scikit-rf Documentation

Release 0.1

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March 27, 2012

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This documentation is also available in pdf form: scikit-rf.pdf

CHAPTER

ONE

TUTORIALS

1.1 Installation

Contents

1.1.1 Introduction

The requirements to run skrf are basically a python environment setup to do numerical/scientific computing. If you are new to Python development, you may want to install a pre-built scientific python IDE like pythonxy. This will install all requirements, as well as provide a nice environment to get started in. If you dont want use pythonxy, you see Requirements.

Note: If you want to use skrf for instrument control you will need to install pyvisa. You may also be interested in Pythics, which provides a simple way to build interfaces to virtual instruments. Links is provided in Requirements section.

1.1.2 skrf Installation

Once the requirements are installed, there are two choices for installing skrf:

- windows installer
- python source package

They can all be found at http://scikit-rf.org/download/

If you dont know how to install a python module and dont care to learn how, you want the windows installer. Otherwise, I recommend the python source package because examples, documentation, and installation instructions are provided with the the python package.

The current version can be accessed through github. This is mainly of interest for developers, and is not stable most of the time.

1.1.3 Requirements

Debian-Based Linux

For debian-based linux users who dont want to install pythonxy, here is a one-shot line to install all requirements,:

```
sudo apt-get install python-pyvisa python-numpy python-scipy python-matplotlib ipython python
```

Necessary

- python (>=2.6) http://www.python.org/
- matplotlib (aka pylab) http://matplotlib.sourceforge.net/
- numpy http://numpy.scipy.org/
- scipy http://www.scipy.org/ (provides tons of good stuff, check it out)

Optional

- ipython http://ipython.scipy.org/moin/ - for interactive shell
- pyvisa http://pyvisa.sourceforge.net/pyvisa/ - for instrument control
- Pythics http://code.google.com/p/pythics - instrument control and gui creation

1.2 Introduction

Contents

This is a brief introduction to skrf, aimed at those who are familiar with python. If you are unfamiliar with python, please see scipy's Getting Started . All of the touchstone files used in these tutorials are provided along with this source code, and are located in the directory `../pyplots/` (relative to this file).

1.2.1 Creating Networks

For this turtorial, and the rest of the mwavpey documentation, we assume that skrf has been imported as `rf`. Whether or not you follow this convention in your own code is up to you:

```
>>> import skrf as rf
```

If this produces an error, please see *Installation*.

The most fundamental object in skrf is a n-port `Network`. Most commonly, a `Network` is constructed from data stored in a touchstone files, like so

```
>>> short = rf.Network('short.s1p')
>>> delay_short = rf.Network('delay_short.s1p')
```

The `Network` object will produce a short description if entered onto the command line:

```
>>> short
1-Port Network.  75-110 GHz.  201 points. z0=[ 50.]
```

1.2.2 Basic Network Properties

The basic attributes of a microwave `Network` are provided by the following properties :

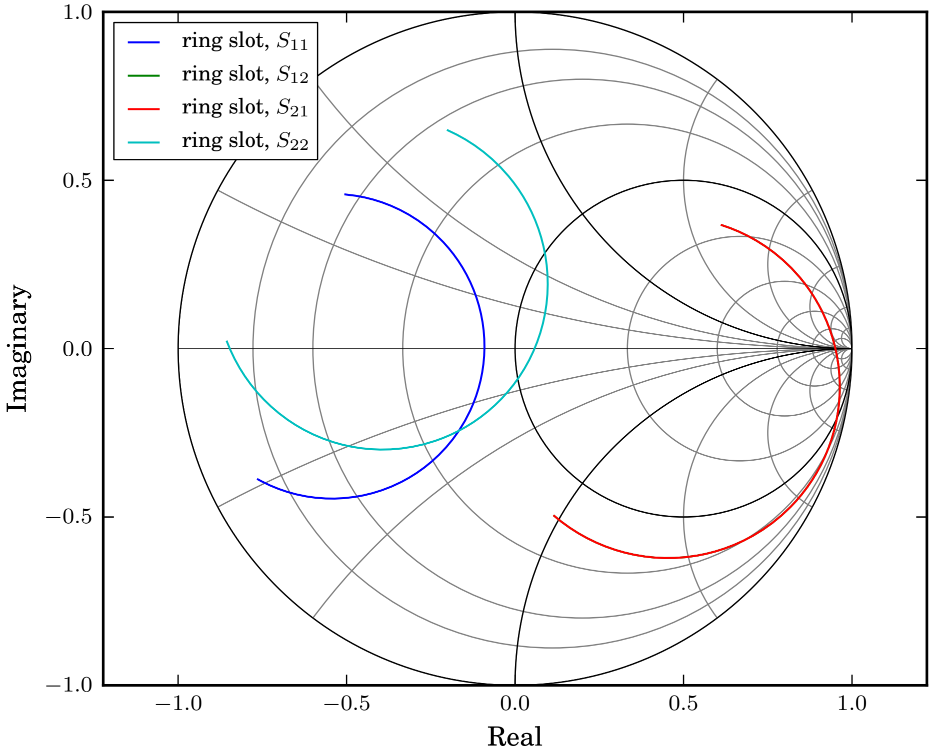
- `Network.s` : Scattering Parameter matrix.
- `Network.z0` : Characterisic Impedance matrix.
- `Network.frequency` : Frequency Object.

These properties are stored as complex numpy.ndarray's. The `Network` class has numerous other properties and methods, which can found in the `Network` docs. If you are using Ipython, then these properties and methods can be 'tabbed' out on the command line. Amongst other things, the methods of the `Network` class provide convenient ways to plot components of the s-parameters, below is a short list of common plotting commands,

- `Network.plot_s_db()` : plot magnitude of s-parameters in log scale
- `Network.plot_s_deg()` : plot phase of s-parameters in degrees
- `Network.plot_s_smith()` : plot complex s-parameters on Smith Chart

For example, to create a 2-port `Network` from a touchstone file, and then plot all s-parameters on the Smith Chart.

```
import pylab
import skrf as rf

# create a Network type from a touchstone file
ring_slot = rf.Network('ring slot.s2p')
ring_slot.plot_s_smith()
pylab.show()
```



For more detailed information about plotting see *Plotting*.

1.2.3 Network Operators

Element-wise Operations

Element-wise mathematical operations on the scattering parameter matrices are accessible through overloaded operators:

```
>>> short + delay_short
>>> short - delay_short
>>> short / delay_short
>>> short * delay_short
```

All of these operations return `Network` types, so all methods and properties of a `Network` are available on the result. For example, the difference operation ('-') can be used to calculate the complex distance between two networks

```
>>> difference = (short- delay_short)
```

Because this returns `Network` type, the distance is accessed through the `Network.s` property. The plotting methods of the `Network` type can also be used. So to plot the magnitude of the complex difference between the networks *short* and *delay_short*:

```
>>> (short - delay_short).plot_s_mag()
```

Another use of operators is calculating the phase difference using the division operator. This can be done

```
>>> (delay_short/short).plot_s_deg()
```

Cascading and Embeding Operations

Cascading and de-embeding 2-port Networks is done so frequently, that it can also be done though operators as well. The cascade function is called by the power operator, `**`, and the de-embedding operation is accomplished by cascading the inverse of a network, which is implemented by the property `Network.inv`. Given the following Networks:

```
>>> line = rf.Network('line.s2p')
>>> short = rf.Network('short.s1p')
```

To calculate a new network which is the cascaded connection of the two individual Networks `line` and `short`:

```
>>> delay_short = line ** short
```

or to de-embed the *short* from *delay_short*:

```
>>> short = line.inv ** delay_short
```

1.2.4 Connecting Multi-ports

skrf supports the connection of arbitrary ports of N-port networks. It accomplishes this using an algorithm call sub-network growth [1]. This algorithm, which is available through the function `connect()`, takes into account port impedances. Terminating one port of a ideal 3-way splitter can be done like so:

```
>>> tee = rf.Network('tee.s3p')
>>> delay_short = rf.Network('delay_short.s1p')
```

to connect port '1' of the tee, to port 0 of the delay short:

```
>>> terminated_tee = rf.connect(tee,1,delay_short,0)
```

1.2.5 Sub-Networks

Frequently, the one-port s-parameters of a multiport network's are of interest. These can be accessed by properties such as:

```
>>> port1_return = line.s11
>>> port1_insertion = line.s21
```

1.2.6 Convenience Functions

Frequently there is an entire directory of touchstone files that need to be analyzed. The function `load_all_touchstones()` is meant deal with this scenario. It takes a string representing the directory, and returns a dictionary type with keys equal to the touchstone filenames, and values equal to `Network` types:

```
>>> ntwk_dict = rf.load_all_touchstones('.')
{'delay_short': 1-Port Network.  75-110 GHz.  201 points. z0=[ 50.],
'line': 2-Port Network.  75-110 GHz.  201 points. z0=[ 50.  50.],
```

[1] Compton, R.C.; , "Perspectives in microwave circuit analysis," Circuits and Systems, 1989., Proceedings of the 32nd Midwest Symposium on , vol., no., pp.716-718 vol.2, 14-16 Aug 1989. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=101955&isnumber=3167

```
'ring slot': 2-Port Network.  75-110 GHz.  201 points. z0=[ 50.  50.],
'short': 1-Port Network.  75-110 GHz.  201 points. z0=[ 50.]}
```

1.2.7 References

1.3 Plotting

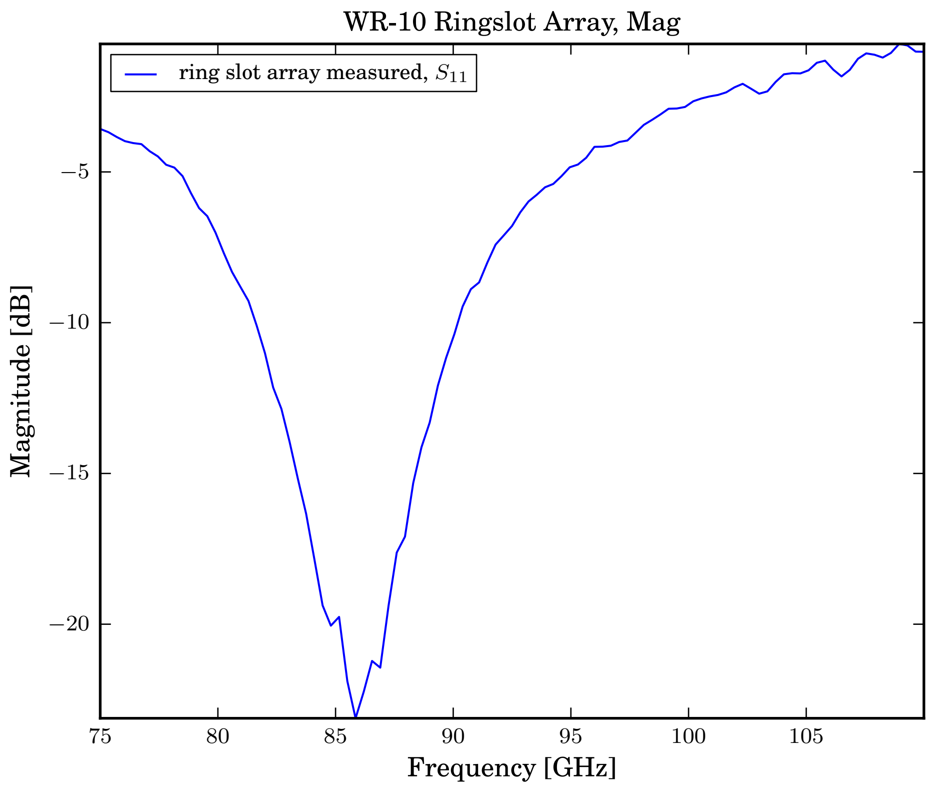
Contents

This tutorial illustrates how to create common plots associated with microwave networks. The plotting functions are implemented as methods of the `Network` class, which is provided by the `skrf.network` module. Below is a list of the some of the plotting functions of network s-parameters,

- `Network.plot_s_re()`
- `Network.plot_s_im()`
- `Network.plot_s_mag()`
- `Network.plot_s_db()`
- `Network.plot_s_deg()`
- `Network.plot_s_deg_unwrapped()`
- `Network.plot_s_rad()`
- `Network.plot_s_rad_unwrapped()`
- `Network.plot_s_smith()`
- `Network.plot_s_complex()`

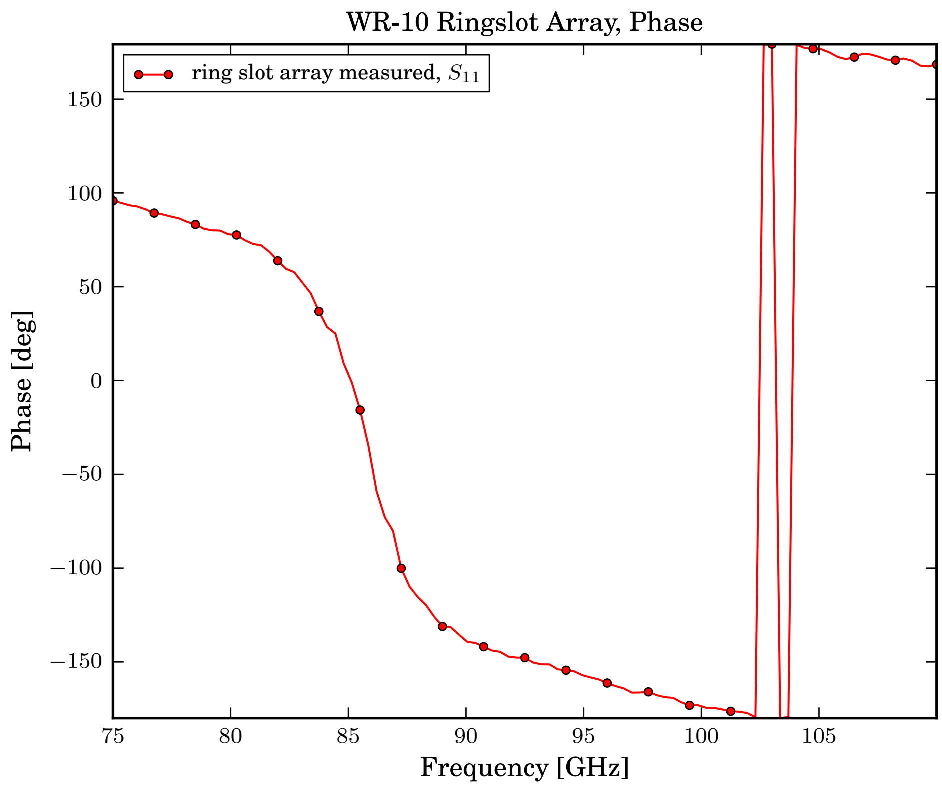
1.3.1 Magnitude

```python
import pylab
import skrf as rf

# create a Network type from a touchstone file of a horn antenna
ring_slot= rf.Network('ring slot array measured.s1p')

# plot magnitude (in db) of S11
pylab.figure(1)
pylab.title('WR-10 Ringslot Array, Mag')
ring_slot.plot_s_db(m=0,n=0) # m,n are S-Matrix indecies
# show the plots
pylab.show()
```



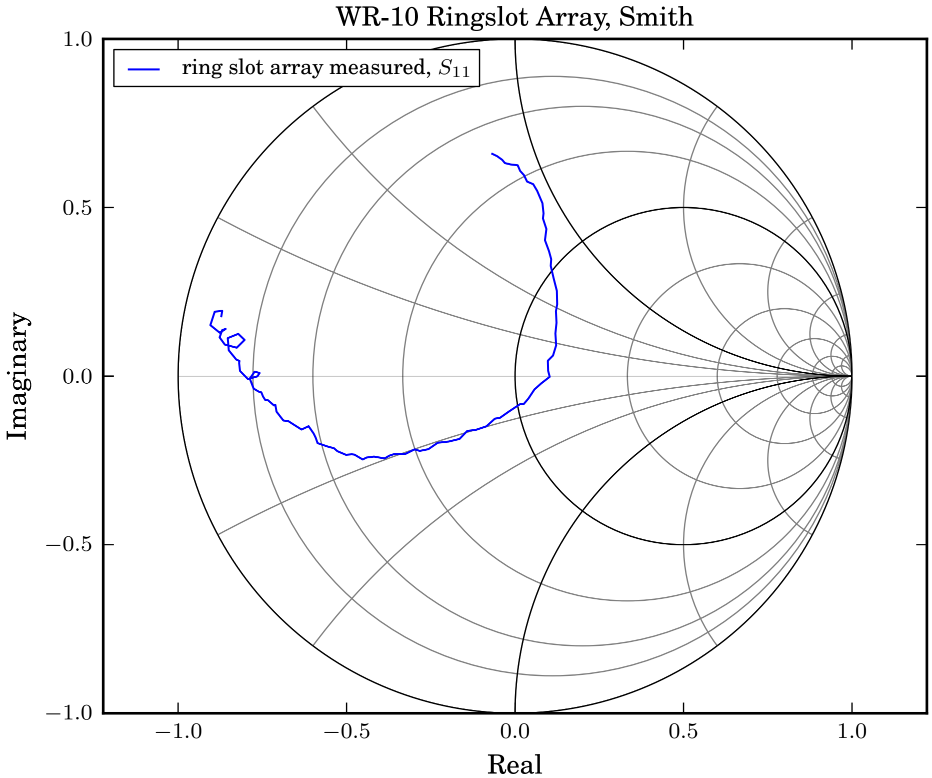
1.3.2 Phase

```
import pylab
import skrf as rf

ring_slot= rf.Network('ring slot array measured.s1p')
pylab.figure(1)
pylab.title('WR-10 Ringslot Array, Phase')
# kwargs given to plot commands are passed through to the pylab.plot
# command
ring_slot.plot_s_deg(m=0,n=0, color='r', markevery=5, marker='o')
pylab.show()
```



1.3.3 Smith Chart

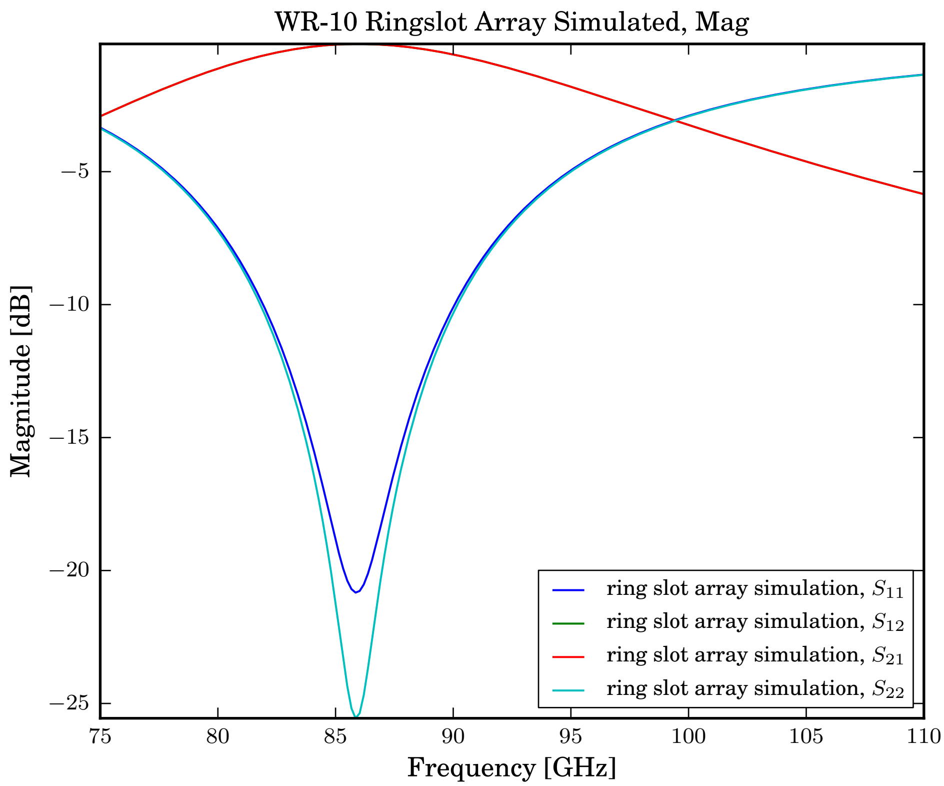
```
import pylab
import skrf as rf

ring_slot= rf.Network('ring slot array measured.s1p')

pylab.figure(1)
pylab.title('WR-10 Ringslot Array, Smith')
ring_slot.plot_s_smith(m=0,n=0) # m,n are S-Matrix indecies
pylab.show()
```



The Smith Chart can be also drawn independently of any `Network` object through the `smith()` function. This function also allows admittance contours can also be drawn.

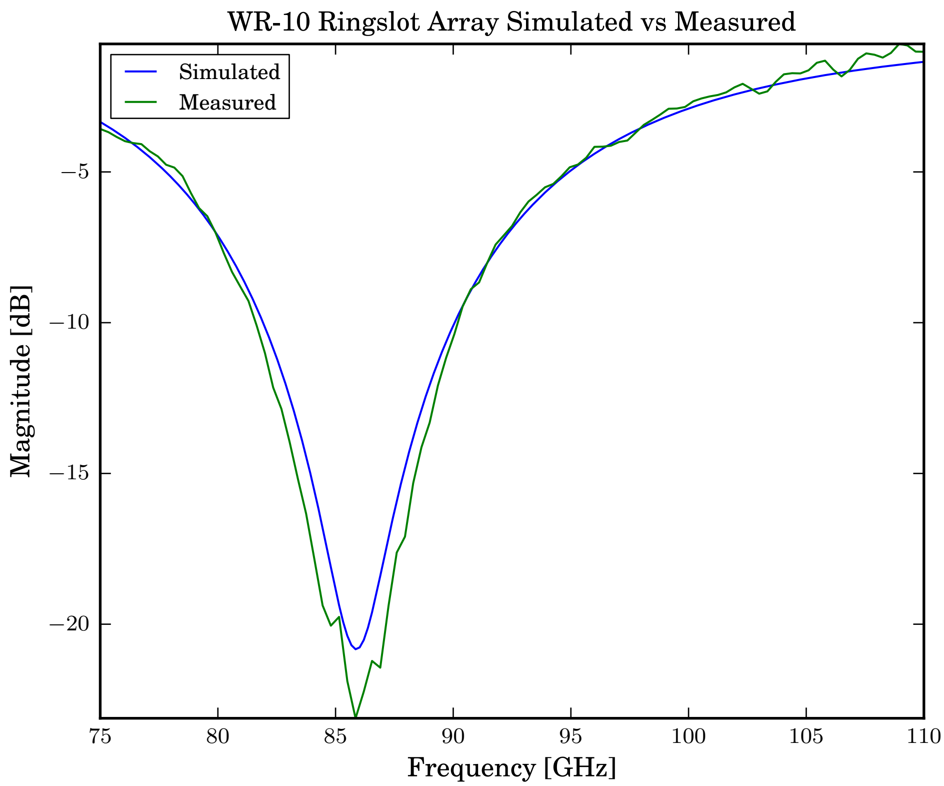
1.3.4 Multiple S-parameters

```
import pylab
import skrf as rf

# from the extension you know this is a 2-port network
ring_slot= rf.Network('ring slot array simulation.s2p')

pylab.figure(1)
pylab.title('WR-10 Ringslot Array Simulated, Mag')
# if no indecies are passed to the plot command it will plot all
# available s-parameters
ring_slot.plot_s_db()
pylab.show()
```



1.3.5 Comparing with Simulation

```
import pylab
import skrf as rf

# from the extension you know this is a 2-port network
ring_slot_sim = rf.Network('ring slot array simulation.s2p')
ring_slot_meas = rf.Network('ring slot array measured.s1p')

pylab.figure(1)
pylab.title('WR-10 Ringslot Array Simulated vs Measured')
# if no indecies are passed to the plot command it will plot all
# available s-parameters
ring_slot_sim.plot_s_db(0,0, label='Simulated')
ring_slot_meas.plot_s_db(0,0, label='Measured')
pylab.show()
```



1.3.6 Saving Plots

Plots can be saved in various file formats using the GUI provided by the matplotlib. However, skrf provides a convenience function, called `save_all_figs()`, that allows all open figures to be saved to disk in multiple file formats, with filenames pulled from each figure's title:

```
>>> rf.save_all_figs('.', format=['eps','pdf'])
./WR-10 Ringslot Array Simulated vs Measured.eps
./WR-10 Ringslot Array Simulated vs Measured.pdf
```

1.4 Calibration

Contents

1.4.1 Intro

This page describes how to use **skrf** to calibrate data taken from a VNA. The explanation of calibration theory and calibration kit design is beyond the scope of this page. This page describes how to calibrate a device under test (DUT), assuming you have measured an acceptable set of standards, and have a coresponding set ideal responses.

skrf's calibration algorithm is generic in that it will work with any set of standards. If you supply more calibration standards than is needed, skrf will implement a simple least-squares solution.

Calibrations are performed through a Calibration class, which makes creating and working with calibrations easy. Since skrf-1.2 the Calibration class only requires two pieces of information:

- a list of measured Networks
- a list of ideal Networks

The Network elements in each list must all be similar, (same #ports, same frequency info, etc) and must be aligned to each other, meaning the first element of ideals list must correspond to the first element of measured list.

Optionally, other information can be provided for explicitness, such as,

- calibration type
- frequency information
- reciprocity of embedding networks
- etc

When this information is not provided skrf will determine it through inspection.

1.4.2 One-Port

See `example_oneport_calibration` for examples.

Below are (hopefully) self-explanatory examples of increasing complexity, which should illustrate, by example, how to make a calibration. Simple One-port

This example is written to be instructive, not concise.:

```
import skrf as rf


## created necessary data for Calibration class

# a list of Network types, holding 'ideal' responses
my_ideals = [\
        rf.Network('ideal/short.s1p'),
        rf.Network('ideal/open.s1p'),
        rf.Network('ideal/load.s1p'),
        ]

# a list of Network types, holding 'measured' responses
my_measured = [\
        rf.Network('measured/short.s1p'),
        rf.Network('measured/open.s1p'),
        rf.Network('measured/load.s1p'),
        ]

## create a Calibration instance
cal = rf.Calibration(\
```

```
        ideals = my_ideals,
        measured = my_measured,
        )


## run, and apply calibration to a DUT

# run calibration algorithm
cal.run()

# apply it to a dut
dut = rf.Network('my_dut.s1p')
dut_caled = cal.apply_cal(dut)

# plot results
dut_caled.plot_s_db()
# save results
dut_caled.write_touchstone()
```

Concise One-port

This example is meant to be the same as the first except more concise.:

```
import skrf as rf

my_ideals = rf.load_all_touchstones_in_dir('ideals/')
my_measured = rf.load_all_touchstones_in_dir('measured/')


## create a Calibration instance
cal = rf.Calibration(\
        ideals = [my_ideals[k] for k in ['short','open','load']],
        measured = [my_measured[k] for k in ['short','open','load']],
        )

## what you do with 'cal' may  may be similar to above example
```

1.4.3 Two-port

Two-port calibration is more involved than one-port. skrf supports two-port calibration using a 8-term error model based on the algorithm described in [2], by R.A. Speciale.

Like the one-port algorithm, the two-port calibration can handle any number of standards, providing that some fundamental constraints are met. In short, you need three two-port standards; one must be transmissive, and one must provide a known impedance and be reflective.

One draw-back of using the 8-term error model formulation (which is the same formulation used in TRL) is that switch-terms may need to be measured in order to achieve a high quality calibration (this was pointed out to me by Dylan Williams).

[2] Speciale, R.A.; , "A Generalization of the TSD Network-Analyzer Calibration Procedure, Covering n-Port Scattering-Parameter Measurements, Affected by Leakage Errors," Microwave Theory and Techniques, IEEE Transactions on , vol.25, no.12, pp. 1100- 1115, Dec 1977. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1129282&isnumber=25047

A note on switch-terms

Switch-terms are explained in a paper by Roger Marks [3]. Basically, switch-terms account for the fact that the error networks change slightly depending on which port is being excited. This is due to the hardware of the VNA.

So how do you measure switch terms? With a custom measurement configuration on the VNA itself. mwavpey has support for switch terms for the HP8510C class, which you can use or extend to different VNA. Without switch-term measurements, your calibration quality will vary depending on properties of you VNA.

See `example_twoport_calibration` for and example

1.4.4 Simple Two Port

Two-port calibration is accomplished in an identical way to one-port, except all the standards are two-port networks. This is even true of reflective standards (S21=S12=0). So if you measure reflective standards you must measure two of them simultaneously, and store information in a two-port. For example, connect a short to port-1 and a load to port-2, and save a two-port measurement as 'short,load.s2p' or similar:

```
import skrf as rf


## created necessary data for Calibration class

# a list of Network types, holding 'ideal' responses
my_ideals = [\
        rf.Network('ideal/thru.s2p'),
        rf.Network('ideal/line.s2p'),
        rf.Network('ideal/short, short.s2p'),
        ]

# a list of Network types, holding 'measured' responses
my_measured = [\
        rf.Network('measured/thru.s2p'),
        rf.Network('measured/line.s2p'),
        rf.Network('measured/short, short.s2p'),
        ]


## create a Calibration instance
cal = rf.Calibration(\
        ideals = my_ideals,
        measured = my_measured,
        )


## run, and apply calibration to a DUT

# run calibration algorithm
cal.run()

# apply it to a dut
dut = rf.Network('my_dut.s2p')
dut_caled = cal.apply_cal(dut)

# plot results
```

[3] Marks, Roger B.; , "Formulations of the Basic Vector Network Analyzer Error Model including Switch-Terms," ARFTG Conference Digest-Fall, 50th , vol.32, no., pp.115-126, Dec. 1997. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4119948&isnumber=4119931

```
dut_caled.plot_s_db()
# save results
dut_caled.write_touchstone()
```

Using s1p ideals in two-port calibration

Commonly, you have data for ideal data for reflective standards in the form of one-port touchstone files (ie s1p). To use this with skrf's two-port calibration method you need to create a two-port network that is a composite of the two networks. There is a function in the WorkingBand Class which will do this for you, called two_port_reflect.:

```
short = rf.Network('ideals/short.s1p')
load = rf.Network('ideals/load.s1p')
short_load = rf.two_port_reflect(short, load)
```

Bibliography

1.5 Circuit Design

Contents

1.5.1 Intro

skrf has basic support for microwave circuit design. Network synthesis is accomplished through the Media Class (`skrf.media`), which represent a transmission line object for a given medium. A Media object contains properties such as propagation constant and characteristic impedance, that are needed to generate network components.

