line object, `h`, with the specified properties. Properties you do not specify retain their default values.

Note See the `rfckt` reference page for a list of functions that act on circuit (`rfckt`) objects.

Circuit Analysis

After you create the `txline` circuit object, use the `analyze` function to calculate the S-parameters and noise figure at specified frequencies. For `rfckt.txline` objects, `freq` must be strictly positive.

```
analyze(h,freq)
```

The `analyze` function stores the results of the analysis in the `AnalyzedResult` property of the circuit object.

Network Parameters

A general transmission line object enables you to model the transmission line as a stub or as a stubless line. The transmission line, which can be lossy or lossless, is treated as a 2-port linear network.

Stubless Transmission Line

If you model the transmission line as a stubless line, the `analyze` function calculates the S-parameters for the specified frequencies, based on the physical length of the transmission line, D, and the complex propagation constant, k.

$$S_{11} = 0$$

$$S_{12} = e^{-kD}$$

$$S_{21} = e^{-kD}$$

$$S_{22} = 0$$

k is a vector whose elements correspond to the elements of the input vector `freq`. $k = \alpha_a + i\beta$, where α_a is the attenuation coefficient and β is the wave number. The attenuation coefficient α_a is related to the loss, α, by

$$\alpha_a = -\ln 10^{-\frac{\alpha}{20}}$$

and the wave number β is related to the phase velocity, V_P, by

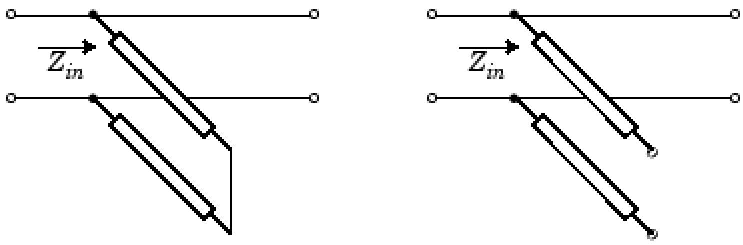
$$\beta = \frac{2\pi f}{V_p}$$

where f is the frequency range specified in the `analyze` input argument `freq`. The phase velocity V_P is derived from the `rfckt.txline` object properties. It is also known as the wave propagation velocity.

Shunt and Series Stubs

If you model the transmission line as a shunt or series stub, the `analyze` function first calculates the ABCD-parameters at the specified frequencies. It then uses the `abcd2s` function to convert the ABCD-parameters to S-parameters.

When you set the `StubMode` property to `'Shunt'`, the 2-port network consists of a stub transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the shunt circuit. The ABCD-parameters for the shunt stub are calculated as

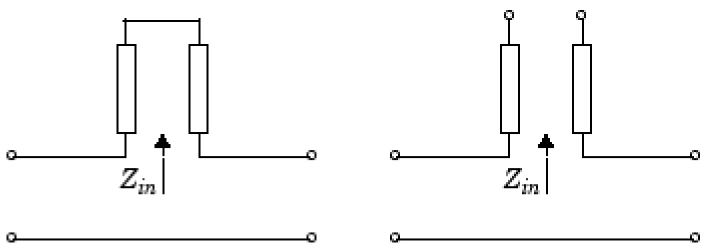
$A = 1$

$B = 0$

$C = 1/Z_{in}$

$D = 1$

When you set the `StubMode` property to `'Series'`, the 2-port network consists of a series transmission line that you can terminate with either a short circuit or an open circuit as shown here.



Z_{in} is the input impedance of the series circuit. The ABCD-parameters for the series stub are calculated as

$A = 1$

$B = Z_{in}$

$C = 0$

$D = 1$

Properties

This table lists properties associated with rfckt.txline objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
AnalyzedResult	rfdata.data object that contains the result of applying the analyze function to the transmission line object.	Handle. Default is [].
Freq	Vector of positive frequencies at which the parameter values are known.	Hertz. Default is [].
IntpType	Interpolation method.	'linear' (default), 'spline', or 'cubic'
LineLength	Scalar that represents the physical length of the transmission line.	Meters. Default is 0.01.
Loss	Vector of line loss values that correspond to the frequencies stored in the Freq property. Line loss is the reduction in strength of the signal as it travels over the transmission line.	Decibels per meter. Must be positive. Default is 0.
Name	Object name (read only).	String. 'Transmission Line'

Property	Description	Units, Values
nPort	Number of ports (read only).	Integer. The value is always 2.
PV	Vector of phase velocity values that correspond to the frequencies stored in the Freq property. Propagation velocity of a uniform plane wave on the transmission line.	Meters per second. Default is 299792458.
StubMode	Type of stub.	String. 'None' (default), 'Series', or 'Shunt'
Termination	Termination for 'Shunt' and 'Series' stub modes.	String. 'None' (default), 'Open', or 'Short'. Use 'None' when StubMode is 'None'.
Z0	Vector of characteristic impedance values that correspond to the frequencies stored in the Freq property.	Ohms. Default is 50.

References

Ludwig, Reinhold and Pavel Bretchko, *RF Circuit Design: Theory and Applications*, Prentice-Hall, 2000.

See Also

analyze	RF Toolbox
calculate	RF Toolbox

`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`rfckt`	RF Toolbox
`rfckt.coaxial`	RF Toolbox
`rfckt.cpw`	RF Toolbox
`rfckt.microstrip`	RF Toolbox
`rfckt.parallelplate`	RF Toolbox
`rfckt.rlcgline`	RF Toolbox
`rfckt.twowire`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct RF data object

Syntax

```
h = rfdata.datatype('Property1',value1,...)
```

Description

`h = rfdata.`*`datatype`*`('Property1',value1,...)` returns a data object, `h`, of type *`datatype`*. The table in the following section lists the available types of data objects. See the individual `rfdata` data object reference pages for information about a specific data object and its properties. See Chapter 2, "Modeling an RF Component" for additional information.

Objects

The `datatype` for an `rfdata` object specifies the type of RF data object. The following table lists the available data objects.

rfdata.datatype	Description
`rfdata.data`	Data object containing network parameter data
`rfdata.ip3`	Data object containing IP3 information
`rfdata.network`	Data object containing network parameter information
`rfdata.nf`	Data object containing noise figure information
`rfdata.noise`	Data object containing noise information
`rfdata.power`	Data object containing power and phase information

Functions

The following table lists the functions that act on data objects and tells you the types of objects on which each can act. These functions are also referred to as methods.

Function	Types of Objects	Purpose
`copy`	All data objects	Copy a data object
`extract`	`rfdata.data`, `rfdata.network`	Extract specified network parameters from a circuit or data object and return the result in an array
`read`	`rfdata.data`	Read RF data parameters from a file to a new or existing data object.
`write`	`rfdata.data`	Write RF data from a data object to a file.

Properties

Properties vary for each type of object. See the individual object reference pages for information about properties.

Viewing Object Properties

You can use `get` to view an `rfdata` object's properties. To see a specific property, use

```
get(h,'PropertyName')
```

To see all properties for an object, use

```
get(h)
```

Changing Object Properties

To see the `rfdata` properties whose values you can change use

```
set(h)
```

To change specific properties, use

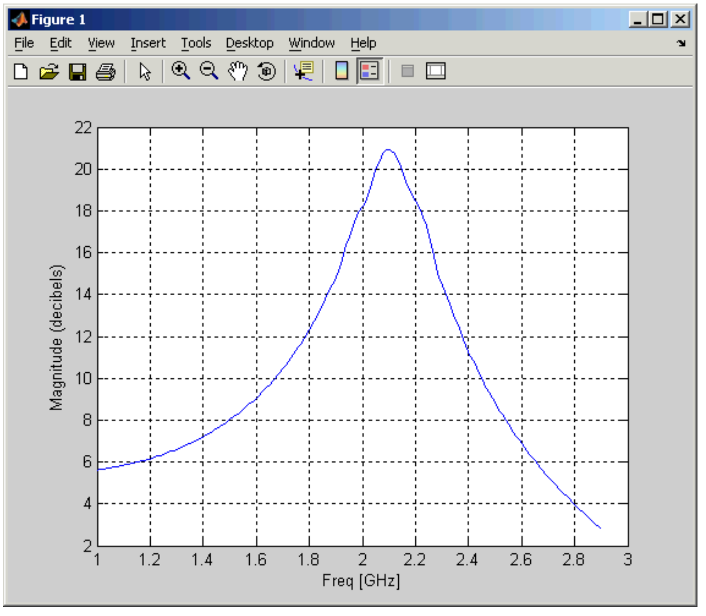
```
set(h,'PropertyName1',value1,'PropertyName2',value2,...)
```

Note You must use single quotation marks around the property name.

Examples

Construct an RF data object from a .s2p data file.

```
file = 'default.s2p';
h = read(rfdata.data,file);  % Read file into data object.
figure
plot(h,'s21','db');   % Plot dB(S21) in XY plane.
```



You can also use other RF Toolbox functions such as `polar` and `smith` to visualize results.

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`copy`	RF Toolbox
`extract`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`rfckt`	RF Toolbox
`smith`	RF Toolbox
`write`	RF Toolbox

Purpose

Store result of circuit object analysis

Description

An `rfdata.data` object contains S-parameters, noise figure in dB, and frequency-dependent, third-order output (OIP3) intercept points.

