PySDRVNA Tutorial

Draft Tutorial 0.9.0

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1 PySDRVNA Tutorial

1.1 Prerequisites

You must install the following software with your package manager or `apt-get install`.

- python-numpy
- python-scipy
- python-matplotlib
- python-qt4
- ipython-notebook
- python-pip

You must install the following python packages with `pip`.

- sudo pip install pyusb
- sudo pip install pyfftw

You must also have a working jack audio setup.

1.2 Starting the VNA

There are two primary ways to start the VNA interactively. The first uses IPython Notebook and is prefered for beginners as the instructions and script steps may be executed directly from your browser. This document was generated with IPython Notebook and can executed interactively by using IPython Notebook.

- `ipython notebook` and then load `PySDRVNA Tutorial.ipynb`
- `python -i VNA.py`

The VNA scripts work with python3, ipython and ipython3 as well.

Before starting the VNA, edit the file `config.py` and make sure the jack names for your SoftRock in and out IQ channels are correct.

In[1]:
```
## This code block starts the VNA
## Click inside the code block and press Shift-Enter to execute a code
```

```
## Remove inline if you want floating (zoomable) plots
%pylab inline
pylab.rcParams['figure.figsize'] = (11,9)
%run VNA.py
```

```
Welcome to pylab, a matplotlib-based Python environment [backend:
module://IPython.zmq.pylab.backend_inline].
For more information, type 'help(pylab)'.
Capture from SoftRock Firmware 15.12
Startup freq 7050000
Run freq 14147656
Address 0x55
Smooth tune 3500
FFT Size: 1024 FFT Bin: 50 Test Freq: 2343.75 Amp: 1.0 RT Frames: 768
Array Length: 2816 Sync Index 768
vna is the VNA object. Type help(vna) for more information. Use
vna.Exit() to exit cleanly.
```

1.3 Calibrate the Audio Round Trip Delay and Levels

Even if you have disabled the PA on your SoftRock, you must reduce the audio drive to your SoftRock to obtain a clean signal. There are two ways to do this. The way I prefer is to adjust the output levels with my Delta-66's Envy24 mixer. The second way is to set the amplitude of the test tone in software. I have to use this second way with my USB soundcard since it has no mixer. Connect your antenna or load standard for audio level calibration. Set your audio output levels to around 20% of maximum.

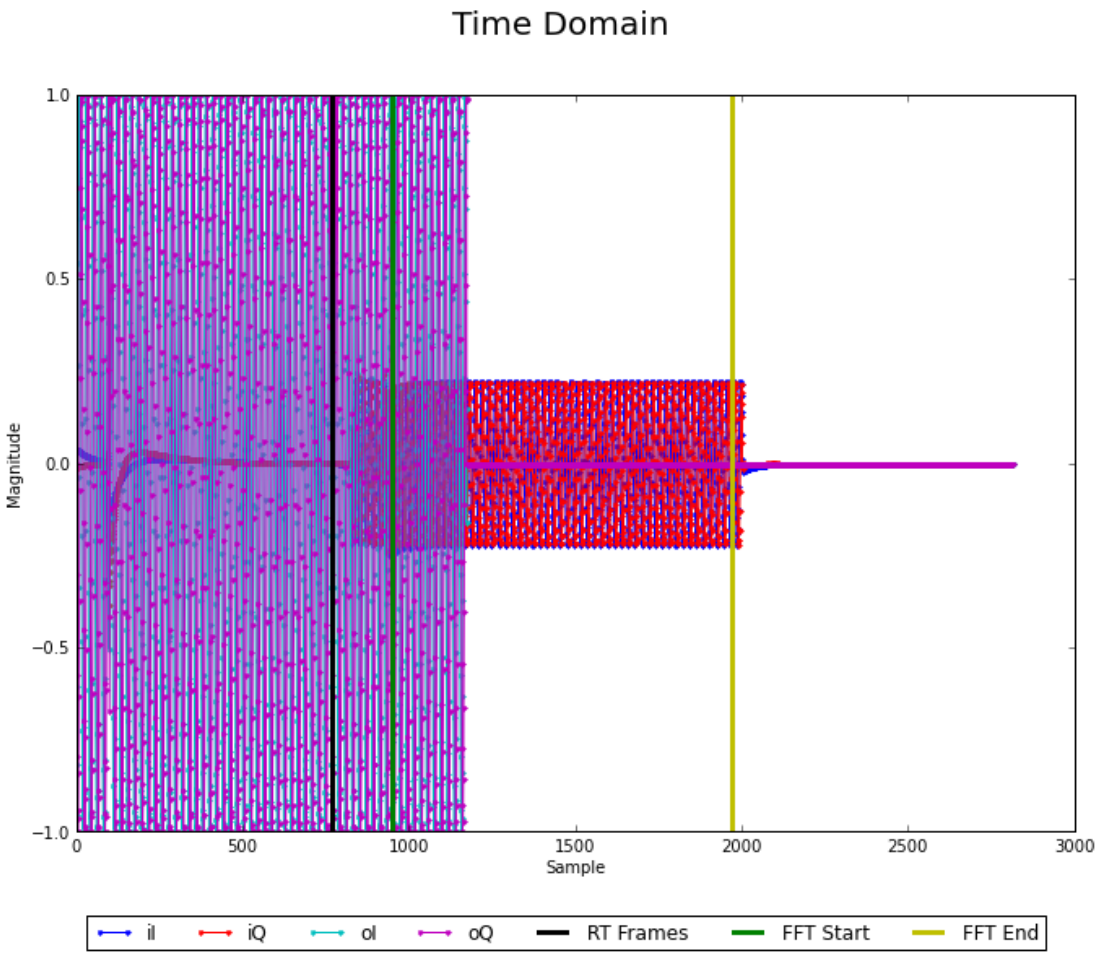
In[]:
```
## If you have no mixer, execute this code block to set the test tone
vna.NewAmp(0.1)
```

In[2]:
```
## Set the SoftRock frequency, change this frequency to whatever you l
vna.SetFreq(14051000)
## Trigger a single measurement to populate the arrays
vna.Test()
```

```
0 Sync:948 Freq:14053344 Real:17.6 Imag:-111.9 Mag:113.2 Phase:-81.0
```

Next, we will plot the time domain of the SoftRock input IQ and output IQ signals so that we can properly align the FFT window.

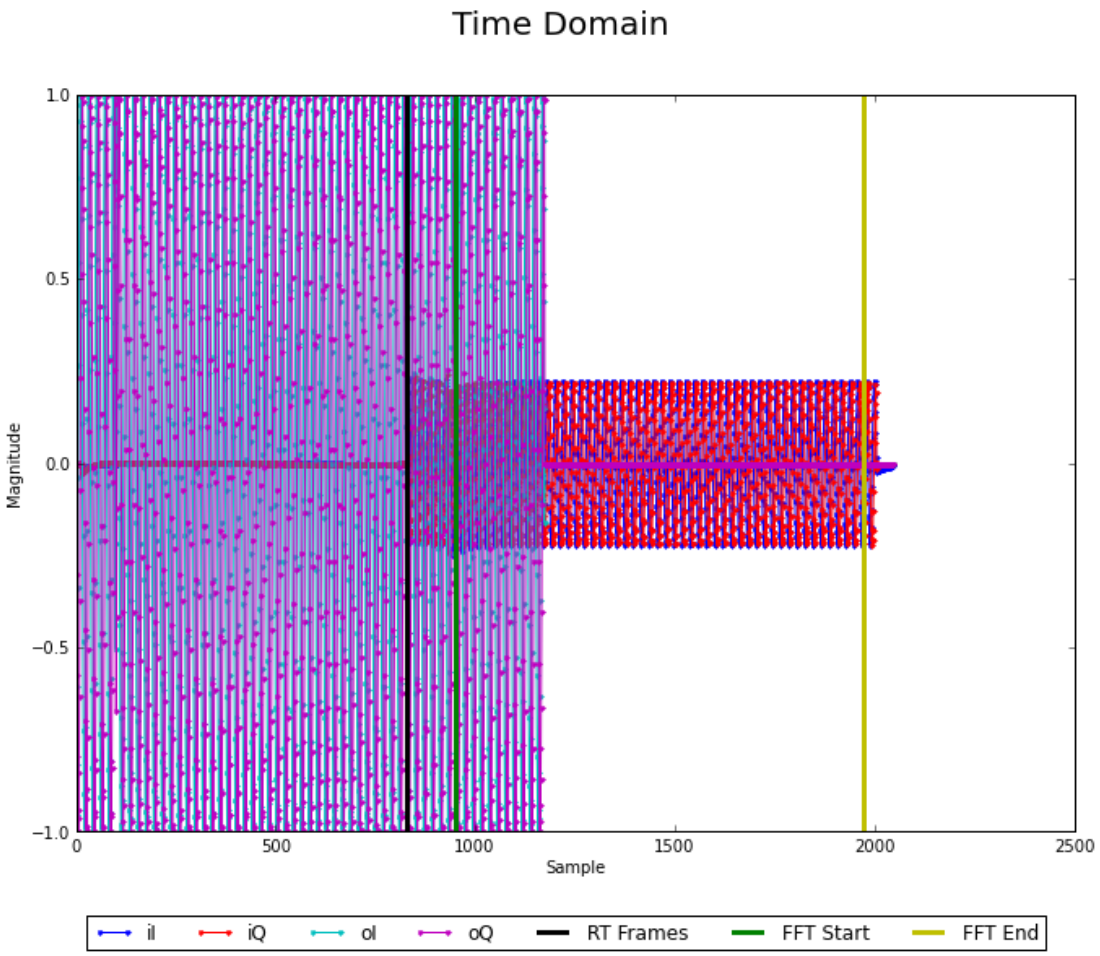
In[3]:
```
## Plot the time domain to align
vna.PlotTD()
```