Typically circuit design is done within a given frequency band. Therefore every Media object is created with a Frequency object to relieve the user of repitously providing frequency information for each new network created.

1.5.2 Media's Supported by skrf

Below is a list of mediums types supported by skrf,

- DistributedCircuit
- Freespace
- RectangularWaveguide
- CPW

More info on all of these classes can be found in the media sub-module section of `skrf.media` mavepy's API.

Here is an example of how to initialize a Media object representing a freespace from 10-20GHz:

```
import skrf as rf
freq = rf.Frequency(10,20,101,'ghz')
my_media = rf.media.Freespace(freq)
```

Here is another example constructing a coplanar waveguide media. The instance has a 10um center conductor and gap of 5um, on a substrate with relative permativity of 10.6,:

```
freq = rf.Frequency(500,750,101,'ghz')
my_media = rf.media.CPW(freq, w=10e-6, s=5e-6, ep_r=10.6)
```

or a WR10 Rectangular Waveguide:

```
from scipy.constants import * # for the 'mil' unit
freq = rf.Frequency(75,110,101,'ghz')
my_media = rf.media.RectangularWaveguide(freq, a=100*mil)
```

1.5.3 Creating Individual Networks

Network components are created through methods of a Media object. Here is a brief, incomplete list of a some generic network components skrf supports,

- match
- short
- open
- load
- line
- tee
- thru
- delay_short
- shunt_delay_open

Details for each component and usage help can be found in their doc-strings. So help(my_media.short) should provide you with enough details to create a short-circuit component. To create a 1-port network for a short,

```
my_media.short()
```

to create a 90deg section of transmission line, with characteristic impedance of 30 ohms:

```
my_media.line(d=90,unit='deg',z0=30)
```

Network components specific to a given medium, such as cpw_short, or microstrip_bend, are implemented in by the Media Classes themselves.

1.5.4 Building Cicuits

Circuits can be built in an intuitive maner from individual networks. To build a the 90deg delay_short standard can be made by:

```
delay_short_90deg = my_media.line(90,'deg') ** my_media.short()
```

For frequently used circuits, it may be worthwhile creating a function for something like this:

```
def delay_short(wb,*args,**kwargs):
        return my_media.line(*args,**kwargs)**my_media.short()

delay_short(wb,90,'deg')
```

This is how many of skrf's network compnents are made internally.

To connect networks with more than two ports together, use the *connect()* function. You must provide the connect function with the two networks to be connected and the port indecies (starting from 0) to be connected.

To connect port# '0' of ntwkA to port# '3' of ntwkB:

```
ntwkC = rf.connect(ntwkA,0,ntwkB,3)
```

Note that the connect function takes into account port impedances. To create a two-port network for a shunted delayed open, you can create an ideal 3-way splitter (a 'tee') and conect the delayed open to one of its ports, like so:

```
tee = my_media.tee()
delay_open = my_media.delay_open(40,'deg')

shunt_open = connect(tee,1,delay_open,0)
```

1.5.5 Single Stub Tuner

This is an example of how to design a single stub tuning network to match a 100ohm resistor to a 50 ohm environment.

```
# calculate reflection coefficient off a 100ohm
Gamma0 = rf.zl_2_Gamma0(z0=50,zl=100)

# create the network for the 100ohm load
load = my_media.load(Gamma0)

# create the single stub  network, parameterized by two delay lengths
# in units of 'deg'
single_stub = my_media.shunt_delay_open(120,'deg') ** my_media.line(40,'deg')

# the resulting network
result = single_stub ** load

result.plot_s_db()
```

1.5.6 Optimizing Designs

The abilities of scipy's optimizers can be used to automate network design. To automate the single stub design, we can create a 'cost' function which returns somthing we want to minimize, such as the reflection coefficient magnitude at band center.

```
from scipy.optmize import fmin

# the load we are trying to match
load = my_media.load(rf.zl_2_Gamma0(100))

# single stub generator function
```

```
def single_stub(wb,d0,d1):
        return my_media.shunt_open(d1,'deg')**my_media.line(d0,'deg')

# cost function we want to minimize (note: this uses sloppy namespace)
def cost(d):
        return (single_stub(wb,d[0],d[1]) ** load)[100].s_mag.squeeze()


# initial guess of optimal delay lengths in degrees
d0= 120,40 # initial guess

#determine the optimal delays
d_opt = fmin(cost,(120,40))
```

1.6 Uncertainty Estimation

Contents

scikit-rf can be used to calculate uncertainty estimates given a set of networks. The `NetworkSet` object holds sets of networks and provides automated methods for calculating and displaying uncertainty bounds.

Although the uncertainty esimation functions operate on any set of networks, the topic of uncertainty estimation is frequently associated with calibration uncertianty. That is, how certain can one be in results of a calibrated measurement.

1.6.1 Simple Case

Assume that numerous touchstone files, representing redudant measurements of a single network are made, such as:

```
In [24]: ls *ro*
    ro,0.s1p  ro,1.s1p  ro,2.s1p  ro,3.s1p  ro,4.s1p  ro,5.s1p
```

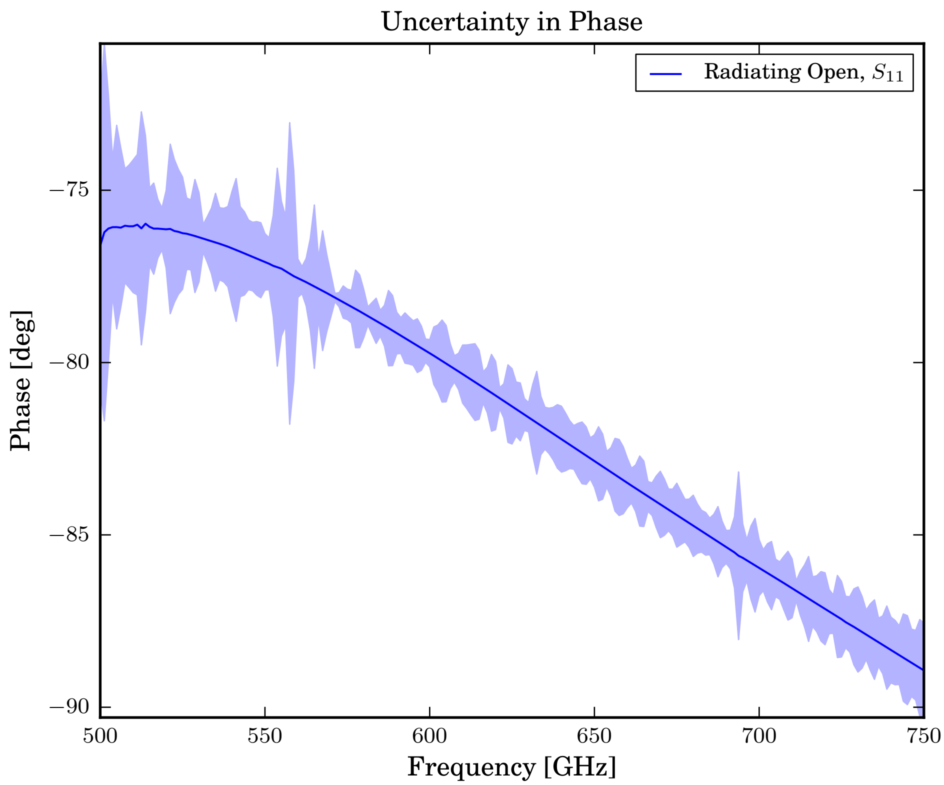
In case you are curious, the network in this example is an open rectangular waveguide radiating into freespace. The numerous touchstone files *ro,0.s1p* , *ro,1.s1p*, ... , are redundant measurements on which we would like to calculate the mean response, with uncertainty bounds.

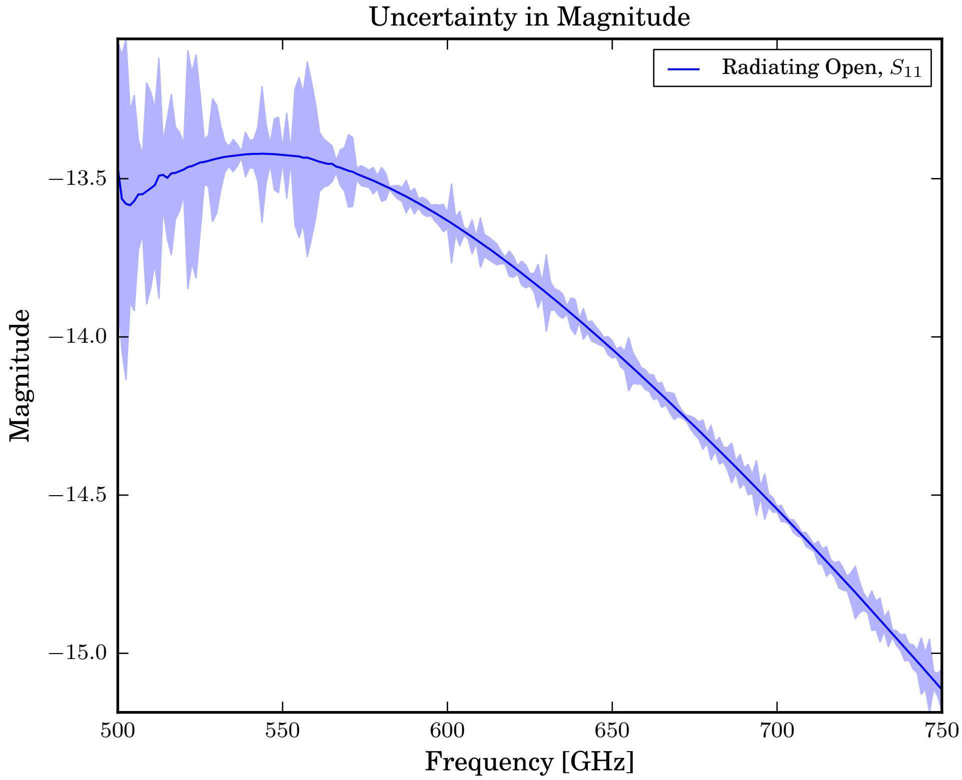
This is most easily done by constructing `NetworkSet` object. The fastest way to achieve this is to use the convenience function `load_all_touchstones()`, which returns a dictionary with `Network` objects for values.

```
import pylab
import skrf as rf

ro_set = rf.NetworkSet(\
        rf.load_all_touchstones('.',contains='ro').values(),\
        name = 'Radiating Open')

pylab.figure()
pylab.title('Uncertainty in Phase')
ro_set.plot_uncertainty_bounds_s_deg()

pylab.figure()
pylab.title('Uncertainty in Magnitude')
```

```
ro_set.plot_uncertainty_bounds_s_db()
```

```
pylab.show()
```





1.7 Developing skrf

Contents

1.7.1 Introduction

Welcome to the skrf's developer docs! This page is for those who are interested in participating those who are interested in developing scikit-rf.

Starting in February, 2012, skrf's codebase has been versioned using git , and hosted on github at https://github.com/scikit-rf/scikit-rf. The easiest way to contribute to any part of scikit-rf is to create an account on github, but if you are not familiar with git, dont hesitate to contact me directly by email at arsenovic@virginia.edu.

1.7.2 Contributing Code

skrf uses the *Fork + Pull* collaborative development model. Please see github's page on this for more information http://help.github.com/send-pull-requests/

1.7.3 Contribute Documentation

skrf's documentation is generated using sphinx. The documentation source code is written using reStructed Text, and can be found in `docs/sphinx/source/`. The reference documentation for the submodules, classes, and functions are documented following the conventions put forth by Numpy/Scipy. Improvements or new documentation is welcomed, and can be submitted using github as well.

1.7.4 Creating Tests

skrf employs the python module *unittest* for testing. The test's are located in `skrf/testCases/`.

CHAPTER

TWO

EXAMPLES

2.1 One-Port Calibration

2.1.1 Instructive

This example is written to be instructive, not concise.:

```
import skrf as rf


## created necessary data for Calibration class

# a list of Network types, holding 'ideal' responses
my_ideals = [\
        rf.Network('ideal/short.s1p'),
        rf.Network('ideal/open.s1p'),
        rf.Network('ideal/load.s1p'),
        ]

# a list of Network types, holding 'measured' responses
my_measured = [\
        rf.Network('measured/short.s1p'),
        rf.Network('measured/open.s1p'),
        rf.Network('measured/load.s1p'),
        ]

## create a Calibration instance
cal = rf.Calibration(\
        ideals = my_ideals,
        measured = my_measured,
        )


## run, and apply calibration to a DUT

# run calibration algorithm
cal.run()

# apply it to a dut
dut = rf.Network('my_dut.s1p')
dut_caled = cal.apply_cal(dut)

# plot results
```

```
dut_caled.plot_s_db()
# save results
dut_caled.write_touchstone()
```

2.1.2 Concise

This example is meant to be the same as the first except more concise:

```
import skrf as rf

my_ideals = rf.load_all_touchstones_in_dir('ideals/')
my_measured = rf.load_all_touchstones_in_dir('measured/')


## create a Calibration instance
cal = rf.Calibration(\
        ideals = [my_ideals[k] for k in ['short','open','load']],
        measured = [my_measured[k] for k in ['short','open','load']],
        )

## what you do with 'cal' may  may be similar to above example
```

2.2 Two-Port Calibration

This is an example of how to setup two-port calibration. For more detailed explaination see `calibration`:

```
import skrf as rf


## created necessary data for Calibration class

# a list of Network types, holding 'ideal' responses
my_ideals = [\
        rf.Network('ideal/thru.s2p'),
        rf.Network('ideal/line.s2p'),
        rf.Network('ideal/short, short.s2p'),
        ]

# a list of Network types, holding 'measured' responses
my_measured = [\
        rf.Network('measured/thru.s2p'),
        rf.Network('measured/line.s2p'),
        rf.Network('measured/short, short.s2p'),
        ]


## create a Calibration instance
cal = rf.Calibration(\
        ideals = my_ideals,
        measured = my_measured,
        )


## run, and apply calibration to a DUT
```

```
# run calibration algorithm
cal.run()

# apply it to a dut
dut = rf.Network('my_dut.s2p')
dut_caled = cal.apply_cal(dut)

# plot results
dut_caled.plot_s_db()
# save results
dut_caled.write_touchstone()
```

2.3 VNA Noise Analysis

This example records a series of sweeps from a VNA to touchstone files, named in a chronological order. These are then used to characterize the noise of a VNA.

2.3.1 Touchstone File Retrieval

```
import skrf as rf
import os,datetime

nsweeps = 101 # number of sweeps to take
dir = datetime.datetime.now().date().__str__() # directory to save files in

myvna = rf.vna.HP8720() # HP8510 also available
os.mkdir(dir)
for k in range(nsweeps):
        print  k
        ntwk = myvna.s11
        date_string = datetime.datetime.now().__str__().replace(':','-')
        ntwk.write_touchstone(dir +'/'+ date_string)

myvna.close()
```

2.3.2 Noise Analysis

Calculates and plots various metrics of noise, given a directory of touchstone files, as would be created from the previous script.

```
import skrf as rf
from pylab import *

dir = '2010-12-03' # directory of touchstone files
npoints = 3 # number of frequency points to calculate statistics for


# load all touchstones in directory into a dictionary, and sort keys
data = rf.load_all_touchstones(dir+'/')
keys=data.keys()
keys.sort()

# length of frequency vector of each network
```

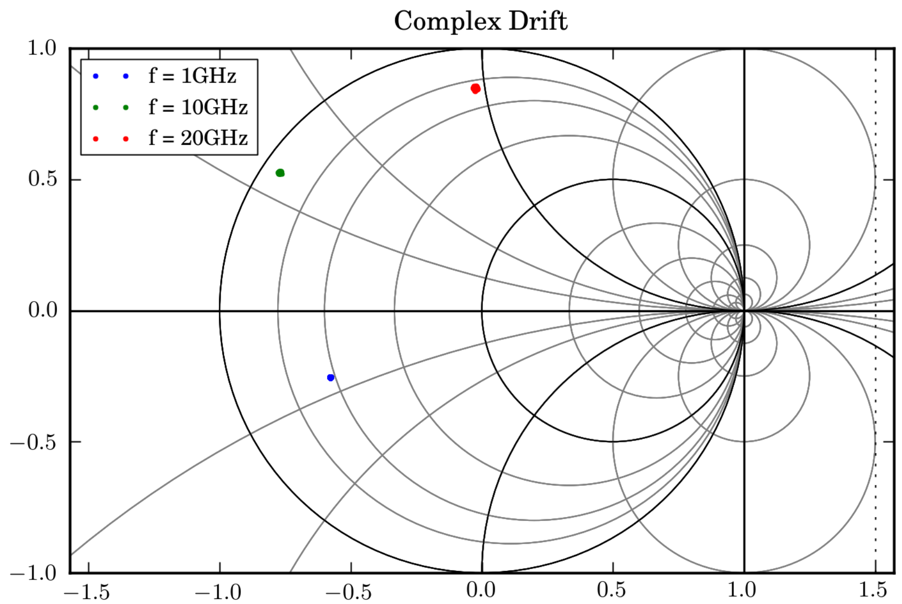
```
f_len = data[keys[0]].frequency.npoints
# frequency vector indecies at which we will calculate the statistics
f_vector = [int(k) for k in linspace(0,f_len-1, npoints)]

#loop through the frequencies of interest and calculate statistics
for f in f_vector:
        # for legends
        f_scaled = data[keys[0]].frequency.f_scaled[f]
        f_unit = data[keys[0]].frequency.unit

        # z is 1d complex array of the s11 at the current frequency, it is
        # as long as the number of touchsone files
        z = array( [(data[keys[k]]).s[f,0,0] for k in range(len(keys))])
        phase_change = rf.complex_2_degree(z * 1/z[0])
        phase_change = phase_change - mean(phase_change)
        mag_change = rf.complex_2_magnitude(z-z[0])

        figure(1)
        title('Complex Drift')
        plot(z.real,z.imag,'.',label='f = %i%s'% ( f_scaled,f_unit))
        axis('equal')
        legend()
        rf.smith()

        figure(2)
        title('Phase Drift vs. Time')
        xlabel('Sample [n]')
        ylabel('Phase From Mean [deg]')
        plot(phase_change,label='f = %i%s, $\sigma=%.1f$'%(f_scaled,f_unit,std(phase_change)))
        legend()

        figure(3)
        title('Phase Drift Distribution')
        xlabel('Phase From Mean[deg]')
        ylabel('Frequency Of Occurrence')
        hist(phase_change,alpha=.5,bins=21,histtype='stepfilled',\
                label='f = %i%s, $\sigma=%.1f$'%(f_scaled,f_unit,std(phase_change)) )
        legend()
        figure(4)
        title('FFT of Phase Drift')
        ylabel('Power [dB]')
        xlabel('Sample Frequency [?]')
        plot(log10(abs(fftshift(fft(phase_change))))[len(keys)/2+1:])

draw();show();
```

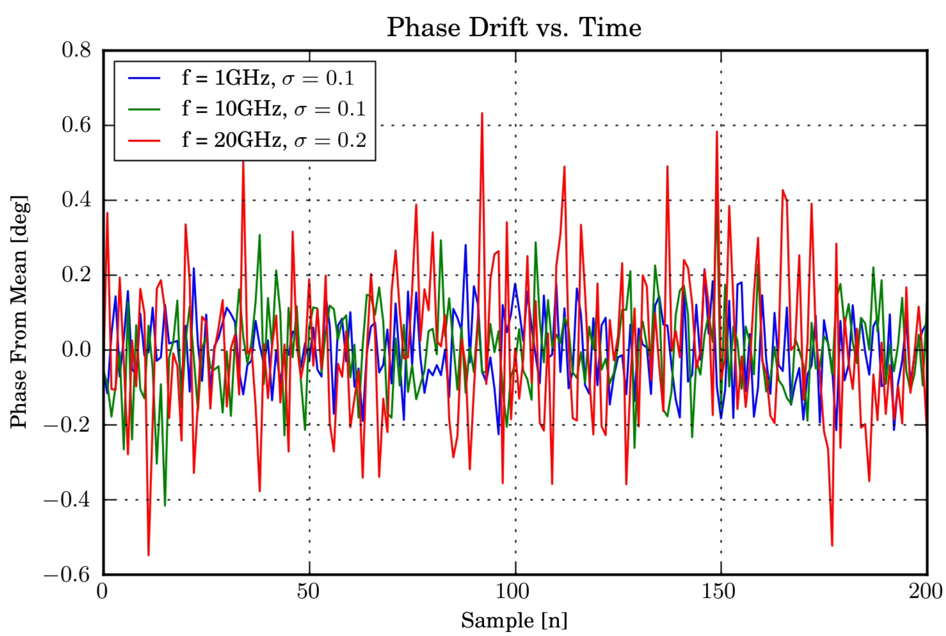
2.4 Circuit Design: Single Stub Matching Network

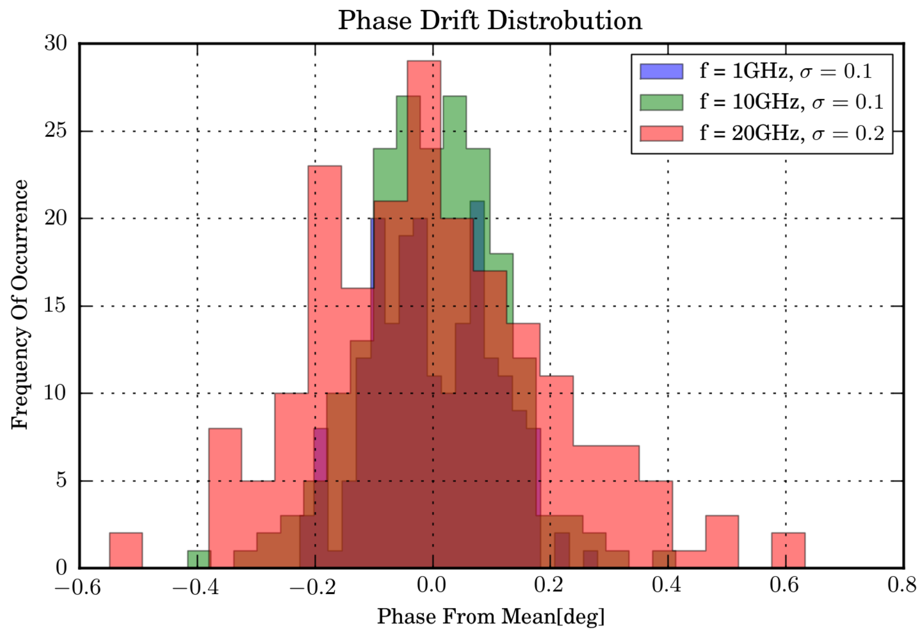
2.4.1 Introduction

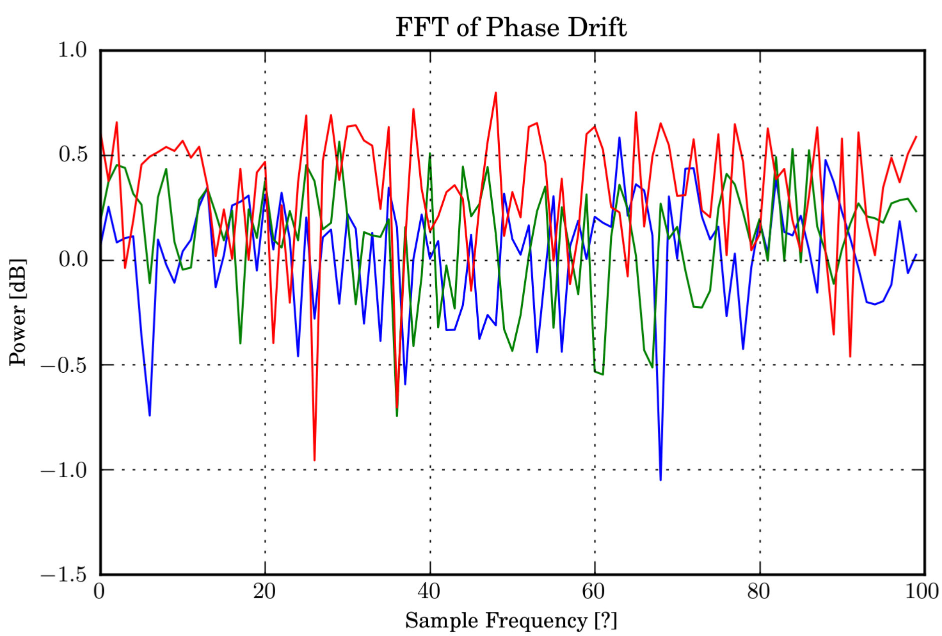
This example illustrates a way to visualize the design space for a single stub matching network. The matching Network consists of a shunt and series stub arranged as shown below, (image taken from R.M. Weikle's Notes)

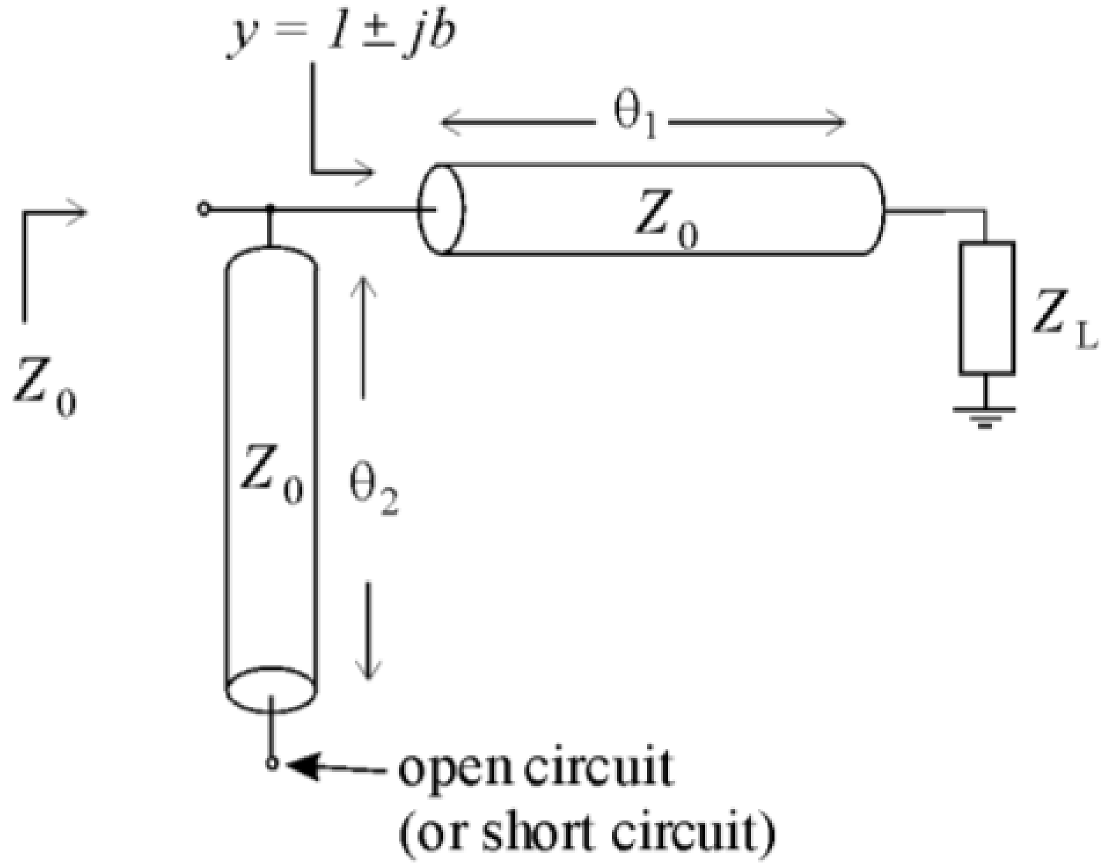
A single stub matching network can be designed to produce maximum power transfer to the load, at a single frequency. The matching network has two design parameters:


Complex Drift
f = 1GHz
f = 10GHz
f = 20GHz
1.0
0.5
0.0
−0.5
−1.0
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5


Phase Drift vs. Time
f = 1GHz, $\sigma = 0.1$
f = 10GHz, $\sigma = 0.1$
f = 20GHz, $\sigma = 0.2$
Phase From Mean [deg]
Sample [n]
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0
50
100
150
200


Phase Drift Distrobution
f = 1GHz, $\sigma = 0.1$
f = 10GHz, $\sigma = 0.1$
f = 20GHz, $\sigma = 0.2$
Frequency Of Occurrence
Phase From Mean[deg]
0
5
10
15
20
25
30
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
0.8


FFT of Phase Drift
Power [dB]
Sample Frequency [?]
1.0
0.5
0.0
−0.5
−1.0
−1.5
0
20
40
60
80
100



$y = 1 \pm jb$
θ_1
Z_0
Z_L
Z_0
Z_0
θ_2
open circuit
(or short circuit)

- length of series tline
- length of shunt tline

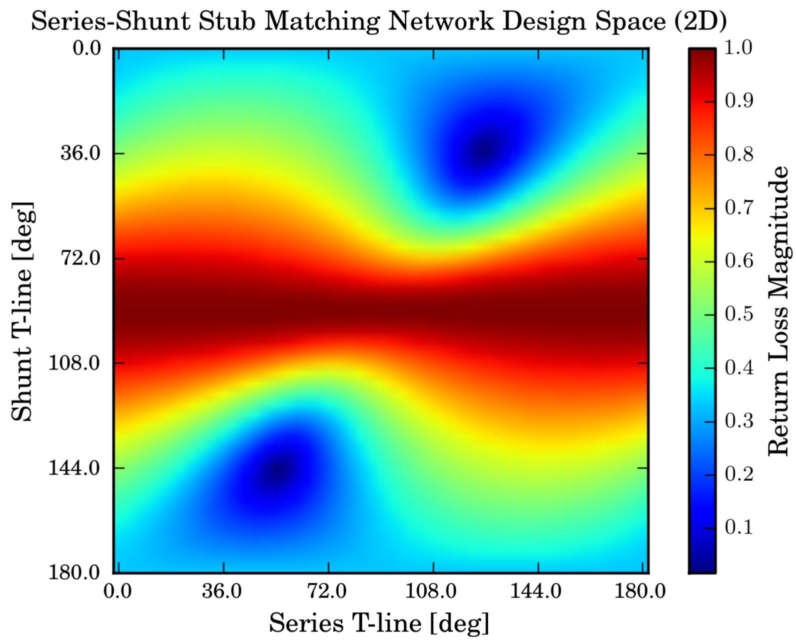
This script illustrates how to create a plot of return loss magnitude off the matched load, vs series and shunt line lengths. The optimal designs are then seen as the minima of a 2D surface.