There are three ways to create an `rfdata.data` object:

- You can construct it by specifying its properties from workspace data using the syntax

  ```
  h = rfdata.data('Property1',value1,...)
  ```

  where the property/value pairs are optional.
- You can create it from file data using the `read` function.
- You can perform frequency domain analysis of a circuit object using the `analyze` function, and the RF Toolbox stores the results in an `rfdata.data` object.

Note See the `rfdata` reference page for a list of functions that act on `rfdata.data` objects.

Use `get` and `set` to view and change `rfdata.data` object properties. To see a specific property, use

```
get(h,'PropertyName')
```

To change specific properties, use

```
set(h,'PropertyName1',value1,'PropertyName2',value2,...)
```

Properties

This table lists properties useful to `rfdata.data` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
Freq	Frequencies of the S-parameters as an M-element vector. The order of the frequencies must correspond to the order of 'S-parameters'. All frequencies must be positive.	Hertz. Default is [].
IntpType	Interpolation method.	'linear' (default), 'spline', or 'cubic'
Name	Object name (read only).	String. 'rfdata.data object'
NF	Noise figure. The amount of noise relative to a noise temperature of 290 degrees kelvin. 0 indicates a noiseless system.	Decibels. Default is 0.
OIP3	Output third-order intercept point.	Watts. Default is Inf.
S_Parameters	S-parameters of the circuit described by the rfdata.data object in a 2-by-2-by-M array. M is the number of S-parameters.	Default is [].
Z0	Reference impedance.	Ohms. Default is 50.

Property	Description	Units, Values
ZL	Load impedance.	Ohms. Default is 50.
ZS	Source impedance.	Ohms. Default is 50.

See Also

extract	RF Toolbox
read	RF Toolbox
rfckt	RF Toolbox
rfdata	RF Toolbox
rfdata.ip3	RF Toolbox
rfdata.network	RF Toolbox
rfdata.nf	RF Toolbox
rfdata.noise	RF Toolbox
rfdata.power	RF Toolbox
write	RF Toolbox

Purpose

Store frequency-dependent, third-order intercept points for amplifiers or mixers

Syntax

```
h = rfdata.ip3('Type',value1,'Freq',value2,'Data',value3)
```

Description

`h = rfdata.ip3('Type',value1,'Freq',value2,'Data',value3)` returns a data object for the frequency-dependent IP3, `h`, based on the specified properties.

Properties

This table lists the properties associated with `rfdata.ip3` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`Data`	Vector of IP3 data that corresponds to the frequencies stored in the `Freq` property.	Watts. Default is `Inf`.
`Freq`	Vector of positive frequency values.	Hertz. Default is `[]`.
`Name`	Object name (read only).	String. `'3rd order intercept'`
`Type`	Type of IP3.	String. `'OIP3'` or `'IIP3'`

See Also

`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`rfdata.data`	RF Toolbox
`rfdata.network`	RF Toolbox
`rfdata.nf`	RF Toolbox

`rfdata.noise`	RF Toolbox
`rfdata.power`	RF Toolbox

Purpose

Store frequency-dependent network parameters

Syntax

```
h =
rfdata.network('Type',value1,'Freq',value2,'Data',value3,'ZO',
 value4)
```

Description

```
h =
rfdata.network('Type',value1,'Freq',value2,'Data',value3,'ZO',value4)
```
returns a data object for the frequency-dependent network parameters, `h`, based on the specified properties.

Properties

This table lists the properties associated with `rfdata.network` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`Data`	Matrix of network parameters that correspond to the frequencies stored in the `Freq` property.	Default is `[]`.
`Freq`	Vector of positive frequency values.	Hertz. Default is `[]`.
`Name`	Object name (read only).	String. `'Network parameters'`
`Type`	Type of network parameters.	String. `'S'`, `'Y'`, `'Z'`, `'H'`, `'G'`, or `'T'`
`ZO`	Scalar reference impedance. This property is only available when the `Type` property is set to `'S'`.	Default is `[]`.

See Also

`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`rfdata.data`	RF Toolbox
`rfdata.ip3`	RF Toolbox
`rfdata.nf`	RF Toolbox
`rfdata.noise`	RF Toolbox
`rfdata.power`	RF Toolbox

Purpose

Store frequency-dependent noise figure data for amplifiers or mixers

Syntax

```
h = rfdata.nf('Freq',value1,'Data',value2)
```

Description

`h = rfdata.nf('Freq',value1,'Data',value2)` returns a data object for the frequency-dependent noise figure, `h`, based on the specified properties.

Properties

This table lists the properties associated with `rfdata.nf` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`Data`	Vector of noise figure values that correspond to the frequencies stored in the `Freq` property.	Decibels. Default is `0`.
`Freq`	Vector of positive frequency values.	Hertz. Default is `[]`.
`Name`	Object name (read only).	String. `'Noise figure'`

See Also

`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`rfdata.data`	RF Toolbox
`rfdata.ip3`	RF Toolbox
`rfdata.network`	RF Toolbox
`rfdata.noise`	RF Toolbox
`rfdata.power`	RF Toolbox

rfdata.noise

Purpose

Store frequency-dependent spot noise data for amplifiers or mixers

Syntax

```
h =
rfdata.noise('Freq',value1,'FMIN',value2,'GAMMAOPT',value3,'RN'
,  value4)
```

Description

`h =`
`rfdata.noise('Freq',value1,'FMIN',value2,'GAMMAOPT',value3,'RN',value4)`
returns a data object for the frequency-dependent spot noise,
`h`, based on the specified properties.

Properties

This table lists the properties associated with `rfdata.noise` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`FMIN`	Vector of minimum noise figure values that correspond to the frequencies stored in the `Freq` property.	Decibels. Default is `1`.
`Freq`	Vector of positive frequency values.	Hertz. Default is `[]`.
`GAMMAOPT`	Vector of optimum source reflection coefficients that correspond to the frequencies stored in the `Freq` property.	Default is `1`.

Property	Description	Units, Values
Name	Object name (read only).	String. 'Spot noise data'
RN	Vector of equivalent normalized noise resistance values that correspond to the frequencies stored in the Freq property.	Default is 1.

See Also

rfckt	RF Toolbox
rfdata	RF Toolbox
rfdata.data	RF Toolbox
rfdata.ip3	RF Toolbox
rfdata.network	RF Toolbox
rfdata.nf	RF Toolbox
rfdata.power	RF Toolbox

Purpose Store output power and phase information for amplifiers or mixers

Syntax

```
h = rfdata.power(`property1',value1,'property2',value2,...)
```

Description

`h = rfdata.power(`property1',value1,'property2',value2,...)` returns a data object for the Pin/Pout power data, `h`, based on the specified properties.

Properties

This table lists the properties associated with `rfdata.power` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`Freq`	Vector of positive frequency values.	Hertz. Default is `[]`.
`Name`	Object name (read only).	String. `'Power data'`
`Phase`	Vector of phase shift values that correspond to the frequencies stored in the `Freq` property.	Degrees. Default is `{}`.

Property	Description	Units, Values
Pin	Cell array of input power values. For example, `Pin = {[A]; [B]; [C]};` where A, B, and C are column vectors that contain the Pin values at the first three frequencies stored in the Freq property.	Watts. Default is {[1,10]}.
Pout	Cell array of output power values.	Watts. Default is {[1,10]}.

See Also

rfckt	RF Toolbox
rfdata	RF Toolbox
rfdata.data	RF Toolbox
rfdata.ip3	RF Toolbox
rfdata.network	RF Toolbox
rfdata.nf	RF Toolbox
rfdata.noise	RF Toolbox

Purpose

Construct RF model object

Syntax

```
h = rfmodel.component('Property1',value1,...)
h = rfmodel.component('Property1',value1,...)
```

Syntax

```
h = rfmodel.component('Property1',value1,...)
```

Description

`h = rfmodel.`*`component`*`('Property1',value1,...)` returns a model object, `h`, of type *`component`*. See the individual `rfmodel` component reference pages for information about a specific model object and its properties. See Chapter 2, "Modeling an RF Component" for additional information about creating and analyzing objects.

Objects

The `component` for an `rfmodel` object specifies the type of RF model object. The following table lists the available RF model objects.

rfmodel.*component*	Description
`rfmodel.rational`	Rational function model

Functions

The following table lists the functions that act on model objects and the types of objects on which each can act. These functions are also referred to as *methods*.

Function	Types of Objects	Purpose
`freqresp`	All model objects	Compute the frequency response of a model object.
`impulse`	All model objects	Compute the impulse response of a model object.
`writeva`	All model objects	Write data from a model object to a file.

Properties

Properties vary for each type of component. See the individual component reference pages for information about properties.

Viewing Object Properties

You can use `get` to view an `rfmodel` object's properties. To see a specific property of an object `h`, use

```
get(h,'PropertyName')
```

To see all properties for an object `h`, use

```
get(h)
```

Changing Object Properties

To see the properties of an object `h` whose values you can change, use

```
set(h)
```

To change specific properties of object `h`, use

```
set(h,'PropertyName1',value1,'PropertyName2',value2,...)
```

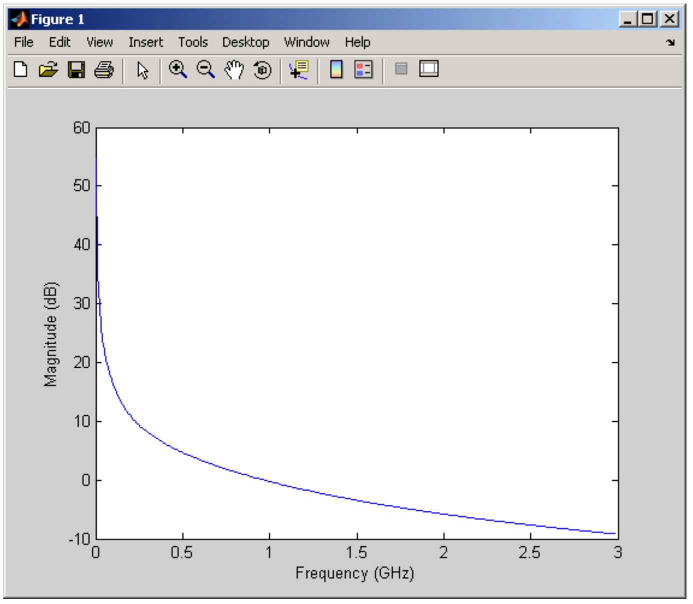
Note You must use single quotation marks around the property name.