In this plot, you see the I and Q signals fed to the SoftRock (oI and oQ) on the left and then after a delay, the I and Q signals (iI and iQ) detected by the SoftRock. The software estimates when the received signal starts (black vertical line) and the FFT window (green to yellow line). This estimate is based on information from Jack and does not include latencies internal to your sound card. This is why the black line occurs a bit before the received signal. Also, the total audio capture window is longer than necessary to accomodate a wide variety of sound cards. You can automatically adjust the round trip latency estimate and trim the audio window with the following command.

In[6]:
```
## Automatically resize the arrays based on a successful test measurem
vna.ResizeArrays()
## Rerun the test measurement
vna.Test()
## Replot time domain
vna.PlotTD()
```

```
RTFrames computed from last Sync index 830
Array length was 2304 now 2048
RTFrames was 850 now 830
0 Sync:950 Freq:14053344 Real:17.1 Imag:-111.8 Mag:113.1 Phase:-81.3
```

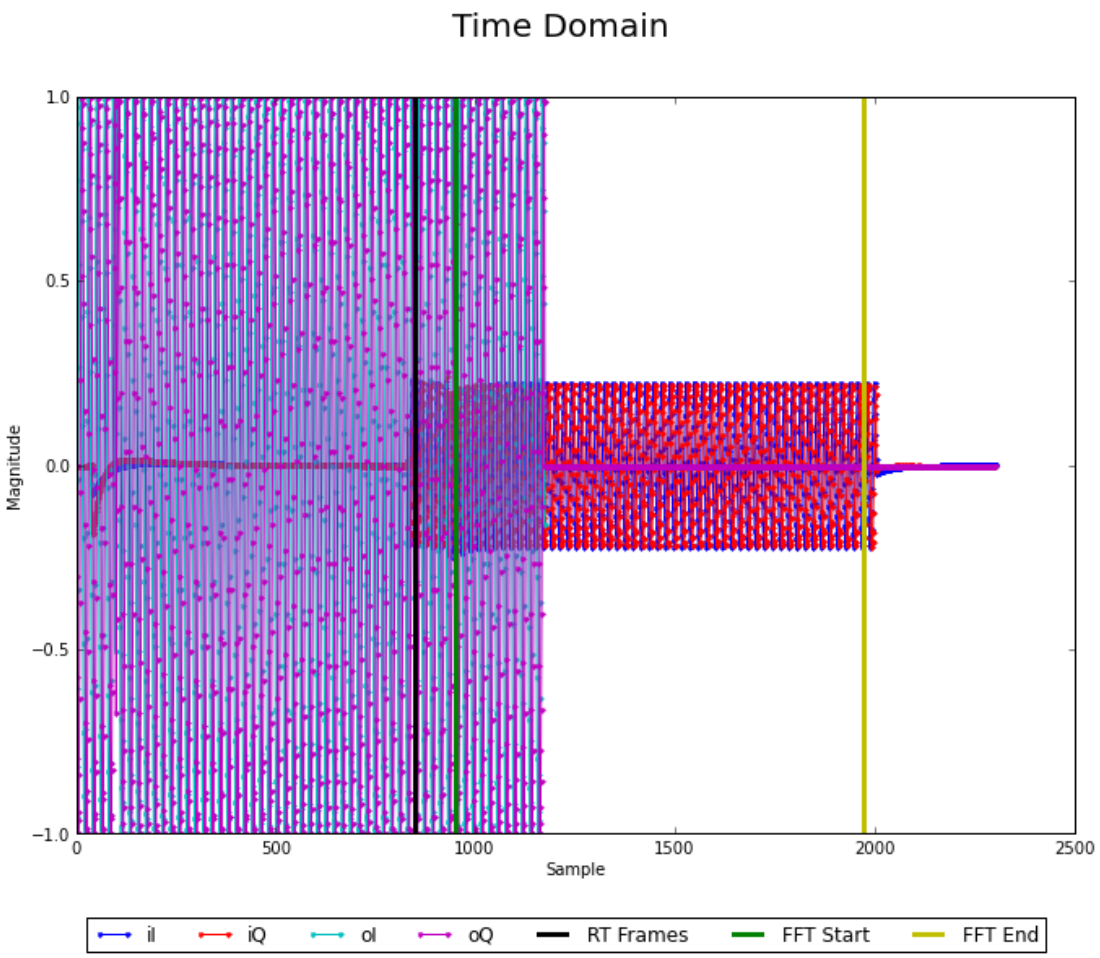


Here we see a better estimate (black line) of when the received signal starts, `RT Frames`. Also, the total audio captured is not much more than what is required for the FFT window. Note that around sample 100 you see a 180 degree phase shift of the sent signal. This phase shift is detected in the received signal and used to lock the FFT window at the same point in time. This is required for consistent measurements, as the round trip latency of my sound card will change by a sample or two every 5 to 10 minutes of operation.

It may be that automatic detection of the received signal did not work for your sound card, usually if your latency is much greater than expected. If this is the case, you can force an estimate for `RT Frames` (the black line) with the following code.

In[5]:
```
## Force resizing of arrays to a specified RT Frames only if you recei
## The value 840 below is your estimate for RT Frames and should be ch
vna.ResizeArrays(850)
vna.Test()
vna.PlotTD()
```

```
Array length was 2048 now 2304
RTFrames was 828 now 850
0 Sync:950 Freq:14053344 Real:17.2 Imag:-111.8 Mag:113.2 Phase:-81.3
```