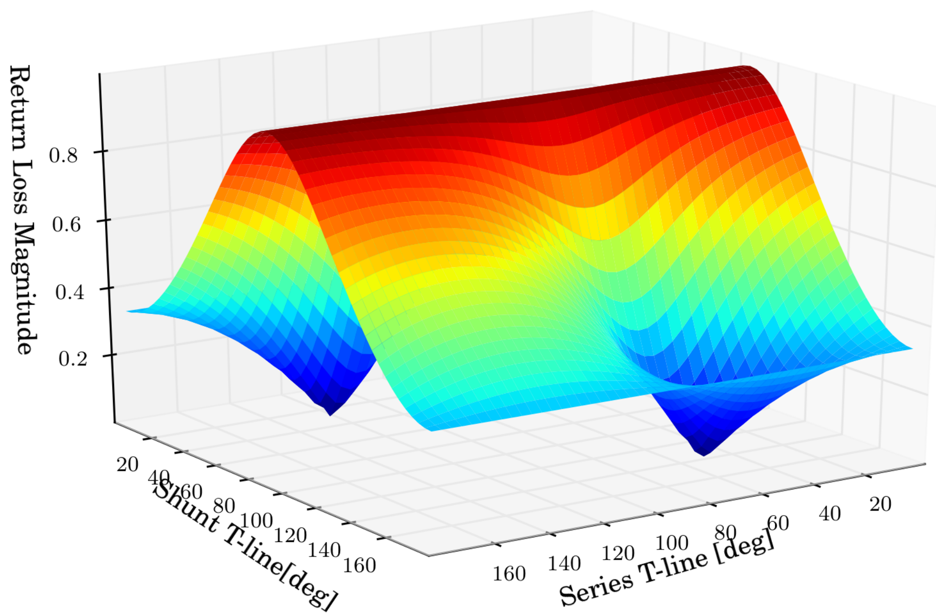
2.4.2 Script

```
import skrf as rf
from pylab import *


# Inputs
wg = rf.wr10 # The Media class
f0 = 90                    # Design Frequency in GHz
d_start, d_stop = 0,180 # span of tline lengths [degrees]
n = 51                     # number of points
Gamma0 = .5      # the reflection coefficient off the load we are matching


# change wg.frequency so we only simulat at f0
wg.frequency = rf.Frequency(f0,f0,1,'ghz')
# create load network
load = wg.load(.5)
# the vector of possible line-lengths to simulate at
d_range = linspace(d_start,d_stop,n)

def single_stub(wg, d):
        '''
        function to return series-shunt stub matching network, given a
        WorkingBand and the electrical lengths of the stubs
        '''
        return wg.shunt_delay_open(d[1],'deg') ** wg.line(d[0],'deg')

# loop through all line-lengths for series and shunt tlines, and store
# reflection coefficient magnitude in array
output = array([[ (single_stub(wg, [d0,d1])**load).s_mag[0,0,0] \
        for d0 in d_range] for d1 in d_range] )


# show the resultant return loss for the parameters space
figure()
title('Series-Shunt Stub Matching Network Design Space (2D)')
imshow(output)
xlabel('Series T-line [deg]')
ylabel('Shunt T-line [deg]')
xticks(range(0,n+1,n/5),d_range[0::n/5])
yticks(range(0,n+1,n/5),d_range[0::n/5])
cbar = colorbar()
cbar.set_label('Return Loss Magnitude')

from mpl_toolkits.mplot3d import Axes3D

fig=figure()
ax = Axes3D(fig)
x,y = meshgrid(d_range, d_range)
ax.plot_surface(x,y,output, rstride=1, cstride=1,cmap=cm.jet)
```

```
ax.set_xlabel('Series T-line [deg]')
ax.set_ylabel('Shunt T-line[deg]')
ax.set_zlabel('Return Loss Magnitude')
ax.set_title(r'Series-Shunt Stub Matching Network Design Space (3D)')
draw()
show()
```

2.4.3 Output




Return Loss Magnitude
0.8
0.6
0.4
0.2
20
40
60
80
100
120
140
160
Shunt T-line[deg]
160
140
120
100
80
60
40
20
Series T-line [deg]

CHAPTER

THREE

REFERENCE

3.1 Major Classes

- Network
- NetworkSet
- Frequency
- Calibration

3.2 Modules

3.2.1 network (skrf.network)

Provides a n-port network class and associated functions.

Most of the functionality in this module is provided as methods and properties of the Network Class.

Network Class

Network([touchstone_file, name])	A n-port electrical network.

skrf.network.Network

class skrf.network.**Network**(*touchstone_file=None*, *name=None*)

A n-port electrical network.

A n-port network may be defined by three quantities,

- scattering parameter matrix (s-matrix)
- port characteristic impedance matrix
- frequency information

The Network class stores these data structures internally in the form of complex numpy.ndarray's. These arrays are not interfaced directly but instead through the use of the properties:

Property	Meaning
s	scattering parameter matrix
z0	characteristic impedance matrix
f	frequency vector

Individual components of the s-matrix are accesable through properties as well. These also return numpy.ndarray's.

Property	Meaning
s_re	real part of the s-matrix
s_im	imaginary part of the s-matrix
s_mag	magnitude of the s-matrix
s_db	magnitude in log scale of the s-matrix
s_deg	phase of the s-matrix in degrees

The following Network operators are available:

Operator	Function
+	element-wise addition of the s-matrix
-	element-wise difference of the s-matrix
*	element-wise multiplication of the s-matrix
/	element-wise division of the s-matrix
**	cascading (only for 2-ports)
//	de-embedding (for 2-ports, see inv)

Different components of the Network can be visualized through various plotting methods. These methods can be used to plot individual elements of the s-matrix or all at once. For more info about plotting see the *Plotting* tutorial.

Method	Meaning
plot_s_smith()	plot complex s-parameters on smith chart
plot_s_re()	plot real part of s-parameters vs frequency
plot_s_im()	plot imaginary part of s-parameters vs frequency
plot_s_mag()	plot magnitude of s-parameters vs frequency
plot_s_db()	plot magnitude (in dB) of s-parameters vs frequency
plot_s_deg()	plot phase of s-parameters (in degrees) vs frequency

Generally, Network objects are created from touchstone files upon initializtion (see __init__()), or are created from a Media object. Network objects can be saved to disk in the form of touchstone files with the write_touchstone() method.

An exhaustive list of Network Methods and Properties (Attributes) are given below

Attributes

f	the frequency vector for the network, in Hz.
frequency	frequency information for the network.
inv	a Network object with 'inverse' s-parameters.
number_of_ports	the number of ports the network has.
passivity	passivity metric for a multi-port network.
s	the scattering parameter matrix [#]_.
Network.s_abs	
Network.s_angle	
Network.s_arcl	
Network.s_arcl_unwrap	

Continued on next page

Table 3.2 – continued from previous page

Network.s_db	
Network.s_deg	
Network.s_deg_unwrap	
Network.s_im	
Network.s_mag	
Network.s_quad	
Network.s_rad	
Network.s_rad_unwrap	
Network.s_re	
t	t-parameters, aka scattering transfer parameters [#]_
y	admittance parameters
z0	the characteristic impedance[s] of the network ports.

skrf.network.Network.f

Network.**f**

the frequency vector for the network, in Hz.

Returns f : numpy.ndarray

frequency vector in Hz

See Also:

frequency frequency property that holds all frequency information

skrf.network.Network.frequency

Network.**frequency**

frequency information for the network.

This property is a Frequency object. It holds the frequency vector, as well frequency unit, and provides other properties related to frequency information, such as start, stop, etc.

Returns frequency : Frequency object

frequency information for the network.

See Also:

f property holding frequency vector in Hz

change_frequency updates frequency property, and interpolates s-parameters if needed

interpolate interpolate function based on new frequency info

skrf.network.Network.inv

Network.**inv**

a Network object with 'inverse' s-parameters.

This is used for de-embeding. It is defined so that the inverse of a Network cascaded with itself is unity.

Returns inv : a Network object

a Network object with 'inverse' s-parameters.

See Also:

inv function which implements the inverse s-matrix

skrf.network.Network.number_of_ports

`Network.number_of_ports`

the number of ports the network has.

Returns **number_of_ports** : number

the number of ports the network has.

skrf.network.Network.passivity

`Network.passivity`

passivity metric for a multi-port network.

This returns a matrix who's diagonals are equal to the total power received at all ports, normalized to the power at a single excitement port.

mathmatically, this is a test for unitary-ness of the s-parameter matrix [1].

for two port this is

$$(|S_{11}|^2 + |S_{21}|^2\,,\;|S_{22}|^2 + |S_{12}|^2)$$

in general it is

$$S^H \cdot S$$

where H is conjugate transpose of S, and $\cdot$ is dot product.

Returns **passivity** : numpy.ndarray of shape fxnxn

References

skrf.network.Network.s

`Network.s`

the scattering parameter matrix [2].

s-matrix is a 3 dimensional numpy.ndarray which has shape *fxnxn*, where *f* is frequency axis and *n* is number of ports

Returns **s** : complex numpy.ndarry of shape *fxnxn*

the scattering parameter matrix.

References

skrf.network.Network.t

`Network.t`

t-parameters, aka scattering transfer parameters [3]

this is also known or the wave cascading matrix, and is only defined for a 2-port Network

Returns **t** : complex numpy.ndarry of shape *fxnxn*

t-parameters, aka scattering transfer parameters

[1] http://en.wikipedia.org/wiki/Scattering_parameters#Lossless_networks
[2] http://en.wikipedia.org/wiki/Scattering_parameters
[3] http://en.wikipedia.org/wiki/Scattering_parameters#Scattering_transfer_parameters

References

skrf.network.Network.y

`Network.y`

admittance parameters

skrf.network.Network.z0

`Network.z0`

the characteristic impedance[s] of the network ports.

This property stores the characteristic impedance of each port of the network. Because it is possible that each port has a different characteristic impedance, that is a function of frequency, *z0* is stored internally as a *fxn* array.

However because frequenty *z0* is simple (like 50ohm),it can be set with just number as well.

Returns **z0** : numpy.ndarray of shape fxn

characteristic impedance for network

Methods

`__init__`	constructor.
`add_noise_polar`	adds a complex zero-mean gaussian white-noise.
`add_noise_polar_flatband`	adds a flatband complex zero-mean gaussian white-noise signal of
`Network.change_frequency`	
`flip`	swaps the ports of a two port Network
`interpolate`	calculates an interpolated network.
`multiply_noise`	multiplys a complex bivariate gaussian white-noise signal
`nudge`	perturb s-parameters by small amount. this is useful to
`plot_passivity`	plots the passivity of a network, possibly for a specific port.
`Network.plot_polar_generic`	
`Network.plot_s_complex`	
`Network.plot_s_polar`	
`plot_s_smith`	plots the scattering parameter on a smith chart
`Network.plot_vs_frequency_generic`	
`read_touchstone`	loads values from a touchstone file.
`write_touchstone`	write a contents of the `Network` to a touchstone file.

skrf.network.Network.__init__

`Network.__init__`(*touchstone_file=None*, *name=None*)

constructor.

Contructs a Network, and optionally populates the s-matrix and frequency information from touchstone file.

Parameters **file: string** :

if given will load information from touchstone file,optional

name: string :

name of this network, optional

skrf.network.Network.add_noise_polar

`Network.add_noise_polar`(*mag_dev*, *phase_dev*, ***kwargs*)

adds a complex zero-mean gaussian white-noise.

adds a complex zero-mean gaussian white-noise of a given standard deviation for magnitude and phase

Parameters **mag_dev** : number

standard deviation of magnitude

phase_dev : number

standard deviation of phase [in degrees]

skrf.network.Network.add_noise_polar_flatband

`Network.`**`add_noise_polar_flatband`**(*mag_dev*, *phase_dev*, ***kwargs*)

adds a flatband complex zero-mean gaussian white-noise signal of given standard deviations for magnitude and phase

Parameters **mag_dev** : number

standard deviation of magnitude

phase_dev : number

standard deviation of phase [in degrees]

skrf.network.Network.flip

`Network.`**`flip`**()

swaps the ports of a two port Network

skrf.network.Network.interpolate

`Network.`**`interpolate`**(*new_frequency*, ***kwargs*)

calculates an interpolated network.

The default interpolation type is linear. see Notes for how to use other interpolation types.

Parameters **new_frequency** : `Frequency`

frequency information to interpolate at

****kwargs** : keyword arguments

passed to `scipy.interpolate.interp1d()` initializer.

Returns **result** : `Network`

an interpolated Network

Notes

useful keyword for `scipy.interpolate.interp1d()`,

kind [str or int] Specifies the kind of interpolation as a string (‘linear’, ‘nearest’, ‘zero’, ‘slinear’, ‘quadratic, ‘cubic’) or as an integer specifying the order of the spline interpolator to use.

skrf.network.Network.multiply_noise

`Network.`**`multiply_noise`**(*mag_dev*, *phase_dev*, ***kwargs*)

multiplys a complex bivariate gaussian white-noise signal of given standard deviations for magnitude and phase. magnitude mean is 1, phase mean is 0

takes: mag_dev: standard deviation of magnitude phase_dev: standard deviation of phase [in degrees] n_ports: number of ports. defualt to 1

returns: nothing

skrf.network.Network.nudge

`Network.nudge(amount=1e-12)`

perturb s-parameters by small amount. this is useful to work-around numerical bugs.

Parameters **amount** : number,

amount to add to s parameters

skrf.network.Network.plot_passivity

`Network.plot_passivity(port=None, ax=None, show_legend=True, *args, **kwargs)`

plots the passivity of a network, possibly for a specific port.

Parameters **port: int** :

calculate passivity of a given port

ax : matplotlib.Axes object, optional

axes to plot on. in case you want to update an existing plot.

show_legend : boolean, optional

to turn legend show legend of not, optional

***args** : arguments, optional

passed to the matplotlib.plot command

****kwargs** : keyword arguments, optional

passed to the matplotlib.plot command

See Also:

`plot_vs_frequency_generic`, `passivity`

Examples

```
>>> myntwk.plot_s_rad()
>>> myntwk.plot_s_rad(m=0,n=1,color='b', marker='x')
```

skrf.network.Network.plot_s_smith

`Network.plot_s_smith(m=None, n=None, r=1, ax=None, show_legend=True, chart_type='z', *args, **kwargs)`

plots the scattering parameter on a smith chart

plots indecies *m*, *n*, where *m* and *n* can be integers or lists of integers.

Parameters **m** : int, optional

first index

n : int, optional

second index

ax : matplotlib.Axes object, optional

axes to plot on. in case you want to update an existing plot.

show_legend : boolean, optional

to turn legend show legend of not, optional

***args** : arguments, optional

passed to the matplotlib.plot command

****kwargs** : keyword arguments, optional

passed to the matplotlib.plot command

See Also:

`plot_vs_frequency_generic`, `smith`

Examples

```
>>> myntwk.plot_s_smith()
>>> myntwk.plot_s_smith(m=0,n=1,color='b', marker='x')
```

skrf.network.Network.read_touchstone

`Network.read_touchstone(filename)`

loads values from a touchstone file.

The work of this function is done through the `touchstone` class.

Parameters **filename** : string

touchstone file name.

Notes

only the scattering parameters format is supported at the moment

skrf.network.Network.write_touchstone

`Network.write_touchstone(filename=None, dir='./')`

write a contents of the `Network` to a touchstone file.

Parameters **filename** : a string, optional

touchstone filename, without extension. if 'None', then will use the network's `name`.

dir : string, optional

the directory to save the file in. Defaults to cwd './'.

Notes

format supported at the moment is, HZ S RI

The functionality of this function should take place in the `touchstone` class.

Connecting Networks

`connect`(ntwkA, k, ntwkB, l)	connect two n-port networks together.
`innerconnect`(ntwkA, k, l)	connect two ports of a single n-port network.
`cascade`(ntwkA, ntwkB)	cascade two 2-port Networks together
`de_embed`(ntwkA, ntwkB)	de-embed *ntwkA* from *ntwkB*. this calls *ntwkA.inv**ntwkB*.

skrf.network.connect

`skrf.network.connect` (*ntwkA*, *k*, *ntwkB*, *l*)

connect two n-port networks together.

specifically, connect port *k* on *ntwkA* to port *l* on *ntwkB*. The resultant network has (ntwkA.nports+ntwkB.nports-2) ports. The port index's ('k','l') start from 0. Port impedances **are** taken into account.

Parameters **ntwkA** : `Network`

network 'A'

k : int

port index on *ntwkA* (port indecies start from 0)

ntwkB : `Network`

network 'B'

l : int

port index on *ntwkB*

Returns **ntwkC** : `Network`

new network of rank (ntwkA.nports+ntwkB.nports -2)-ports

See Also:

`connect_s` actual S-parameter connection algorithm.

`innerconnect_s` actual S-parameter connection algorithm.

Notes

the effect of mis-matched port impedances is handled by inserting a 2-port 'mismatch' network between the two connected ports. This mismatch Network is calculated with the :func:impedance_mismatch function.

Examples

To implement a *cascade* of two networks

```
>>> ntwkA = rf.Network('ntwkA.s2p')
>>> ntwkB = rf.Network('ntwkB.s2p')
>>> ntwkC = rf.connect(ntwkA, 1, ntwkB,0)
```

skrf.network.innerconnect

`skrf.network.innerconnect(ntwkA, k, l)`

connect two ports of a single n-port network.

this results in a (n-2)-port network. remember port indecies start from 0.

Parameters **ntwkA** : `Network`

network 'A'

k : int

port index on ntwkA (port indecies start from 0)

l : int

port index on ntwkB

Returns **ntwkC** : `Network`

new network of rank (ntwkA.nports+ntwkB.nports -2)-ports

See Also:

`connect_s` actual S-parameter connection algorithm.

`innerconnect_s` actual S-parameter connection algorithm.

Notes

a 2-port 'mismatch' network between the two connected ports.

Examples

To connect ports '0' and port '1' on ntwkA

```
>>> ntwkA = rf.Network('ntwkA.s3p')
>>> ntwkC = rf.innerconnect(ntwkA, 0,1)
```

skrf.network.cascade

`skrf.network.cascade(ntwkA, ntwkB)`

cascade two 2-port Networks together

connects port 1 of *ntwkA* to port 0 of *ntwkB*. This calls *connect(ntwkA,1, ntwkB,0)*, which is a more general function.

Parameters **ntwkA** : `Network`

network *ntwkA*

ntwkB : Network

network *ntwkB*

Returns **C** : Network

the resultant network of ntwkA cascaded with ntwkB

See Also:

`connect` connects two Networks together at arbitrary ports.

skrf.network.de_embed

`skrf.network.de_embed(ntwkA, ntwkB)`

de-embed *ntwkA* from *ntwkB*. this calls *ntwkA.inv**ntwkB*. the syntax of cascading an inverse is more explicit, it is recomended that it be used instead of this function.

Parameters **ntwkA** : `Network`

network *ntwkA*

ntwkB : `Network`

network *ntwkB*

Returns **C** : Network

the resultant network of ntwkB de-embeded from ntwkA

See Also:

`connect` connects two Networks together at arbitrary ports.

Interpolation

`Network.interpolate`(new_frequency, **kwargs)	calculates an interpolated network.
`Network.interpolate_self`(new_frequency, **kwargs)	interpolates s-parameters given a new
`Network.interpolate_self_npoints`(npoints, ...)	interpolate network based on a new number of frequency points

skrf.network.Network.interpolate

`Network.interpolate(new_frequency, **kwargs)`

calculates an interpolated network.

The default interpolation type is linear. see Notes for how to use other interpolation types.

Parameters **new_frequency** : `Frequency`

frequency information to interpolate at

****kwargs** : keyword arguments

passed to `scipy.interpolate.interp1d()` initializer.

Returns **result** : `Network`

an interpolated Network

Notes

useful keyword for `scipy.interpolate.interp1d()`,

kind [str or int] Specifies the kind of interpolation as a string ('linear', 'nearest', 'zero', 'slinear', 'quadratic, 'cubic') or as an integer specifying the order of the spline interpolator to use.

skrf.network.Network.interpolate_self

`Network.interpolate_self(new_frequency, **kwargs)`

interpolates s-parameters given a new :class:'~skrf.frequency.Frequency' object.

The default interpolation type is linear. see Notes for how to use other interpolation types.

Parameters **new_frequency** : `Frequency`

frequency information to interpolate at

****kwargs** : keyword arguments

passed to `scipy.interpolate.interp1d()` initializer.

See Also:

`interpolate` same function, but returns a new Network

Notes

useful keyword for `scipy.interpolate.interp1d()`,

kind [str or int] Specifies the kind of interpolation as a string ('linear', 'nearest', 'zero', 'slinear', 'quadratic, 'cubic') or as an integer specifying the order of the spline interpolator to use.

skrf.network.Network.interpolate_self_npoints

`Network.interpolate_self_npoints(npoints, **kwargs)`

interpolate network based on a new number of frequency points

Parameters **npoints** : int

number of frequency points

****kwargs** : keyword arguments

passed to `scipy.interpolate.interp1d()` initializer.

See Also:

`interpolate_self` same functionality but takes a Frequency object

`interpolate` same functionality but takes a Frequency object and returns a new Network, instead of updating itself.

Supporting Functions

`inv`(s)	calculates 'inverse' s-parameter matrix, used for de-embeding
`connect_s`(A, k, B, l)	connect two n-port networks' s-matricies together.
`innerconnect_s`(A, k, l)	connect two ports of a single n-port network's s-matrix.
`s2z`(s)	convert scattering parameters to impedance parameters [#]_
`s2y`(s)	convert scattering parameters to admittance parameters [#]_
`s2t`(s)	converts scattering parameters to scattering transfer parameters.
`z2s`(z)	convert impedance parameters to scattering parameters [#]_

Continued on next page

Table 3.6 – continued from previous page

z2y(z)	convert impedance parameters to admittance parameters [#]_
z2t(z)	convert impedance parameters to scattering transfer parameters [#]_
y2s(y)	convert admittance parameters to scattering parameters [#]_
y2z(y)	convert admittance parameters to impedance parameters [#]_
y2t(y)	convert admittance parameters to scattering-transfer parameters [#]_
t2s(t)	converts scattering transfer parameters to scattering parameters
t2z(t)	convert scattering transfer parameters to impedance parameters [#]_
t2y(t)	convert scattering transfer parameters to admittance parameters [#]_

skrf.network.inv

skrf.network.**inv**(*s*)

calculates 'inverse' s-parameter matrix, used for de-embeding

this is not literally the inverse of the s-parameter matrix. it is defined such that the inverse of the s-matrix cascaded with itself is unity.

$$inv(s) = t2s(s2t(s)^{-1})$$

where x^{-1} is the matrix inverse. in other words this is the inverse of the scattering transfer parameters matrix transformed into a scattering parameters matrix.

Parameters **s** : numpy.ndarray (shape fx2x2)

scattering parameter matrix.

Returns **s'** : numpy.ndarray

inverse scattering parameter matrix.

See Also:

t2s converts scattering transfer parameters to scattering parameters

s2t converts scattering parameters to scattering transfer parameters

skrf.network.connect_s

skrf.network.**connect_s**(*A*, *k*, *B*, *l*)

connect two n-port networks' s-matricies together.

specifically, connect port *k* on network *A* to port *l* on network *B*. The resultant network has nports = (A.rank + B.rank-2). This function operates on, and returns s-matricies. The function connect() operates on Network types.

Parameters **A** : numpy.ndarray

S-parameter matrix of *A*, shape is fxnxn

k : int

port index on *A* (port indecies start from 0)

B : numpy.ndarray

S-parameter matrix of *B*, shape is fxnxn

l : int

port index on *B*

Returns **C** : numpy.ndarray

new S-parameter matrix

See Also:

`connect` operates on `Network` types

`innerconnect_s` function which implements the connection connection algorithm

Notes

internally, this function creates a larger composite network and calls the `innerconnect_s()` function. see that function for more details about the implementation

skrf.network.innerconnect_s

`skrf.network.innerconnect_s(A, k, l)`

connect two ports of a single n-port network's s-matrix.

Specifically, connect port *k* to port *l* on *A*. This results in a (n-2)-port network. This function operates on, and returns s-matricies. The function `innerconnect()` operates on `Network` types.

Parameters **A** : numpy.ndarray

S-parameter matrix of *A*, shape is fxnxn

k : int

port index on *A* (port indecies start from 0)

l : int

port index on *A*

Returns **C** : numpy.ndarray

new S-parameter matrix

Notes

The algorithm used to calculate the resultant network is called a 'sub-network growth', can be found in [4]. The original paper describing the algorithm is given in [5].

[4] Compton, R.C.; , "Perspectives in microwave circuit analysis," Circuits and Systems, 1989., Proceedings of the 32nd Midwest Symposium on , vol., no., pp.716-718 vol.2, 14-16 Aug 1989. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=101955&isnumber=3167

[5] Filipsson, Gunnar; , "A New General Computer Algorithm for S-Matrix Calculation of Interconnected Multiports," Microwave Conference, 1981. 11th European , vol., no., pp.700-704, 7-11 Sept. 1981. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4131699&isnumber=4131585

References

skrf.network.s2z

`skrf.network.s2z(s)`

convert scattering parameters to impedance parameters [6]

$$s = \frac{1+s}{1-s}$$

Parameters **s** : complex array-like or number

scattering parameters

Returns **z** : complex array-like or number

impedance parameters

See Also:

`s2z` converts scattering parameters to impedance parameters

`s2y` converts scattering parameters to admittance parameters

`s2t` converts scattering parameters to scattering transfer parameters

`z2s` converts impedance parameters to scattering parameters

`z2y` converts impedance parameters to impedance parameters

`z2t` converts impedance parameters to scattering transfer parameters

`y2s` converts admittance parameters to impedance parameters

`y2z` converts admittance parameters to impedance parameters

`y2z` converts admittance parameters to scattering transfer parameters

`t2s` converts scattering transfer paramerters to scattering parameters

`t2z` converts scattering transfer paramerters to impedance parameters

`t2y` converts scattering transfer paramerters to admittance parameters

References

skrf.network.s2y

`skrf.network.s2y(s)`

convert scattering parameters to admittance parameters [7]

$$s = \frac{1+s}{1-s}$$

Parameters **s** : complex array-like or number

scattering parameters

[6] http://en.wikipedia.org/wiki/Two-port_network

[7] http://en.wikipedia.org/wiki/Two-port_network

Returns **y** : complex array-like or number

admittance parameters

See Also:

s2z converts scattering parameters to impedance parameters

s2y converts scattering parameters to admittance parameters

s2t converts scattering parameters to scattering transfer parameters

z2s converts impedance parameters to scattering parameters

z2y converts impedance parameters to impedance parameters

z2t converts impedance parameters to scattering transfer parameters

y2s converts admittance parameters to impedance parameters

y2z converts admittance parameters to impedance parameters

y2z converts admittance parameters to scattering transfer parameters

t2s converts scattering transfer paramerters to scattering parameters

t2z converts scattering transfer paramerters to impedance parameters

t2y converts scattering transfer paramerters to admittance parameters

References

skrf.network.s2t

skrf.network.**s2t**(*s*)

converts scattering parameters to scattering transfer parameters.

transfer parameters [8] are also refered to as 'wave cascading matrix', this function only operates on 2-port networks.