Examples

Construct a rational function model, `rat`, with poles at -4 MHz, -3 GHz, and -5 GHz and residues at 600 MHz, 2 GHz, and 4 GHz. Then, perform frequency-domain analysis from 1.0 MHz to 3.0 GHz. Plot the resulting frequency response in dB on the X-Y plane.

```
rat=rfmodel.rational...
     ('A',[-5e9,-3e9,-4e6],...
      'C',[6e8,2e9,4e9]);      % Create model
f = [1e6:1.0e7:3e9];           % Simulation frequencies
[resp,freq]=freqresp(rat,f);   % Compute frequency response
figure
```

```
plot(freq/1e9,db(resp));      % Plot frequency response
xlabel('Frequency (GHz)')
ylabel('Magnitude (dB)')
```



See Also

`freqresp`	RF Toolbox
`impulse`	RF Toolbox
`rationalfit`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`rfmodel.rational`	RF Toolbox
`write`	RF Toolbox

Purpose

Construct rational function model object

Syntax

```
h = rfmodel.rational
h = rfmodel.rational('Property1',value1,'Property2',value2,
   ...)
```

Description

The `rfmodel.rational` object is a rational function model of the form

$$F(s) = \left(\sum_{k=1}^{n} \frac{C_k}{s - A_k} + D \right) e^{-s^*Delay}, \quad s = j2\pi * freq$$

`h = rfmodel.rational` returns an rational function model object whose properties are set to their default values.

`h = rfmodel.rational('Property1',value1,'Property2',value2,...)` returns a rational function model object, `h`, with the specified properties. Properties you do not specify retain their default values.

Properties

This table lists the properties associated with `rfmodel.rational` objects along with property descriptions, units, and valid values.

Property	Description	Units, Values
`A`	Complex vector containing poles of the rational function. Its length, shown in the preceding equation as `k`, must be equal to the length of the vector you provide for `'C'`. `k` is the number of poles in the rational function model.	Hertz. Default is `[]`.

Property	Description	Units, Values
C	Complex vector containing the residues of the rational function.	Hertz. Default is [].
D	Scalar value specifying the constant offset in the frequency response of the rational function.	None. Default is 0.
Delay	Scalar value specifying the time delay in the frequency response of the rational function.	Seconds. Default is 0.
Name	Object name (read only).	String. 'Rational Function'

See Also

freqresp	RF Toolbox
impulse	RF Toolbox
rationalfit	RF Toolbox
rfckt	RF Toolbox
rfdata	RF Toolbox
writeva	RF Toolbox

Purpose Open RF Analysis Tool (RF Tool)

Syntax

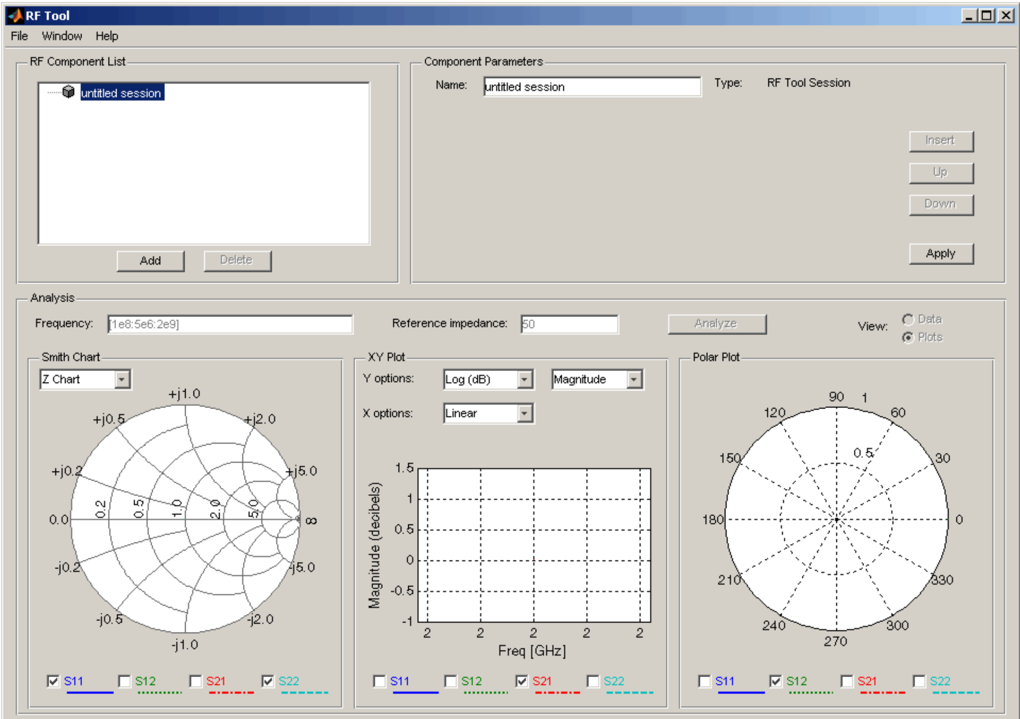
```
rftool
```

Description `rftool` opens RF Tool. Use this tool to

- Create circuit components and set their parameters.
- Analyze components over a specified frequency range and step size.
- Plot the analysis results.
- Import component objects to and export them from the MATLAB workspace.
- Save RF Tool sessions for later use.

See Chapter 4, "RF Tool: An RF Analysis GUI" for more information.

The following figure shows the RF Tool in its default state.


RF Tool
File
Window
Help
RF Component List
untitled session
Add
Delete
Component Parameters
Name:
untitled session
Type:
RF Tool Session
Insert
Up
Down
Apply
Analysis
Frequency:
[1e8:5e6:2e9]
Reference impedance:
50
Analyze
View:
Data
Plots
Smith Chart
Z Chart
+j1.0
+j0.5
+j2.0
+j0.2
+j5.0
0.0
0.2
0.5
1.0
2.0
5.0
∞
-j0.2
-j5.0
-j0.5
-j2.0
-j1.0
S11
S12
S21
S22
XY Plot
Y options:
Log (dB)
Magnitude
X options:
Linear
1.5
1
0.5
0
-0.5
-1
Magnitude (decibels)
2
2
2
2
2
Freq [GHz]
S11
S12
S21
S22
Polar Plot
90
1
120
60
150
0.5
30
180
0
210
330
240
300
270
S11
S12
S21
S22

Purpose

Convert S-parameters to ABCD-parameters

Syntax

```
abcd_params = s2abcd(s_params,z0)
```

Description

`abcd_params = s2abcd(s_params,z0)` converts the scattering parameters `s_params` into the ABCD-parameters `abcd_params`. The `s_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters. `z0` is the reference impedance; its default is 50 ohms. `abcd_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port ABCD-parameters.

See Also

`abcd2s`	RF Toolbox
`h2abcd`	RF Toolbox
`s2h`	RF Toolbox
`s2y`	RF Toolbox
`s2z`	RF Toolbox
`y2abcd`	RF Toolbox
`z2abcd`	RF Toolbox

Purpose

Convert S-parameters to hybrid h-parameters

Syntax

```
h_params = s2h(s_params,z0)
```

Description

`h_params = s2h(s_params,z0)` converts the scattering parameters `s_params` into the hybrid parameters `h_params`. The `s_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters. `z0` is the reference impedance; its default is 50 ohms. `h_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port hybrid h-parameters.

See Also

`abcd2h`	RF Toolbox
`h2s`	RF Toolbox
`s2abcd`	RF Toolbox
`s2y`	RF Toolbox
`s2z`	RF Toolbox
`y2h`	RF Toolbox
`z2h`	RF Toolbox

Purpose

Convert S-parameters to S-parameters with different impedance

Syntax

```
s_params_new = s2s(s_params,z0)
s_params_new = s2s(s_params,z0,z0_new)
```

Description

`s_params_new = s2s(s_params,z0)` converts the scattering parameters `s_params` with reference impedance `z0` into the scattering parameters `s_params_new` with a default reference impedance of 50 ohms. Both `s_params` and `s_params_new` are complex `n`-by-`n`-by-`m` arrays, representing `m` n-port S-parameters.

`s_params_new = s2s(s_params,z0,z0_new)` converts the scattering parameters `s_params` with reference impedance `z0` into the scattering parameters `s_params_new` with reference impedance `z0_new`.