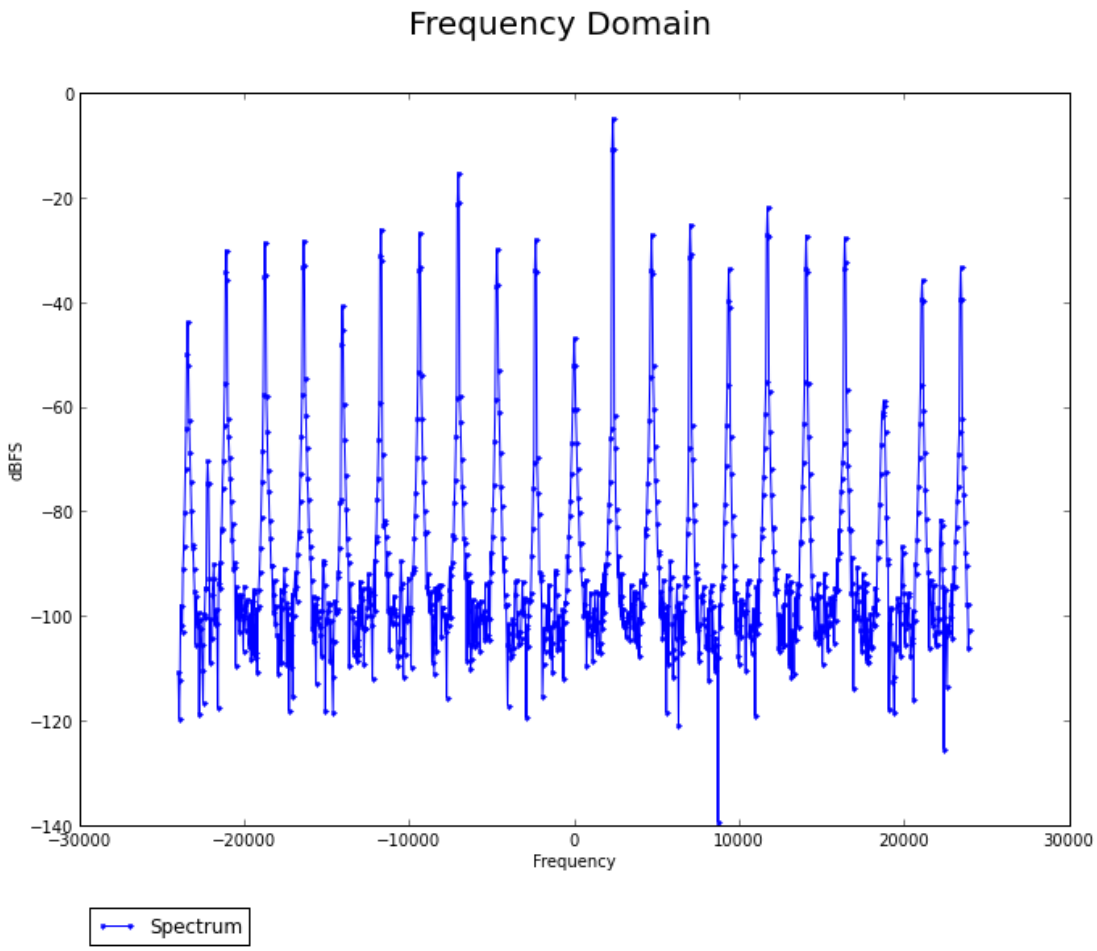


You may have to execute the above block of code several times to find a working estimate. Once you find a value for `RT Frames` that works, you can perform automatic array resizing as seen earlier to optimize your arrays.

Next, we can look at the frequency domain to see how clean the received signal is.

In[7]:
```
## Rerun test measurement to make sure arrays have good data
vna.Test()
## Plot Frequency Domain
vna.PlotFD()
```

```
0 Sync:949 Freq:14053344 Real:213.6 Imag:-201.4 Mag:293.6 Phase:-43.3
```



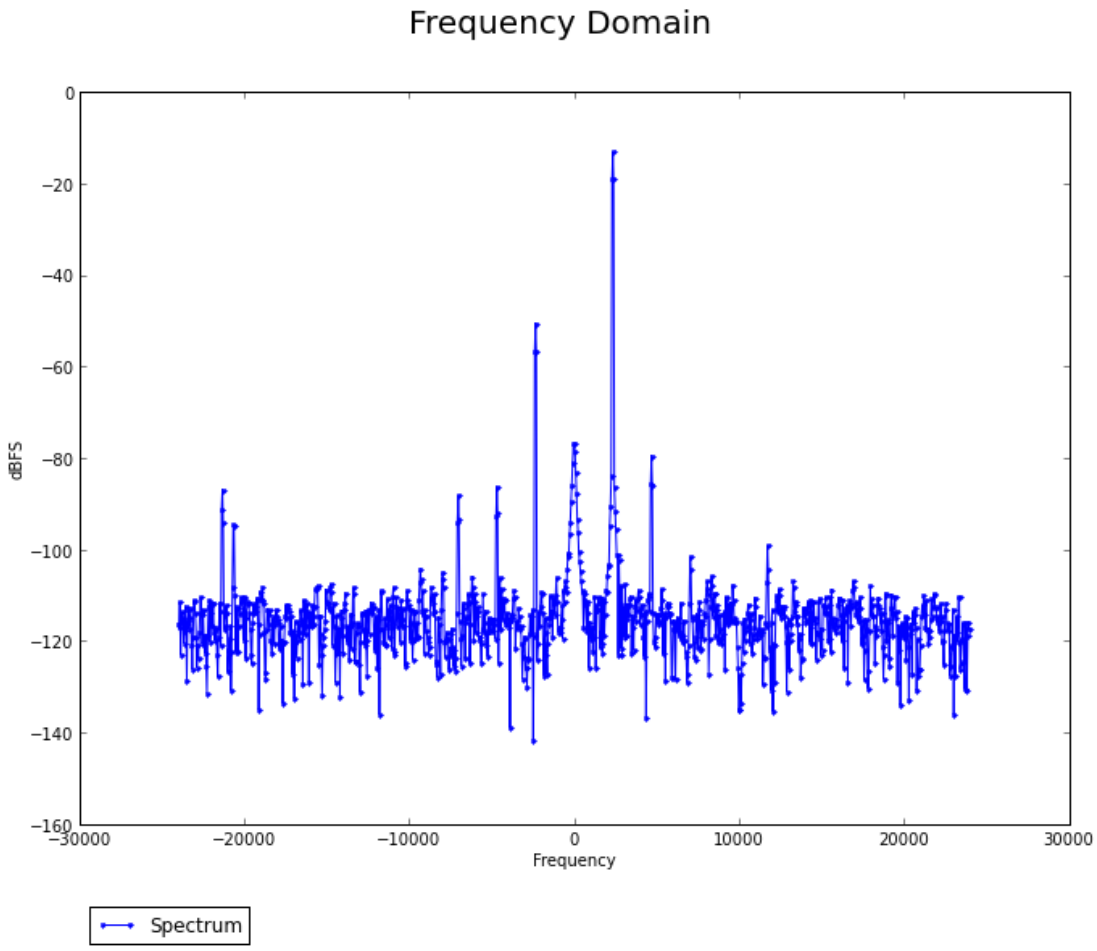
This plot indicates that the amplitude of the test tone is too large as there are numerous spikes in the frequency domain. You must lower the amplitude either with your external mixer or the following code block until you see only two (main and image) major spikes.

In[11]:
```
## Adjust amplitude
vna.NewAmp(0.08)
```

```
Amplitude was 0.08 now 1.0
```

In[8]:
```
## Regenerate test data
vna.Test()
## Replot Frequency domain
vna.PlotFD()
```

```
0 Sync:949 Freq:14053344 Real:17.0 Imag:-111.8 Mag:113.1 Phase:-81.3
```



You can reexecute the previous code block until you find a setting which has the maximum magnitude for the main test tone (around 2350 kHz) yet produces few distortion spikes. This should provide the best signal to noise ratio. Note that no IQ balancing is done as I don't believe it will improve the VNA measurements.

Now that you have calibrated your sound card audio with your SoftRock, you probably don't want to go through this calibration process again. Execute the following code block, and edit your `config.py` file to reflect your settings for `rtframes` and `amp`. You may also change the FFT size and test tone frequency. The software will adjust the test tone frequency to align to the nearest FFT bin.

In[9]:
```
vna.Info()
```

```
FFT Size: 1024 FFT Bin: 50 Test Freq: 2343.75 Amp: 1.0 RT Frames: 830
Array Length: 2048 Sync Index 949
```

Now that audio delays and levels have been set, you can execute multiple iterations of `Test()` to verify that your

VNA is making fairly consistent measurements.

In[10]:
```
## Execute 15 test measurements
vna.Test(15)
```

```
0 Sync:949 Freq:14053344 Real:17.0 Imag:-111.8 Mag:113.1 Phase:-81.4
1 Sync:949 Freq:14053344 Real:16.9 Imag:-111.7 Mag:113.0 Phase:-81.4
2 Sync:949 Freq:14053344 Real:16.8 Imag:-111.7 Mag:113.0 Phase:-81.4
3 Sync:949 Freq:14053344 Real:16.8 Imag:-111.7 Mag:112.9 Phase:-81.4
4 Sync:949 Freq:14053344 Real:16.8 Imag:-111.7 Mag:112.9 Phase:-81.5
5 Sync:949 Freq:14053344 Real:16.8 Imag:-111.7 Mag:112.9 Phase:-81.5
6 Sync:949 Freq:14053344 Real:16.8 Imag:-111.7 Mag:112.9 Phase:-81.5
7 Sync:949 Freq:14053344 Real:16.7 Imag:-111.6 Mag:112.9 Phase:-81.5
8 Sync:949 Freq:14053344 Real:16.7 Imag:-111.6 Mag:112.9 Phase:-81.5
9 Sync:949 Freq:14053344 Real:16.7 Imag:-111.6 Mag:112.9 Phase:-81.5
10 Sync:949 Freq:14053344 Real:16.7 Imag:-111.6 Mag:112.9 Phase:-81.5
11 Sync:949 Freq:14053344 Real:16.7 Imag:-111.6 Mag:112.9 Phase:-81.5
12 Sync:949 Freq:14053344 Real:16.7 Imag:-111.6 Mag:112.9 Phase:-81.5
13 Sync:949 Freq:14053344 Real:16.7 Imag:-111.6 Mag:112.9 Phase:-81.5
14 Sync:949 Freq:14053344 Real:16.7 Imag:-111.6 Mag:112.9 Phase:-81.5
```

The maginitude (Mag) and phase numbers should only vary by a few tenths as seen above. Notice that the measurements stabalize over time. I believe this is due to the SoftRock heating up.