Parameters **s** : numpy.ndarray (shape fx2x2)

scattering parameter matrix

Returns **t** : numpy.ndarray

scattering transfer parameters (aka wave cascading matrix)

See Also:

t2s converts scattering transfer parameters to scattering parameters

inv calculates inverse s-parameters

[8] http://en.wikipedia.org/wiki/Scattering_transfer_parameters#Scattering_transfer_parameters

References

skrf.network.z2s

`skrf.network.z2s(z)`

convert impedance parameters to scattering parameters [9]

$$s = \frac{1-s}{1+s}$$

Parameters z : complex array-like or number

impedance parameters

Returns s : complex array-like or number

scattering parameters

See Also:

s2z converts scattering parameters to impedance parameters

s2y converts scattering parameters to admittance parameters

s2t converts scattering parameters to scattering transfer parameters

z2s converts impedance parameters to scattering parameters

z2y converts impedance parameters to impedance parameters

z2t converts impedance parameters to scattering transfer parameters

y2s converts admittance parameters to impedance parameters

y2z converts admittance parameters to impedance parameters

y2z converts admittance parameters to scattering transfer parameters

t2s converts scattering transfer paramerters to scattering parameters

t2z converts scattering transfer paramerters to impedance parameters

t2y converts scattering transfer paramerters to admittance parameters

References

skrf.network.z2y

`skrf.network.z2y(z)`

convert impedance parameters to admittance parameters [10]

$$s = \frac{1-s}{1+s}$$

Parameters z : complex array-like or number

impedance parameters

[9] http://en.wikipedia.org/wiki/Two-port_network

[10] http://en.wikipedia.org/wiki/Two-port_network

Returns **s** : complex array-like or number

scattering parameters

See Also:

`s2z` converts scattering parameters to impedance parameters

`s2y` converts scattering parameters to admittance parameters

`s2t` converts scattering parameters to scattering transfer parameters

`z2s` converts impedance parameters to scattering parameters

`z2y` converts impedance parameters to impedance parameters

`z2t` converts impedance parameters to scattering transfer parameters

`y2s` converts admittance parameters to impedance parameters

`y2z` converts admittance parameters to impedance parameters

`y2z` converts admittance parameters to scattering transfer parameters

`t2s` converts scattering transfer paramerters to scattering parameters

`t2z` converts scattering transfer paramerters to impedance parameters

`t2y` converts scattering transfer paramerters to admittance parameters

References

skrf.network.z2t

`skrf.network.`**`z2t`**`(z)`

convert impedance parameters to scattering transfer parameters [11]

$$s = \frac{1-s}{1+s}$$

Parameters **z** : complex array-like or number

impedance parameters

Returns **s** : complex array-like or number

scattering parameters

See Also:

`s2z` converts scattering parameters to impedance parameters

`s2y` converts scattering parameters to admittance parameters

`s2t` converts scattering parameters to scattering transfer parameters

`z2s` converts impedance parameters to scattering parameters

`z2y` converts impedance parameters to impedance parameters

`z2t` converts impedance parameters to scattering transfer parameters

[11] http://en.wikipedia.org/wiki/Two-port_network

y2s converts admittance parameters to impedance parameters

y2z converts admittance parameters to impedance parameters

y2z converts admittance parameters to scattering transfer parameters

t2s converts scattering transfer paramerters to scattering parameters

t2z converts scattering transfer paramerters to impedance parameters

t2y converts scattering transfer paramerters to admittance parameters

References

skrf.network.y2s

`skrf.network.y2s(y)`

convert admittance parameters to scattering parameters [12]

$$s = \frac{1-s}{1+s}$$

Parameters **z** : complex array-like or number

impedance parameters

Returns **s** : complex array-like or number

scattering parameters

See Also:

s2z converts scattering parameters to impedance parameters

s2y converts scattering parameters to admittance parameters

s2t converts scattering parameters to scattering transfer parameters

z2s converts impedance parameters to scattering parameters

z2y converts impedance parameters to impedance parameters

z2t converts impedance parameters to scattering transfer parameters

y2s converts admittance parameters to impedance parameters

y2z converts admittance parameters to impedance parameters

y2z converts admittance parameters to scattering transfer parameters

t2s converts scattering transfer paramerters to scattering parameters

t2z converts scattering transfer paramerters to impedance parameters

t2y converts scattering transfer paramerters to admittance parameters

[12] http://en.wikipedia.org/wiki/Two-port_network

References

skrf.network.y2z

`skrf.network.y2z(y)`

convert admittance parameters to impedance parameters [13]

$$s = \frac{1 - s}{1 + s}$$

Parameters **z** : complex array-like or number

impedance parameters

Returns **s** : complex array-like or number

scattering parameters

See Also:

`s2z` converts scattering parameters to impedance parameters

`s2y` converts scattering parameters to admittance parameters

`s2t` converts scattering parameters to scattering transfer parameters

`z2s` converts impedance parameters to scattering parameters

`z2y` converts impedance parameters to impedance parameters

`z2t` converts impedance parameters to scattering transfer parameters

`y2s` converts admittance parameters to impedance parameters

`y2z` converts admittance parameters to impedance parameters

`y2z` converts admittance parameters to scattering transfer parameters

`t2s` converts scattering transfer paramerters to scattering parameters

`t2z` converts scattering transfer paramerters to impedance parameters

`t2y` converts scattering transfer paramerters to admittance parameters

References

skrf.network.y2t

`skrf.network.y2t(y)`

convert admittance parameters to scattering-transfer parameters [14]

$$s = \frac{1 - s}{1 + s}$$

Parameters **z** : complex array-like or number

impedance parameters

[13] http://en.wikipedia.org/wiki/Two-port_network
[14] http://en.wikipedia.org/wiki/Two-port_network

Returns **s** : complex array-like or number

scattering parameters

See Also:

`s2z` converts scattering parameters to impedance parameters

`s2y` converts scattering parameters to admittance parameters

`s2t` converts scattering parameters to scattering transfer parameters

`z2s` converts impedance parameters to scattering parameters

`z2y` converts impedance parameters to impedance parameters

`z2t` converts impedance parameters to scattering transfer parameters

`y2s` converts admittance parameters to impedance parameters

`y2z` converts admittance parameters to impedance parameters

`y2z` converts admittance parameters to scattering transfer parameters

`t2s` converts scattering transfer paramerters to scattering parameters

`t2z` converts scattering transfer paramerters to impedance parameters

`t2y` converts scattering transfer paramerters to admittance parameters

References

skrf.network.t2s

`skrf.network.`**`t2s`**(*t*)

converts scattering transfer parameters to scattering parameters

transfer parameters [15] are also refered to as 'wave cascading matrix', this function only operates on 2-port networks. this function only operates on 2-port scattering parameters.

Parameters **t** : numpy.ndarray (shape fx2x2)

scattering transfer parameters

Returns **s** : numpy.ndarray

scattering parameter matrix.

See Also:

`t2s` converts scattering transfer parameters to scattering parameters

`inv` calculates inverse s-parameters

[15] http://en.wikipedia.org/wiki/Scattering_transfer_parameters#Scattering_transfer_parameters

References

skrf.network.t2z

skrf.network.**t2z**(*t*)

convert scattering transfer parameters to impedance parameters [16]

$$s = \frac{1-s}{1+s}$$

Parameters **z** : complex array-like or number

impedance parameters

Returns **s** : complex array-like or number

scattering parameters

See Also:

s2z converts scattering parameters to impedance parameters

s2y converts scattering parameters to admittance parameters

s2t converts scattering parameters to scattering transfer parameters

z2s converts impedance parameters to scattering parameters

z2y converts impedance parameters to impedance parameters

z2t converts impedance parameters to scattering transfer parameters

y2s converts admittance parameters to impedance parameters

y2z converts admittance parameters to impedance parameters

y2z converts admittance parameters to scattering transfer parameters

t2s converts scattering transfer paramerters to scattering parameters

t2z converts scattering transfer paramerters to impedance parameters

t2y converts scattering transfer paramerters to admittance parameters

References

skrf.network.t2y

skrf.network.**t2y**(*t*)

convert scattering transfer parameters to admittance parameters [17]

$$s = \frac{1-s}{1+s}$$

Parameters **z** : complex array-like or number

impedance parameters

[16] http://en.wikipedia.org/wiki/Two-port_network

[17] http://en.wikipedia.org/wiki/Two-port_network

Returns s : complex array-like or number

scattering parameters

See Also:

s2z converts scattering parameters to impedance parameters

s2y converts scattering parameters to admittance parameters

s2t converts scattering parameters to scattering transfer parameters

z2s converts impedance parameters to scattering parameters

z2y converts impedance parameters to impedance parameters

z2t converts impedance parameters to scattering transfer parameters

y2s converts admittance parameters to impedance parameters

y2z converts admittance parameters to impedance parameters

y2z converts admittance parameters to scattering transfer parameters

t2s converts scattering transfer paramerters to scattering parameters

t2z converts scattering transfer paramerters to impedance parameters

t2y converts scattering transfer paramerters to admittance parameters

References

Misc Functions

`average`(list_of_networks)	calculates the average network from a list of Networks.
`one_port_2_two_port`(ntwk)	calculates the two-port network given a symetric, reciprocal and
`impedance_mismatch`(z1, z2)	creates a two-port network for a impedance mis-match
`load_all_touchstones`([dir, contains, f_unit])	loads all touchtone files in a given dir into a dictionary.
`write_dict_of_networks`(ntwkDict[, dir])	saves a dictionary of networks touchstone files in a given directory
`csv_2_touchstone`(filename)	converts a csv file to a `Network`

skrf.network.average

`skrf.network.`**`average`**(*list_of_networks*)

calculates the average network from a list of Networks.

this is complex average of the s-parameters for a list of Networks

Parameters list_of_networks: list :

a list of `Network` objects

Returns ntwk : `Network`

the resultant averaged Network

Notes

This same function can be accomplished with properties of a `NetworkSet` class.

Examples

```
>>> ntwk_list = [rf.Network('myntwk.s1p'), rf.Network('myntwk2.s1p')]
>>> mean_ntwk = rf.average(ntwk_list)
```

skrf.network.one_port_2_two_port

skrf.network.**one_port_2_two_port**(*ntwk*)
calculates the two-port network given a symetric, reciprocal and lossless one-port network.

takes: ntwk: a symetric, reciprocal and lossless one-port network.

returns: ntwk: the resultant two-port Network

skrf.network.impedance_mismatch

skrf.network.**impedance_mismatch**(*z1*, *z2*)
creates a two-port network for a impedance mis-match

Parameters **z1** : number or array-like

complex impedance of port 1

z2 : number or array-like

complex impedance of port 2

Returns **s'** : 2-port s-matrix for the impedance mis-match

skrf.network.load_all_touchstones

skrf.network.**load_all_touchstones**(*dir='.'*, *contains=None*, *f_unit=None*)
loads all touchtone files in a given dir into a dictionary.

Parameters **dir** : string

the path

contains : string

a string the filenames must contain to be loaded.

f_unit : ['hz','mhz','ghz']

the frequency unit to assign all loaded networks. see `frequency.Frequency.unit`.

Returns **ntwkDict** : a dictonary with keys equal to the file name (without

a suffix), and values equal to the corresponding ntwk types

Examples

```
>>> ntwk_dict = rf.load_all_touchstones('.', contains ='20v')
```

skrf.network.write_dict_of_networks

skrf.network.**write_dict_of_networks**(*ntwkDict*, *dir='.'*)
saves a dictionary of networks touchstone files in a given directory

The filenames assigned to the touchstone files are taken from the keys of the dictionary.

Parameters **ntwkDict** : dictionary

dictionary of Network objects

dir : string

directory to write touchstone file to

skrf.network.csv_2_touchstone

skrf.network.**csv_2_touchstone**(*filename*)
converts a csv file to a Network

specifically, this converts csv files saved from a Rohde Shcwarz ZVA-40, and possibly other network analyzers, into a Network object.

Parameters **filename** : string

name of file

Returns **ntwk** : Network object

the network representing data in the csv file

3.2.2 networkSet (skrf.networkSet)

Provides a class representing an un-ordered set of n-port microwave networks.

Frequently one needs to make calculations, such as mean or standard deviation, on an entire set of n-port networks. To facilitate these calculations the NetworkSet class provides convenient ways to make such calculations.

The results are returned in Network objects, so they can be plotted and saved in the same way one would do with a Network.

The functionality in this module is provided as methods and properties of the NetworkSet Class.

NetworkSet Class

NetworkSet(ntwk_set[, name])	A set of Networks.

skrf.networkSet.NetworkSet

class skrf.networkSet.**NetworkSet**(*ntwk_set*, *name=None*)
A set of Networks.

This class allows functions on sets of Networks, such as mean or standard deviation, to be calculated conveniently. The results are returned in Network objects, so that they may be plotted and saved in like Network objects.

This class also provides methods which can be used to plot uncertainty bounds for a set of Network.

The names of the NetworkSet properties are generated dynamically upon ititialization, and thus documentation for individual properties and methods is not available. However, the properties do follow the convention:

```
>>> my_network_set.function_name_network_property_name
```

For example, the complex average (mean) Network for a NetworkSet is:

```
>>> my_network_set.mean_s
```

This accesses the property 's', for each element in the set, and **then** calculates the 'mean' of the resultant set. The order of operations is important.

Results are returned as Network objects, so they may be plotted or saved in the same way as for Network objects:

```
>>> my_network_set.mean_s.plot_s_mag()
>>> my_network_set.mean_s.write_touchstone('mean_response')
```

If you are calculating functions that return scalar variables, then the result is accessable through the Network property .s_re. For example:

```
>>> std_s_deg = my_network_set.std_s_deg
```

This result would be plotted by:

```
>>> std_s_deg.plot_s_re()
```

The operators, properties, and methods of NetworkSet object are dynamically generated by private methods

- `__add_a_operator()`
- `__add_a_func_on_property()`
- `__add_a_element_wise_method()`
- `__add_a_plot_uncertainty()`

thus, documentation on the individual methods and properties are not available.

Attributes

inv	
mean_s_db	the mean magnitude in dB.
std_s_db	the mean magnitude in dB.

skrf.networkSet.NetworkSet.inv

NetworkSet.**inv**

skrf.networkSet.NetworkSet.mean_s_db

NetworkSet.**mean_s_db**

the mean magnitude in dB.

note:

the mean is taken on the magnitude before convertedto db, so magnitude_2_db(mean(s_mag))

which is NOT the same as mean(s_db)

skrf.networkSet.NetworkSet.std_s_db

`NetworkSet.std_s_db`

the mean magnitude in dB.

note:

the mean is taken on the magnitude before convertedto db, so magnitude_2_db(mean(s_mag))

which is NOT the same as mean(s_db)

Methods

`__init__`	Initializer for NetworkSet
`element_wise_method`	calls a given method of each element and returns the result as
`plot_uncertainty_bounds_component`	plots mean value of the NetworkSet with +- uncertainty bounds
`plot_uncertainty_bounds_s_db`	this just calls
`set_wise_function`	calls a function on a specific property of the networks in
`uncertainty_ntwk_triplet`	returns a 3-tuple of Network objects which contain the

skrf.networkSet.NetworkSet.__init__

`NetworkSet.__init__`(*ntwk_set*, *name=None*)

Initializer for NetworkSet

Parameters **ntwk_set** : list of `Network` objects

the set of `Network` objects

name : string

the name of the NetworkSet, given to the Networks returned from properties of this class.

skrf.networkSet.NetworkSet.element_wise_method

`NetworkSet.element_wise_method`(*network_method_name*, **args*, ***kwargs*)

calls a given method of each element and returns the result as a new NetworkSet if the output is a Network.

skrf.networkSet.NetworkSet.plot_uncertainty_bounds_component

`NetworkSet.plot_uncertainty_bounds_component`(*attribute*, *m=0*, *n=0*, *type='shade'*, *n_deviations=3*, *alpha=0.3*, *color_error=None*, *markevery_error=20*, *ax=None*, *ppf=None*, *kwargs_error={}*, **args*, ***kwargs*)

plots mean value of the NetworkSet with +- uncertainty bounds in an Network's attribute. This is designed to represent uncertainty in a scalar component of the s-parameter. for example ploting the uncertainty in the magnitude would be expressed by,

mean(abs(s)) +- std(abs(s))

the order of mean and abs is important.

takes: attribute: attribute of Network type to analyze [string] m: first index of attribute matrix [int] n: second index of attribute matrix [int] type: ['shade' | 'bar'], type of plot to draw n_deviations: number of std deviations to plot as bounds [number] alpha: passed to matplotlib.fill_between() command. [number, 0-1] color_error: color of the +- std dev fill shading markevery_error: if type=='bar', this controls frequency

of error bars

ax: Axes to plot on ppf: post processing function. a function applied to the

upper and low

***args,**kwargs: passed to Network.plot_s_re command used** to plot mean response

kwargs_error: dictionary of kwargs to pass to the fill_between or errorbar plot command depending on value of type.

returns: None

Note: for phase uncertainty you probably want s_deg_unwrap, or similar. uncerainty for wrapped phase blows up at +-pi.

skrf.networkSet.NetworkSet.plot_uncertainty_bounds_s_db

`NetworkSet.plot_uncertainty_bounds_s_db(*args, **kwargs)`

this just calls plot_uncertainty_bounds(attribute= 's_mag',*args,**kwargs)

see plot_uncertainty_bounds for help

skrf.networkSet.NetworkSet.set_wise_function

`NetworkSet.set_wise_function(func, a_property, *args, **kwargs)`

calls a function on a specific property of the networks in this NetworkSet.

example: my_ntwk_set.set_wise_func(mean,'s')

skrf.networkSet.NetworkSet.uncertainty_ntwk_triplet

`NetworkSet.uncertainty_ntwk_triplet(attribute, n_deviations=3)`

returns a 3-tuple of Network objects which contain the mean, upper_bound, and lower_bound for the given Network attribute.

Used to save and plot uncertainty information data

3.2.3 frequency (`skrf.frequency`)

Provides a frequency object and related functions.

Most of the functionality is provided as methods and properties of the `Frequency` Class.

Frequency Class

`Frequency`(start, stop, npoints[, unit, ...])	A frequency band.

skrf.frequency.Frequency

class `skrf.frequency.Frequency(start, stop, npoints, unit='hz', sweep_type='lin')`

A frequency band.

The frequency object provides a convenient way to work with and access a frequency band. It contains a fruequency vector as well as a frequency unit. This allows a frequency vector in a given unit to be available (`f_scaled`), as well as an absolute frquency axis in 'Hz' (`f`).

Attributes

`center`	Center frequency.
`f`	Frequency vector in Hz
`f_scaled`	Frequency vector in units of `unit`
`multiplier`	Multiplier for formating axis
`unit`	Unit of this frequency band.
`w`	Frequency vector in radians/s

skrf.frequency.Frequency.center

`Frequency.center`

Center frequency.

Returns **center** : number

the exact center frequency in units of `unit`

skrf.frequency.Frequency.f

`Frequency.f`

Frequency vector in Hz

Returns **f** : `numpy.ndarray`

The frequency vector in Hz

See Also:

`f_scaled` frequency vector in units of `unit`

`w` angular frequency vector in rad/s

skrf.frequency.Frequency.f_scaled

`Frequency.f_scaled`

Frequency vector in units of `unit`

Returns **f_scaled** : `numpy.ndarray`

A frequency vector in units of `unit`

See Also:

`f` frequency vector in Hz

`w` frequency vector in rad/s

skrf.frequency.Frequency.multiplier

`Frequency.multiplier`

Multiplier for formating axis

This accesses the internal dictionary *multiplier_dict* using the value of `unit`

Returns **multiplier** : number

multiplier for this Frequencies unit

skrf.frequency.Frequency.unit

`Frequency.`**`unit`**

Unit of this frequency band.

Possible strings for this attribute are: 'hz', 'khz', 'mhz', 'ghz', 'thz'

Setting this attribute is not case sensitive.

Returns **unit** : string

lower-case string representing the frequency units

skrf.frequency.Frequency.w

`Frequency.`**`w`**

Frequency vector in radians/s

The frequency vector in rad/s

Returns **w** : `numpy.ndarray`

The frequency vector in rad/s

See Also:

`f_scaled` frequency vector in units of `unit`

`f` frequency vector in Hz

Methods

`__init__`	Frequency initializer.
`from_f`	Alternative constructor of a Frequency object from a frequency
`labelXAxis`	Label the x-axis of a plot.

skrf.frequency.Frequency.__init__

`Frequency.`**`__init__`**(*start*, *stop*, *npoints*, *unit='hz'*, *sweep_type='lin'*)

Frequency initializer.

Creates a Frequency object from start/stop/npoints and a unit. Alternatively, the class method `from_f()` can be used to create a Frequency object from a frequency vector instead.

Parameters **start** : number

start frequency in units of *unit*

stop : number

stop frequency in units of *unit*

npoints : int

number of points in the band.

unit : ['hz','khz','mhz','ghz']

frequency unit of the band. This is used to create the attribute `f_scaled`. It is also used by the `Network` class for plots vs. frequency.

See Also:

`from_f` constructs a Frequency object from a frequency vector instead of start/stop/npoints.

Notes

The attribute unit sets the property freqMultiplier, which is used to scale the frequency when f_scaled is referenced.

Examples

```
>>> wr1p5band = Frequency(500,750,401, 'ghz')
```

skrf.frequency.Frequency.from_f

classmethod `Frequency.from_f`(*f*, **args*, ***kwargs*)

Alternative constructor of a Frequency object from a frequency vector,

Parameters **f** : array-like

frequency vector

***args, **kwargs** : arguments, keyword arguments

passed on to `__init__()`.

Returns **myfrequency** : `Frequency` object

the Frequency object

Examples

```
>>> f = np.linspace(75,100,101)
>>> rf.Frequency.from_f(f, unit='ghz')
```

skrf.frequency.Frequency.labelXAxis

`Frequency.labelXAxis`(*ax=None*)

Label the x-axis of a plot.

Sets the labels of a plot using `matplotlib.x_label()` with string containing the frequency unit.

Parameters **ax** : `matplotlib.Axes`, optional

Axes on which to label the plot, defaults what is returned by `matplotlib.gca()`

3.2.4 plotting (`skrf.plotting`)

This module provides general plotting functions.

Charts

`smith`([smithR, chart_type, ax])	plots the smith chart of a given radius
`plot_smith`(z[, smith_r, chart_type, ...])	plot complex data on smith chart
`plot_rectangular`(x, y[, x_label, y_label, ...])	plots rectangular data and optionally label axes.

Continued on next page

Table 3.14 – continued from previous page

plot_polar(theta, r[, x_label, y_label, ...])	plots polar data on a polar plot and optionally label axes.
plot_complex_rectangular(z[, x_label, ...])	plot complex data on the complex plane
plot_complex_polar(z[, x_label, y_label, ...])	plot complex data in polar format.

skrf.plotting.smith

skrf.plotting.**smith**(*smithR=1*, *chart_type='z'*, *ax=None*)

plots the smith chart of a given radius

Parameters **smithR** : number

radius of smith chart

chart_type : ['z','y']

Contour type. Possible values are

- *'z'* : lines of constant impedance
- *'y'* : lines of constant admittance

ax : matplotlib.axes object

existing axes to draw smith chart on

skrf.plotting.plot_smith

skrf.plotting.**plot_smith**(*z*, *smith_r=1*, *chart_type='z'*, *x_label='Real'*, *y_label='Imag'*, *title='Complex Plane'*, *show_legend=True*, *axis='equal'*, *ax=None*, *force_chart=False*, **args*, ***kwargs*)

plot complex data on smith chart

Parameters **z** : array-like, of complex data

data to plot

smith_r : number

radius of smith chart

chart_type : ['z','y']

Contour type for chart.

- *'z'* : lines of constant impedance
- *'y'* : lines of constant admittance

x_label : string

x-axis label

y_label : string

y-axis label

title : string

plot title

show_legend : Boolean

controls the drawing of the legend

axis_equal: Boolean :

sets axis to be equal increments (calls axis('equal'))

force_chart : Boolean

forces the re-drawing of smith chart

ax : `matplotlib.axes.AxesSubplot` object

axes to draw on

***args,**kwargs** : passed to pylab.plot

See Also:

`plot_rectangular` plots rectangular data

`plot_complex_rectangular` plot complex data on complex plane

`plot_polar` plot polar data

`plot_complex_polar` plot complex data on polar plane

`plot_smith` plot complex data on smith chart

skrf.plotting.plot_rectangular

`skrf.plotting.`**`plot_rectangular`**(*x*, *y*, *x_label=None*, *y_label=None*, *title=None*, *show_legend=True*, *axis='tight'*, *ax=None*, **args*, ***kwargs*)

plots rectangular data and optionally label axes.

Parameters **z** : array-like, of complex data

data to plot

x_label : string

x-axis label

y_label : string

y-axis label

title : string

plot title

show_legend : Boolean

controls the drawing of the legend

ax : `matplotlib.axes.AxesSubplot` object

axes to draw on

***args,**kwargs** : passed to pylab.plot

skrf.plotting.plot_polar

`skrf.plotting.`**`plot_polar`**(*theta*, *r*, *x_label=None*, *y_label=None*, *title=None*, *show_legend=True*, *axis_equal=False*, *ax=None*, **args*, ***kwargs*)

plots polar data on a polar plot and optionally label axes.

Parameters **theta** : array-like

data to plot

r : array-like

x_label : string

x-axis label

y_label : string

y-axis label

title : string

plot title

show_legend : Boolean

controls the drawing of the legend

ax : `matplotlib.axes.AxesSubplot` object

axes to draw on

***args,**kwargs** : passed to pylab.plot

See Also:

`plot_rectangular` plots rectangular data

`plot_complex_rectangular` plot complex data on complex plane

`plot_polar` plot polar data

`plot_complex_polar` plot complex data on polar plane

`plot_smith` plot complex data on smith chart

skrf.plotting.plot_complex_rectangular

`skrf.plotting.`**`plot_complex_rectangular`**(*z, x_label='Real', y_label='Imag', title='Complex Plane', show_legend=True, axis='equal', ax=None, *args, **kwargs*)

plot complex data on the complex plane

Parameters **z** : array-like, of complex data

data to plot

x_label : string

x-axis label

y_label : string

y-axis label

title : string

plot title

show_legend : Boolean

controls the drawing of the legend

ax : `matplotlib.axes.AxesSubplot` object

axes to draw on

***args,**kwargs** : passed to pylab.plot

See Also:

`plot_rectangular` plots rectangular data

`plot_complex_rectangular` plot complex data on complex plane

`plot_polar` plot polar data

`plot_complex_polar` plot complex data on polar plane

`plot_smith` plot complex data on smith chart

skrf.plotting.plot_complex_polar

`skrf.plotting.plot_complex_polar`(*z*, *x_label=None*, *y_label=None*, *title=None*, *show_legend=True*, *axis_equal=False*, *ax=None*, **args*, ***kwargs*)

plot complex data in polar format.

Parameters **z** : array-like, of complex data

data to plot

x_label : string

x-axis label

y_label : string

y-axis label

title : string

plot title

show_legend : Boolean

controls the drawing of the legend

ax : `matplotlib.axes.AxesSubplot` object

axes to draw on

***args,**kwargs** : passed to pylab.plot

See Also:

`plot_rectangular` plots rectangular data

`plot_complex_rectangular` plot complex data on complex plane

`plot_polar` plot polar data

`plot_complex_polar` plot complex data on polar plane

`plot_smith` plot complex data on smith chart

3.2.5 touchstone (`skrf.touchstone`)

This module provides a class to represent touchstone files.

This module was written by Werner Hoch.

touchstone Class

touchstone(filename)	class to read touchstone s-parameter files

skrf.touchstone.touchstone

class skrf.touchstone.**touchstone** (*filename*)

class to read touchstone s-parameter files The reference for writing this class is the draft of the Touchstone(R) File Format Specification Rev 2.0 http://www.eda-stds.org/ibis/adhoc/interconnect/touchstone_spec2_draft.pdf

Methods

__init__	
get_format	returns the file format string used for the given format.
get_noise_data	TODO: NIY
get_noise_names	TODO: NIY
get_sparameter_arrays	returns the sparameters as a tuple of arrays, where the first element is
get_sparameter_data	get the data of the sparameter with the given format.
get_sparameter_names	generate a list of column names for the s-parameter data
load_file	Load the touchstone file into the interal data structures

skrf.touchstone.touchstone.__init__

touchstone.**__init__** (*filename*)

skrf.touchstone.touchstone.get_format

touchstone.**get_format** (*format='ri'*)

returns the file format string used for the given format. This is usefull to get some informations.

skrf.touchstone.touchstone.get_noise_data

touchstone.**get_noise_data** ()

TODO: NIY

skrf.touchstone.touchstone.get_noise_names

touchstone.**get_noise_names** ()

TODO: NIY

skrf.touchstone.touchstone.get_sparameter_arrays

touchstone.**get_sparameter_arrays** ()

returns the sparameters as a tuple of arrays, where the first element is the frequency vector (in Hz) and the s-parameters are a 3d numpy array. The values of the sparameters are complex number. usage:

f,a = self.sgetparameter_arrays() s11 = a[:,0,0]

skrf.touchstone.touchstone.get_sparameter_data

touchstone.**get_sparameter_data** (*format='ri'*)

get the data of the sparameter with the given format. supported formats are:

orig: unmodified s-parameter data ri: data in real/imaginary ma: data in magnitude and angle (degree) db: data in log magnitute and angle (degree)

Returns a list of numpy.arrays

skrf.touchstone.touchstone.get_sparameter_names

`touchstone.`**`get_sparameter_names`**(*format='ri'*)

generate a list of column names for the s-parameter data The names are different for each format. posible format parameters:

ri, ma, db, orig (where orig refers to one of the three others)

returns a list of strings.

skrf.touchstone.touchstone.load_file

`touchstone.`**`load_file`**(*filename*)

Load the touchstone file into the interal data structures

contains touchstone class

3.2.6 convenience (`skrf.convenience`)

Holds pre-initialized objects's and functions that are general conveniences.

Functions

`save_all_figs`([dir, format])	Save all open Figures to disk.
`add_markers_to_lines`([ax, marker_list, ...])	
`legend_off`([ax])	turn off the legend for a given axes. if no axes is given then
`now_string`()	
`find_nearest`(array, value)	find nearest value in array.
`find_nearest_index`(array, value)	find nearest value in array.

skrf.convenience.save_all_figs

`skrf.convenience.`**`save_all_figs`**(*dir='./', format=['eps', 'pdf', 'png']*)

Save all open Figures to disk.

Parameters **dir** : string

path to save figures into

format : list of strings

the types of formats to save figures as. The elements of this list are passed to **:matplotlib:'savefig'**. This is a list so that you can save each figure in multiple formats.

skrf.convenience.add_markers_to_lines

`skrf.convenience.`**`add_markers_to_lines`**(*ax=None, marker_list=['o', 'D', 's', '+', 'x'], markevery=10*)

skrf.convenience.legend_off

`skrf.convenience.legend_off(ax=None)`
turn off the legend for a given axes. if no axes is given then it will use current axes.

skrf.convenience.now_string

`skrf.convenience.now_string()`

skrf.convenience.find_nearest

`skrf.convenience.find_nearest(array, value)`
find nearest value in array. taken from http://stackoverflow.com/questions/2566412/find-nearest-value-in-numpy-array

skrf.convenience.find_nearest_index

`skrf.convenience.find_nearest_index(array, value)`
find nearest value in array. taken from http://stackoverflow.com/questions/2566412/find-nearest-value-in-numpy-array

Pre-initialized Objects

`Frequency` Objects

These are predefined `Frequency` objects that correspond to standard waveguide bands. This information is taken from the VDI Application Note 1002 [18] . The naming convenction is f_wr# where '#' is the band number.