See Also

`abcd2s`	RF Toolbox
`h2s`	RF Toolbox
`s2abcd`	RF Toolbox
`s2h`	RF Toolbox
`s2y`	RF Toolbox
`s2z`	RF Toolbox
`y2s`	RF Toolbox
`z2s`	RF Toolbox

s2scc

Purpose

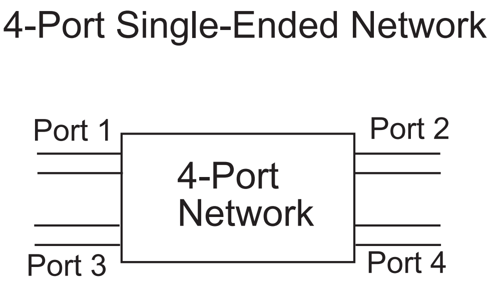
Convert 4-port, single-ended S-parameters to 2-port, common mode S-parameters (S_{cc})

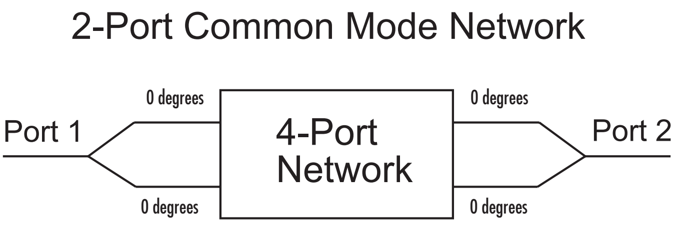
Syntax

```
scc_params = s2scc(s_params)
```

Description

`scc_params = s2scc(s_params)` converts the 4-port, single-ended S-parameters, `s_params`, to 2-port, common mode S-parameters, `scc_params`. `scc_params` is a complex 2-by-2-by-M array that represents M 2-port S-parameters. `s_params` is a complex 4-by-4-by-M array that represents M 4-port S-parameters.





References

Fan, W., A. C. W. Lu, L. L. Wai, and B. K. Lok. "Mixed-Mode S-Parameter Characterization of Differential Structures." Electronic Packaging Technology Conference, pp. 533-537, 2003.

See Also

`s2scd`	RF Toolbox
`s2sdc`	RF Toolbox
`s2sdd`	RF Toolbox

s2scd

Purpose

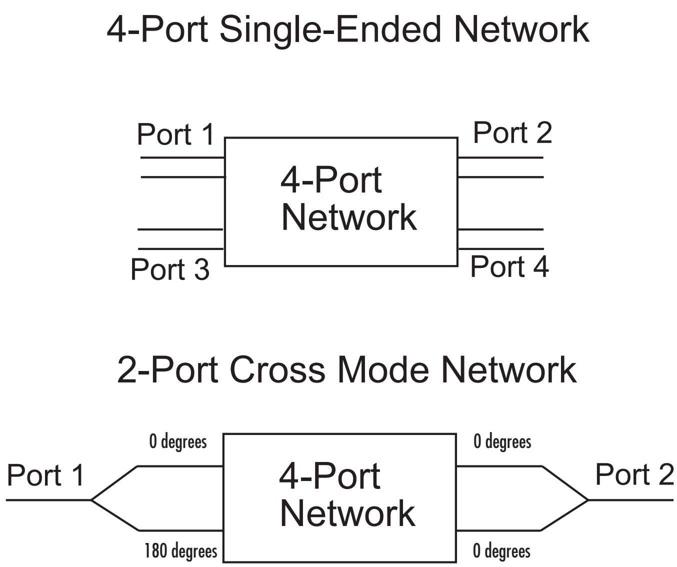
Convert 4-port, single-ended S-parameters to 2-port, cross mode S-parameters (S_{cd})

Syntax

```
scd_params = s2scd(s_params)
```

Description

`scd_params = s2scd(s_params)` converts the 4-port, single-ended S-parameters, `s_params`, to 2-port, cross mode S-parameters, `scd_params`. `scd_params` is a complex 2-by-2-by-M array that represents M 2-port cross mode S-parameters (S_{cd}). `s_params` is a complex 4-by-4-by-M array that represents M 4-port S-parameters.



References

Fan, W., A. C. W. Lu, L. L. Wai, and B. K. Lok. "Mixed-Mode S-Parameter Characterization of Differential Structures." Electronic Packaging Technology Conference, pp. 533-537, 2003.

See Also

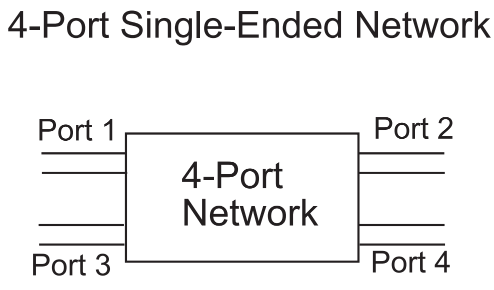
`s2scc`	RF Toolbox
`s2sdc`	RF Toolbox
`s2sdd`	RF Toolbox

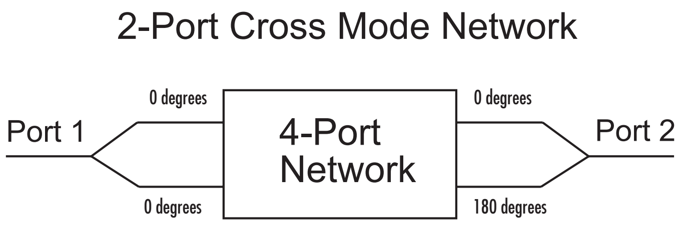
Purpose Convert 4-port, single-ended S-parameters to 2-port, cross mode S-parameters (S_{dc})

Syntax

```
sdc_params = s2sdc(s_params)
```

Description `sdc_params = s2sdc(s_params)` converts the 4-port, single-ended S-parameters, `s_params`, to 2-port, cross mode S-parameters, `sdc_params`. `sdc_params` is a complex 2-by-2-by-M array that represents M 2-port cross mode S-parameters (S_{dc}). `s_params` is a complex 4-by-4-by-M array that represents M 4-port S-parameters.





References

Fan, W., A. C. W. Lu, L. L. Wai, and B. K. Lok. "Mixed-Mode S-Parameter Characterization of Differential Structures." Electronic Packaging Technology Conference, pp. 533-537, 2003.

See Also

`s2scc`	RF Toolbox
`s2scd`	RF Toolbox
`s2sdd`	RF Toolbox

s2sdd

Purpose

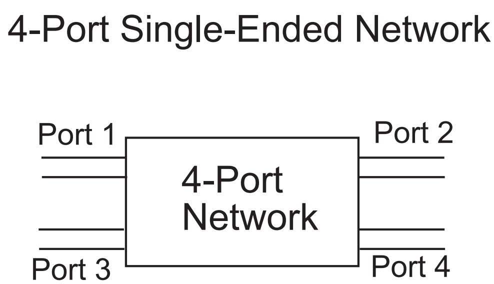
Convert 4-port, single-ended S-parameters to 2-port, differential mode S-parameters (S_{dd})

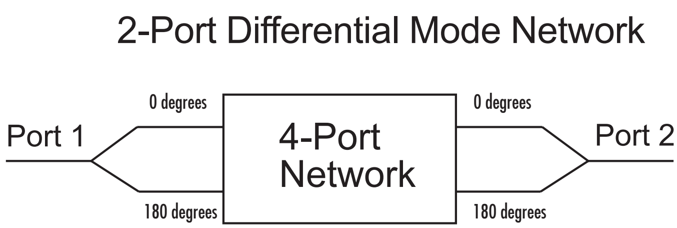
Syntax

```
sdd_params = s2sdd(s_params)
```

Description

`sdd_params = s2sdd(s_params)` converts the 4-port, single-ended S-parameters, `s_params`, to 2-port, differential mode S-parameters, `sdd_params`. `sdd_params` is a complex 2-by-2-by-M array that represents M 2-port differential mode S-parameters. `s_params` is a complex 4-by-4-by-M array that represents M 4-port S-parameters.





References

Fan, W., A. C. W. Lu, L. L. Wai, and B. K. Lok. “Mixed-Mode S-Parameter Characterization of Differential Structures.” Electronic Packaging Technology Conference, pp. 533-537, 2003.

See Also

`s2scc`	RF Toolbox
`s2scd`	RF Toolbox
`s2sdc`	RF Toolbox

Purpose

Convert S-parameters to T-parameters

Syntax

```
t_params = s2t(s_params)
```

Description

t_params = s2t(s_params) converts the scattering parameters s_params into the chain scattering parameters t_params. The s_params input is a complex 2-by-2-by-m array, representing m 2-port S-parameters. t_params is a complex 2-by-2-by-m array, representing m 2-port T-parameters.

See Also

s2abcd	RF Toolbox
s2h	RF Toolbox
s2y	RF Toolbox
s2z	RF Toolbox
t2s	RF Toolbox

Purpose

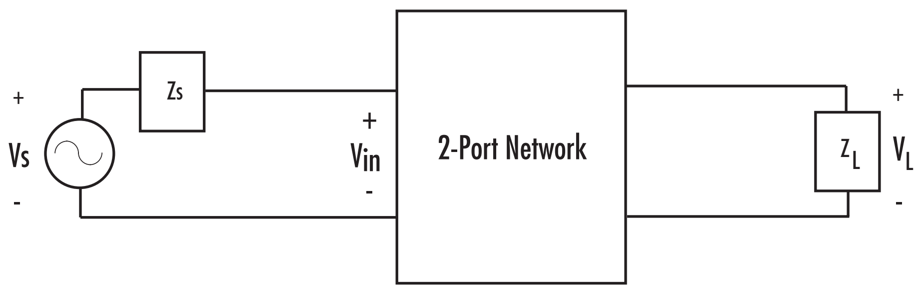
Convert 2-port S-parameters to transfer function

Syntax

```
tf = s2tf(s_params, z0, zs, zl,option)
```

Description

`tf = s2tf(s_params, z0, zs, zl,option)` converts the 2-port scattering parameters, `s_params`, into a transfer function that represents the normalized voltage gain of a 2-port network. The following figure shows the impedances and voltages that are used to define the gain.