1.4 Calibrate the VNA

Your VNA is now ready to make real measurements. The software uses a measurement object to store open, load, short and DUT measurements for a range of frequencies. The following code creates a measurement object `m` that will sweep over the 20M band in 5 kHz steps. In this example, the expected impedance of your load standard `eloadz` and feedline `feedlinez` is also specified. Default settings for these values may also be specified in `config.py`.

In[11]:
```
## Create a measurement object for 20M
m = Measurement(14,14.351,fstep=0.005,eloadz=60+0j,feedlinez=50+0j)
```

Connect your load standard to your SoftRock (mine is 60 Ohms) and execute the following calibration code for your measurement object `m`.

In[12]:
```
## Load Calibration
vna.ML(m)
```

```
Beginning Load Measurements
Sync:949 Freq:14000000 Real:31.6 Imag:-54.7 Mag:63.1 Phase:-60.0
Sync:949 Freq:14005000 Real:31.4 Imag:-54.8 Mag:63.1 Phase:-60.2
Sync:949 Freq:14010000 Real:31.2 Imag:-54.9 Mag:63.1 Phase:-60.4
Sync:949 Freq:14015000 Real:31.0 Imag:-55.0 Mag:63.1 Phase:-60.6
Sync:949 Freq:14020000 Real:30.8 Imag:-55.1 Mag:63.1 Phase:-60.7
Sync:949 Freq:14025000 Real:30.7 Imag:-55.2 Mag:63.1 Phase:-60.9
Sync:949 Freq:14030000 Real:30.5 Imag:-55.3 Mag:63.1 Phase:-61.1
Sync:949 Freq:14035000 Real:30.4 Imag:-55.4 Mag:63.1 Phase:-61.3
Sync:949 Freq:14040000 Real:30.2 Imag:-55.5 Mag:63.2 Phase:-61.4
Sync:949 Freq:14045000 Real:30.1 Imag:-55.6 Mag:63.2 Phase:-61.6
```

Sync:949 Freq:14050000 Real:29.9 Imag:-55.7 Mag:63.2 Phase:-61.8
Sync:949 Freq:14055000 Real:29.7 Imag:-55.8 Mag:63.2 Phase:-61.9
Sync:949 Freq:14060000 Real:29.6 Imag:-55.9 Mag:63.2 Phase:-62.1
Sync:949 Freq:14065000 Real:29.4 Imag:-56.0 Mag:63.2 Phase:-62.3
Sync:949 Freq:14070000 Real:29.2 Imag:-56.1 Mag:63.2 Phase:-62.4
Sync:949 Freq:14075000 Real:29.1 Imag:-56.1 Mag:63.2 Phase:-62.6
Sync:949 Freq:14080000 Real:28.9 Imag:-56.2 Mag:63.3 Phase:-62.8
Sync:949 Freq:14085000 Real:28.8 Imag:-56.3 Mag:63.3 Phase:-62.9
Sync:949 Freq:14090000 Real:28.6 Imag:-56.4 Mag:63.3 Phase:-63.1
Sync:949 Freq:14095000 Real:28.5 Imag:-56.5 Mag:63.3 Phase:-63.3
Sync:949 Freq:14100000 Real:28.3 Imag:-56.6 Mag:63.3 Phase:-63.4
Sync:949 Freq:14105000 Real:28.1 Imag:-56.7 Mag:63.3 Phase:-63.6
Sync:949 Freq:14110000 Real:28.0 Imag:-56.8 Mag:63.3 Phase:-63.8
Sync:949 Freq:14115000 Real:27.8 Imag:-56.9 Mag:63.3 Phase:-63.9
Sync:949 Freq:14120000 Real:27.7 Imag:-57.0 Mag:63.3 Phase:-64.1
Sync:949 Freq:14125000 Real:27.5 Imag:-57.1 Mag:63.4 Phase:-64.3
Sync:949 Freq:14130000 Real:27.3 Imag:-57.2 Mag:63.4 Phase:-64.4
Sync:949 Freq:14135000 Real:27.2 Imag:-57.3 Mag:63.4 Phase:-64.6
Sync:949 Freq:14140000 Real:27.0 Imag:-57.3 Mag:63.4 Phase:-64.8
Sync:949 Freq:14145000 Real:26.8 Imag:-57.4 Mag:63.4 Phase:-64.9
Sync:949 Freq:14150000 Real:26.7 Imag:-57.5 Mag:63.4 Phase:-65.1
Sync:949 Freq:14155000 Real:26.5 Imag:-57.6 Mag:63.4 Phase:-65.3
Sync:949 Freq:14160000 Real:26.3 Imag:-57.7 Mag:63.4 Phase:-65.4
Sync:949 Freq:14165000 Real:26.2 Imag:-57.8 Mag:63.4 Phase:-65.6
Sync:949 Freq:14170000 Real:26.0 Imag:-57.9 Mag:63.4 Phase:-65.8
Sync:949 Freq:14175000 Real:25.9 Imag:-57.9 Mag:63.5 Phase:-65.9
Sync:949 Freq:14180000 Real:25.7 Imag:-58.0 Mag:63.5 Phase:-66.1
Sync:949 Freq:14185000 Real:25.6 Imag:-58.1 Mag:63.5 Phase:-66.3
Sync:949 Freq:14190000 Real:25.4 Imag:-58.2 Mag:63.5 Phase:-66.4
Sync:949 Freq:14195000 Real:25.2 Imag:-58.3 Mag:63.5 Phase:-66.6
Sync:949 Freq:14200000 Real:25.1 Imag:-58.4 Mag:63.5 Phase:-66.8
Sync:949 Freq:14205000 Real:24.9 Imag:-58.4 Mag:63.5 Phase:-66.9
Sync:949 Freq:14210000 Real:24.7 Imag:-58.5 Mag:63.5 Phase:-67.1
Sync:949 Freq:14215000 Real:24.6 Imag:-58.6 Mag:63.6 Phase:-67.3
Sync:949 Freq:14220000 Real:24.4 Imag:-58.7 Mag:63.6 Phase:-67.4
Sync:949 Freq:14225000 Real:24.3 Imag:-58.8 Mag:63.6 Phase:-67.6
Sync:949 Freq:14230000 Real:24.1 Imag:-58.9 Mag:63.6 Phase:-67.7
Sync:949 Freq:14235000 Real:23.9 Imag:-59.0 Mag:63.6 Phase:-67.9
Sync:949 Freq:14240000 Real:23.8 Imag:-59.0 Mag:63.7 Phase:-68.1
Sync:949 Freq:14245000 Real:23.6 Imag:-59.1 Mag:63.7 Phase:-68.2
Sync:949 Freq:14250000 Real:23.4 Imag:-59.2 Mag:63.7 Phase:-68.4
Sync:949 Freq:14255000 Real:23.3 Imag:-59.3 Mag:63.7 Phase:-68.6
Sync:949 Freq:14260000 Real:23.1 Imag:-59.4 Mag:63.7 Phase:-68.7
Sync:949 Freq:14265000 Real:22.9 Imag:-59.4 Mag:63.7 Phase:-68.9
Sync:949 Freq:14270000 Real:22.8 Imag:-59.5 Mag:63.7 Phase:-69.1
Sync:949 Freq:14275000 Real:22.6 Imag:-59.5 Mag:63.7 Phase:-69.2
Sync:949 Freq:14280000 Real:22.4 Imag:-59.6 Mag:63.7 Phase:-69.4
Sync:949 Freq:14285000 Real:22.3 Imag:-59.7 Mag:63.7 Phase:-69.6
Sync:949 Freq:14290000 Real:22.1 Imag:-59.8 Mag:63.7 Phase:-69.7
Sync:950 Freq:14295000 Real:21.9 Imag:-59.8 Mag:63.7 Phase:-69.9
Sync:950 Freq:14300000 Real:21.7 Imag:-59.9 Mag:63.7 Phase:-70.1
Sync:950 Freq:14305000 Real:21.6 Imag:-60.0 Mag:63.7 Phase:-70.2
Sync:950 Freq:14310000 Real:21.4 Imag:-60.0 Mag:63.7 Phase:-70.4
Sync:950 Freq:14315000 Real:21.2 Imag:-60.1 Mag:63.7 Phase:-70.5

```
Sync:950 Freq:14320000 Real:21.1 Imag:-60.1 Mag:63.7 Phase:-70.7
Sync:950 Freq:14325000 Real:20.9 Imag:-60.2 Mag:63.7 Phase:-70.9
Sync:950 Freq:14330000 Real:20.7 Imag:-60.3 Mag:63.7 Phase:-71.0
Sync:950 Freq:14335000 Real:20.6 Imag:-60.3 Mag:63.7 Phase:-71.2
Sync:950 Freq:14340000 Real:20.4 Imag:-60.4 Mag:63.7 Phase:-71.4
Sync:950 Freq:14345000 Real:20.2 Imag:-60.4 Mag:63.7 Phase:-71.5
Sync:950 Freq:14350000 Real:20.0 Imag:-60.5 Mag:63.7 Phase:-71.7
```