Object Name	Description
f_wr10	WR-10, 75-110 GHz
f_wr3	WR-3, 220-325 GHz
f_wr2p2	WR-2.2, 330-500 GHz
f_wr1p5	WR-1.5, 500-750 GHz
f_wr1	WR-1, 750-1100 GHz

`Media` Objects

These are predefined `Media` objects that represent Standardized transmission line media's. This information

Rectangular Waveguide Media's `RectangularWaveguide` Objects for standard bands.

Object Name	Description
wr10	WR-10, 75-110 GHz
wr3	WR-3, 220-325 GHz
wr2p2	WR-2.2, 330-500 GHz
wr1p5	WR-1.5, 500-750 GHz
wr1	WR-1, 750-1100 GHz

[18] VDI Application Note: VDI Waveguide Band Designations (VDI-1002) http://vadiodes.com/VDI/pdf/waveguidechart200908.pdf

References

3.2.7 mathFunctions (`skrf.mathFunctions`)

Provides commonly used mathematical functions.

Complex Component Conversion

`complex_2_reim`(z)	takes:
`complex_2_magnitude`(input)	returns the magnitude of a complex number.
`complex_2_db`(input)	returns the magnitude in dB of a complex number.
`complex_2_radian`(input)	returns the angle complex number in radians.
`complex_2_degree`(input)	returns the angle complex number in radians.
`complex_2_magnitude`(input)	returns the magnitude of a complex number.

skrf.mathFunctions.complex_2_reim

`skrf.mathFunctions.`**`complex_2_reim`**(*z*)

takes: input: complex number or array

return: real: real part of input imag: imaginary part of input

note: this just calls 'complex_components'

skrf.mathFunctions.complex_2_magnitude

`skrf.mathFunctions.`**`complex_2_magnitude`**(*input*)
returns the magnitude of a complex number.

skrf.mathFunctions.complex_2_db

`skrf.mathFunctions.`**`complex_2_db`**(*input*)
returns the magnitude in dB of a complex number.

returns: 20*log10(|z|)

where z is a complex number

skrf.mathFunctions.complex_2_radian

`skrf.mathFunctions.`**`complex_2_radian`**(*input*)
returns the angle complex number in radians.

skrf.mathFunctions.complex_2_degree

`skrf.mathFunctions.`**`complex_2_degree`**(*input*)
returns the angle complex number in radians.

skrf.mathFunctions.complex_2_magnitude

skrf.mathFunctions.**complex_2_magnitude**(*input*)
returns the magnitude of a complex number.

Phase Unwrapping

unwrap_rad(input)	unwraps a phase given in radians
sqrt_phase_unwrap(input)	takes the square root of a complex number with unwraped phase

skrf.mathFunctions.unwrap_rad

skrf.mathFunctions.**unwrap_rad**(*input*)
unwraps a phase given in radians

the normal numpy unwrap is not what you usually want for some reason

skrf.mathFunctions.sqrt_phase_unwrap

skrf.mathFunctions.**sqrt_phase_unwrap**(*input*)
takes the square root of a complex number with unwraped phase

this idea came from Lihan Chen

Unit Conversion

radian_2_degree(rad)	
degree_2_radian(deg)	
np_2_db(x)	converts a value in dB to neper's
db_2_np(x)	converts a value in nepers to dB

skrf.mathFunctions.radian_2_degree

skrf.mathFunctions.**radian_2_degree**(*rad*)

skrf.mathFunctions.degree_2_radian

skrf.mathFunctions.**degree_2_radian**(*deg*)

skrf.mathFunctions.np_2_db

skrf.mathFunctions.**np_2_db**(*x*)
converts a value in dB to neper's

skrf.mathFunctions.db_2_np

`skrf.mathFunctions.db_2_np(x)`

converts a value in nepers to dB

Scalar-Complex Conversion

These conversions are useful for wrapping other functions that dont support complex numbers.

complex2Scalar(input)	
scalar2Complex(input)	

skrf.mathFunctions.complex2Scalar

`skrf.mathFunctions.complex2Scalar(input)`

skrf.mathFunctions.scalar2Complex

`skrf.mathFunctions.scalar2Complex(input)`

Special Functions

dirac_delta(x)	the dirac function.
neuman(x)	neumans number
null(A[, eps])	calculates the null space of matrix A.

skrf.mathFunctions.dirac_delta

`skrf.mathFunctions.dirac_delta(x)`

the dirac function.

can take numpy arrays or numbers returns 1 or 0

skrf.mathFunctions.neuman

`skrf.mathFunctions.neuman(x)`

neumans number

2-dirac_delta(x)

skrf.mathFunctions.null

`skrf.mathFunctions.null(A, eps=1e-15)`

calculates the null space of matrix A. i found this on stack overflow.

3.2.8 tlineFunctions (`skrf.tlineFunctions`)

This module provides functions related to transmission line theory.

Impedance and Reflection Coefficient

These functions relate basic tranmission line quantities such as characteristic impedance, input impedance, reflection coefficient, etc. Each function has two names. One is a long-winded but readable name and the other is a short-hand variable-like names. Below is a table relating these two names with each other as well as common mathematical symbols.

Symbol	Variable Name	Long Name
Z_l	z_l	load_impedance
Z_{in}	z_in	input_impedance
Γ_0	Gamma_0	reflection_coefficient
Γ_{in}	Gamma_in	reflection_coefficient_at_theta
θ	theta	electrical_length

There may be a bit of confusion about the difference between the load impedance the input impedance. This is because the load impedance **is** the input impedance at the load. An illustration may provide some useful reference.

Below is a (bad) illustration of a section of uniform transmission line of characteristic impedance Z_0, and electrical length θ. The line is terminated on the right with some load impedance, Z_l. The input impedance Z_{in} and input reflection coefficient Γ_{in} are looking in towards the load from the distance θ from the load.

$$Z_0, \theta$$

$$\text{o===============o=}[Z_l]$$

$$\rightarrow \qquad\qquad\qquad\qquad \rightarrow$$

$$Z_{in}, \Gamma_{in} \qquad\qquad\qquad Z_l, \Gamma_0$$

So, to clarify the confusion,

$$Z_{in} = Z_l, \qquad \Gamma_{in} = \Gamma_l \text{ at } \theta = 0$$

Short names

`theta`(gamma, f, d[, deg])	Calculates the electrical length of a section of transmission line.
`zl_2_Gamma0`(z0, zl)	Returns the reflection coefficient for a given load impedance, and characteristic impedan
`Gamma0_2_zl`(z0, Gamma)	calculates the input impedance given a reflection coefficient and
`zl_2_zin`(z0, zl, theta)	input impedance of load impedance zl at a given electrical length,
`zl_2_Gamma_in`(z0, zl, theta)	
`Gamma0_2_Gamma_in`(Gamma0, theta)	reflection coefficient at a given electrical length.
`Gamma0_2_zin`(z0, Gamma0, theta)	calculates the input impedance at electrical length theta, given a

skrf.tlineFunctions.theta

`skrf.tlineFunctions.`**`theta`**(*gamma*, *f*, *d*, *deg=False*)

Calculates the electrical length of a section of transmission line.

$$\theta = \gamma(f) \cdot d$$

Parameters **gamma** : function

propagation constant function, which takes frequency in hz as a sole argument. see Notes.

l : number or array-like

length of line, in meters

f : number or array-like

frequency at which to calculate

deg : Boolean

return in degrees or not.

Returns **theta** : number or array-like

electrical length in radians or degrees, depending on value of deg.

See Also:

`electrical_length_2_distance` opposite conversion

Notes

the convention has been chosen that forward propagation is represented by the positive imaginary part of the value returned by the gamma function

skrf.tlineFunctions.zl_2_Gamma0

`skrf.tlineFunctions.zl_2_Gamma0(z0, zl)`

Returns the reflection coefficient for a given load impedance, and characteristic impedance.

For a transmission line of characteristic impedance Z_0 terminated with load impedance Z_l, the complex reflection coefficient is given by,

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

Parameters **z0** : number or array-like

characteristic impedance

zl : number or array-like

load impedance (aka input impedance)

Returns **gamma** : number or array-like

reflection coefficient

See Also:

`Gamma0_2_zl` reflection coefficient to load impedance

Notes

inputs are typecasted to 1D complex array

skrf.tlineFunctions.Gamma0_2_zl

`skrf.tlineFunctions.Gamma0_2_zl(z0, Gamma)`

calculates the input impedance given a reflection coefficient and characterisitc impedance

$$Z_0(\frac{1+\Gamma}{1-\Gamma})$$

Parameters **Gamma** : number or array-like

complex reflection coefficient

z0 : number or array-like

characteristic impedance

Returns **zin** : number or array-like

input impedance

skrf.tlineFunctions.zl_2_zin

`skrf.tlineFunctions.zl_2_zin(z0, zl, theta)`

input impedance of load impedance zl at a given electrical length, given characteristic impedance z0.

Parameters **z0** : characteristic impedance.

zl : load impedance

theta : electrical length of the line, (may be complex)

skrf.tlineFunctions.zl_2_Gamma_in

`skrf.tlineFunctions.zl_2_Gamma_in(z0, zl, theta)`

skrf.tlineFunctions.Gamma0_2_Gamma_in

`skrf.tlineFunctions.Gamma0_2_Gamma_in(Gamma0, theta)`

reflection coefficient at a given electrical length.

$$\Gamma_{in} = \Gamma_0 e^{-2j\theta}$$

Parameters **Gamma0** : number or array-like

reflection coefficient at theta=0

theta : number or array-like

electrical length, (may be complex)

Returns **Gamma_in** : number or array-like

input reflection coefficient

skrf.tlineFunctions.Gamma0_2_zin

`skrf.tlineFunctions.Gamma0_2_zin(z0, Gamma0, theta)`

calculates the input impedance at electrical length theta, given a reflection coefficient and characterisitc impedance of the medium Parameters ———-

z0 - characteristic impedance. Gamma: reflection coefficient theta: electrical length of the line, (may be complex)

returns zin: input impedance at theta

Long-names

distance_2_electrical_length(gamma, f, d[, deg])	Calculates the electrical length of a section of tran
electrical_length_2_distance(theta, gamma, f0)	Convert electrical length to a physical distance.
reflection_coefficient_at_theta(Gamma0, theta)	reflection coefficient at a given electrical length.
reflection_coefficient_2_input_impedance(z0, ...)	calculates the input impedance given a reflection c
reflection_coefficient_2_input_impedance_at_theta(z0, ...)	calculates the input impedance at electrical length
input_impedance_at_theta(z0, zl, theta)	input impedance of load impedance zl at a given el
load_impedance_2_reflection_coefficient(z0, zl)	Returns the reflection coefficient for a given load i
load_impedance_2_reflection_coefficient_at_theta(z0, ...)	

skrf.tlineFunctions.distance_2_electrical_length

skrf.tlineFunctions.**distance_2_electrical_length**(*gamma*, *f*, *d*, *deg=False*)

Calculates the electrical length of a section of transmission line.

$$\theta = \gamma(f) \cdot d$$

Parameters **gamma** : function

propagation constant function, which takes frequency in hz as a sole argument. see Notes.

l : number or array-like

length of line, in meters

f : number or array-like

frequency at which to calculate

deg : Boolean

return in degrees or not.

Returns **theta** : number or array-like

electrical length in radians or degrees, depending on value of deg.

See Also:

electrical_length_2_distance opposite conversion

Notes

the convention has been chosen that forward propagation is represented by the positive imaginary part of the value returned by the gamma function

skrf.tlineFunctions.electrical_length_2_distance

`skrf.tlineFunctions.electrical_length_2_distance(theta, gamma, f0, deg=True)`

Convert electrical length to a physical distance.

$$d = \frac{\theta}{\gamma(f_0)}$$

Parameters **theta** : number or array-like

electical length. units depend on *deg* option

gamma : function

propagation constant function, which takes frequency in hz as a sole argument. see Notes

f0 : number or array-like

frequency at which to calculate

deg : Boolean

return in degrees or not.

Returns **d: physical distance** :

See Also:

distance_2_electrical_length opposite conversion

Notes

the convention has been chosen that forward propagation is represented by the positive imaginary part of the value returned by the gamma function

skrf.tlineFunctions.reflection_coefficient_at_theta

`skrf.tlineFunctions.reflection_coefficient_at_theta(Gamma0, theta)`

reflection coefficient at a given electrical length.

$$\Gamma_{in} = \Gamma_0 e^{-2j\theta}$$

Parameters **Gamma0** : number or array-like

reflection coefficient at theta=0

theta : number or array-like

electrical length, (may be complex)

Returns **Gamma_in** : number or array-like

input reflection coefficient

skrf.tlineFunctions.reflection_coefficient_2_input_impedance

`skrf.tlineFunctions.`**`reflection_coefficient_2_input_impedance`**(*z0*, *Gamma*)

calculates the input impedance given a reflection coefficient and characterisitc impedance

$$Z_0(\frac{1+\Gamma}{1-\Gamma})$$

Parameters **Gamma** : number or array-like

complex reflection coefficient

z0 : number or array-like

characteristic impedance

Returns **zin** : number or array-like

input impedance

skrf.tlineFunctions.reflection_coefficient_2_input_impedance_at_theta

`skrf.tlineFunctions.`**`reflection_coefficient_2_input_impedance_at_theta`**(*z0*, *Gamma0*, *theta*)

calculates the input impedance at electrical length theta, given a reflection coefficient and characterisitc impedance of the medium Parameters ———-

z0 - characteristic impedance. Gamma: reflection coefficient theta: electrical length of the line, (may be complex)

returns zin: input impedance at theta

skrf.tlineFunctions.input_impedance_at_theta

`skrf.tlineFunctions.`**`input_impedance_at_theta`**(*z0*, *zl*, *theta*)

input impedance of load impedance zl at a given electrical length, given characteristic impedance z0.

Parameters **z0** : characteristic impedance.

zl : load impedance

theta : electrical length of the line, (may be complex)

skrf.tlineFunctions.load_impedance_2_reflection_coefficient

`skrf.tlineFunctions.`**`load_impedance_2_reflection_coefficient`**(*z0*, *zl*)

Returns the reflection coefficient for a given load impedance, and characteristic impedance.

For a transmission line of characteristic impedance Z_0 terminated with load impedance Z_l, the complex reflection coefficient is given by,

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

Parameters **z0** : number or array-like

characteristic impedance

zl : number or array-like

load impedance (aka input impedance)

Returns **gamma** : number or array-like

reflection coefficient

See Also:

`Gamma0_2_zl` reflection coefficient to load impedance

Notes

inputs are typecasted to 1D complex array

skrf.tlineFunctions.load_impedance_2_reflection_coefficient_at_theta

`skrf.tlineFunctions.`**`load_impedance_2_reflection_coefficient_at_theta`**(*z0*, *zl*, *theta*)

Distributed Circuit and Wave Quantities

`distributed_circuit_2_propagation_impedance`(...)	Converts distrubuted circuit values to wave quantities.
`propagation_impedance_2_distributed_circuit`(...)	Converts wave quantities to distrubuted circuit values.

skrf.tlineFunctions.distributed_circuit_2_propagation_impedance

`skrf.tlineFunctions.`**`distributed_circuit_2_propagation_impedance`**(*distributed_admittance*, *distributed_impedance*)

Converts distrubuted circuit values to wave quantities.

This converts complex distributed impedance and admittance to propagation constant and characteristic impedance. The relation is

$$Z_0 = \sqrt{\frac{Z'}{Y'}} \qquad \gamma = \sqrt{Z'Y'}$$

Parameters **distributed_admittance** : number, array-like

distributed admittance

distributed_impedance : number, array-like

distributed impedance

Returns **propagation_constant** : number, array-like

distributed impedance

characteristic_impedance : number, array-like

distributed impedance

See Also:

`propagation_impedance_2_distributed_circuit` opposite conversion

skrf.tlineFunctions.propagation_impedance_2_distributed_circuit

skrf.tlineFunctions.**propagation_impedance_2_distributed_circuit**(*propagation_constant, characteristic_impedance*)

Converts wave quantities to distrubuted circuit values.

Converts complex propagation constant and characteristic impedance to distributed impedance and admittance. The relation is,

$$Z^{'} = \gamma Z_0 \qquad Y^{'} = \frac{\gamma}{Z_0}$$

Parameters **propagation_constant** : number, array-like

distributed impedance

characteristic_impedance : number, array-like

distributed impedance

Returns **distributed_admittance** : number, array-like

distributed admittance

distributed_impedance : number, array-like

distributed impedance

See Also:

distributed_circuit_2_propagation_impedance opposite conversion

Transmission Line Physics

skin_depth(f, rho, mu_r)	the skin depth for a material.
surface_resistivity(f, rho, mu_r)	surface resistivity.

skrf.tlineFunctions.skin_depth

skrf.tlineFunctions.**skin_depth**(*f, rho, mu_r*)

the skin depth for a material.

see www.microwaves101.com for more info.

Parameters **f** : number or array-like

frequency, in Hz

rho : number of array-like

bulk resistivity of material, in ohm*m

mu_r : number or array-like

relative permiability of material

Returns **skin depth** : number or array-like

the skin depth, in m

skrf.tlineFunctions.surface_resistivity

`skrf.tlineFunctions.surface_resistivity(f, rho, mu_r)`

surface resistivity.

see www.microwaves101.com for more info.

Parameters **f** : number or array-like

frequency, in Hz

rho : number or array-like

bulk resistivity of material, in ohm*m

mu_r : number or array-like

relative permiability of material

Returns **surface resistivity: ohms/square** :

3.3 Packages

3.3.1 calibration (`skrf.calibration`)

This Package provides a high-level class representing a calibration instance, as well as calibration algorithms and supporting functions.

Both one and two port calibrations are supported. These calibration algorithms allow for redundant measurements, by using a simple least squares estimator to solve for the embedding network.

Modules

calibration (`skrf.calibration.calibration`)

Contains the Calibration class, and supporting functions

`Calibration`(measured, ideals[, type, ...])	An object to represent a VNA calibration instance.

Calibration Class

skrf.calibration.calibration.Calibration

class `skrf.calibration.calibration.Calibration(measured, ideals, type=None, is_reciprocal=False, name=None, sloppy_input=False, **kwargs)`

An object to represent a VNA calibration instance.

A Calibration object is used to perform a calibration given a set meaurements and ideals responses. It can run a calibration, store results, and apply the results to calculate corrected measurements.

Attributes

`Ts`	T-matricies used for de-embeding, a two-port calibration.
`coefs`	coefs: a dictionary holding the calibration coefficients
`error_ntwk`	a Network type which represents the error network being
`Calibration.frequency`	
`nports`	the number of ports in the calibration
`nstandards`	number of ideal/measurement pairs in calibration
`output_from_cal`	a dictionary holding all of the output from the calibration
`residual_ntwks`	returns a the residuals for each calibration standard in the
`residuals`	if calibration is overdeteremined, this holds the residuals
`type`	string representing what type of calibration is to be

skrf.calibration.calibration.Calibration.Ts

`Calibration.`**`Ts`**

T-matricies used for de-embeding, a two-port calibration.

skrf.calibration.calibration.Calibration.coefs

`Calibration.`**`coefs`**

coefs: a dictionary holding the calibration coefficients

for one port cal's 'directivity':e00 'reflection tracking':e01e10 'source match':e11

for 7-error term two port cal's TODO:

skrf.calibration.calibration.Calibration.error_ntwk

`Calibration.`**`error_ntwk`**

a Network type which represents the error network being calibrated out.

skrf.calibration.calibration.Calibration.nports

`Calibration.`**`nports`**

the number of ports in the calibration

skrf.calibration.calibration.Calibration.nstandards

`Calibration.`**`nstandards`**

number of ideal/measurement pairs in calibration

skrf.calibration.calibration.Calibration.output_from_cal

`Calibration.`**`output_from_cal`**

a dictionary holding all of the output from the calibration algorithm

skrf.calibration.calibration.Calibration.residual_ntwks

`Calibration.`**`residual_ntwks`**

returns a the residuals for each calibration standard in the form of a list of Network types.

these residuals are calculated in the 'calibrated domain', meaning they are

r = (E.inv ** m - i)

where, r: residual network, E: embedding network, m: measured network i: ideal network

This way the units of the residual networks are meaningful

note: the residuals are only calculated if they are not existent.

so, if you want to re-calculate the residual networks then you delete the property '_residual_ntwks'.

skrf.calibration.calibration.Calibration.residuals

`Calibration.residuals`

if calibration is overdeteremined, this holds the residuals in the form of a vector.

also available are the complex residuals in the form of skrf.Network's, see the property 'residual_ntwks'

from numpy.lstsq: residues: the sum of the residues; squared euclidean norm for each column vector in b (given ax=b)

skrf.calibration.calibration.Calibration.type

`Calibration.type`

string representing what type of calibration is to be performed. supported types at the moment are:

'one port': standard one-port cal. if more than 2 measurement/ideal pairs are given it will calculate the least squares solution.

'two port': two port calibration based on the error-box model

note: algorithms referenced by calibration_algorithm_dict, are stored in calibrationAlgorithms.py

Methods

`__init__`	Calibration initializer.
`apply_cal`	apply the current calibration to a measurement.
`apply_cal_to_all_in_dir`	convience function to apply calibration to an entire directory
`biased_error`	estimate of biased error for overdetermined calibration with
`func_per_standard`	
`mean_residuals`	
`plot_coefs_db`	plot magnitude of the error coeficient dictionary
`plot_errors`	plot calibration error metrics for an over-determined calibration.
`plot_residuals`	plots a component of the residual errors on the Calibration-plane.
`plot_residuals_db`	see plot_residuals
`plot_residuals_mag`	see plot_residuals
`plot_residuals_smith`	see plot_residuals
`plot_uncertainty_per_standard`	see uncertainty_per_standard
`run`	runs the calibration algorihtm.
`total_error`	estimate of total error for overdetermined calibration with
`unbiased_error`	estimate of unbiased error for overdetermined calibration with
`uncertainty_per_standard`	given that you have repeat-connections of single standard,

skrf.calibration.calibration.Calibration.__init__

`Calibration.__init__`(*measured*, *ideals*, *type=None*, *is_reciprocal=False*, *name=None*, *sloppy_input=False*, ***kwargs*)

Calibration initializer.

Parameters **measured** : list of `Network` objects

Raw measurements of the calibration standards. The order must align with the *ideals* parameter

ideals : list of `Network` objects

Predicted ideal response of the calibration standards. The order must align with *ideals* list

Other Parameters **type** : string

the calibration algorithm. If *None*, the class will inspect number of ports on first *measured* Network and choose either *'one port'* or *'two port'*. See **Notes_** section for more infor

is_reciprocal : Boolean

enables the reciprocity assumption on the calculation of the error_network, which is only relevant for one-port calibrations.

switch_terms : tuple of `Network` objects

The two measured switch terms in the order (forward, reverse). This is only applicable in two-port calibrations. See Roger Mark's paper on switch terms [19] for explanation of what they are.

name: string :

the name of calibration, just for your convenience [None].

sloppy_input : Boolean.

Allows ideals and measured lists to be 'aligned' based on the network names

****kwargs** : key-word arguments

passed to the calibration algorithm, defined by *type*

Notes

All calibration algorithms are in stored in `skrf.calibration.calibrationAlgorithms` , refer to that file for documentation on the algorithms themselves. The Calibration class accesses those functions through the attribute *'calibration_algorihtm_dict'*.

References

Examples

See the *Calibration* tutorial, or the examples sections for *One-Port Calibration* and *Two-Port Calibration*

skrf.calibration.calibration.Calibration.apply_cal

`Calibration.apply_cal(input_ntwk)`

apply the current calibration to a measurement.

takes:

input_ntwk: the measurement to apply the calibration to, a Network type.

returns: caled: the calibrated measurement, a Network type.

[19] Marks, Roger B.; , "Formulations of the Basic Vector Network Analyzer Error Model including Switch-Terms," ARFTG Conference Digest-Fall, 50th , vol.32, no., pp.115-126, Dec. 1997. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4119948&isnumber=4119931

skrf.calibration.calibration.Calibration.apply_cal_to_all_in_dir

`Calibration.apply_cal_to_all_in_dir` (*dir*, *contains=None*, *f_unit='ghz'*)

convience function to apply calibration to an entire directory of measurements, and return a dictionary of the calibrated results, optionally the user can 'grep' the direction by using the contains switch.

takes: dir: directory of measurements (string) contains: will only load measurements who's filename contains

this string.

f_unit: frequency unit, to use for all networks. see frequency.Frequency.unit for info.

returns:

ntwkDict: a dictionary of calibrated measurements, the keys are the filenames.

skrf.calibration.calibration.Calibration.biased_error

`Calibration.biased_error` (*std_names=None*)

estimate of biased error for overdetermined calibration with multiple connections of each standard

takes:

std_names: list of strings to uniquely identify each standard.*

returns:

systematic error: skrf.Network type who's .s_mag is proportional to the systematic error metric

note:

mathematically, this is mean_s(**|mean_c(r)|**)

where: r: complex residual errors mean_c: complex mean taken accross connection mean_s: complex mean taken accross standard

skrf.calibration.calibration.Calibration.func_per_standard

`Calibration.func_per_standard` (*func*, *attribute='s'*, *std_names=None*)

skrf.calibration.calibration.Calibration.mean_residuals

`Calibration.mean_residuals` ()

skrf.calibration.calibration.Calibration.plot_coefs_db

`Calibration.plot_coefs_db` (*ax=None*, *show_legend=True*, ***kwargs*)

plot magnitude of the error coeficient dictionary

skrf.calibration.calibration.Calibration.plot_errors

`Calibration.plot_errors` (*std_names=None*, **args*, ***kwargs*)

plot calibration error metrics for an over-determined calibration.

see biased_error, unbiased_error, and total_error for more info

skrf.calibration.calibration.Calibration.plot_residuals

`Calibration.plot_residuals` (*attribute*, **args*, ***kwargs*)

plots a component of the residual errors on the Calibration-plane.

takes:

attribute: name of ploting method of Network class to call

possible options are: 'mag', 'db', 'smith', 'deg', etc

*args,**kwargs: passed to **plot_s_**'atttribute'()

note: the residuals are calculated by:

(self.apply_cal(self.measured[k])-self.ideals[k])

skrf.calibration.calibration.Calibration.plot_residuals_db

`Calibration.plot_residuals_db(*args, **kwargs)`

see plot_residuals

skrf.calibration.calibration.Calibration.plot_residuals_mag

`Calibration.plot_residuals_mag(*args, **kwargs)`

see plot_residuals

skrf.calibration.calibration.Calibration.plot_residuals_smith

`Calibration.plot_residuals_smith(*args, **kwargs)`

see plot_residuals

skrf.calibration.calibration.Calibration.plot_uncertainty_per_standard

`Calibration.plot_uncertainty_per_standard(*args, **kwargs)`

see uncertainty_per_standard

skrf.calibration.calibration.Calibration.run

`Calibration.run()`

runs the calibration algorihtm.

this is automatically called the first time any dependent property is referenced (like error_ntwk), but only the first time. if you change something and want to re-run the calibration

use this.

skrf.calibration.calibration.Calibration.total_error

`Calibration.total_error(std_names=None)`

estimate of total error for overdetermined calibration with multiple connections of each standard. This is the combined effects of both biased and un-biased errors

takes:

std_names: list of strings to uniquely identify each standard.*

returns:

composit error: skrf.Network type who's .s_mag is proportional to the composit error metric

note:

mathematically, this is std_cs(r)

where: r: complex residual errors std_cs: standard deviation taken accross connections

and standards

skrf.calibration.calibration.Calibration.unbiased_error

`Calibration.unbiased_error(std_names=None)`

estimate of unbiased error for overdetermined calibration with multiple connections of each standard

takes:

std_names: list of strings to uniquely identify each standard.*

returns:

stochastic error: skrf.Network type who's .s_mag is proportional to the stochastic error metric

see also: uncertainty_per_standard, for this a measure of unbiased errors for each standard

note:

mathematically, this is mean_s(std_c(r))

where: r: complex residual errors std_c: standard deviation taken accross connections mean_s: complex mean taken accross standards

skrf.calibration.calibration.Calibration.uncertainty_per_standard

`Calibration.uncertainty_per_standard(std_names=None, attribute='s')`

given that you have repeat-connections of single standard, this calculates the complex standard deviation (distance) for each standard in the calibration across connection #.

takes:

std_names: list of strings to uniquely identify each standard.*

attribute: string passed to func_on_networks to calculate std deviation on a component if desired. ['s']

returns: list of skrf.Networks, whose magnitude of s-parameters is proportional to the standard deviation for that standard

***example:**

if your calibration had ideals named like: 'short 1', 'short 2', 'open 1', 'open 2', etc.

you would pass this mycal.uncertainty_per_standard(['short','open','match'])

calibrationAlgorithms (`skrf.calibration.calibrationAlgorithms`)

Contains calibrations algorithms and related functions, which are used in the `Calibration` class.

`one_port`(measured, ideals)	Standard algorithm for a one port calibration.
`one_port_nls`(measured, ideals)	one port non-linear least squares.
`two_port`(measured, ideals[, switch_terms])	Two port calibration based on the 8-term error model.
`parameterized_self_calibration`(measured, ideals)	An iterative, general self-calibration routine.
`parameterized_self_calibration_nls`(measured, ...)	An iterative, general self-calibration routine.

Calibration Algorithms

skrf.calibration.calibrationAlgorithms.one_port

`skrf.calibration.calibrationAlgorithms.one_port(measured, ideals)`

Standard algorithm for a one port calibration.

If more than three standards are supplied then a least square algorithm is applied.