The impedances shown in the figure are optional arguments to the `s2tf` function and are defined as follows:

- `z0` is the reference impedance of the S-parameters.
- `zs` is the source impedance.
- `zl` is the load impedance.

The default value of these impedances is 50 ohms.

The voltages in the figure are defined as follows:

- V_L is the output voltage over the load impedance.
- V_S is the source voltage.
- V_{in} is the input voltage when the input impedance of the 2-port network matches the source impedance. That is, $V_{in}=V_S/2$.

The definition of the transfer function is determined by the optional `option` argument.

`option` can be

- `1` — The transfer function is the gain from the input voltage to the output voltage:

  $$tf = \frac{V_L}{V_{in}} = \frac{S_{21} * (1 + \Gamma_l) * (1 - \Gamma_s)}{(1 - S_{22} * \Gamma_l)(1 - \Gamma_{in} * \Gamma_s)}$$

  where

  $$\Gamma_l = \frac{Z_l - Z_o}{Z_l + Z_o}$$

  $$\Gamma_s = \frac{Z_s - Z_o}{Z_s + Z_o}$$

  $$\Gamma_{in} = S_{11} + \left(S_{12} * S_{21} * \frac{\Gamma_l}{(1 - S_{22} * \Gamma_l)} \right)$$

- `2` — The transfer function is the gain from the source voltage to the output voltage:

  $$tf = \frac{V_L}{V_S} = \frac{S_{21} * (1 + \Gamma_l) * (1 - \Gamma_s)}{2 * (1 - S_{22} * \Gamma_l)(1 - \Gamma_{in} * \Gamma_s)}$$

The default value of `option` is `1`.

See Also

`rationalfit`	RF Toolbox
`s2scc`	RF Toolbox

`s2scd`	RF Toolbox
`s2sdc`	RF Toolbox
`s2sdd`	RF Toolbox

Purpose

Convert S-parameters to Y-parameters

Syntax

```
y_params = s2y(s_params,z0)
```

Description

`y_params = s2y(s_params'z0)` converts the scattering parameters `s_params` into the admittance parameters `y_params`. The `s_params` input is a complex `n`-by-`n`-by-`m` array, representing `m` n-port S-parameters. `z0` is the reference impedance; its default is 50 ohms. `y_params` is a complex `n`-by-`n`-by-`m` array, representing `m` n-port Y-parameters.

See Also

`abcd2y`	RF Toolbox
`h2y`	RF Toolbox
`s2abcd`	RF Toolbox
`s2h`	RF Toolbox
`s2z`	RF Toolbox
`y2s`	RF Toolbox
`z2y`	RF Toolbox

Purpose

Convert S-parameters to Z-parameters

Syntax

```
z_params = s2z(s_params,z0)
```

Description

`z_params = s2z(s_params,z0)` converts the scattering parameters `s_params` into the impedance parameters `z_params`. The `s_params` input is a complex `n`-by-`n`-by-`m` array, representing `m` n-port S-parameters. `z0` is the reference impedance; its default is 50 ohms. `z_params` is a complex `n`-by-`n`-by-`m` array, representing `m` n-port Z-parameters.

See Also

`abcd2z`	RF Toolbox
`h2z`	RF Toolbox
`s2abcd`	RF Toolbox
`s2h`	RF Toolbox
`s2y`	RF Toolbox
`y2z`	RF Toolbox
`z2s`	RF Toolbox

Purpose

Plot specified circuit object parameters on Smith chart

Syntax

```
[lineseries,hsm] = smith(h,parameter1,...,parametern,type)
```

Description

`[lineseries,hsm] = smith(h,parameter1,...,parametern,type)` plots the network parameters `parameter1,...,` `parametern` from the object `h` on a Smith chart. `h` is the handle of a circuit (`rfckt`) or data (`rfdata`) object. `type` is a string, `'z'` (default),`'y'`, or `'zy'`, specifying the type of Smith chart.

Type `listparam(h)` to get a list of valid parameters for a circuit object `h`.

Note For all circuit objects except those that contain data from a data file, you must use the `analyze` function to perform a frequency domain analysis before calling `smith`.

Note Use the `smithchart` function to plot network parameters that are not part of a circuit (`rfckt`) or data (`rfdata`) object, but are specified as vector data.

Changing Properties of the Plotted Lines

The `smith` function returns `lineseries`, a column vector of handles to `lineseries` objects, one handle per plotted line. Use the MATLAB `lineseries properties` function to change the properties of these lines.

Changing Properties of the Smith Chart

The `smith` function returns the handle `hsm` of the Smith chart. Use the properties listed below to change the properties of the chart itself.

Properties

`smith` creates the plot using the default property values of a Smith chart. Use `set(hsm,'PropertyName1',PropertyValue1,...) to` change the property values of the chart. Use get(hsm) to get the property values.

This table lists all properties you can specify for a Smith chart object along with units, valid values, and a descriptions of their use.

Property Name	Description	Units, Values
Color	Line color for a Z or Y Smith chart. For a ZY Smith chart, the Z line color.	ColorSpec. Default is [0.4 0.4 0.4] (dark gray).
LabelColor	Color of the line labels.	ColorSpec. Default is [0 0 0] (black).
LabelSize	Size of the line labels.	FontSize. Default is 10. See the Annotation Textbox Properties reference page for more information on specifying font size.
LabelVisible	Visibility of the line labels.	'on' (default) or 'off'
LineType	Line spec for a Z or Y Smith chart. For a ZY Smith chart, the Z line spec.	LineSpec. Default is '-' (solid line).
LineWidth	Line width for a Z or Y Smith chart. For a ZY Smith chart, the Z line width.	Number of points. Default is 0.5.
SubColor	The Y line color for a ZY Smith chart.	ColorSpec. Default is [0.8 0.8 0.8] (medium gray).

Property Name	Description	Units, Values
SubLineType	The Y line spec for a ZY Smith chart.	LineSpec. Default is ':' (dotted line).
SubLineWidth	The Y line width for a ZY Smith chart.	Number of points. Default is 0.5.
Type	Type of Smith chart.	'z' (default), 'y', or 'zy'
Value	Two-row matrix. Row 1 specifies the constant resistance lines. Row 2 specifies the constant reactance lines.	2-by-n matrix. Default is [0.2000 0.5000 1.0000 2.0000 5.0000; 1.0000 2.0000 5.0000 5.0000 30.0000]

See Also

analyze	RF Toolbox
calculate	RF Toolbox
getz0	RF Toolbox
listformat	RF Toolbox
listparam	RF Toolbox
plot	RF Toolbox
polar	RF Toolbox
read	RF Toolbox
restore	RF Toolbox
rfckt	RF Toolbox
rfdata	RF Toolbox
write	RF Toolbox

Purpose

Plot complex vector on Smith chart

Syntax

```
[lineseries,hsm] = smithchart(y)
hsm = smithchart
```

Description

`[lineseries,hsm] = smithchart(y)` plots the complex vector `y` on a Smith chart and returns

- `hsm`, which is the handle of the Smith chart object.

  Change the properties of the chart by changing the `smithchart` object properties described in the next section.

- `lineseries`, which is a column vector of handles to `lineseries` objects, one handle per plotted line.

  Change the properties of the plotted lines by changing the `lineseries properties`.

`hsm = smithchart` draws a blank Smith chart and returns the handle `hsm` of the Smith chart object.

Note To plot multiple sets of data on a Smith chart, use the following syntax:

```
[lineseries1,hsm] = smithchart(y)
hold on
lineseries2 = smithchart(z)
```

You can use change the properties of the lines, `lineseries1` and `lineseries2`, and of the properties of the chart, `hsm`.

Note To plot network parameters from a circuit (`rfckt`) or data (`rfdata`) object on a Smith chart, use the `smith` function.

Properties

smithchart creates the plot using default property values of a Smith chart. Use set(h,'PropertyName1',PropertyValue1,...) to change the property values. Use get(h) to get the property values.

This table lists all properties you can specify for smithchart objects along with units, valid values, and a descriptions of their use.

Property Name	Description	Units, Values
Color	Line color for a Z or Y Smith chart. For a ZY Smith chart, the Z line color.	ColorSpec. Default is [0.4 0.4 0.4] (dark gray).
LabelColor	Color of the line labels.	ColorSpec. Default is [0 0 0] (black).
LabelSize	Size of the line labels.	FontSize. Default is 10. See the Annotation Textbox Properties reference page for more information on specifying font size.
LabelVisible	Visibility of the line labels.	'on' (default) or 'off'
LineType	Line spec for a Z or Y Smith chart. For a ZY Smith chart, the Z line spec.	LineSpec. Default is '-' (solid line).
LineWidth	Line width for a Z or Y Smith chart. For a ZY Smith chart, the Z line width.	Number of points. Default is 0.5.
SubColor	The Y line color for a ZY Smith chart.	ColorSpec. Default is [0.8 0.8 0.8] (medium gray).