Connect your short standard and execute the following code.

In[13]:
```
## Short Calibration
vna.MS(m)
```

```
Beginning Short Measurements
Sync:950 Freq:14000000 Real:25.2 Imag:-13.2 Mag:28.5 Phase:-27.5
Sync:950 Freq:14005000 Real:25.3 Imag:-13.4 Mag:28.6 Phase:-27.9
Sync:950 Freq:14010000 Real:25.4 Imag:-13.4 Mag:28.7 Phase:-27.9
Sync:950 Freq:14015000 Real:25.5 Imag:-13.6 Mag:28.9 Phase:-28.2
Sync:950 Freq:14020000 Real:25.5 Imag:-13.8 Mag:29.0 Phase:-28.3
Sync:950 Freq:14025000 Real:25.6 Imag:-13.9 Mag:29.2 Phase:-28.5
Sync:950 Freq:14030000 Real:25.7 Imag:-13.9 Mag:29.2 Phase:-28.5
Sync:950 Freq:14035000 Real:25.7 Imag:-13.6 Mag:29.1 Phase:-28.0
Sync:950 Freq:14040000 Real:25.8 Imag:-13.9 Mag:29.2 Phase:-28.3
Sync:950 Freq:14045000 Real:25.8 Imag:-13.8 Mag:29.2 Phase:-28.1
Sync:950 Freq:14050000 Real:25.9 Imag:-14.1 Mag:29.5 Phase:-28.5
Sync:950 Freq:14055000 Real:26.0 Imag:-14.4 Mag:29.7 Phase:-29.0
Sync:950 Freq:14060000 Real:26.1 Imag:-14.5 Mag:29.8 Phase:-29.1
Sync:950 Freq:14065000 Real:26.1 Imag:-14.4 Mag:29.8 Phase:-29.0
Sync:950 Freq:14070000 Real:26.1 Imag:-14.1 Mag:29.7 Phase:-28.4
Sync:950 Freq:14075000 Real:26.2 Imag:-14.0 Mag:29.7 Phase:-28.1
Sync:950 Freq:14080000 Real:26.2 Imag:-14.1 Mag:29.8 Phase:-28.3
Sync:950 Freq:14085000 Real:26.3 Imag:-14.2 Mag:29.9 Phase:-28.4
Sync:950 Freq:14090000 Real:26.4 Imag:-14.8 Mag:30.3 Phase:-29.3
Sync:950 Freq:14095000 Real:26.5 Imag:-15.1 Mag:30.5 Phase:-29.7
Sync:950 Freq:14100000 Real:26.6 Imag:-15.0 Mag:30.5 Phase:-29.5
Sync:950 Freq:14105000 Real:26.6 Imag:-14.5 Mag:30.3 Phase:-28.6
Sync:950 Freq:14110000 Real:26.6 Imag:-14.5 Mag:30.3 Phase:-28.6
Sync:950 Freq:14115000 Real:26.7 Imag:-15.0 Mag:30.7 Phase:-29.3
Sync:950 Freq:14120000 Real:26.9 Imag:-15.7 Mag:31.1 Phase:-30.2
Sync:950 Freq:14125000 Real:26.9 Imag:-15.8 Mag:31.2 Phase:-30.3
Sync:950 Freq:14130000 Real:27.0 Imag:-16.0 Mag:31.4 Phase:-30.6
Sync:950 Freq:14135000 Real:27.1 Imag:-16.1 Mag:31.5 Phase:-30.7
Sync:950 Freq:14140000 Real:27.1 Imag:-16.2 Mag:31.6 Phase:-30.8
Sync:950 Freq:14145000 Real:27.2 Imag:-16.0 Mag:31.5 Phase:-30.5
Sync:950 Freq:14150000 Real:27.2 Imag:-16.3 Mag:31.8 Phase:-31.0
Sync:950 Freq:14155000 Real:27.3 Imag:-16.5 Mag:31.9 Phase:-31.1
Sync:950 Freq:14160000 Real:27.3 Imag:-16.2 Mag:31.8 Phase:-30.7
Sync:950 Freq:14165000 Real:27.4 Imag:-16.4 Mag:31.9 Phase:-30.9
Sync:950 Freq:14170000 Real:27.4 Imag:-16.6 Mag:32.1 Phase:-31.2
Sync:950 Freq:14175000 Real:27.5 Imag:-16.9 Mag:32.3 Phase:-31.6
Sync:950 Freq:14180000 Real:27.6 Imag:-16.8 Mag:32.3 Phase:-31.4
Sync:950 Freq:14185000 Real:27.6 Imag:-17.2 Mag:32.5 Phase:-31.9
Sync:950 Freq:14190000 Real:27.7 Imag:-17.3 Mag:32.6 Phase:-32.0
Sync:950 Freq:14195000 Real:27.7 Imag:-17.0 Mag:32.5 Phase:-31.6
```

```
Sync:950 Freq:14200000 Real:27.8 Imag:-17.3 Mag:32.7 Phase:-31.8
Sync:950 Freq:14205000 Real:27.8 Imag:-17.6 Mag:33.0 Phase:-32.4
Sync:950 Freq:14210000 Real:27.9 Imag:-17.7 Mag:33.1 Phase:-32.5
Sync:950 Freq:14215000 Real:27.9 Imag:-17.8 Mag:33.1 Phase:-32.6
Sync:950 Freq:14220000 Real:28.0 Imag:-17.9 Mag:33.2 Phase:-32.7
Sync:950 Freq:14225000 Real:28.0 Imag:-18.1 Mag:33.4 Phase:-32.8
Sync:950 Freq:14230000 Real:28.1 Imag:-18.2 Mag:33.5 Phase:-32.9
Sync:950 Freq:14235000 Real:28.1 Imag:-18.3 Mag:33.6 Phase:-33.0
Sync:950 Freq:14240000 Real:28.2 Imag:-18.3 Mag:33.6 Phase:-32.9
Sync:950 Freq:14245000 Real:28.2 Imag:-18.3 Mag:33.7 Phase:-32.9
Sync:950 Freq:14250000 Real:28.3 Imag:-18.2 Mag:33.7 Phase:-32.8
Sync:950 Freq:14255000 Real:28.4 Imag:-18.3 Mag:33.8 Phase:-32.9
Sync:950 Freq:14260000 Real:28.4 Imag:-18.1 Mag:33.7 Phase:-32.5
Sync:950 Freq:14265000 Real:28.5 Imag:-18.3 Mag:33.8 Phase:-32.7
Sync:950 Freq:14270000 Real:28.5 Imag:-18.6 Mag:34.0 Phase:-33.1
Sync:950 Freq:14275000 Real:28.6 Imag:-18.6 Mag:34.1 Phase:-33.0
Sync:950 Freq:14280000 Real:28.7 Imag:-18.0 Mag:33.9 Phase:-32.1
Sync:950 Freq:14285000 Real:28.7 Imag:-18.0 Mag:33.9 Phase:-32.0
Sync:950 Freq:14290000 Real:28.8 Imag:-18.4 Mag:34.1 Phase:-32.6
Sync:950 Freq:14295000 Real:28.8 Imag:-18.7 Mag:34.3 Phase:-33.0
Sync:950 Freq:14300000 Real:28.8 Imag:-19.4 Mag:34.7 Phase:-34.0
Sync:950 Freq:14305000 Real:28.8 Imag:-19.6 Mag:34.8 Phase:-34.2
Sync:950 Freq:14310000 Real:28.8 Imag:-19.8 Mag:35.0 Phase:-34.5
Sync:950 Freq:14315000 Real:28.9 Imag:-19.4 Mag:34.8 Phase:-33.9
Sync:950 Freq:14320000 Real:29.0 Imag:-19.7 Mag:35.0 Phase:-34.3
Sync:950 Freq:14325000 Real:29.0 Imag:-19.6 Mag:35.0 Phase:-34.0
Sync:950 Freq:14330000 Real:29.1 Imag:-19.5 Mag:35.1 Phase:-33.9
Sync:950 Freq:14335000 Real:29.1 Imag:-19.8 Mag:35.2 Phase:-34.3
Sync:950 Freq:14340000 Real:29.1 Imag:-20.2 Mag:35.4 Phase:-34.7
Sync:950 Freq:14345000 Real:29.1 Imag:-20.4 Mag:35.6 Phase:-35.0
Sync:950 Freq:14350000 Real:29.2 Imag:-20.5 Mag:35.6 Phase:-35.0
```