Parameters **measured** : list of `Network` objects or numpy.ndarray

a list of the measured reflection coefficients. The elements of the list can either a kxnxn numpy.ndarray, representing a s-matrix, or list of 1-port `Network` objects.

ideals : list of `Network` objects or numpy.ndarray

a list of the ideal reflection coefficients. The elements of the list can either a kxnxn numpy.ndarray, representing a s-matrix, or list of 1-port `Network` objects.

Returns **output** : a dictionary

output information from the calibration, the keys are

- 'error coeffcients': dictionary containing standard error coefficients
- 'residuals': a matrix of residuals from the least squared calculation. see numpy.linalg.lstsq() for more info

See Also:

`one_port_nls` for a non-linear least square implementation

Notes

uses numpy.linalg.lstsq() for least squares calculation

skrf.calibration.calibrationAlgorithms.one_port_nls

`skrf.calibration.calibrationAlgorithms.`**`one_port_nls`**`(`*measured*, *ideals*`)`

one port non-linear least squares.

Parameters **measured** : list of `Network` objects or numpy.ndarray

a list of the measured reflection coefficients. The elements of the list can either a kxnxn numpy.ndarray, representing a s-matrix, or list of 1-port `Network` objects.

ideals : list of `Network` objects or numpy.ndarray

a list of the ideal reflection coefficients. The elements of the list can either a kxnxn numpy.ndarray, representing a s-matrix, or list of 1-port `Network` objects.

Returns **output** : a dictionary

a dictionary containing the following keys:

- 'error coeffcients': dictionary containing standard error coefficients
- 'residuals': a matrix of residuals from the least squared calculation. see numpy.linalg.lstsq() for more info
- 'cov_x': covariance matrix

Notes

Uses `scipy.optmize.leastsq()` for non-linear least squares calculation

skrf.calibration.calibrationAlgorithms.two_port

`skrf.calibration.calibrationAlgorithms.two_port(measured, ideals, switch_terms=None)`

Two port calibration based on the 8-term error model.

Takes two ordered lists of measured and ideal responses. Optionally, switch terms [R5] can be taken into account by passing a tuple containing the forward and reverse switch terms as 1-port Networks. This algorithm is based on the work in [R6] .

Parameters **measured** : list of 2-port `Network` objects

Raw measurements of the calibration standards. The order must align with the *ideals* parameter

ideals : list of 2-port `Network` objects

Predicted ideal response of the calibration standards. The order must align with *ideals* list measured: ordered list of measured networks. list elements

switch_terms : tuple of `Network` objects

The two measured switch terms in the order (forward, reverse). This is only applicable in two-port calibrations. See Roger Mark's paper on switch terms [R5] for explanation of what they are.

Returns **output** : a dictionary

output information, contains the following keys: * 'error coefficients': * 'error vector': * 'residuals':

Notes

support for gathering switch terms on HP8510C is in `skrf.virtualInstruments.vna`

References

[R5], [R6]

skrf.calibration.calibrationAlgorithms.parameterized_self_calibration

`skrf.calibration.calibrationAlgorithms.parameterized_self_calibration(measured, ideals, showProgress=True, **kwargs)`

An iterative, general self-calibration routine.

A self calibration routine based off of residual error minimization which can take any mixture of parameterized standards.

Parameters **measured** : list of `Network` objects

a list of the measured networks

ideals : list of `ParametricStandard` objects

a list of the ideal networks

showProgress : Boolean

turn printing progress on/off

**kwargs : key-word arguments

passed to minimization algorithm (scipy.optimize.fmin)

Returns **output** : a dictionary

a dictionary containing the following keys:

- 'error_coefficients' : dictionary of error coefficients
- 'residuals': residual matrix (shape depends on #stds)
- 'parameter_vector_final': final results for parameter vector
- **'mean_residual_list': the mean, magnitude of the residuals at each** iteration of calibration. this is the variable being minimized.

See Also:

parametricStandard sub-module for more info on them

parameterized_self_calibration_nls similar algorithm, but uses a non-linear least-squares estimator

skrf.calibration.calibrationAlgorithms.parameterized_self_calibration_nls

skrf.calibration.calibrationAlgorithms.**parameterized_self_calibration_nls**(*measured*, *ideals_ps*, *showProgress=True*, ***kwargs*)

An iterative, general self-calibration routine.

A self calibration routine based off of residual error minimization which can take any mixture of parameterized standards. Uses a non-linear least squares estimator to calculate the residuals.

Parameters **measured** : list of `Network` objects

a list of the measured networks

ideals : list of `Network` objects

a list of the ideal networks

showProgress : Boolean

turn printing progress on/off

****kwargs** : key-word arguments

passed to minimization algorithm (scipy.optimize.fmin)

Returns **output** : a dictionary

a dictionary containing the following keys:

- 'error_coefficients' : dictionary of error coefficients
- 'residuals': residual matrix (shape depends on #stds)
- 'parameter_vector_final': final results for parameter vector
- **'mean_residual_list': the mean, magnitude of the residuals at each** iteration of calibration. this is the variable being minimized.

See Also:

parametricStandard sub-module for more info on them

parameterized_self_calibration_nls similar algorithm, but uses a non-linear least-squares estimator

unterminate_switch_terms(two_port, gamma_f, ...)	unterminates switch terms from raw measurements.
abc_2_coefs_dict(abc)	converts an abc ndarry to a dictionarry containing the error
eight_term_2_one_port_coefs(coefs)	

Supporting Functions

skrf.calibration.calibrationAlgorithms.unterminate_switch_terms

skrf.calibration.calibrationAlgorithms.**unterminate_switch_terms**(*two_port*, *gamma_f*, *gamma_r*)

unterminates switch terms from raw measurements.

takes: two_port: the raw measurement, a 2-port Network type. gamma_f: the measured forward switch term, a 1-port Network type gamma_r: the measured reverse switch term, a 1-port Network type

returns: un-terminated measurement, a 2-port Network type

see: 'Formulations of the Basic Vector Network Analyzer Error Model including Switch Terms' by Roger B. Marks

skrf.calibration.calibrationAlgorithms.abc_2_coefs_dict

skrf.calibration.calibrationAlgorithms.**abc_2_coefs_dict**(*abc*)

converts an abc ndarry to a dictionarry containing the error coefficients.

takes:

abc [Nx3 numpy.ndarray, which holds the complex calibration]

coefficients. the components of abc are a[:] = abc[:,0] b[:] = abc[:,1] c[:] = abc[:,2],

a, b and c are related to the error network by a = det(e) = e01*e10 - e00*e11 b = e00 c = e11

returns:

coefsDict: dictionary containing the following 'directivity':e00 'reflection tracking':e01e10 'source match':e11

note: e00 = directivity error e10e01 = reflection tracking error e11 = source match error

skrf.calibration.calibrationAlgorithms.eight_term_2_one_port_coefs

skrf.calibration.calibrationAlgorithms.**eight_term_2_one_port_coefs**(*coefs*)

calibrationFunctions (skrf.calibration.calibrationFunctions)

Functions which operate on or pertain to Calibration Objects

cartesian_product_calibration_set(ideals, ...)	This function is used for calculating calibration uncertainty due to un-b

skrf.calibration.calibrationFunctions.cartesian_product_calibration_set

`skrf.calibration.calibrationFunctions.cartesian_product_calibration_set`(*ideals*, *measured*, **args*, ***kwargs*)

This function is used for calculating calibration uncertainty due to un-biased, non-systematic errors.

It creates an ensemble of calibration instances. the set of measurement lists used in the ensemble is the Cartesian Product of all instances of each measured standard.

The idea is that if you have multiple measurements of each standard, then the multiple calibrations can be made by generating all possible combinations of measurements. This produces a conceptually simple, but computationally expensive way to estimate calibration uncertainty.

takes: ideals: list of ideal Networks measured: list of measured Networks *args,**kwargs: passed to Calibration initializer

returns: cal_ensemble: a list of Calibration instances.

you can use the output to estimate uncertainty by calibrating a DUT with all calibrations, and then running statistics on the resultant set of Networks. for example

import skrf as rf # define you lists of ideals and measured networks cal_ensemble = rf.cartesian_product_calibration_ensemble(ideals, measured) dut = rf.Network('dut.s1p') network_ensemble = [cal.apply_cal(dut) for cal in cal_ensemble] rf.plot_uncertainty_mag(network_ensemble) [network.plot_s_smith() for network in network_ensemble]

Classes

`Calibration`(measured, ideals[, type, ...])	An object to represent a VNA calibration instance.

skrf.calibration.calibration.Calibration

class `skrf.calibration.calibration.Calibration`(*measured*, *ideals*, *type=None*, *is_reciprocal=False*, *name=None*, *sloppy_input=False*, ***kwargs*)

An object to represent a VNA calibration instance.

A Calibration object is used to perform a calibration given a set meaurements and ideals responses. It can run a calibration, store results, and apply the results to calculate corrected measurements.

Attributes

`Ts`	T-matricies used for de-embeding, a two-port calibration.
`coefs`	coefs: a dictionary holding the calibration coefficients
`error_ntwk`	a Network type which represents the error network being
`Calibration.frequency`	
`nports`	the number of ports in the calibration
`nstandards`	number of ideal/measurement pairs in calibration
`output_from_cal`	a dictionary holding all of the output from the calibration
`residual_ntwks`	returns a the residuals for each calibration standard in the
`residuals`	if calibration is overdeteremined, this holds the residuals

Continued on next page

Table 3.34 – continued from previous page

type	string representing what type of calibration is to be

skrf.calibration.calibration.Calibration.Ts

`Calibration.Ts`

T-matricies used for de-embeding, a two-port calibration.

skrf.calibration.calibration.Calibration.coefs

`Calibration.coefs`

coefs: a dictionary holding the calibration coefficients

for one port cal's 'directivity':e00 'reflection tracking':e01e10 'source match':e11

for 7-error term two port cal's TODO:

skrf.calibration.calibration.Calibration.error_ntwk

`Calibration.error_ntwk`

a Network type which represents the error network being calibrated out.

skrf.calibration.calibration.Calibration.nports

`Calibration.nports`

the number of ports in the calibration

skrf.calibration.calibration.Calibration.nstandards

`Calibration.nstandards`

number of ideal/measurement pairs in calibration

skrf.calibration.calibration.Calibration.output_from_cal

`Calibration.output_from_cal`

a dictionary holding all of the output from the calibration algorithm

skrf.calibration.calibration.Calibration.residual_ntwks

`Calibration.residual_ntwks`

returns a the residuals for each calibration standard in the form of a list of Network types.

these residuals are calculated in the 'calibrated domain', meaning they are

r = (E.inv ** m - i)

where, r: residual network, E: embedding network, m: measured network i: ideal network

This way the units of the residual networks are meaningful

note: the residuals are only calculated if they are not existent.

so, if you want to re-calculate the residual networks then you delete the property '_residual_ntwks'.

skrf.calibration.calibration.Calibration.residuals

`Calibration.residuals`

if calibration is overdeteremined, this holds the residuals in the form of a vector.

also available are the complex residuals in the form of skrf.Network's, see the property 'residual_ntwks'

from numpy.lstsq: residues: the sum of the residues; squared euclidean norm for each column vector in b (given ax=b)

skrf.calibration.calibration.Calibration.type

`Calibration.type`

string representing what type of calibration is to be performed. supported types at the moment are:

'one port': standard one-port cal. if more than 2 measurement/ideal pairs are given it will calculate the least squares solution.

'two port': two port calibration based on the error-box model

note: algorithms referenced by calibration_algorithm_dict, are stored in calibrationAlgorithms.py

Methods

`__init__`	Calibration initializer.
`apply_cal`	apply the current calibration to a measurement.
`apply_cal_to_all_in_dir`	convience function to apply calibration to an entire directory
`biased_error`	estimate of biased error for overdetermined calibration with
`func_per_standard`	
`mean_residuals`	
`plot_coefs_db`	plot magnitude of the error coeficient dictionary
`plot_errors`	plot calibration error metrics for an over-determined calibration.
`plot_residuals`	plots a component of the residual errors on the Calibration-plane.
`plot_residuals_db`	see plot_residuals
`plot_residuals_mag`	see plot_residuals
`plot_residuals_smith`	see plot_residuals
`plot_uncertainty_per_standard`	see uncertainty_per_standard
`run`	runs the calibration algorihtm.
`total_error`	estimate of total error for overdetermined calibration with
`unbiased_error`	estimate of unbiased error for overdetermined calibration with
`uncertainty_per_standard`	given that you have repeat-connections of single standard,

skrf.calibration.calibration.Calibration.__init__

`Calibration.__init__`(*measured*, *ideals*, *type=None*, *is_reciprocal=False*, *name=None*, *sloppy_input=False*, ***kwargs*)

Calibration initializer.

Parameters **measured** : list of `Network` objects

Raw measurements of the calibration standards. The order must align with the *ideals* parameter

ideals : list of `Network` objects

Predicted ideal response of the calibration standards. The order must align with *ideals* list

Other Parameters **type** : string

the calibration algorithm. If *None*, the class will inspect number of ports on first *measured* Network and choose either *'one port'* or *'two port'*. See **Notes_** section for more infor

is_reciprocal : Boolean

enables the reciprocity assumption on the calculation of the error_network, which is only relevant for one-port calibrations.

switch_terms : tuple of `Network` objects

The two measured switch terms in the order (forward, reverse). This is only applicable in two-port calibrations. See Roger Mark's paper on switch terms [20] for explanation of what they are.

name: string :

the name of calibration, just for your convenience [None].

sloppy_input : Boolean.

Allows ideals and measured lists to be 'aligned' based on the network names

****kwargs** : key-word arguments

passed to the calibration algorithm, defined by *type*

Notes

All calibration algorithms are in stored in `skrf.calibration.calibrationAlgorithms`, refer to that file for documentation on the algorithms themselves. The Calibration class accesses those functions through the attribute *'calibration_algorihtm_dict'*.

References

Examples

See the *Calibration* tutorial, or the examples sections for *One-Port Calibration* and *Two-Port Calibration*

skrf.calibration.calibration.Calibration.apply_cal

`Calibration.apply_cal(input_ntwk)`

apply the current calibration to a measurement.

takes:

input_ntwk: the measurement to apply the calibration to, a Network type.

returns: caled: the calibrated measurement, a Network type.

skrf.calibration.calibration.Calibration.apply_cal_to_all_in_dir

`Calibration.apply_cal_to_all_in_dir(dir, contains=None, f_unit='ghz')`

convience function to apply calibration to an entire directory of measurements, and return a dictionary of the calibrated results, optionally the user can 'grep' the direction by using the contains switch.

takes: dir: directory of measurements (string) contains: will only load measurements who's filename contains

[20] Marks, Roger B.; , "Formulations of the Basic Vector Network Analyzer Error Model including Switch-Terms," ARFTG Conference Digest-Fall, 50th , vol.32, no., pp.115-126, Dec. 1997. URL: http://ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=4119948&isnumber=4119931

this string.

f_unit: frequency unit, to use for all networks. see frequency.Frequency.unit for info.

returns:

ntwkDict: a dictionary of calibrated measurements, the keys are the filenames.

skrf.calibration.calibration.Calibration.biased_error

`Calibration.`**`biased_error`**`(`*std_names=None*`)`

estimate of biased error for overdetermined calibration with multiple connections of each standard

takes:

std_names: list of strings to uniquely identify each standard.*

returns:

systematic error: skrf.Network type who's .s_mag is proportional to the systematic error metric

note:

mathematically, this is mean_s(**|mean_c(r)|**)

where: r: complex residual errors mean_c: complex mean taken accross connection mean_s: complex mean taken accross standard

skrf.calibration.calibration.Calibration.func_per_standard

`Calibration.`**`func_per_standard`**`(`*func*, *attribute='s'*, *std_names=None*`)`

skrf.calibration.calibration.Calibration.mean_residuals

`Calibration.`**`mean_residuals`**`()`

skrf.calibration.calibration.Calibration.plot_coefs_db

`Calibration.`**`plot_coefs_db`**`(`*ax=None*, *show_legend=True*, ***kwargs*`)`

plot magnitude of the error coeficient dictionary

skrf.calibration.calibration.Calibration.plot_errors

`Calibration.`**`plot_errors`**`(`*std_names=None*, **args*, ***kwargs*`)`

plot calibration error metrics for an over-determined calibration.

see biased_error, unbiased_error, and total_error for more info

skrf.calibration.calibration.Calibration.plot_residuals

`Calibration.`**`plot_residuals`**`(`*attribute*, **args*, ***kwargs*`)`

plots a component of the residual errors on the Calibration-plane.

takes:

attribute: name of ploting method of Network class to call

possible options are: 'mag', 'db', 'smith', 'deg', etc

*****args,**kwargs: passed to **plot_s_**'atttribute'()

note: the residuals are calculated by:

(self.apply_cal(self.measured[k])-self.ideals[k])

skrf.calibration.calibration.Calibration.plot_residuals_db

`Calibration.plot_residuals_db(*args, **kwargs)`

see plot_residuals

skrf.calibration.calibration.Calibration.plot_residuals_mag

`Calibration.plot_residuals_mag(*args, **kwargs)`

see plot_residuals

skrf.calibration.calibration.Calibration.plot_residuals_smith

`Calibration.plot_residuals_smith(*args, **kwargs)`

see plot_residuals

skrf.calibration.calibration.Calibration.plot_uncertainty_per_standard

`Calibration.plot_uncertainty_per_standard(*args, **kwargs)`

see uncertainty_per_standard

skrf.calibration.calibration.Calibration.run

`Calibration.run()`

runs the calibration algorihtm.

this is automatically called the first time any dependent property is referenced (like error_ntwk), but only the first time. if you change something and want to re-run the calibration

use this.

skrf.calibration.calibration.Calibration.total_error

`Calibration.total_error(std_names=None)`

estimate of total error for overdetermined calibration with multiple connections of each standard. This is the combined effects of both biased and un-biased errors

takes:

std_names: list of strings to uniquely identify each standard.*

returns:

composit error: skrf.Network type who's .s_mag is proportional to the composit error metric

note:

mathematically, this is std_cs(r)

where: r: complex residual errors std_cs: standard deviation taken accross connections

and standards

skrf.calibration.calibration.Calibration.unbiased_error

`Calibration.unbiased_error(std_names=None)`

estimate of unbiased error for overdetermined calibration with multiple connections of each standard

takes:

std_names: list of strings to uniquely identify each standard.*

returns:

stochastic error: skrf.Network type who's .s_mag is proportional to the stochastic error metric

see also: uncertainty_per_standard, for this a measure of unbiased errors for each standard

note:

mathematically, this is mean_s(std_c(r))

where: r: complex residual errors std_c: standard deviation taken accross connections mean_s: complex mean taken accross standards

skrf.calibration.calibration.Calibration.uncertainty_per_standard

`Calibration.`**`uncertainty_per_standard`**(*std_names=None*, *attribute='s'*)

given that you have repeat-connections of single standard, this calculates the complex standard deviation (distance) for each standard in the calibration across connection #.

takes:

std_names: list of strings to uniquely identify each standard.*

attribute: string passed to func_on_networks to calculate std deviation on a component if desired. ['s']

returns: list of skrf.Networks, whose magnitude of s-parameters is proportional to the standard deviation for that standard

***example:**

if your calibration had ideals named like: 'short 1', 'short 2', 'open 1', 'open 2', etc.

you would pass this mycal.uncertainty_per_standard(['short','open','match'])

3.3.2 media (`skrf.media`)

This package provides objects representing transmission line mediums.

The `Media` object is the base-class that is inherited by specific transmission line instances, such as `Freespace`, or `RectangularWaveguide`. The `Media` object provides generic methods to produce `Network`'s for any transmision line medium, such as `line()` and `delay_short()`. These methods are inherited by the specific tranmission line classes, which interally define relevant quantities such as propagation constant, and characteristic impedance. This allows the specific transmission line mediums to produce networks without re-implementing methods for each specific media instance.

Network components specific to an given transmission line medium such as `cpw_short()` and `microstrip_bend()`, are implemented in those object

Media base-class

`Media`	The base-class for all transmission line mediums.

skrf.media.media.Media

class `skrf.media.media.`**`Media`**(*frequency*, *propagation_constant*, *characteristic_impedance*, *z0=None*)

The base-class for all transmission line mediums.

The `Media` object provides generic methods to produce `Network`'s for any transmision line medium, such as `line()` and `delay_short()`.

The initializer for this class has flexible argument types. This allows for the important attributes of the `Media` object to be dynamic. For example, if a Media object's propagation constant is a function of some attribute of that object, say *conductor_width*, then the propagation constant will change when that attribute changes. See `__init__()` for details.

The network creation methods build off of each other. For example, the speicial load cases, suc as `short()` and `open()` call `load()` with given arguments for Gamma0, and the **delay_** and **shunt_** functions call `line()` and `shunt()` respectively. This minimizes re-implementation.

Most methods initialize the `Network` by calling `match()` to create a 'blank' `Network`, and then fill in the s-matrix.

Attributes

`characteristic_impedance`	Characterisitc impedance
`propagation_constant`	Propagation constant
`z0`	Port Impedance

skrf.media.media.Media.characteristic_impedance

`Media.`**`characteristic_impedance`**

Characterisitc impedance

The characteristic_impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the characterisitc impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **characteristic_impedance** : `numpy.ndarray`

skrf.media.media.Media.propagation_constant

`Media.`**`propagation_constant`**

Propagation constant

The propagation constant can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the propagation constant to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **propagation_constant** : `numpy.ndarray`

complex propagation constant for this media

Notes

***propagation_constant* must adhere to the following convention,**

- positive real(propagation_constant) = attenuation
- positive imag(propagation_constant) = forward propagation

skrf.media.media.Media.z0

`Media.`**`z0`**

Port Impedance

The port impedance is usually equal to the `characteristic_impedance`. Therefore, if the port impedance is *None* then this will return `characteristic_impedance`.

However, in some cases such as rectangular waveguide, the port impedance is traditionally set to 1 (normalized). In such a case this property may be used.

The Port Impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the Port Impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **port_impedance** : `numpy.ndarray`

the media's port impedance

Methods

`__init__`	The Media initializer.
`capacitor`	Capacitor
`delay_load`	Delayed load
`delay_open`	Delayed open transmission line
`delay_short`	Delayed Short
`electrical_length`	calculates the electrical length for a given distance, at
`guess_length_of_delay_short`	Guess physical length of a delay short.
`impedance_mismatch`	Two-port network for an impedance miss-match
`inductor`	Inductor
`line`	Matched transmission line of given length
`load`	Load of given reflection coefficient.
`match`	Perfect matched load ($\Gamma_0 = 0$).
`open`	Open ($\Gamma_0 = 1$)
`short`	Short ($\Gamma_0 = -1$)
`shunt`	Shunts a `Network`
`shunt_capacitor`	Shunted capacitor
`shunt_delay_load`	Shunted delayed load
`shunt_delay_open`	Shunted delayed open
`shunt_delay_short`	Shunted delayed short
`shunt_inductor`	Shunted inductor
`splitter`	Ideal, lossless n-way splitter.
`tee`	Ideal, lossless tee.
`theta_2_d`	Converts electrical length to physical distance.
`thru`	Matched transmission line of length 0.
`white_gaussian_polar`	Complex zero-mean gaussian white-noise network.

skrf.media.media.Media.__init__

`Media.`**`__init__`**(*frequency*, *propagation_constant*, *characteristic_impedance*, *z0=None*)

The Media initializer.

This initializer has flexible argument types. The parameters *propagation_constant*, *characterisitc_impedance* and *z0* can all be either static or dynamic. This is achieved by allowing those arguments to be either:

- functions which take no arguments or
- values (numbers or arrays)

In the case where the media's propagation constant may change after initialization, because you adjusted a parameter of the media, then passing the propagation_constant as a function allows it to change when the media's parameters do.

Parameters **frequency** : `Frequency` object frequency band of this transmission line medium

propagation_constant : number, array-like, or a function

propagation constant for the medium.

characteristic_impedance : number,array-like, or a function

characteristic impedance of transmission line medium.

z0 : number, array-like, or a function

the port impedance for media , IF its different from the characterisitc impedance of the transmission line medium (None) [a number]. if z0= None then will set to characterisitc_impedance

Notes

propagation_constant **must adhere to the following convention,**

- positive real(gamma) = attenuation
- positive imag(gamma) = forward propagation

the z0 parameter is needed in some cases. For example, the `RectangularWaveguide` is an example where you may need this, because the characteristic impedance is frequency dependent, but the touchstone's created by most VNA's have z0=1

skrf.media.media.Media.capacitor

`Media.capacitor(C, **kwargs)`

Capacitor

Parameters **C** : number, array

Capacitance, in Farads. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **capacitor** : `Network` object

a n-port capacitor

See Also:

`match` function called to create a 'blank' network

skrf.media.media.Media.delay_load

`Media.delay_load(Gamma0, d, unit='m', **kwargs)`

Delayed load

A load with reflection coefficient *Gamma0* at the end of a matched line of length *d*.

Parameters **Gamma0** : number, array-like

reflection coefficient of load (not in dB)

d : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_load** : `Network` object

a delayed load

See Also:

line creates the network for line

load creates the network for the load

Notes

This calls

`line(d,unit, **kwargs) ** load(Gamma0, **kwargs)`

Examples

```
>>> my_media.delay_load(-.5, 90, 'deg', z0=50)
```

skrf.media.media.Media.delay_open

`Media.delay_open(d, unit='m', **kwargs)`

Delayed open transmission line

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_open** : `Network` object

a delayed open

See Also:

delay_load delay_short just calls this function

skrf.media.media.Media.delay_short

`Media.delay_short(d, unit='m', **kwargs)`

Delayed Short

A transmission line of given length terminated with a short.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_short** : `Network` object

a delayed short

See Also:

delay_load delay_short just calls this function

skrf.media.media.Media.electrical_length

`Media.electrical_length(d, deg=False)`

calculates the electrical length for a given distance, at the center frequency.

Parameters **d: distance, in meters** :

deg: is d in deg?[Boolean]

Returns **theta: electrical length in radians or degrees,** :

depending on value of deg.

skrf.media.media.Media.guess_length_of_delay_short

`Media.guess_length_of_delay_short(aNtwk)`

Guess physical length of a delay short.

Unwraps the phase and determines the slope, which is then used in conjunction with `propagation_constant` to estimate the physical distance to the short.

Parameters **aNtwk** : `Network` object

(note: if this is a measurment it needs to be normalized to the reference plane)

skrf.media.media.Media.impedance_mismatch

`Media.impedance_mismatch(z1, z2, **kwargs)`

Two-port network for an impedance miss-match

Parameters **z1** : number, or array-like

complex impedance of port 1

z2 : number, or array-like

complex impedance of port 2

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **missmatch** : `Network` object

a 2-port network representing the impedance missmatch

See Also:

`match` called to create a 'blank' network

Notes

If z1 and z2 are arrays, they must be of same length as the `Media.frequency.npoints`

skrf.media.media.Media.inductor

`Media.inductor(L, **kwargs)`

Inductor

Parameters **L** : number, array

Inductance, in Henrys. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **inductor** : `Network` object

a n-port inductor

See Also:

`match` called to create a 'blank' network

skrf.media.media.Media.line

`Media.line(d, unit='m', **kwargs)`

Matched transmission line of given length

The units of *length* are interpreted according to the value of *unit*.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)

- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **line** : `Network` object

matched tranmission line of given length

Examples

```
>>> my_media.line(90, 'deg', z0=50)
```

skrf.media.media.Media.load

`Media.load(Gamma0, nports=1, **kwargs)`

Load of given reflection coefficient.

Parameters **Gamma0** : number, array-like

Reflection coefficient of load (linear, not in db). If its an array it must be of shape: kxnxn, where k is #frequency points in media, and n is *nports*

nports : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **load :class:'~skrf.network.Network' object** :

n-port load, where S = Gamma0*eye(...)

skrf.media.media.Media.match

`Media.match(nports=1, z0=None, **kwargs)`

Perfect matched load ($\Gamma_0 = 0$).

Parameters **nports** : int

number of ports

z0 : number, or array-like

characterisitc impedance. Default is None, in which case the Media's `z0` is used. This sets the resultant Network's `z0`.

****kwargs** : key word arguments

passed to `Network` initializer

Returns **match** : `Network` object

a n-port match

Examples

```
>>> my_match = my_media.match(2,z0 = 50, name='Super Awesome Match')
```

skrf.media.media.Media.open

Media.**open**(*nports=1*, ***kwargs*)

Open ($\Gamma_0 = 1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port open circuit

See Also:

match function called to create a 'blank' network

skrf.media.media.Media.short

Media.**short**(*nports=1*, ***kwargs*)

Short ($\Gamma_0 = -1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port short circuit

See Also:

match function called to create a 'blank' network

skrf.media.media.Media.shunt

Media.**shunt**(*ntwk*, ***kwargs*)

Shunts a `Network`

This creates a `tee()` and connects connects *ntwk* to port 1, and returns the result

Parameters **ntwk** : `Network` object

****kwargs** : keyword arguments

passed to `tee()`

Returns **shunted_ntwk** : `Network` object

a shunted a ntwk. The resultant shunted_ntwk will have (2 + ntwk.number_of_ports -1) ports.

skrf.media.media.Media.shunt_capacitor

`Media.shunt_capacitor(C, *args, **kwargs)`

Shunted capacitor

Parameters **C** : number, array-like

Capacitance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_capacitor** : `Network` object

shunted capcitor(2-port)

Notes

This calls:

```
shunt(capacitor(C,*args, **kwargs))
```

skrf.media.media.Media.shunt_delay_load

`Media.shunt_delay_load(*args, **kwargs)`

Shunted delayed load

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_load*

Returns **shunt_delay_load** : `Network` object

a shunted delayed load (2-port)

Notes

This calls:

```
shunt(delay_load(*args, **kwargs))
```

skrf.media.media.Media.shunt_delay_open

`Media.shunt_delay_open(*args, **kwargs)`

Shunted delayed open

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_open** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

```
shunt(delay_open(*args, **kwargs))
```

skrf.media.media.Media.shunt_delay_short

`Media.`**`shunt_delay_short`**`(*args, **kwargs)`

Shunted delayed short

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_load** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

```
shunt(delay_short(*args, **kwargs))
```

skrf.media.media.Media.shunt_inductor

`Media.`**`shunt_inductor`**`(L, *args, **kwargs)`

Shunted inductor

Parameters **L** : number, array-like

Inductance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_inductor** : `Network` object

shunted inductor(2-port)

Notes

This calls:

```
shunt(inductor(C,*args, **kwargs))
```

skrf.media.media.Media.splitter

`Media.`**`splitter`**`(nports, **kwargs)`

Ideal, lossless n-way splitter.