Property Name	Description	Units, Values
SubLineType	The Y line spec for a ZY Smith chart.	LineSpec. Default is ':' (dotted line).
SubLineWidth	The Y line width for a ZY Smith chart.	Number of points. Default is 0.5.
Type	Type of Smith chart.	'z' (default), 'y', or 'zy'
Value	Two-row matrix. Row 1 specifies the constant resistance lines. Row 2 specifies the constant reactance lines.	2-by-n matrix. Default is [0.2000 0.5000 1.0000 2.0000 5.0000; 1.0000 2.0000 5.0000 5.0000 30.0000]

See Also

get	RF Toolbox
rfckt	RF Toolbox
rfdata	RF Toolbox
set	RF Toolbox
smith	RF Toolbox

stabilityk

Purpose

Calculate stability factor K of 2-port network

Syntax

```
[k,b1,b2,delta] = stabilityk(s_params)
```

Description

`[k,b1,b2,delta] = stabilityk(s_params)` calculates and returns the stability factor `k`, as well as the conditions `b1`, `b2`, and `delta` for stability of a 2-port network. The input `s_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters.

$$K = 1 - |S_{11}|^2 - |S_{22}|^2 + |\Delta|^2 / (2|S_{12}S_{21}|)$$

$$B_1 = 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2$$

$$B_2 = 1 - |S_{11}|^2 + |S_{22}|^2 - |\Delta|^2$$

where

- S_{11}, S_{12}, S_{21}, and S_{22} are vectors of S-parameters, taken from the input argument `s_params`.
- $\Delta = S_{11}S_{22} - S_{12}S_{21}$

References

Gonzalez, Guillermo, *Microwave Transistor Amplifiers: Analysis and Design*, 2nd edition, Prentice-Hall, pp. 217-228, 1997.

See Also

`stabilitymu`	RF Toolbox

Purpose

Calculate stability factor, mu, of 2-port network

Syntax

```
[mu,muprime] = stabilitymu(s_params)
```

Description

`[mu,muprime] = stabilitymu(s_params)` calculates and returns the stability factors μ and μ', of a 2-port network. The input `s_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters.

$$\mu = (1 - |S_{11}|^2)/(|S_{22} - S_{11}^*\Delta| + |S_{21}S_{12}|)$$

$$\mu' = (1 - |S_{22}|^2)/(|S_{11} - S_{22}^*\Delta| + |S_{21}S_{12}|)$$

where

- S_{11}, S_{12}, S_{21}, and S_{22} are vectors of S-parameters, taken from the input argument `s_params`.
- $\Delta = S_{11}S_{22} - S_{12}S_{21}$
- S^* is the complex conjugate of the designated S-parameter.

μ defines the minimum distance between the center of the unit Smith chart and the unstable region in the load plane (the load is considered port 2).

μ' defines the minimum distance between the center of the unit Smith chart and the unstable region in the source plane (the source is considered port 1).

Having $\mu > 1$ (or $\mu' > 1$) is necessary and sufficient for the 2-port linear network, described by the S-parameters, to be unconditionally stable.

References

Edwards, Marion Lee, and Jeffrey H. Sinsky, "A New Criterion for Linear 2-Port Stability Using a Single Geometrically Derived Parameter," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 40, No. 12, pp. 2303-2311, December 1992.

See Also

`stabilityk`	RF Toolbox

Purpose

Convert T-parameters to S-parameters

Syntax

```
s_params = t2s(t_params)
```

Description

`s_params = t2s(t_params)` converts the chain scattering parameters `t_params` into the scattering parameters `s_params`. The `t_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port T-parameters. `s_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port S-parameters.

See Also

`abcd2s`	RF Toolbox
`h2s`	RF Toolbox
`s2t`	RF Toolbox
`y2s`	RF Toolbox
`z2s`	RF Toolbox

Purpose Calculate VSWR at given reflection coefficient gamma

Syntax

```
result = vswr(gamma)
```

Description

`result = vswr(gamma)` calculates the voltage standing-wave ratio (VSWR) at the given reflection coefficient gamma as

$$\mathrm{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

where Γ is the given reflection coefficient `gamma`. The input `gamma` is a complex vector. `result` is a real vector of the same length as `gamma`.

See Also

`gammain`	RF Toolbox
`gammaout`	RF Toolbox

Purpose

Write RF data from circuit or data object to file

Syntax

```
status = write(data,filename,dataformat,funit,printformat,
freqformat)
```

Description

`status = write(data,filename,dataformat,funit,printformat,freqformat)` writes information from `data` to the specified file. `data` is a circuit object or `rfdata.data` object that contains sufficient information to write the specified file. `filename` is a string representing the filename of a `.snp`, `.ynp`, `.znp`, `.hnp`, or `.amp` file, where `n` is the number of ports. The default `filename` extension is `.snp`. See Appendix A, "AMP File Format" for information about the `.amp` format. `write` returns `True` if the operation is successful and returns `False` otherwise.

`dataformat` specifies the format of the data to be written. It must be one of the case-insensitive strings in the following table.

Format	Description
`'DB'`	Data is given in (dB-magnitude, angle) pairs with angle in degrees.
`'MA'`	Data is given in (magnitude, angle) pairs with angle in degrees.
`'RI'`	Data is given in (real, imaginary) pairs (default).

`funit` specifies the frequency units of the data to be written. It must be `'GHz'`, `'MHz'`, `'KHz'`, or `'Hz'`. If you do not specify `funit`, its value is taken from the object `data`. All values are case-insensitive.

`printformat` is a string that specifies the precision of the network and noise parameters. See the Format String specification for `fprintf`.

`freqformat` is a string that specifies the precision of the frequency. See the Format String specification for `fprintf`.

Note Touchstone files, which have the `.snp`, `.ynp`, `.znp`, or `.hnp` extension, do not support noise figure, output third-order intercept point, source impedance, load impedance, or interpolation method data. Consequently, the `write` function does not write these property values to these files. AMP files do not support source impedance, load impedance, or interpolation method data. Consequently, the `write` function does not write these property values to these files.

References

EIA/IBIS Open Forum, "Touchstone File Format Specification," Rev. 1.1, 2002 (`http://www.vhdl.org/pub/ibis/connector/touchstone_spec11.pdf`).

See Also

`analyze`	RF Toolbox
`calculate`	RF Toolbox
`getz0`	RF Toolbox
`listformat`	RF Toolbox
`listparam`	RF Toolbox
`plot`	RF Toolbox
`polar`	RF Toolbox
`read`	RF Toolbox
`restore`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`smith`	RF Toolbox

Purpose Write Verilog-A description of RF model object

Syntax

```
status = writeva(h,filename,innets,outnets, ...
          printformat,discipline,filestoinclude)
```

Description

`status = writeva(h,filename,innets,outnets,printformat, discipline,filestoinclude)` writes a Verilog-A module that describes an `rfmodel` object `h` to the file specified by `filename`. The function implements the object in Verilog-A using Laplace Transform S-domain filters. It returns a `status` of `True`, if the operation is successful, and `False` if it is unsuccessful.

`h` is the handle to the `rfmodel.rational` object. Typically, the `rationalfit` function creates this object when you fit a rational function to a set of data.

`filename` is a string representing the name of the Verilog-A file to which to write the module. The `filename` can be specified with or without a path name and extension. The default extension, `.va`, is added automatically if `filename` does not end in this extension. The module name that is used in the file is the part of the `filename` that remains when the path name and extension are removed.

`innets` is a string or a cell of two strings that specifies the name of each of the module's input nets. The default is `'in'`.

`outnets` is a string or a cell of two strings that specifies the name of each of the module's output nets. The default is `'out'`.

`printformat` is a string that specifies the precision of the following Verilog-A module parameters using the C language conversion specifications:

- The numerator and denominator coefficients of the Verilog-A filter.
- The module's delay value and constant offset (or direct feedthrough), which are taken directly from the `rfmodel` object.

The default is `'%15.10e'`. For more information on how to specify `printformat`, see the Format String specification for `fprintf`.

`discipline` is a string that specifies the predefined Verilog-A discipline of the nets. The discipline defines attributes and characteristics associated with the nets. The default is `'electrical'`.

`filestoinclude` is a cell of strings that specifies a list of header files to include in the module using Verilog-A `'`include'` statements. By default, `filestoinclude` is set to `'`include discipline.vams'`.

For more information on Verilog-A, see the Verilog-A Reference Manual.

See Also

`freqresp`	RF Toolbox
`impulse`	RF Toolbox
`rationalfit`	RF Toolbox
`rfckt`	RF Toolbox
`rfdata`	RF Toolbox
`rfmodel.rational`	RF Toolbox

Purpose

Convert Y-parameters to ABCD-parameters

Syntax

```
abcd_params = y2abcd(y_params)
```

Description

`abcd_params = y2abcd(y_params)` converts the admittance parameters `y_params` into the ABCD-parameters `abcd_params`. The `y_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port Y-parameters. `abcd_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port ABCD-parameters.

See Also

`abcd2y`	RF Toolbox
`h2abcd`	RF Toolbox
`s2abcd`	RF Toolbox
`y2h`	RF Toolbox
`y2s`	RF Toolbox
`y2z`	RF Toolbox
`z2abcd`	RF Toolbox

Purpose

Convert Y-parameters to hybrid h-parameters

Syntax

```
h_params = y2h(y_params)
```

Description

`h_params = y2h(y_params)` converts the admittance parameters `y_params` into the hybrid parameters `h_params`. The `y_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port Y-parameters. `h_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port hybrid h-parameters.