Connect your open standard.

In[14]:
```
## Open Calibration
vna.MO(m)
```

```
Beginning Open Measurements
Sync:950 Freq:14000000 Real:57.5 Imag:-110.9 Mag:124.9 Phase:-62.6
Sync:950 Freq:14005000 Real:59.8 Imag:-109.0 Mag:124.3 Phase:-61.2
Sync:950 Freq:14010000 Real:56.6 Imag:-111.4 Mag:124.9 Phase:-63.1
Sync:950 Freq:14015000 Real:56.2 Imag:-111.6 Mag:125.0 Phase:-63.3
Sync:950 Freq:14020000 Real:55.8 Imag:-111.9 Mag:125.0 Phase:-63.5
Sync:950 Freq:14025000 Real:55.4 Imag:-112.1 Mag:125.1 Phase:-63.7
Sync:950 Freq:14030000 Real:55.0 Imag:-112.4 Mag:125.1 Phase:-63.9
Sync:950 Freq:14035000 Real:54.7 Imag:-112.7 Mag:125.2 Phase:-64.1
Sync:950 Freq:14040000 Real:54.3 Imag:-112.9 Mag:125.3 Phase:-64.3
Sync:950 Freq:14045000 Real:53.9 Imag:-113.2 Mag:125.3 Phase:-64.5
Sync:950 Freq:14050000 Real:53.5 Imag:-113.4 Mag:125.4 Phase:-64.8
Sync:950 Freq:14055000 Real:53.1 Imag:-113.7 Mag:125.5 Phase:-65.0
Sync:950 Freq:14060000 Real:52.7 Imag:-113.9 Mag:125.5 Phase:-65.2
Sync:950 Freq:14065000 Real:52.3 Imag:-114.2 Mag:125.6 Phase:-65.4
Sync:950 Freq:14070000 Real:51.9 Imag:-114.5 Mag:125.7 Phase:-65.6
Sync:950 Freq:14075000 Real:51.5 Imag:-114.7 Mag:125.8 Phase:-65.8
```

Sync:950 Freq:14080000 Real:51.2 Imag:-115.0 Mag:125.8 Phase:-66.0
Sync:950 Freq:14085000 Real:50.8 Imag:-115.2 Mag:125.9 Phase:-66.2
Sync:950 Freq:14090000 Real:50.4 Imag:-115.5 Mag:126.0 Phase:-66.4
Sync:950 Freq:14095000 Real:50.0 Imag:-115.7 Mag:126.1 Phase:-66.6
Sync:950 Freq:14100000 Real:49.6 Imag:-116.0 Mag:126.2 Phase:-66.9
Sync:950 Freq:14105000 Real:49.2 Imag:-116.2 Mag:126.2 Phase:-67.1
Sync:950 Freq:14110000 Real:48.8 Imag:-116.5 Mag:126.3 Phase:-67.3
Sync:950 Freq:14115000 Real:48.4 Imag:-116.8 Mag:126.4 Phase:-67.5
Sync:950 Freq:14120000 Real:48.0 Imag:-117.0 Mag:126.5 Phase:-67.7
Sync:950 Freq:14125000 Real:47.6 Imag:-117.3 Mag:126.6 Phase:-67.9
Sync:950 Freq:14130000 Real:47.2 Imag:-117.5 Mag:126.7 Phase:-68.1
Sync:950 Freq:14135000 Real:46.8 Imag:-117.8 Mag:126.7 Phase:-68.3
Sync:950 Freq:14140000 Real:46.4 Imag:-118.0 Mag:126.8 Phase:-68.5
Sync:950 Freq:14145000 Real:46.0 Imag:-118.3 Mag:126.9 Phase:-68.8
Sync:950 Freq:14150000 Real:45.6 Imag:-118.5 Mag:127.0 Phase:-69.0
Sync:950 Freq:14155000 Real:45.2 Imag:-118.8 Mag:127.1 Phase:-69.2
Sync:950 Freq:14160000 Real:44.7 Imag:-119.0 Mag:127.1 Phase:-69.4
Sync:950 Freq:14165000 Real:44.3 Imag:-119.3 Mag:127.2 Phase:-69.6
Sync:950 Freq:14170000 Real:43.9 Imag:-119.5 Mag:127.3 Phase:-69.8
Sync:950 Freq:14175000 Real:43.5 Imag:-119.7 Mag:127.4 Phase:-70.0
Sync:950 Freq:14180000 Real:43.1 Imag:-120.0 Mag:127.5 Phase:-70.2
Sync:950 Freq:14185000 Real:42.7 Imag:-120.3 Mag:127.6 Phase:-70.5
Sync:950 Freq:14190000 Real:42.3 Imag:-120.5 Mag:127.7 Phase:-70.7
Sync:950 Freq:14195000 Real:41.8 Imag:-120.7 Mag:127.8 Phase:-70.9
Sync:950 Freq:14200000 Real:41.4 Imag:-121.0 Mag:127.9 Phase:-71.1
Sync:950 Freq:14205000 Real:41.0 Imag:-121.2 Mag:128.0 Phase:-71.3
Sync:950 Freq:14210000 Real:40.6 Imag:-121.5 Mag:128.1 Phase:-71.5
Sync:950 Freq:14215000 Real:40.1 Imag:-121.7 Mag:128.1 Phase:-71.7
Sync:950 Freq:14220000 Real:39.7 Imag:-122.0 Mag:128.3 Phase:-72.0
Sync:950 Freq:14225000 Real:39.3 Imag:-122.2 Mag:128.3 Phase:-72.2
Sync:950 Freq:14230000 Real:38.8 Imag:-122.4 Mag:128.4 Phase:-72.4
Sync:950 Freq:14235000 Real:38.4 Imag:-122.7 Mag:128.5 Phase:-72.6
Sync:950 Freq:14240000 Real:38.0 Imag:-122.9 Mag:128.6 Phase:-72.8
Sync:950 Freq:14245000 Real:37.5 Imag:-123.1 Mag:128.7 Phase:-73.0
Sync:950 Freq:14250000 Real:37.1 Imag:-123.4 Mag:128.8 Phase:-73.3
Sync:950 Freq:14255000 Real:36.7 Imag:-123.6 Mag:128.9 Phase:-73.5
Sync:950 Freq:14260000 Real:36.2 Imag:-123.8 Mag:129.0 Phase:-73.7
Sync:950 Freq:14265000 Real:35.8 Imag:-124.1 Mag:129.1 Phase:-73.9
Sync:950 Freq:14270000 Real:35.3 Imag:-124.3 Mag:129.2 Phase:-74.1
Sync:950 Freq:14275000 Real:34.9 Imag:-124.5 Mag:129.3 Phase:-74.4
Sync:950 Freq:14280000 Real:34.4 Imag:-124.8 Mag:129.4 Phase:-74.6
Sync:950 Freq:14285000 Real:34.0 Imag:-125.0 Mag:129.5 Phase:-74.8
Sync:950 Freq:14290000 Real:33.5 Imag:-125.2 Mag:129.6 Phase:-75.0
Sync:950 Freq:14295000 Real:33.1 Imag:-125.5 Mag:129.8 Phase:-75.2
Sync:950 Freq:14300000 Real:32.6 Imag:-125.7 Mag:129.8 Phase:-75.5
Sync:950 Freq:14305000 Real:32.1 Imag:-125.9 Mag:130.0 Phase:-75.7
Sync:950 Freq:14310000 Real:31.7 Imag:-126.1 Mag:130.1 Phase:-75.9
Sync:950 Freq:14315000 Real:31.2 Imag:-126.4 Mag:130.2 Phase:-76.1
Sync:950 Freq:14320000 Real:30.7 Imag:-126.6 Mag:130.3 Phase:-76.3
Sync:950 Freq:14325000 Real:30.3 Imag:-126.8 Mag:130.4 Phase:-76.6
Sync:950 Freq:14330000 Real:29.8 Imag:-127.0 Mag:130.5 Phase:-76.8
Sync:950 Freq:14335000 Real:29.3 Imag:-127.3 Mag:130.6 Phase:-77.0
Sync:950 Freq:14340000 Real:28.9 Imag:-127.5 Mag:130.7 Phase:-77.2
Sync:950 Freq:14345000 Real:28.4 Imag:-127.7 Mag:130.8 Phase:-77.5

```
Sync:950 Freq:14350000 Real:27.9 Imag:-127.9 Mag:130.9 Phase:-77.7
```