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a n-port splitter

See Also:

match called to create a 'blank' network

skrf.media.media.Media.tee

`Media.tee(**kwargs)`

Ideal, lossless tee. (3-port splitter)

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a 3-port splitter

See Also:

splitter this just calls splitter(3)

match called to create a 'blank' network

skrf.media.media.Media.theta_2_d

`Media.theta_2_d(theta, deg=True)`

Converts electrical length to physical distance.

The given electrical length is to be at the center frequency.

Parameters **theta** : number

electrical length, at band center (see deg for unit)

deg : Boolean

is theta in degrees?

Returns **d** : number

physical distance in meters

skrf.media.media.Media.thru

`Media.thru(**kwargs)`

Matched transmission line of length 0.

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **thru** : `Network` object

matched tranmission line of 0 length

See Also:

line this just calls line(0)

skrf.media.media.Media.white_gaussian_polar

`Media.white_gaussian_polar`(*phase_dev*, *mag_dev*, *n_ports=1*, ***kwargs*)

Complex zero-mean gaussian white-noise network.

Creates a network whose s-matrix is complex zero-mean gaussian white-noise, of given standard deviations for phase and magnitude components. This 'noise' network can be added to networks to simulate additive noise.

Parameters **phase_mag** : number

standard deviation of magnitude

phase_dev : number

standard deviation of phase

n_ports : int

number of ports.

****kwargs** : passed to `Network`

initializer

Returns **result** : `Network` object

a noise network

Transmission Line Classes

`DistributedCircuit`	Generic, distributed circuit TEM transmission line
`RectangularWaveguide`	Rectangular Waveguide medium.
`CPW`	Coplanar waveguide class
`Freespace`	Represents a plane-wave in a homogeneous freespace, defined by the space's relative permativity and

skrf.media.distributedCircuit.DistributedCircuit

class `skrf.media.distributedCircuit.DistributedCircuit`(*frequency*, *C*, *I*, *R*, *G*, **args*, ***kwargs*)

Generic, distributed circuit TEM transmission line

A TEM transmission line, defined in terms of distributed impedance and admittance values. A Distributed Circuit may be defined in terms of the following attributes,

Quantity	Symbol	Property
Distributed Capacitance	$C^{'}$	`C`
Distributed Inductance	$I^{'}$	`I`
Distributed Resistance	$R^{'}$	`R`
Distributed Conductance	$G^{'}$	`G`

From these, the following quantities may be calculated, which are functions of angular frequency (ω):

Quantity	Symbol	Property
Distributed Impedance	$Z^{'} = \omega R^{'} + j\omega I^{'}$	`Z`
Distributed Admittance	$Y^{'} = \omega G^{'} + j\omega C^{'}$	`Y`

from these we can calculate properties which define their wave behavior:

Quantity	Symbol	Method
Characteristic Impedance	$Z_0 = \sqrt{\frac{Z'}{Y'}}$	Z0()
Propagation Constant	$\gamma = \sqrt{Z'Y'}$	gamma()

Given the following definitions, the components of propagation constant are interpreted as follows:

$$+\Re e\{\gamma\} = \text{attenuation}$$
$$-\Im m\{\gamma\} = \text{forward propagation}$$

Attributes

Y	Distributed Admittance, $Y^{'}$
Z	Distributed Impedance, $Z^{'}$
characteristic_impedance	Characterisitc impedance
propagation_constant	Propagation constant
z0	Port Impedance

skrf.media.distributedCircuit.DistributedCircuit.Y

`DistributedCircuit.`**`Y`**

Distributed Admittance, $Y^{'}$

..math:: gamma = sqrt{ Z^{'} Y^{'}}

Returns **Y** : numpy.ndarray

Distributed Admittance in units of S/m

skrf.media.distributedCircuit.DistributedCircuit.Z

`DistributedCircuit.`**`Z`**

Distributed Impedance, $Z^{'}$

Defined as

$$Z^{'} = \omega R^{'} + j\omega I^{'}$$

Returns **Z** : numpy.ndarray

Distributed impedance in units of ohm/m

skrf.media.distributedCircuit.DistributedCircuit.characteristic_impedance

`DistributedCircuit.`**`characteristic_impedance`**

Characterisitc impedance

The characteristic_impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the characterisitc impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **characteristic_impedance** : `numpy.ndarray`

skrf.media.distributedCircuit.DistributedCircuit.propagation_constant

`DistributedCircuit.propagation_constant`

Propagation constant

The propagation constant can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the propagation constant to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns propagation_constant : `numpy.ndarray`

complex propagation constant for this media

Notes

***propagation_constant* must adhere to the following convention,**

- positive real(propagation_constant) = attenuation
- positive imag(propagation_constant) = forward propagation

skrf.media.distributedCircuit.DistributedCircuit.z0

`DistributedCircuit.z0`

Port Impedance

The port impedance is usually equal to the `characteristic_impedance`. Therefore, if the port impedance is *None* then this will return `characteristic_impedance`.

However, in some cases such as rectangular waveguide, the port impedance is traditionally set to 1 (normalized). In such a case this property may be used.

The Port Impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the Port Impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns port_impedance : `numpy.ndarray`

the media's port impedance

Methods

`Z0`	Characteristic Impedance, $Z0$
`__init__`	Distributed Circuit constructor.
`capacitor`	Capacitor
`delay_load`	Delayed load
`delay_open`	Delayed open transmission line
`delay_short`	Delayed Short
`electrical_length`	calculates the electrical length for a given distance, at
`from_Media`	Initializes a DistributedCircuit from an existing
`gamma`	Propagation Constant, γ
`guess_length_of_delay_short`	Guess physical length of a delay short.
`impedance_mismatch`	Two-port network for an impedance miss-match
`inductor`	Inductor
`line`	Matched transmission line of given length
`load`	Load of given reflection coefficient.

Continued on next page

Table 3.41 – continued from previous page

match	Perfect matched load ($\Gamma_0 = 0$).
open	Open ($\Gamma_0 = 1$)
short	Short ($\Gamma_0 = -1$)
shunt	Shunts a Network
shunt_capacitor	Shunted capacitor
shunt_delay_load	Shunted delayed load
shunt_delay_open	Shunted delayed open
shunt_delay_short	Shunted delayed short
shunt_inductor	Shunted inductor
splitter	Ideal, lossless n-way splitter.
tee	Ideal, lossless tee.
theta_2_d	Converts electrical length to physical distance.
thru	Matched transmission line of length 0.
white_gaussian_polar	Complex zero-mean gaussian white-noise network.

skrf.media.distributedCircuit.DistributedCircuit.Z0

`DistributedCircuit.Z0()`

Characteristic Impedance, $Z0$

$$Z_0 = \sqrt{\frac{Z'}{Y'}}$$

Returns **Z0** : numpy.ndarray

Characteristic Impedance in units of ohms

skrf.media.distributedCircuit.DistributedCircuit.__init__

`DistributedCircuit.__init__(`*frequency*, *C*, *I*, *R*, *G*, **args*, ***kwargs*`)`

Distributed Circuit constructor.

Parameters **frequency** : Frequency object

C : number, or array-like

distributed capacitance, in F/m

I : number, or array-like

distributed inductance, in H/m

R : number, or array-like

distributed resistance, in Ohm/m

G : number, or array-like

distributed conductance, in S/m

Notes

C,I,R,G can all be vectors as long as they are the same length

This object can be constructed from a Media instance too, see the classmethod from_Media()

skrf.media.distributedCircuit.DistributedCircuit.capacitor

`DistributedCircuit.`**`capacitor`**`(`*C*, ***kwargs*`)`

Capacitor

Parameters **C** : number, array

Capacitance, in Farads. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **capacitor** : `Network` object

a n-port capacitor

See Also:

`match` function called to create a 'blank' network

skrf.media.distributedCircuit.DistributedCircuit.delay_load

`DistributedCircuit.`**`delay_load`**`(`*Gamma0*, *d*, *unit='m'*, ***kwargs*`)`

Delayed load

A load with reflection coefficient *Gamma0* at the end of a matched line of length *d*.

Parameters **Gamma0** : number, array-like

reflection coefficient of load (not in dB)

d : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_load** : `Network` object

a delayed load

See Also:

`line` creates the network for line

`load` creates the network for the load

Notes

This calls

```
line(d,unit, **kwargs) ** load(Gamma0, **kwargs)
```

Examples

```
>>> my_media.delay_load(-.5, 90, 'deg', z0=50)
```

skrf.media.distributedCircuit.DistributedCircuit.delay_open

`DistributedCircuit.delay_open(d, unit='m', **kwargs)`

Delayed open transmission line

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_open** : `Network` object

a delayed open

See Also:

`delay_load` delay_short just calls this function

skrf.media.distributedCircuit.DistributedCircuit.delay_short

`DistributedCircuit.delay_short(d, unit='m', **kwargs)`

Delayed Short

A transmission line of given length terminated with a short.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_short** : `Network` object

a delayed short

See Also:

delay_load delay_short just calls this function

skrf.media.distributedCircuit.DistributedCircuit.electrical_length

`DistributedCircuit.electrical_length(d, deg=False)`

calculates the electrical length for a given distance, at the center frequency.

Parameters **d: distance, in meters** :

deg: is d in deg?[Boolean]

Returns **theta: electrical length in radians or degrees,** :

depending on value of deg.

skrf.media.distributedCircuit.DistributedCircuit.from_Media

classmethod `DistributedCircuit.from_Media(my_media, *args, **kwargs)`

Initializes a DistributedCircuit from an existing :class:'~skrf.media.media.Media' instance.

skrf.media.distributedCircuit.DistributedCircuit.gamma

`DistributedCircuit.gamma()`

Propagation Constant, γ

Defined as,

$$\gamma = \sqrt{Z'Y'}$$

Returns **gamma** : numpy.ndarray

Propagation Constant,

Notes

The components of propagation constant are interpreted as follows:

positive real(gamma) = attenuation positive imag(gamma) = forward propagation

skrf.media.distributedCircuit.DistributedCircuit.guess_length_of_delay_short

`DistributedCircuit.guess_length_of_delay_short(aNtwk)`

Guess physical length of a delay short.

Unwraps the phase and determines the slope, which is then used in conjunction with `propagation_constant` to estimate the physical distance to the short.

Parameters **aNtwk** : `Network` object

(note: if this is a measurment it needs to be normalized to the reference plane)

skrf.media.distributedCircuit.DistributedCircuit.impedance_mismatch

`DistributedCircuit.impedance_mismatch(z1, z2, **kwargs)`

Two-port network for an impedance miss-match

Parameters **z1** : number, or array-like

complex impedance of port 1

z2 : number, or array-like

complex impedance of port 2

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **missmatch** : `Network` object

a 2-port network representing the impedance missmatch

See Also:

`match` called to create a 'blank' network

Notes

If z1 and z2 are arrays, they must be of same length as the `Media.frequency.npoints`

skrf.media.distributedCircuit.DistributedCircuit.inductor

`DistributedCircuit.`**`inductor`**(*L*, ***kwargs*)

Inductor

Parameters **L** : number, array

Inductance, in Henrys. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **inductor** : `Network` object

a n-port inductor

See Also:

`match` called to create a 'blank' network

skrf.media.distributedCircuit.DistributedCircuit.line

`DistributedCircuit.`**`line`**(*d*, *unit='m'*, ***kwargs*)

Matched transmission line of given length

The units of *length* are interpreted according to the value of *unit*.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **line** : Network object

matched tranmission line of given length

Examples

```
>>> my_media.line(90, 'deg', z0=50)
```

skrf.media.distributedCircuit.DistributedCircuit.load

DistributedCircuit.**load**(*Gamma0*, *nports=1*, ***kwargs*)

Load of given reflection coefficient.

Parameters **Gamma0** : number, array-like

Reflection coefficient of load (linear, not in db). If its an array it must be of shape: kxnxn, where k is #frequency points in media, and n is *nports*

nports : int

number of ports

****kwargs** : key word arguments

passed to match(), which is called initially to create a 'blank' network.

Returns **load :class:'~skrf.network.Network' object** :

n-port load, where S = Gamma0*eye(...)

skrf.media.distributedCircuit.DistributedCircuit.match

DistributedCircuit.**match**(*nports=1*, *z0=None*, ***kwargs*)

Perfect matched load ($\Gamma_0 = 0$).

Parameters **nports** : int

number of ports

z0 : number, or array-like

characterisitc impedance. Default is None, in which case the Media's z0 is used. This sets the resultant Network's z0.

****kwargs** : key word arguments

passed to Network initializer

Returns **match** : Network object

a n-port match

Examples

```
>>> my_match = my_media.match(2,z0 = 50, name='Super Awesome Match')
```

skrf.media.distributedCircuit.DistributedCircuit.open

`DistributedCircuit.open(nports=1, **kwargs)`

Open ($\Gamma_0 = 1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port open circuit

See Also:

match function called to create a 'blank' network

skrf.media.distributedCircuit.DistributedCircuit.short

`DistributedCircuit.short(nports=1, **kwargs)`

Short ($\Gamma_0 = -1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port short circuit

See Also:

match function called to create a 'blank' network

skrf.media.distributedCircuit.DistributedCircuit.shunt

`DistributedCircuit.shunt(ntwk, **kwargs)`

Shunts a `Network`

This creates a `tee()` and connects connects *ntwk* to port 1, and returns the result

Parameters **ntwk** : `Network` object

****kwargs** : keyword arguments

passed to `tee()`

Returns **shunted_ntwk** : `Network` object

a shunted a ntwk. The resultant shunted_ntwk will have (2 + ntwk.number_of_ports -1) ports.

skrf.media.distributedCircuit.DistributedCircuit.shunt_capacitor

`DistributedCircuit.shunt_capacitor(C, *args, **kwargs)`

Shunted capacitor

Parameters **C** : number, array-like

Capacitance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_capacitor** : `Network` object

shunted capcitor(2-port)

Notes

This calls:

```
shunt(capacitor(C,*args, **kwargs))
```

skrf.media.distributedCircuit.DistributedCircuit.shunt_delay_load

`DistributedCircuit.`**`shunt_delay_load`**`(`**args*, ***kwargs*`)`

Shunted delayed load

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_load*

Returns **shunt_delay_load** : `Network` object

a shunted delayed load (2-port)

Notes

This calls:

```
shunt(delay_load(*args, **kwargs))
```

skrf.media.distributedCircuit.DistributedCircuit.shunt_delay_open

`DistributedCircuit.`**`shunt_delay_open`**`(`**args*, ***kwargs*`)`

Shunted delayed open

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_open** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

```
shunt(delay_open(*args, **kwargs))
```

skrf.media.distributedCircuit.DistributedCircuit.shunt_delay_short

`DistributedCircuit.shunt_delay_short(*args, **kwargs)`

Shunted delayed short

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_load** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

`shunt(delay_short(*args, **kwargs))`

skrf.media.distributedCircuit.DistributedCircuit.shunt_inductor

`DistributedCircuit.shunt_inductor(L, *args, **kwargs)`

Shunted inductor

Parameters **L** : number, array-like

Inductance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_inductor** : `Network` object

shunted inductor(2-port)

Notes

This calls:

`shunt(inductor(C,*args, **kwargs))`

skrf.media.distributedCircuit.DistributedCircuit.splitter

`DistributedCircuit.splitter(nports, **kwargs)`

Ideal, lossless n-way splitter.

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a n-port splitter

See Also:

`match` called to create a 'blank' network

skrf.media.distributedCircuit.DistributedCircuit.tee

`DistributedCircuit.tee(**kwargs)`

Ideal, lossless tee. (3-port splitter)

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a 3-port splitter

See Also:

`splitter` this just calls splitter(3)

`match` called to create a 'blank' network

skrf.media.distributedCircuit.DistributedCircuit.theta_2_d

`DistributedCircuit.theta_2_d(theta, deg=True)`

Converts electrical length to physical distance.

The given electrical length is to be at the center frequency.

Parameters **theta** : number

electrical length, at band center (see deg for unit)

deg : Boolean

is theta in degrees?

Returns **d** : number

physical distance in meters

skrf.media.distributedCircuit.DistributedCircuit.thru

`DistributedCircuit.thru(**kwargs)`

Matched transmission line of length 0.

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **thru** : `Network` object

matched tranmission line of 0 length

See Also:

`line` this just calls line(0)

skrf.media.distributedCircuit.DistributedCircuit.white_gaussian_polar

`DistributedCircuit.white_gaussian_polar(phase_dev, mag_dev, n_ports=1, **kwargs)`

Complex zero-mean gaussian white-noise network.

Creates a network whose s-matrix is complex zero-mean gaussian white-noise, of given standard deviations for phase and magnitude components. This 'noise' network can be added to networks to simulate additive noise.

Parameters **phase_mag** : number

standard deviation of magnitude

phase_dev : number

standard deviation of phase

n_ports : int

number of ports.

****kwargs** : passed to `Network`

initializer

Returns **result** : `Network` object

a noise network

skrf.media.rectangularWaveguide.RectangularWaveguide

class `skrf.media.rectangularWaveguide.`**`RectangularWaveguide`**(*frequency*, *a*, *b=None*, *mode_type='te'*, *m=1*, *n=0*, *ep_r=1*, *mu_r=1*, **args*, ***kwargs*)

Rectangular Waveguide medium.

Represents a single mode of a homogeneously filled rectangular waveguide of cross-section *a* x *b*. The mode is determined by mode-type (te or tm) and mode indecies (m and n).

Quantity	Symbol	Variable
Characteristic Wave Number	k_0	`k0`
Cut-off Wave Number	k_c	`kc`
Longitudinal Wave Number	k_z	`kz`
Transverse Wave Number (a)	k_x	`kx`
Transverse Wave Number (b)	k_y	`ky`
Characteristic Impedance	Z_0	`Z0`

Attributes

`characteristic_impedance`	Characterisitc impedance
`ep`	The permativity of the filling material
`k0`	Characteristic wave number
`kc`	Cut-off wave number
`kx`	Eigen value in the 'a' direction
`ky`	Eigen-value in the *b* direction.
`mu`	The permeability of the filling material
`propagation_constant`	Propagation constant
`z0`	Port Impedance

skrf.media.rectangularWaveguide.RectangularWaveguide.characteristic_impedance

`RectangularWaveguide.`**`characteristic_impedance`**

Characterisitc impedance

The characteristic_impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the characterisitc impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **characteristic_impedance** : `numpy.ndarray`

skrf.media.rectangularWaveguide.RectangularWaveguide.ep

`RectangularWaveguide.ep`

The permativity of the filling material

Returns ep : number

filling material's relative permativity

skrf.media.rectangularWaveguide.RectangularWaveguide.k0

`RectangularWaveguide.k0`

Characteristic wave number

Returns k0 : number

characteristic wave number

skrf.media.rectangularWaveguide.RectangularWaveguide.kc

`RectangularWaveguide.kc`

Cut-off wave number

Defined as

$$k_c = \sqrt{k_x^2 + k_y^2} = \sqrt{m\frac{\pi}{a}^2 + n\frac{\pi}{b}^2}$$

Returns kc : number

cut-off wavenumber

skrf.media.rectangularWaveguide.RectangularWaveguide.kx

`RectangularWaveguide.kx`

Eigen value in the 'a' direction

Defined as

$$k_x = m\frac{\pi}{a}$$

Returns kx : number

eigen-value in *a* direction

skrf.media.rectangularWaveguide.RectangularWaveguide.ky

`RectangularWaveguide.ky`

Eigen-value in the *b* direction.

Defined as

$$k_y = n\frac{\pi}{b}$$

Returns ky : number

eigen-value in *b* direction

skrf.media.rectangularWaveguide.RectangularWaveguide.mu

`RectangularWaveguide.mu`

The permeability of the filling material

Returns mu : number

filling material's relative permeability

skrf.media.rectangularWaveguide.RectangularWaveguide.propagation_constant

`RectangularWaveguide.propagation_constant`

Propagation constant

The propagation constant can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the propagation constant to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **propagation_constant** : `numpy.ndarray`

complex propagation constant for this media

Notes

propagation_constant **must adhere to the following convention,**

- positive real(propagation_constant) = attenuation
- positive imag(propagation_constant) = forward propagation

skrf.media.rectangularWaveguide.RectangularWaveguide.z0

`RectangularWaveguide.z0`

Port Impedance

The port impedance is usually equal to the `characteristic_impedance`. Therefore, if the port impedance is *None* then this will return `characteristic_impedance`.

However, in some cases such as rectangular waveguide, the port impedance is traditionally set to 1 (normalized). In such a case this property may be used.

The Port Impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the Port Impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **port_impedance** : `numpy.ndarray`

the media's port impedance

Methods

Z0	The characteristic impedance
__init__	RectangularWaveguide initializer
capacitor	Capacitor
delay_load	Delayed load
delay_open	Delayed open transmission line
delay_short	Delayed Short
electrical_length	calculates the electrical length for a given distance, at
guess_length_of_delay_short	Guess physical length of a delay short.
impedance_mismatch	Two-port network for an impedance miss-match
inductor	Inductor
kz	The Longitudinal wave number, aka propagation constant.
line	Matched transmission line of given length
load	Load of given reflection coefficient.
match	Perfect matched load ($\Gamma_0 = 0$).

Continued on next page

Table 3.43 – continued from previous page

`open`	Open ($\Gamma_0 = 1$)
`short`	Short ($\Gamma_0 = -1$)
`shunt`	Shunts a `Network`
`shunt_capacitor`	Shunted capacitor
`shunt_delay_load`	Shunted delayed load
`shunt_delay_open`	Shunted delayed open
`shunt_delay_short`	Shunted delayed short
`shunt_inductor`	Shunted inductor
`splitter`	Ideal, lossless n-way splitter.
`tee`	Ideal, lossless tee.
`theta_2_d`	Converts electrical length to physical distance.
`thru`	Matched transmission line of length 0.
`white_gaussian_polar`	Complex zero-mean gaussian white-noise network.

skrf.media.rectangularWaveguide.RectangularWaveguide.Z0

`RectangularWaveguide.Z0()`

The characteristic impedance

skrf.media.rectangularWaveguide.RectangularWaveguide.__init__

`RectangularWaveguide.__init__(`*frequency*, *a*, *b=None*, *mode_type='te'*, *m=1*, *n=0*, *ep_r=1*, *mu_r=1*, **args*, ***kwargs*`)`

RectangularWaveguide initializer

Parameters **frequency** : class:~*skrf.frequency.Frequency* object

frequency band for this media

a : number

width of waveguide, in meters.

b : number

height of waveguide, in meters. If *None* defaults to a/2

mode_type : ['te','tm']

mode type, transverse electric (te) or transverse magnetic (tm) to-z. where z is direction of propagation

m : int

mode index in 'a'-direction

n : int

mode index in 'b'-direction

ep_r : number, array-like,

filling material's relative permativity

mu_r : number, array-like

filling material's relative permeability

***args,**kwargs** : arguments, keywrod arguments

passed to `Media`'s constructor (`__init__()`

Examples

Most common usage is standard aspect ratio (2:1) dominant mode, TE10 mode of wr10 waveguide can be constructed by

```
>>> freq = rf.Frequency(75,110,101,'ghz')
>>> rf.RectangularWaveguide(freq, 100*mil)
```

skrf.media.rectangularWaveguide.RectangularWaveguide.capacitor

`RectangularWaveguide.capacitor(C, **kwargs)`

Capacitor

Parameters **C** : number, array

Capacitance, in Farads. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **capacitor** : `Network` object

a n-port capacitor

See Also:

`match` function called to create a 'blank' network

skrf.media.rectangularWaveguide.RectangularWaveguide.delay_load

`RectangularWaveguide.delay_load(Gamma0, d, unit='m', **kwargs)`

Delayed load

A load with reflection coefficient *Gamma0* at the end of a matched line of length *d*.

Parameters **Gamma0** : number, array-like

reflection coefficient of load (not in dB)

d : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_load** : `Network` object

a delayed load

See Also:

`line` creates the network for line

`load` creates the network for the load

Notes

This calls

```
line(d,unit, **kwargs) ** load(Gamma0, **kwargs)
```

Examples

```
>>> my_media.delay_load(-.5, 90, 'deg', z0=50)
```

skrf.media.rectangularWaveguide.RectangularWaveguide.delay_open

`RectangularWaveguide.delay_open`(*d*, *unit='m'*, ***kwargs*)

Delayed open transmission line

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_open** : `Network` object

a delayed open

See Also:

`delay_load` delay_short just calls this function

skrf.media.rectangularWaveguide.RectangularWaveguide.delay_short

`RectangularWaveguide.delay_short`(*d*, *unit='m'*, ***kwargs*)

Delayed Short

A transmission line of given length terminated with a short.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees

- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_short** : `Network` object

a delayed short

See Also:

delay_load delay_short just calls this function

skrf.media.rectangularWaveguide.RectangularWaveguide.electrical_length

`RectangularWaveguide.electrical_length(d, deg=False)`

calculates the electrical length for a given distance, at the center frequency.

Parameters **d: distance, in meters** :

deg: is d in deg?[Boolean]

Returns **theta: electrical length in radians or degrees,** :

depending on value of deg.

skrf.media.rectangularWaveguide.RectangularWaveguide.guess_length_of_delay_short

`RectangularWaveguide.guess_length_of_delay_short(aNtwk)`

Guess physical length of a delay short.

Unwraps the phase and determines the slope, which is then used in conjunction with `propagation_constant` to estimate the physical distance to the short.

Parameters **aNtwk** : `Network` object

(note: if this is a measurment it needs to be normalized to the reference plane)

skrf.media.rectangularWaveguide.RectangularWaveguide.impedance_mismatch

`RectangularWaveguide.impedance_mismatch(z1, z2, **kwargs)`

Two-port network for an impedance miss-match

Parameters **z1** : number, or array-like

complex impedance of port 1

z2 : number, or array-like

complex impedance of port 2

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **missmatch** : `Network` object

a 2-port network representing the impedance missmatch

See Also:

match called to create a 'blank' network

Notes

If z1 and z2 are arrays, they must be of same length as the `Media.frequency.npoints`

skrf.media.rectangularWaveguide.RectangularWaveguide.inductor

`RectangularWaveguide.inductor(L, **kwargs)`

Inductor

Parameters **L** : number, array

Inductance, in Henrys. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **inductor** : `Network` object

a n-port inductor

See Also:

`match` called to create a 'blank' network

skrf.media.rectangularWaveguide.RectangularWaveguide.kz

`RectangularWaveguide.kz()`

The Longitudinal wave number, aka propagation constant.

Defined as

$$k_z = \pm\sqrt{k_0^2 - k_c^2}$$

This is.

- IMAGINARY for propagating modes
- REAL for non-propagating modes,

Returns **kz** : number

The propagation constant

skrf.media.rectangularWaveguide.RectangularWaveguide.line

`RectangularWaveguide.line(d, unit='m', **kwargs)`

Matched transmission line of given length

The units of *length* are interpreted according to the value of *unit*.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **line** : `Network` object

matched tranmission line of given length

Examples

```
>>> my_media.line(90, 'deg', z0=50)
```

skrf.media.rectangularWaveguide.RectangularWaveguide.load

`RectangularWaveguide.load(Gamma0, nports=1, **kwargs)`

Load of given reflection coefficient.

Parameters **Gamma0** : number, array-like

Reflection coefficient of load (linear, not in db). If its an array it must be of shape: kxnxn, where k is #frequency points in media, and n is *nports*

nports : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **load :class:'~skrf.network.Network' object** :

n-port load, where S = Gamma0*eye(...)

skrf.media.rectangularWaveguide.RectangularWaveguide.match

`RectangularWaveguide.match(nports=1, z0=None, **kwargs)`

Perfect matched load ($\Gamma_0 = 0$).

Parameters **nports** : int

number of ports

z0 : number, or array-like

characterisitc impedance. Default is None, in which case the Media's `z0` is used. This sets the resultant Network's `z0`.