See Also

`abcd2h`	RF Toolbox
`h2y`	RF Toolbox
`s2h`	RF Toolbox
`y2abcd`	RF Toolbox
`y2s`	RF Toolbox
`y2z`	RF Toolbox
`z2h`	RF Toolbox

Purpose

Convert Y-parameters to S-parameters

Syntax

```
s_params = y2s(y_params,z0)
```

Description

`s_params = y2s(y_params,z0)` converts the admittance parameters `y_params` into the scattering parameters `s_params`. The `y_params` input is a complex `n`-by-`n`-by-`m` array, representing `m` `n`-port Y-parameters. `z0` is the reference impedance; its default is 50 ohms. `s_params` is a complex `n`-by-`n`-by-`m` array, representing `m` `n`-port S-parameters.

See Also

`abcd2s`	RF Toolbox
`h2s`	RF Toolbox
`s2y`	RF Toolbox
`y2abcd`	RF Toolbox
`y2h`	RF Toolbox
`y2s`	RF Toolbox
`y2z`	RF Toolbox
`z2s`	RF Toolbox

Purpose

Convert Y-parameters to Z-parameters

Syntax

```
z_params = y2z(y_params)
```

Description

`z_params = y2z(y_params)` converts the admittance parameters `y_params` into the impedance parameters `z_params`. The `y_params` input is a complex `n`-by-`n`-by-`m` array, representing `m` n-port Y-parameters. `z_params` is a complex `n`-by-`n`-by-`m` array, representing `m` n-port Z-parameters.

See Also

`abcd2z`	RF Toolbox
`h2z`	RF Toolbox
`y2abcd`	RF Toolbox
`y2h`	RF Toolbox
`y2s`	RF Toolbox
`y2z`	RF Toolbox
`z2s`	RF Toolbox
`z2y`	RF Toolbox

Purpose

Convert Z-parameters to ABCD-parameters

Syntax

`abcd_params = z2abcd(z_params)`

Description

`abcd_params = z2abcd(z_params)` converts the impedance parameters `z_params` into the ABCD-parameters `abcd_params`. The `z_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port Z-parameters. `abcd_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port ABCD-parameters.

See Also

`abcd2z`	RF Toolbox
`h2abcd`	RF Toolbox
`s2abcd`	RF Toolbox
`y2abcd`	RF Toolbox
`z2h`	RF Toolbox
`z2s`	RF Toolbox
`z2y`	RF Toolbox

Purpose

Convert Z-parameters to hybrid h-parameters

Syntax

```
h_params = z2h(z_params)
```

Description

`h_params = z2h(z_params)` converts the impedance parameters `z_params` into the hybrid parameters `h_params`. The `z_params` input is a complex 2-by-2-by-`m` array, representing `m` 2-port Z-parameters. `h_params` is a complex 2-by-2-by-`m` array, representing `m` 2-port hybrid h-parameters.

See Also

`abcd2h`	RF Toolbox
`h2z`	RF Toolbox
`s2h`	RF Toolbox
`y2h`	RF Toolbox
`z2abcd`	RF Toolbox
`z2s`	RF Toolbox
`z2y`	RF Toolbox

Purpose Convert Z-parameters to S-parameters

Syntax

```
s_params = z2s(z_params,z0)
```

Description

s_params = z2s(z_params,z0) converts the impedance parameters z_params into the scattering parameters s_params. The z_params input is a complex n-by-n-by-m array, representing m n-port Z-parameters. z0 is the reference impedance; its default is 50 ohms. s_params is a complex n-by-n-by-m array, representing m n-port S-parameters.

See Also

abcd2s	RF Toolbox
h2s	RF Toolbox
s2z	RF Toolbox
y2s	RF Toolbox
z2abcd	RF Toolbox
z2h	RF Toolbox
z2y	RF Toolbox

Purpose

Convert Z-parameters to Y-parameters

Syntax

```
y_params = z2y(z_params)
```

Description

`y_params = z2y(z_params)` converts the impedance parameters `z_params` into the admittance parameters `y_params`. The `z_params` input is a complex `n`-by-`n`-by-`m` array, representing `m` n-port Z-parameters. `y_params` is a complex `n`-by-`n`-by-`m` array, representing `m` n-port Y-parameters.

See Also

`abcd2y`	RF Toolbox
`h2y`	RF Toolbox
`s2y`	RF Toolbox
`y2z`	RF Toolbox
`z2abcd`	RF Toolbox
`z2h`	RF Toolbox
`z2s`	RF Toolbox

AMP File Format

Overview

The AMP data file describes a single nonlinear device. Its format can contain the following types of data:

- S, Y, or Z network parameters
- Noise parameters
- Noise figure data
- Power data
- IP3 data

An AMP file must contain either power data or network parameter data to be valid. To accommodate analysis at more than one frequency, the file can contain more than one section of power data. Noise data, noise figure data, and IP3 data are optional.

Note If the file contains both network parameter data and power data, the RF Toolbox checks the data for consistency. If the amplifier gain computed from the network parameters is not consistent with the gain computed from the power data, a warning appears. For more information, see "Inconsistent Data Sections" on page A-14.

Two AMP files, `samplepa1.amp` and `default.amp`, ship with the RF Toolbox to show the AMP format. They describe a nonlinear 2-port amplifier with noise. See for an example that shows how to use an AMP file.

For information on specifying data in an AMP file, see "Data Sections" on page A-4. For information about adding comments to an AMP file, see "Denoting Comments" on page A-3.

Denoting Comments

An asterisk (`*`) or an exclamation point (`!`) precedes a comment that appears on a separate line.

A semicolon (`;`) precedes a comment that appears following data on the same line.

Data Sections

Each kind of data resides in its own section. Each section consists of a two-line header followed by lines of numeric data. Numeric values can be in any valid MATLAB format.

A new header indicates the end of the previous section. The data sections can appear in any order in the file.

Note In the data section descriptions, brackets (`[]`) indicate optional data or characters. All values are case insensitive.

This section contains the following topics:

S, Y, or Z Network Parameters

Header Line 1

The first line of the header has the format

```
Keyword [Parameter] [R[REF][=]value]
```

`Keyword` indicates the type of network parameter. Its value can be `S[PARAMETERS]`, `Y[PARAMETERS]`, or `Z[PARAMETERS]`. `Parameter` indicates the form of the data. Its value can be `MA`, `DB`, or `RI`. The default for S-parameters is `MA`. The default for Y- and Z-parameters is `RI`. `R[REF][=]value` is the reference impedance. The default reference impedance is 50 ohms.

The following table explains the meaning of the allowable `Parameter` values.

Parameter	Description
MA	Data is given in (magnitude, angle) pairs with angle in degrees (default for S-parameters).
DB	Data is given in (dB-magnitude, angle) pairs with angle in degrees.
RI	Data is given in (real, imaginary) pairs (default for Y- and Z-parameters).

This example of a first line indicates that the section contains S-parameter data given in (real, imaginary) pairs, and that the reference impedance is 50 ohms.

```
S RI R 50
```

Header Line 2

The second line of the header has the format

```
Independent_variable Units
```

The data in a section is a function of the `Independent_variable`. Currently, for S-, Y-, and Z-parameters, the value of Independent_variable is always `F[REQ]`. `Units` indicates the default units of the frequency data. It can be `GHz`, `MHz`, or `KHz`. You must specify `Units`, but you can override this default on any given line of data.

This example of a second line indicates that the default units for frequency data is GHz.

```
FREQ GHZ
```

Data

The data that follows the header typically consists of nine columns.

The first column contains the frequency points where network parameters are measured. They can appear in any order. If the frequency is given in units other than those you specified as the default, you must follow the value with the appropriate units; there should be no intervening spaces. For example,

```
FREQ GHZ
1000MHZ  ...
2000MHZ  ...
3000MHZ  ...
```

Columns two though nine contain 2-port network parameters in the order N11, N21, N12, N22. Similar to the Touchstone format, each Nnn corresponds to two consecutive columns of data in the chosen form: MA, DB, or RI. The data can be in any valid MATLAB format.

This example is derived from the file `default.amp`. A comment line explains the column arrangement of the data where `re` indicates real and `im` indicates imaginary.

```
S RI R 50
FREQ GHZ
* FREQ     reS11      imS11      reS21      imS21      reS12      imS12      reS22      imS22
  1.00  -0.724725  -0.481324  -0.685727   1.782660   0.000000   0.000000  -0.074122  -0.321568
  1.01  -0.731774  -0.471453  -0.655990   1.798041   0.001399   0.000463  -0.076091  -0.319025
  1.02  -0.738760  -0.461585  -0.626185   1.813092   0.002733   0.000887  -0.077999  -0.316488
```

Noise Parameters

Header Line 1

The first line of the header has the format

```
Keyword
```

`Keyword` must be `NOI[SE]`.

Header Line 2

The second line of the header has the format

```
Variable Units
```

`Variable` must be `F[REQ]`. `Units` indicates the default units of the frequency data. It can be `GHz`, `MHz`, or `KHz`. You can override this default on any given line of data. This example of a second line indicates that frequency data is assumed to be in GHz, unless other units are specified.

```
FREQ GHz
```

Data

The data that follows the header must consist of five columns.