Finally, connect your DUT.

In[6]:
```
## DUT Measurement
vna.MD(m)
```

```
Beginning DUT Measurements
Sync:949 Freq:14000000 Real:25.7 Imag:-79.6 Mag:83.6 Phase:-72.1
Sync:949 Freq:14005000 Real:25.3 Imag:-79.3 Mag:83.3 Phase:-72.3
Sync:949 Freq:14010000 Real:24.9 Imag:-79.0 Mag:82.9 Phase:-72.5
Sync:949 Freq:14015000 Real:24.6 Imag:-78.8 Mag:82.5 Phase:-72.7
Sync:949 Freq:14020000 Real:24.2 Imag:-78.5 Mag:82.1 Phase:-72.9
Sync:949 Freq:14025000 Real:23.9 Imag:-78.2 Mag:81.8 Phase:-73.0
Sync:949 Freq:14030000 Real:23.5 Imag:-77.9 Mag:81.4 Phase:-73.2
Sync:949 Freq:14035000 Real:23.2 Imag:-77.6 Mag:81.0 Phase:-73.4
Sync:949 Freq:14040000 Real:22.9 Imag:-77.3 Mag:80.7 Phase:-73.5
Sync:949 Freq:14045000 Real:22.7 Imag:-77.1 Mag:80.3 Phase:-73.6
Sync:949 Freq:14050000 Real:22.4 Imag:-76.8 Mag:80.0 Phase:-73.7
Sync:949 Freq:14055000 Real:22.2 Imag:-76.5 Mag:79.6 Phase:-73.8
Sync:949 Freq:14060000 Real:22.0 Imag:-76.2 Mag:79.3 Phase:-73.9
Sync:949 Freq:14065000 Real:21.8 Imag:-76.0 Mag:79.0 Phase:-74.0
Sync:949 Freq:14070000 Real:21.6 Imag:-75.7 Mag:78.7 Phase:-74.1
Sync:949 Freq:14075000 Real:21.4 Imag:-75.4 Mag:78.4 Phase:-74.1
Sync:949 Freq:14080000 Real:21.3 Imag:-75.2 Mag:78.1 Phase:-74.2
Sync:949 Freq:14085000 Real:21.2 Imag:-75.0 Mag:77.9 Phase:-74.2
Sync:949 Freq:14090000 Real:21.0 Imag:-74.7 Mag:77.6 Phase:-74.3
Sync:949 Freq:14095000 Real:21.0 Imag:-74.5 Mag:77.4 Phase:-74.3
Sync:949 Freq:14100000 Real:20.9 Imag:-74.3 Mag:77.2 Phase:-74.3
Sync:949 Freq:14105000 Real:20.8 Imag:-74.1 Mag:77.0 Phase:-74.3
Sync:949 Freq:14110000 Real:20.8 Imag:-73.9 Mag:76.8 Phase:-74.3
Sync:949 Freq:14115000 Real:20.7 Imag:-73.8 Mag:76.6 Phase:-74.3
Sync:949 Freq:14120000 Real:20.7 Imag:-73.6 Mag:76.5 Phase:-74.3
Sync:949 Freq:14125000 Real:20.7 Imag:-73.5 Mag:76.3 Phase:-74.3
Sync:949 Freq:14130000 Real:20.7 Imag:-73.4 Mag:76.2 Phase:-74.3
Sync:949 Freq:14135000 Real:20.7 Imag:-73.3 Mag:76.1 Phase:-74.2
Sync:949 Freq:14140000 Real:20.7 Imag:-73.2 Mag:76.0 Phase:-74.2
Sync:949 Freq:14145000 Real:20.7 Imag:-73.1 Mag:76.0 Phase:-74.2
Sync:949 Freq:14150000 Real:20.8 Imag:-73.1 Mag:76.0 Phase:-74.1
Sync:949 Freq:14155000 Real:20.8 Imag:-73.0 Mag:75.9 Phase:-74.1
Sync:949 Freq:14160000 Real:20.8 Imag:-73.0 Mag:75.9 Phase:-74.1
Sync:949 Freq:14165000 Real:20.8 Imag:-73.0 Mag:75.9 Phase:-74.1
Sync:949 Freq:14170000 Real:20.9 Imag:-73.0 Mag:76.0 Phase:-74.0
Sync:949 Freq:14175000 Real:20.9 Imag:-73.1 Mag:76.0 Phase:-74.0
Sync:949 Freq:14180000 Real:21.0 Imag:-73.1 Mag:76.1 Phase:-74.0
Sync:949 Freq:14185000 Real:21.0 Imag:-73.2 Mag:76.2 Phase:-74.0
Sync:949 Freq:14190000 Real:21.1 Imag:-73.3 Mag:76.3 Phase:-74.0
Sync:949 Freq:14195000 Real:21.1 Imag:-73.4 Mag:76.4 Phase:-74.0
Sync:949 Freq:14200000 Real:21.1 Imag:-73.6 Mag:76.5 Phase:-74.0
Sync:949 Freq:14205000 Real:21.2 Imag:-73.7 Mag:76.7 Phase:-74.0
Sync:949 Freq:14210000 Real:21.2 Imag:-73.8 Mag:76.8 Phase:-74.0
Sync:949 Freq:14215000 Real:21.2 Imag:-74.0 Mag:77.0 Phase:-74.0
Sync:949 Freq:14220000 Real:21.2 Imag:-74.2 Mag:77.2 Phase:-74.0
Sync:949 Freq:14225000 Real:21.2 Imag:-74.4 Mag:77.4 Phase:-74.1
```