****kwargs** : key word arguments

passed to `Network` initializer

Returns **match** : `Network` object

a n-port match

Examples

```
>>> my_match = my_media.match(2,z0 = 50, name='Super Awesome Match')
```

skrf.media.rectangularWaveguide.RectangularWaveguide.open

`RectangularWaveguide.open(nports=1, **kwargs)`

Open ($\Gamma_0 = 1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port open circuit

See Also:

`match` function called to create a 'blank' network

skrf.media.rectangularWaveguide.RectangularWaveguide.short

`RectangularWaveguide.short(nports=1, **kwargs)`

Short ($\Gamma_0 = -1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port short circuit

See Also:

`match` function called to create a 'blank' network

skrf.media.rectangularWaveguide.RectangularWaveguide.shunt

`RectangularWaveguide.shunt(ntwk, **kwargs)`

Shunts a `Network`

This creates a `tee()` and connects connects *ntwk* to port 1, and returns the result

Parameters **ntwk** : `Network` object

****kwargs** : keyword arguments

passed to `tee()`

Returns **shunted_ntwk** : `Network` object

a shunted a ntwk. The resultant shunted_ntwk will have (2 + ntwk.number_of_ports -1) ports.

skrf.media.rectangularWaveguide.RectangularWaveguide.shunt_capacitor

`RectangularWaveguide.shunt_capacitor(C, *args, **kwargs)`

Shunted capacitor

Parameters **C** : number, array-like

Capacitance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_capacitor** : `Network` object

shunted capcitor(2-port)

Notes

This calls:

`shunt(capacitor(C,*args, **kwargs))`

skrf.media.rectangularWaveguide.RectangularWaveguide.shunt_delay_load

`RectangularWaveguide.`**`shunt_delay_load`**`(`**args*, ***kwargs*`)`

Shunted delayed load

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_load*

Returns **shunt_delay_load** : `Network` object

a shunted delayed load (2-port)

Notes

This calls:

`shunt(delay_load(*args, **kwargs))`

skrf.media.rectangularWaveguide.RectangularWaveguide.shunt_delay_open

`RectangularWaveguide.`**`shunt_delay_open`**`(`**args*, ***kwargs*`)`

Shunted delayed open

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_open** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

`shunt(delay_open(*args, **kwargs))`

skrf.media.rectangularWaveguide.RectangularWaveguide.shunt_delay_short

`RectangularWaveguide.shunt_delay_short(*args, **kwargs)`

Shunted delayed short

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_load** : Network object

shunted delayed open (2-port)

Notes

This calls:

```
shunt(delay_short(*args, **kwargs))
```

skrf.media.rectangularWaveguide.RectangularWaveguide.shunt_inductor

`RectangularWaveguide.shunt_inductor(L, *args, **kwargs)`

Shunted inductor

Parameters **L** : number, array-like

Inductance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_inductor** : Network object

shunted inductor(2-port)

Notes

This calls:

```
shunt(inductor(C,*args, **kwargs))
```

skrf.media.rectangularWaveguide.RectangularWaveguide.splitter

`RectangularWaveguide.splitter(nports, **kwargs)`

Ideal, lossless n-way splitter.

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : Network object

a n-port splitter

See Also:

match called to create a 'blank' network

skrf.media.rectangularWaveguide.RectangularWaveguide.tee

`RectangularWaveguide.tee(**kwargs)`

Ideal, lossless tee. (3-port splitter)

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a 3-port splitter

See Also:

`splitter` this just calls splitter(3)

`match` called to create a 'blank' network

skrf.media.rectangularWaveguide.RectangularWaveguide.theta_2_d

`RectangularWaveguide.theta_2_d(theta, deg=True)`

Converts electrical length to physical distance.

The given electrical length is to be at the center frequency.

Parameters **theta** : number

electrical length, at band center (see deg for unit)

deg : Boolean

is theta in degrees?

Returns **d** : number

physical distance in meters

skrf.media.rectangularWaveguide.RectangularWaveguide.thru

`RectangularWaveguide.thru(**kwargs)`

Matched transmission line of length 0.

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **thru** : `Network` object

matched tranmission line of 0 length

See Also:

`line` this just calls line(0)

skrf.media.rectangularWaveguide.RectangularWaveguide.white_gaussian_polar

`RectangularWaveguide.white_gaussian_polar(phase_dev, mag_dev, n_ports=1, **kwargs)`

Complex zero-mean gaussian white-noise network.

Creates a network whose s-matrix is complex zero-mean gaussian white-noise, of given standard deviations for phase and magnitude components. This 'noise' network can be added to networks to simulate additive noise.

Parameters **phase_mag** : number

standard deviation of magnitude

phase_dev : number

standard deviation of phase

n_ports : int

number of ports.

****kwargs** : passed to `Network`

initializer

Returns **result** : `Network` object

a noise network

skrf.media.cpw.CPW

class `skrf.media.cpw.CPW`(*frequency*, *w*, *s*, *ep_r*, *t=None*, *rho=None*, **args*, ***kwargs*)

Coplanar waveguide class

This class was made from the technical documentation [21] provided by the qucs project [22] . The variables and properties of this class are coincident with their derivations.

Attributes

`K_ratio`	intermediary parameter. see qucs docs on cpw lines.
`alpha_conductor`	Losses due to conductor resistivity
`characteristic_impedance`	Characterisitc impedance
`ep_re`	intermediary parameter. see qucs docs on cpw lines.
`k1`	intermediary parameter. see qucs docs on cpw lines.
`propagation_constant`	Propagation constant
`z0`	Port Impedance

skrf.media.cpw.CPW.K_ratio

`CPW.K_ratio`

intermediary parameter. see qucs docs on cpw lines.

skrf.media.cpw.CPW.alpha_conductor

`CPW.alpha_conductor`

Losses due to conductor resistivity

Returns **alpha_conductor** : array-like

lossyness due to conductor losses

See Also :

———- :

surface_resistivity : calculates surface resistivity

skrf.media.cpw.CPW.characteristic_impedance

[21] http://qucs.sourceforge.net/docs/technical.pdf

[22] http://www.qucs.sourceforge.net/

`CPW.`**`characteristic_impedance`**

Characterisitc impedance

The characteristic_impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the characterisitc impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **characteristic_impedance** : `numpy.ndarray`

skrf.media.cpw.CPW.ep_re

`CPW.`**`ep_re`**

intermediary parameter. see qucs docs on cpw lines.

skrf.media.cpw.CPW.k1

`CPW.`**`k1`**

intermediary parameter. see qucs docs on cpw lines.

skrf.media.cpw.CPW.propagation_constant

`CPW.`**`propagation_constant`**

Propagation constant

The propagation constant can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the propagation constant to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **propagation_constant** : `numpy.ndarray`

complex propagation constant for this media

Notes

propagation_constant **must adhere to the following convention,**

- positive real(propagation_constant) = attenuation
- positive imag(propagation_constant) = forward propagation

skrf.media.cpw.CPW.z0

`CPW.`**`z0`**

Port Impedance

The port impedance is usually equal to the `characteristic_impedance`. Therefore, if the port impedance is *None* then this will return `characteristic_impedance`.

However, in some cases such as rectangular waveguide, the port impedance is traditionally set to 1 (normalized). In such a case this property may be used.

The Port Impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the Port Impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **port_impedance** : `numpy.ndarray`

the media's port impedance

Methods

`Z0`	Characterisitc impedance
`__init__`	Coplanar Waveguide initializer
`capacitor`	Capacitor
`delay_load`	Delayed load
`delay_open`	Delayed open transmission line
`delay_short`	Delayed Short
`electrical_length`	calculates the electrical length for a given distance, at
`gamma`	Propagation constant ..
`guess_length_of_delay_short`	Guess physical length of a delay short.
`impedance_mismatch`	Two-port network for an impedance miss-match
`inductor`	Inductor
`line`	Matched transmission line of given length
`load`	Load of given reflection coefficient.
`match`	Perfect matched load ($\Gamma_0 = 0$).
`open`	Open ($\Gamma_0 = 1$)
`short`	Short ($\Gamma_0 = -1$)
`shunt`	Shunts a `Network`
`shunt_capacitor`	Shunted capacitor
`shunt_delay_load`	Shunted delayed load
`shunt_delay_open`	Shunted delayed open
`shunt_delay_short`	Shunted delayed short
`shunt_inductor`	Shunted inductor
`splitter`	Ideal, lossless n-way splitter.
`tee`	Ideal, lossless tee.
`theta_2_d`	Converts electrical length to physical distance.
`thru`	Matched transmission line of length 0.
`white_gaussian_polar`	Complex zero-mean gaussian white-noise network.

skrf.media.cpw.CPW.Z0

`CPW.Z0()`

Characterisitc impedance

skrf.media.cpw.CPW.__init__

`CPW.__init__`(*frequency*, *w*, *s*, *ep_r*, *t=None*, *rho=None*, **args*, ***kwargs*)

Coplanar Waveguide initializer

Parameters **frequency** : `Frequency` object

frequency band of this transmission line medium

w : number, or array-like

width of center conductor, in m.

s : number, or array-like

width of gap, in m.

ep_r : number, or array-like

relative permativity of substrate

t : number, or array-like, optional

conductor thickness, in m.

rho: number, or array-like, optional :

resistivity of conductor (None)

skrf.media.cpw.CPW.capacitor

`CPW.capacitor(C, **kwargs)`

Capacitor

Parameters **C** : number, array

Capacitance, in Farads. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **capacitor** : `Network` object

a n-port capacitor

See Also:

`match` function called to create a 'blank' network

skrf.media.cpw.CPW.delay_load

`CPW.delay_load(Gamma0, d, unit='m', **kwargs)`

Delayed load

A load with reflection coefficient *Gamma0* at the end of a matched line of length *d*.

Parameters **Gamma0** : number, array-like

reflection coefficient of load (not in dB)

d : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_load** : `Network` object

a delayed load

See Also:

`line` creates the network for line

`load` creates the network for the load

Notes

This calls

`line(d,unit, **kwargs) ** load(Gamma0, **kwargs)`

Examples

```
>>> my_media.delay_load(-.5, 90, 'deg', z0=50)
```

skrf.media.cpw.CPW.delay_open

`CPW.delay_open(d, unit='m', **kwargs)`

Delayed open transmission line

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_open** : `Network` object

a delayed open

See Also:

`delay_load` delay_short just calls this function

skrf.media.cpw.CPW.delay_short

`CPW.delay_short(d, unit='m', **kwargs)`

Delayed Short

A transmission line of given length terminated with a short.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_short** : `Network` object

a delayed short

See Also:

`delay_load` delay_short just calls this function

skrf.media.cpw.CPW.electrical_length

`CPW.electrical_length(d, deg=False)`

calculates the electrical length for a given distance, at the center frequency.

Parameters **d: distance, in meters** :

deg: is d in deg?[Boolean]

Returns **theta: electrical length in radians or degrees,** :

depending on value of deg.

skrf.media.cpw.CPW.gamma

`CPW.gamma()`

Propagation constant

See Also:

`alpha_conductor` calculates losses to conductors

skrf.media.cpw.CPW.guess_length_of_delay_short

`CPW.guess_length_of_delay_short(aNtwk)`

Guess physical length of a delay short.

Unwraps the phase and determines the slope, which is then used in conjunction with `propagation_constant` to estimate the physical distance to the short.

Parameters **aNtwk** : `Network` object

(note: if this is a measurment it needs to be normalized to the reference plane)

skrf.media.cpw.CPW.impedance_mismatch

`CPW.impedance_mismatch(z1, z2, **kwargs)`

Two-port network for an impedance miss-match

Parameters **z1** : number, or array-like

complex impedance of port 1

z2 : number, or array-like

complex impedance of port 2

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **missmatch** : `Network` object

a 2-port network representing the impedance missmatch

See Also:

match called to create a 'blank' network

Notes

If z1 and z2 are arrays, they must be of same length as the `Media.frequency.npoints`

skrf.media.cpw.CPW.inductor

`CPW.`**`inductor`**(*L*, ***kwargs*)

Inductor

Parameters **L** : number, array

Inductance, in Henrys. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **inductor** : `Network` object

a n-port inductor

See Also:

match called to create a 'blank' network

skrf.media.cpw.CPW.line

`CPW.`**`line`**(*d*, *unit='m'*, ***kwargs*)

Matched transmission line of given length

The units of *length* are interpreted according to the value of *unit*.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **line** : `Network` object

matched tranmission line of given length

Examples

```
>>> my_media.line(90, 'deg', z0=50)
```

skrf.media.cpw.CPW.load

`CPW.load(Gamma0, nports=1, **kwargs)`

Load of given reflection coefficient.

Parameters **Gamma0** : number, array-like

Reflection coefficient of load (linear, not in db). If its an array it must be of shape: kxnxn, where k is #frequency points in media, and n is *nports*

nports : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **load :class:'~skrf.network.Network' object** :

n-port load, where S = Gamma0*eye(...)

skrf.media.cpw.CPW.match

`CPW.match(nports=1, z0=None, **kwargs)`

Perfect matched load ($\Gamma_0 = 0$).

Parameters **nports** : int

number of ports

z0 : number, or array-like

characterisitc impedance. Default is None, in which case the Media's `z0` is used. This sets the resultant Network's `z0`.

****kwargs** : key word arguments

passed to `Network` initializer

Returns **match** : `Network` object

a n-port match

Examples

```
>>> my_match = my_media.match(2,z0 = 50, name='Super Awesome Match')
```

skrf.media.cpw.CPW.open

`CPW.open(nports=1, **kwargs)`

Open ($\Gamma_0 = 1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port open circuit

See Also:

match function called to create a 'blank' network

skrf.media.cpw.CPW.short

`CPW.short(nports=1, **kwargs)`

Short ($\Gamma_0 = -1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port short circuit

See Also:

match function called to create a 'blank' network

skrf.media.cpw.CPW.shunt

`CPW.shunt(ntwk, **kwargs)`

Shunts a `Network`

This creates a `tee()` and connects connects *ntwk* to port 1, and returns the result

Parameters **ntwk** : `Network` object

****kwargs** : keyword arguments

passed to `tee()`

Returns **shunted_ntwk** : `Network` object

a shunted a ntwk. The resultant shunted_ntwk will have (2 + ntwk.number_of_ports -1) ports.

skrf.media.cpw.CPW.shunt_capacitor

`CPW.shunt_capacitor(C, *args, **kwargs)`

Shunted capacitor

Parameters **C** : number, array-like

Capacitance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_capacitor** : `Network` object

shunted capcitor(2-port)

Notes

This calls:

```
shunt(capacitor(C,*args, **kwargs))
```

skrf.media.cpw.CPW.shunt_delay_load

`CPW.shunt_delay_load(*args, **kwargs)`

Shunted delayed load

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_load*

Returns **shunt_delay_load** : `Network` object

a shunted delayed load (2-port)

Notes

This calls:

```
shunt(delay_load(*args, **kwargs))
```

skrf.media.cpw.CPW.shunt_delay_open

`CPW.shunt_delay_open(*args, **kwargs)`

Shunted delayed open

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_open** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

```
shunt(delay_open(*args, **kwargs))
```

skrf.media.cpw.CPW.shunt_delay_short

`CPW.shunt_delay_short(*args, **kwargs)`

Shunted delayed short

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_load** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

```
shunt(delay_short(*args, **kwargs))
```

skrf.media.cpw.CPW.shunt_inductor

`CPW.shunt_inductor(L, *args, **kwargs)`

Shunted inductor

Parameters **L** : number, array-like

Inductance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_inductor** : `Network` object

shunted inductor(2-port)

Notes

This calls:

`shunt(inductor(C,*args, **kwargs))`

skrf.media.cpw.CPW.splitter

`CPW.splitter(nports, **kwargs)`

Ideal, lossless n-way splitter.

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a n-port splitter

See Also:

`match` called to create a 'blank' network

skrf.media.cpw.CPW.tee

`CPW.tee(**kwargs)`

Ideal, lossless tee. (3-port splitter)

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a 3-port splitter

See Also:

`splitter` this just calls splitter(3)

`match` called to create a 'blank' network

skrf.media.cpw.CPW.theta_2_d

`CPW.theta_2_d(theta, deg=True)`

Converts electrical length to physical distance.

The given electrical length is to be at the center frequency.

Parameters **theta** : number

electrical length, at band center (see deg for unit)

deg : Boolean

is theta in degrees?

Returns **d** : number

physical distance in meters

skrf.media.cpw.CPW.thru

`CPW.thru(**kwargs)`

Matched transmission line of length 0.

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **thru** : `Network` object

matched tranmission line of 0 length

See Also:

line this just calls line(0)

skrf.media.cpw.CPW.white_gaussian_polar

`CPW.white_gaussian_polar(phase_dev, mag_dev, n_ports=1, **kwargs)`

Complex zero-mean gaussian white-noise network.

Creates a network whose s-matrix is complex zero-mean gaussian white-noise, of given standard deviations for phase and magnitude components. This 'noise' network can be added to networks to simulate additive noise.

Parameters **phase_mag** : number

standard deviation of magnitude

phase_dev : number

standard deviation of phase

n_ports : int

number of ports.

****kwargs** : passed to `Network`

initializer

Returns **result** : `Network` object

a noise network

skrf.media.freespace.Freespace

class `skrf.media.freespace.Freespace` (*frequency*, *ep_r=1*, *mu_r=1*, **args*, ***kwargs*)

Represents a plane-wave in a homogeneous freespace, defined by the space's relative permativity and relative permeability.

The field properties of space are related to a disctributed circuit transmission line model given in circuit theory by:

Circuit Property	Field Property
distributed_capacitance	real(ep_0*ep_r)
distributed_resistance	imag(ep_0*ep_r)
distributed_inductance	real(mu_0*mu_r)
distributed_conductance	imag(mu_0*mu_r)

This class's inheritence is; `Media`-> `DistributedCircuit`-> `Freespace`

Attributes

`Y`	Distributed Admittance, $Y^{'}$
`Z`	Distributed Impedance, $Z^{'}$
`characteristic_impedance`	Characterisitc impedance
`propagation_constant`	Propagation constant
`z0`	Port Impedance

skrf.media.freespace.Freespace.Y

`Freespace.Y`

Distributed Admittance, $Y^{'}$

..math:: gamma = sqrt{ Z^{'} Y^{'}}

Returns **Y** : numpy.ndarray

Distributed Admittance in units of S/m

skrf.media.freespace.Freespace.Z

`Freespace.Z`

Distributed Impedance, $Z^{'}$

Defined as

$$Z^{'} = \omega R^{'} + j\omega I^{'}$$

Returns **Z** : numpy.ndarray

Distributed impedance in units of ohm/m

skrf.media.freespace.Freespace.characteristic_impedance

`Freespace.characteristic_impedance`

Characterisitc impedance

The characteristic_impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the characterisitc impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **characteristic_impedance** : `numpy.ndarray`

skrf.media.freespace.Freespace.propagation_constant

`Freespace.`**`propagation_constant`**

Propagation constant

The propagation constant can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the propagation constant to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **propagation_constant** : `numpy.ndarray`

complex propagation constant for this media

Notes

***propagation_constant* must adhere to the following convention,**

- positive real(propagation_constant) = attenuation
- positive imag(propagation_constant) = forward propagation

skrf.media.freespace.Freespace.z0

`Freespace.`**`z0`**

Port Impedance

The port impedance is usually equal to the `characteristic_impedance`. Therefore, if the port impedance is *None* then this will return `characteristic_impedance`.

However, in some cases such as rectangular waveguide, the port impedance is traditionally set to 1 (normalized). In such a case this property may be used.

The Port Impedance can be either a number, array-like, or a function. If it is a function is must take no arguments. The reason to make it a function is if you want the Port Impedance to be dynamic, meaning changing with some attribute of the media. See `__init__()` for more explanation.

Returns **port_impedance** : `numpy.ndarray`

the media's port impedance

Methods

`Z0`	Characteristic Impedance, $Z0$
`__init__`	Freespace initializer
`capacitor`	Capacitor
`delay_load`	Delayed load
`delay_open`	Delayed open transmission line
`delay_short`	Delayed Short
`electrical_length`	calculates the electrical length for a given distance, at
`from_Media`	Initializes a DistributedCircuit from an existing

Continued on next page

Table 3.47 – continued from previous page

gamma	Propagation Constant, γ
guess_length_of_delay_short	Guess physical length of a delay short.
impedance_mismatch	Two-port network for an impedance miss-match
inductor	Inductor
line	Matched transmission line of given length
load	Load of given reflection coefficient.
match	Perfect matched load ($\Gamma_0 = 0$).
open	Open ($\Gamma_0 = 1$)
short	Short ($\Gamma_0 = -1$)
shunt	Shunts a Network
shunt_capacitor	Shunted capacitor
shunt_delay_load	Shunted delayed load
shunt_delay_open	Shunted delayed open
shunt_delay_short	Shunted delayed short
shunt_inductor	Shunted inductor
splitter	Ideal, lossless n-way splitter.
tee	Ideal, lossless tee.
theta_2_d	Converts electrical length to physical distance.
thru	Matched transmission line of length 0.
white_gaussian_polar	Complex zero-mean gaussian white-noise network.

skrf.media.freespace.Freespace.Z0

`Freespace.Z0()`

Characteristic Impedance, $Z0$

$$Z_0 = \sqrt{\frac{Z'}{Y'}}$$

Returns **Z0** : numpy.ndarray

Characteristic Impedance in units of ohms

skrf.media.freespace.Freespace.__init__

`Freespace.__init__(`*frequency*, *ep_r=1*, *mu_r=1*, **args*, ***kwargs*`)`

Freespace initializer

Parameters **frequency** : Frequency object

frequency band of this transmission line medium

ep_r : number, array-like

complex relative permativity

mu_r : number, array-like

possibly complex, relative permiability

***args, **kwargs** : arguments and keyword arguments

Notes

The distributed circuit parameters are related to a space's field properties by

Circuit Property	Field Property
distributed_capacitance	real(ep_0*ep_r)
distributed_resistance	imag(ep_0*ep_r)
distributed_inductance	real(mu_0*mu_r)
distributed_conductance	imag(mu_0*mu_r)

skrf.media.freespace.Freespace.capacitor

`Freespace.capacitor(C, **kwargs)`

Capacitor

Parameters **C** : number, array

Capacitance, in Farads. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **capacitor** : `Network` object

a n-port capacitor

See Also:

match function called to create a 'blank' network

skrf.media.freespace.Freespace.delay_load

`Freespace.delay_load(Gamma0, d, unit='m', **kwargs)`

Delayed load

A load with reflection coefficient *Gamma0* at the end of a matched line of length *d*.

Parameters **Gamma0** : number, array-like

reflection coefficient of load (not in dB)

d : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_load** : `Network` object

a delayed load

See Also:

line creates the network for line

load creates the network for the load

Notes

This calls

`line(d,unit, **kwargs) ** load(Gamma0, **kwargs)`

Examples

```
>>> my_media.delay_load(-.5, 90, 'deg', z0=50)
```

skrf.media.freespace.Freespace.delay_open

`Freespace.delay_open(d, unit='m', **kwargs)`

Delayed open transmission line

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_open** : `Network` object

a delayed open

See Also:

`delay_load` delay_short just calls this function

skrf.media.freespace.Freespace.delay_short

`Freespace.delay_short(d, unit='m', **kwargs)`

Delayed Short

A transmission line of given length terminated with a short.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)
- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **delay_short** : `Network` object

a delayed short

See Also:

`delay_load` delay_short just calls this function

skrf.media.freespace.Freespace.electrical_length

`Freespace.electrical_length(d, deg=False)`

calculates the electrical length for a given distance, at the center frequency.

Parameters **d: distance, in meters** :

deg: is d in deg?[Boolean]

Returns **theta: electrical length in radians or degrees,** :

depending on value of deg.

skrf.media.freespace.Freespace.from_Media

classmethod `Freespace.from_Media(my_media, *args, **kwargs)`

Initializes a DistributedCircuit from an existing :class:'~skrf.media.media.Media' instance.

skrf.media.freespace.Freespace.gamma

`Freespace.gamma()`

Propagation Constant, γ

Defined as,

$$\gamma = \sqrt{Z'Y'}$$

Returns **gamma** : numpy.ndarray

Propagation Constant,

Notes

The components of propagation constant are interpreted as follows:

positive real(gamma) = attenuation positive imag(gamma) = forward propagation

skrf.media.freespace.Freespace.guess_length_of_delay_short

`Freespace.guess_length_of_delay_short(aNtwk)`

Guess physical length of a delay short.

Unwraps the phase and determines the slope, which is then used in conjunction with `propagation_constant` to estimate the physical distance to the short.

Parameters **aNtwk** : `Network` object

(note: if this is a measurment it needs to be normalized to the reference plane)

skrf.media.freespace.Freespace.impedance_mismatch

`Freespace.impedance_mismatch(z1, z2, **kwargs)`

Two-port network for an impedance miss-match

Parameters **z1** : number, or array-like

complex impedance of port 1

z2 : number, or array-like

complex impedance of port 2

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **missmatch** : `Network` object

a 2-port network representing the impedance missmatch

See Also:

`match` called to create a 'blank' network

Notes

If z1 and z2 are arrays, they must be of same length as the `Media.frequency.npoints`

skrf.media.freespace.Freespace.inductor

`Freespace.inductor(L, **kwargs)`

Inductor

Parameters **L** : number, array

Inductance, in Henrys. If this is an array, must be of same length as frequency vector.

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **inductor** : `Network` object

a n-port inductor

See Also:

`match` called to create a 'blank' network

skrf.media.freespace.Freespace.line

`Freespace.line(d, unit='m', **kwargs)`

Matched transmission line of given length

The units of *length* are interpreted according to the value of *unit*.

Parameters **d** : number

the length of transmissin line (see unit argument)

unit : ['m','deg','rad']

the units of d. possible options are:

- *m* : meters, physical length in meters (default)

- *deg* :degrees, electrical length in degrees
- *rad* :radians, electrical length in radians

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **line** : `Network` object

matched tranmission line of given length

Examples

```
>>> my_media.line(90, 'deg', z0=50)
```

skrf.media.freespace.Freespace.load

`Freespace.load(Gamma0, nports=1, **kwargs)`

Load of given reflection coefficient.

Parameters **Gamma0** : number, array-like

Reflection coefficient of load (linear, not in db). If its an array it must be of shape: kxnxn, where k is #frequency points in media, and n is *nports*

nports : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **load :class:'~skrf.network.Network' object** :

n-port load, where S = Gamma0*eye(...)

skrf.media.freespace.Freespace.match

`Freespace.match(nports=1, z0=None, **kwargs)`

Perfect matched load ($\Gamma_0 = 0$).

Parameters **nports** : int

number of ports

z0 : number, or array-like

characterisitc impedance. Default is None, in which case the Media's `z0` is used. This sets the resultant Network's `z0`.

****kwargs** : key word arguments

passed to `Network` initializer

Returns **match** : `Network` object

a n-port match

Examples

```
>>> my_match = my_media.match(2,z0 = 50, name='Super Awesome Match')
```

skrf.media.freespace.Freespace.open

Freespace.**open**(*nports=1*, ***kwargs*)

Open ($\Gamma_0 = 1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port open circuit

See Also:

match function called to create a 'blank' network

skrf.media.freespace.Freespace.short

Freespace.**short**(*nports=1*, ***kwargs*)

Short ($\Gamma_0 = -1$)

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **match** : `Network` object

a n-port short circuit

See Also:

match function called to create a 'blank' network

skrf.media.freespace.Freespace.shunt

Freespace.**shunt**(*ntwk*, ***kwargs*)

Shunts a `Network`

This creates a `tee()` and connects connects *ntwk* to port 1, and returns the result

Parameters **ntwk** : `Network` object

****kwargs** : keyword arguments

passed to `tee()`

Returns **shunted_ntwk** : `Network` object

a shunted a ntwk. The resultant shunted_ntwk will have (2 + ntwk.number_of_ports -1) ports.

skrf.media.freespace.Freespace.shunt_capacitor

`Freespace.shunt_capacitor(C, *args, **kwargs)`

Shunted capacitor

Parameters **C** : number, array-like

Capacitance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_capacitor** : `Network` object

shunted capcitor(2-port)

Notes

This calls:

`shunt(capacitor(C,*args, **kwargs))`

skrf.media.freespace.Freespace.shunt_delay_load

`Freespace.shunt_delay_load(*args, **kwargs)`

Shunted delayed load

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_load*

Returns **shunt_delay_load** : `Network` object

a shunted delayed load (2-port)

Notes

This calls:

`shunt(delay_load(*args, **kwargs))`

skrf.media.freespace.Freespace.shunt_delay_open

`Freespace.shunt_delay_open(*args, **kwargs)`

Shunted delayed open

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_open** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

```
shunt(delay_open(*args, **kwargs))
```

skrf.media.freespace.Freespace.shunt_delay_short

`Freespace.shunt_delay_short(*args, **kwargs)`

Shunted delayed short

Parameters ***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_delay_load** : `Network` object

shunted delayed open (2-port)

Notes

This calls:

```
shunt(delay_short(*args, **kwargs))
```

skrf.media.freespace.Freespace.shunt_inductor

`Freespace.shunt_inductor(L, *args, **kwargs)`

Shunted inductor

Parameters **L** : number, array-like

Inductance in Farads.

***args,**kwargs** : arguments, keyword arguments

passed to func:*delay_open*

Returns **shunt_inductor** : `Network` object

shunted inductor(2-port)

Notes

This calls:

```
shunt(inductor(C,*args, **kwargs))
```

skrf.media.freespace.Freespace.splitter

`Freespace.splitter(nports, **kwargs)`

Ideal, lossless n-way splitter.

Parameters **nports** : int

number of ports

****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a n-port splitter

See Also:

match called to create a 'blank' network

skrf.media.freespace.Freespace.tee

`Freespace.tee(**kwargs)`

Ideal, lossless tee. (3-port splitter)

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **tee** : `Network` object

a 3-port splitter

See Also:

splitter this just calls splitter(3)

match called to create a 'blank' network

skrf.media.freespace.Freespace.theta_2_d

`Freespace.theta_2_d(theta, deg=True)`

Converts electrical length to physical distance.

The given electrical length is to be at the center frequency.

Parameters **theta** : number

electrical length, at band center (see deg for unit)

deg : Boolean

is theta in degrees?

Returns **d** : number

physical distance in meters

skrf.media.freespace.Freespace.thru

`Freespace.thru(**kwargs)`

Matched transmission line of length 0.

Parameters ****kwargs** : key word arguments

passed to `match()`, which is called initially to create a 'blank' network.

Returns **thru** : `Network` object

matched tranmission line of 0 length

See Also:

line this just calls line(0)

skrf.media.freespace.Freespace.white_gaussian_polar

`Freespace.`**`white_gaussian_polar`**(*phase_dev*, *mag_dev*, *n_ports=1*, ***kwargs*)

Complex zero-mean gaussian white-noise network.

Creates a network whose s-matrix is complex zero-mean gaussian white-noise, of given standard deviations for phase and magnitude components. This 'noise' network can be added to networks to simulate additive noise.

Parameters **phase_mag** : number

standard deviation of magnitude

phase_dev : number

standard deviation of phase

n_ports : int

number of ports.

****kwargs** : passed to `Network`

initializer

Returns **result** : `Network` object

a noise network

3.3.3 Indices and tables

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