The first column contains the frequency points at which noise parameters were measured. The frequency points can appear in any order. If the frequency is given in units other than those you specified as the default, you must follow the value with the appropriate units; there should be no intervening spaces. For example,

```
NOI
FREQ GHZ
1000MHZ  ...
2000MHZ  ...
3        ...
4        ...
5        ...
```

Columns two through five contain, in order,

- Minimum noise figure in decibels
- Magnitude of the source reflection coefficient to realize minimum noise figure
- Phase in degrees of the source reflection coefficient
- Effective noise resistance normalized to the reference impedance of the network parameters

This example is taken from the file `default.amp`. A comment line explains the column arrangement of the data.

```
NOI RN
FREQ GHz
* Freq  Fmin(dB)  GammmaOpt(MA:Mag) GammmaOpt(MA:Ang) RN/Zo
  1.90  10.200000 1.234000         -78.400000         0.240000
  1.93  12.300000 1.235000         -68.600000         0.340000
  2.06  13.100000 1.254000         -56.700000         0.440000
  2.08  13.500000 1.534000         -52.800000         0.540000
  2.10  13.900000 1.263000         -44.400000         0.640000
```

Noise Figure Data

The AMP file format supports the use of frequency-dependent noise figure (NF) data.

Header Line 1

The first line of the header has the format

```
Keyword [Units]
```

For noise figure data, `Keyword` must be `NF`. The optional `Units` field indicates the default units of the NF data. Its value must be `dB`, i.e., data must be given in decibels.

This example of a first line indicates that the section contains NF data, which is assumed to be in decibels.

```
NF
```

Header Line 2

The second line of the header has the format

```
Variable Units
```

`Variable` must be `F[REQ]`. `Units` indicates the default units of the frequency data. It can be `GHz`, `MHz`, or `KHz`. This example of a second line indicates that frequency data is assumed to be in GHz.

```
FREQ GHz
```

Data

The data that follows the header typically consists of two columns.

The first column contains the frequency points at which the NF data are measured. Frequency points can appear in any order. For example,

```
NF
FREQ MHz
2090  ...
2180  ...
2270  ...
```

Column two contains the corresponding NF data in decibels.

This example is derived from the file `samplepa1.amp`.

```
NF dB
FREQ GHz
1.900   10.3963213
2.000   12.8797965
2.100   14.0611765
2.200   13.2556751
2.300   12.9498642
2.400   13.3244309
2.500   12.7545104
```

Note If your noise figure data consists of a single scalar value with no associated frequency, that same value is used for all frequencies. Enter the value in column 1 of the line following header line 2. You must include the second line of the header, but it is ignored.

Power Data

An AMP file describes power data as input power-dependent output power.

Header Line 1

The first line of the header has the format

```
Keyword [Units]
```

For power data, `Keyword` must be `POUT`, indicating that this section contains power data. Because output power is complex, `Units` indicates the default units of the magnitude of the output power data. It can be `dBW`, `dBm`, `mW`, or `W`. The default is `W`. You can override this default on any given line of data.

The following table explains the meaning of the allowable `Units` values.

Allowable Power Data Units

Units	Description
dBW	Decibels referenced to one watt
dBm	Decibels referenced to one milliwatt
mW	Milliwatts
W	Watts

This example of a first line indicates that the section contains output power data whose magnitude is assumed to be in decibels referenced to one milliwatt, unless other units are specified.

```
POUT dBm
```

Header Line 2

The second line of the header has the format

```
Keyword [Units] FREQ[=]value
```

`Keyword` must be `PIN`. `Units` indicates the default units of the input power data. See Allowable Power Data Units on page A-10 for a complete list of valid values. The default is `W`. You can override this default on any given line of data. `FREQ[=]value` is the frequency point at which the power is measured. The units of the frequency point must be specified explicitly using the abbreviations `GHz`, `MHz`, `kHz`, or `Hz`.

This example of a second line indicates that the section contains input power data that is assumed to be in decibels referenced to one milliwatt, unless other units are specified. It also indicates that the power data was measured at a frequency of 2.1E+009 Hz.

```
PIN dBm FREQ=2.1E+009Hz
```

Data

The data that follows the header typically consists of three columns:

- The first column contains input power data. The data can appear in any order.
- The second column contains the corresponding output power magnitude.
- The third column contains the output phase shift in degrees.

Note The RF Toolbox does not use the phase data directly. The RF Blockset uses this data in conjunction with the RF Toolbox to create the AM/PM conversion table for the General Amplifier and General Mixer blocks.

If all phases are zero, you can omit the third column. If all phases are zero or omitted, the RF Toolbox assumes that the small signal phase from the network parameter section of the file (`180*angle(`S_{21}`(f))/pi`) is the phase for all power levels.

In contrast, if one or more phases in the power data section are nonzero, the RF Toolbox interpolates and extrapolates the data to determine the phase at all power levels. The small signal phase (`180*angle(`S_{21}`(f))/pi`) from the network parameter section is ignored.

Inconsistency between the power data and network parameter sections of the file may cause incorrect results. To avoid this outcome, verify that the following criteria must is met:

- The lowest input power value for which power data exists falls in the small signal (linear) region.
- In the power table for each frequency point `f`, the power gain and phase at the lowest input power value are equal to `20*log10(abs(`S_{21}`(f)))` and `180*angle(`S_{21}`(f))/pi`, respectively, in the network parameter section.

If the power is given in units other than those you specified as the default, you must follow the value with the appropriate units. There should be no intervening spaces.

This example is derived from the file `default.amp`. A comment line explains the column arrangement of the data.

```
POUT dbm
PIN dBm FREQ = 2.10GHz
* Pin     Pout             Phase(degrees)
  0.0     19.28            0.0
  1.0     20.27            0.0
  2.0     21.26            0.0
```

IP3 Data

An AMP file can include frequency-dependent, third-order input (IIP3) or output (OIP3) intercept points.

Header Line 1

The first line of the header has the format

```
Keyword [Units]
```

For IP3 data, `Keyword` can be either `IIP3` or `OIP3`, indicating that this section contains input IP3 data or output IP3 data. `Units` indicates the default units of the IP3 data. Valid values are `dBW`, `dBm`, `mW`, and `W`. The default is `W`. See Allowable Power Data Units on page A-10 for an explanation of the allowable `Units` values.

This example of a first line indicates that the section contains input IP3 data which is assumed to be in decibels referenced to one milliwatt.

```
IIP3 dBm
```

Header Line 2

The second line of the header has the format

```
Variable Units
```

`Variable` must be `FREQ`. `Units` indicates the default units of the frequency data. Valid values are `GHz`, `MHz`, and `KHz`. This example of a second line indicates that frequency data is assumed to be in GHz.

```
FREQ GHz
```

Data

The data that follows the header typically consists of two columns.

The first column contains the frequency points at which the IP3 parameters are measured. Frequency points can appear in any order.

```
OIP3
FREQ GHz
2.010  ...
2.020  ...
2.030  ...
```

Column two contains the corresponding IP3 data.

This example is derived from the file `samplepa1.amp`.

```
OIP3 dBm
FREQ GHz
2.100   38.8730377
```

Note If your IP3 data consists of a single scalar value with no associated frequency, then that same value is used for all frequencies. Enter the value in column 1 of the line following header line 2. You must include the second line of the header, but the application ignores it.

Inconsistent Data Sections

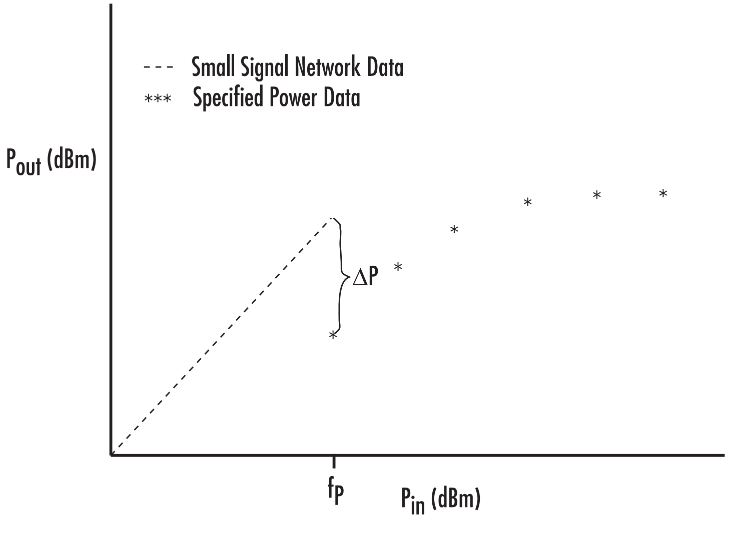
If an AMP file contains both network parameter data and power data, the RF Toolbox checks the data for consistency.

The RF Toolbox compares the small-signal amplifier gain defined by the network parameters, S_{21}, and by the power data, P_{out}-P_{in}. The discrepancy between the two is computed in dBm using the following equation:

$$\Delta P = S_{21}(f_P) - P_{out}(f_P) + P_{in}(f_P) \quad (dBm)$$

where f_P is the lowest frequency for which power data is specified.

The discrepancy is shown in the following graph.



If ΔP is more than 0.4 dB, a warning appears. Large discrepancies may indicate measurement errors that require resolution.

B

Examples

Use this list to find examples in the documentation.

Modeling a Cascaded RF Network

"Example — Modeling a Cascaded RF Network" on page 1-15

Modeling a Transmission Line

"Example — Using a Rational Function Model to Analyze a Transmission Line" on page 1-23

Working with Objects

"Example — Setting Circuit Object Properties Using Data Objects" on page 2-11
"Reading and Analyzing RF Data from a Touchstone Data File" on page 2-23
"De-Embedding S-Parameters" on page 2-25
"Impedance Matching" on page 2-30

Modeling an RF Network Using RF Tool

"Example — Modeling an RF Network Using RF Tool" on page 4-30

Index

D

E

O

P

R