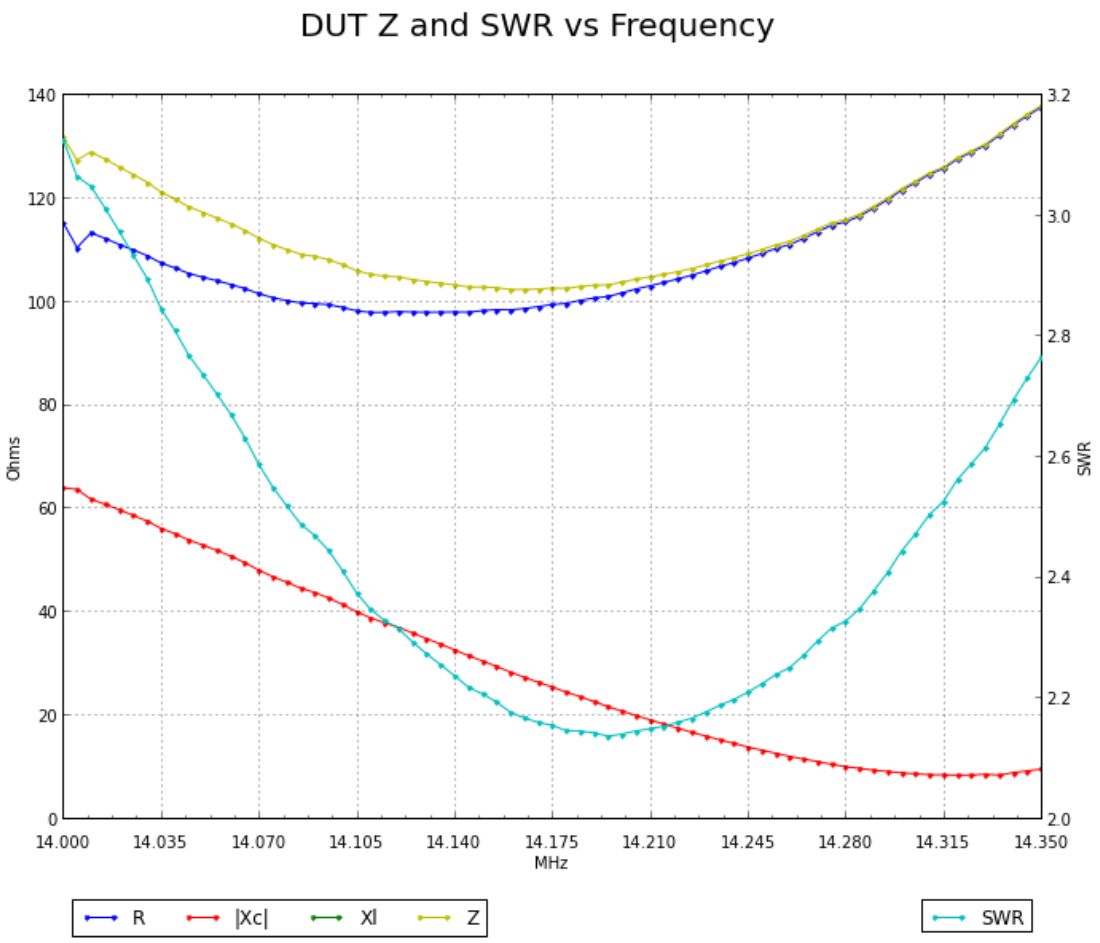
```
Sync:949 Freq:14230000 Real:21.2 Imag:-74.6 Mag:77.6 Phase:-74.1
Sync:949 Freq:14235000 Real:21.2 Imag:-74.9 Mag:77.8 Phase:-74.2
Sync:949 Freq:14240000 Real:21.2 Imag:-75.1 Mag:78.1 Phase:-74.2
Sync:949 Freq:14245000 Real:21.2 Imag:-75.4 Mag:78.3 Phase:-74.3
Sync:949 Freq:14250000 Real:21.1 Imag:-75.7 Mag:78.6 Phase:-74.4
Sync:949 Freq:14255000 Real:21.1 Imag:-76.0 Mag:78.9 Phase:-74.5
Sync:949 Freq:14260000 Real:21.0 Imag:-76.3 Mag:79.1 Phase:-74.6
Sync:949 Freq:14265000 Real:21.0 Imag:-76.6 Mag:79.4 Phase:-74.7
Sync:949 Freq:14270000 Real:20.9 Imag:-76.9 Mag:79.7 Phase:-74.8
Sync:949 Freq:14275000 Real:20.8 Imag:-77.3 Mag:80.0 Phase:-74.9
Sync:949 Freq:14280000 Real:20.7 Imag:-77.6 Mag:80.3 Phase:-75.1
Sync:949 Freq:14285000 Real:20.6 Imag:-78.0 Mag:80.6 Phase:-75.2
Sync:949 Freq:14290000 Real:20.4 Imag:-78.3 Mag:80.9 Phase:-75.4
Sync:949 Freq:14295000 Real:20.3 Imag:-78.7 Mag:81.3 Phase:-75.6
Sync:949 Freq:14300000 Real:20.1 Imag:-79.1 Mag:81.6 Phase:-75.7
Sync:949 Freq:14305000 Real:19.9 Imag:-79.5 Mag:81.9 Phase:-75.9
Sync:949 Freq:14310000 Real:19.7 Imag:-79.9 Mag:82.3 Phase:-76.1
Sync:949 Freq:14315000 Real:19.5 Imag:-80.3 Mag:82.6 Phase:-76.3
Sync:949 Freq:14320000 Real:19.3 Imag:-80.7 Mag:82.9 Phase:-76.6
Sync:949 Freq:14325000 Real:19.0 Imag:-81.1 Mag:83.3 Phase:-76.8
Sync:949 Freq:14330000 Real:18.8 Imag:-81.5 Mag:83.6 Phase:-77.0
Sync:949 Freq:14335000 Real:18.6 Imag:-81.9 Mag:84.0 Phase:-77.2
Sync:949 Freq:14340000 Real:18.2 Imag:-82.4 Mag:84.3 Phase:-77.5
Sync:949 Freq:14345000 Real:17.9 Imag:-82.8 Mag:84.7 Phase:-77.8
Sync:949 Freq:14350000 Real:17.6 Imag:-83.2 Mag:85.0 Phase:-78.1
```

You can save your measurement object with the following code. It is useful to save a measurement object as you can later reload it and only repeat the DUT measurement step. I find that I can make fairly accurate measurements without repeating OSL calibration from a saved measurement object provided my mixer settings are the same and the SoftRock power supply hasn't changed.

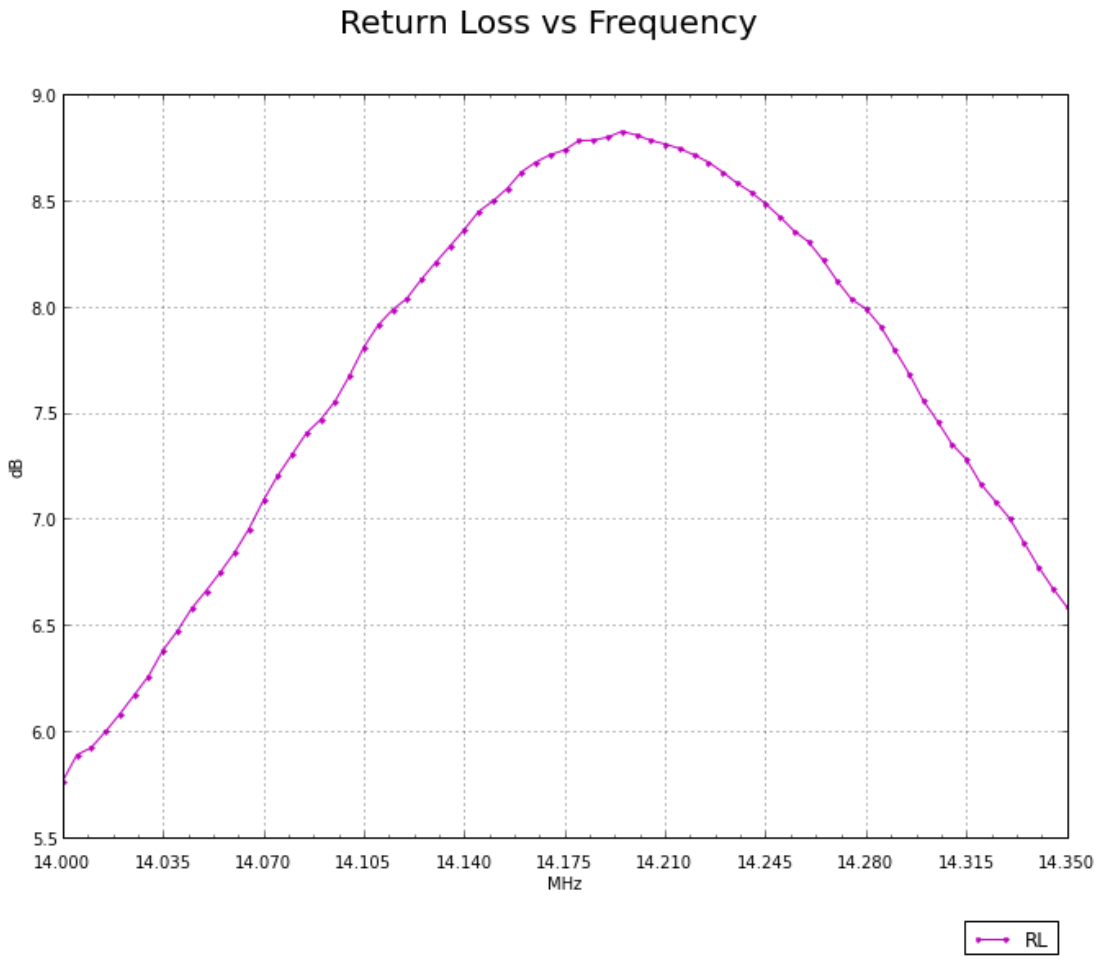
In[16]:
```
## Save your measurement (.vam file)
m.SaveMeasurement("Tutorial20M")
```

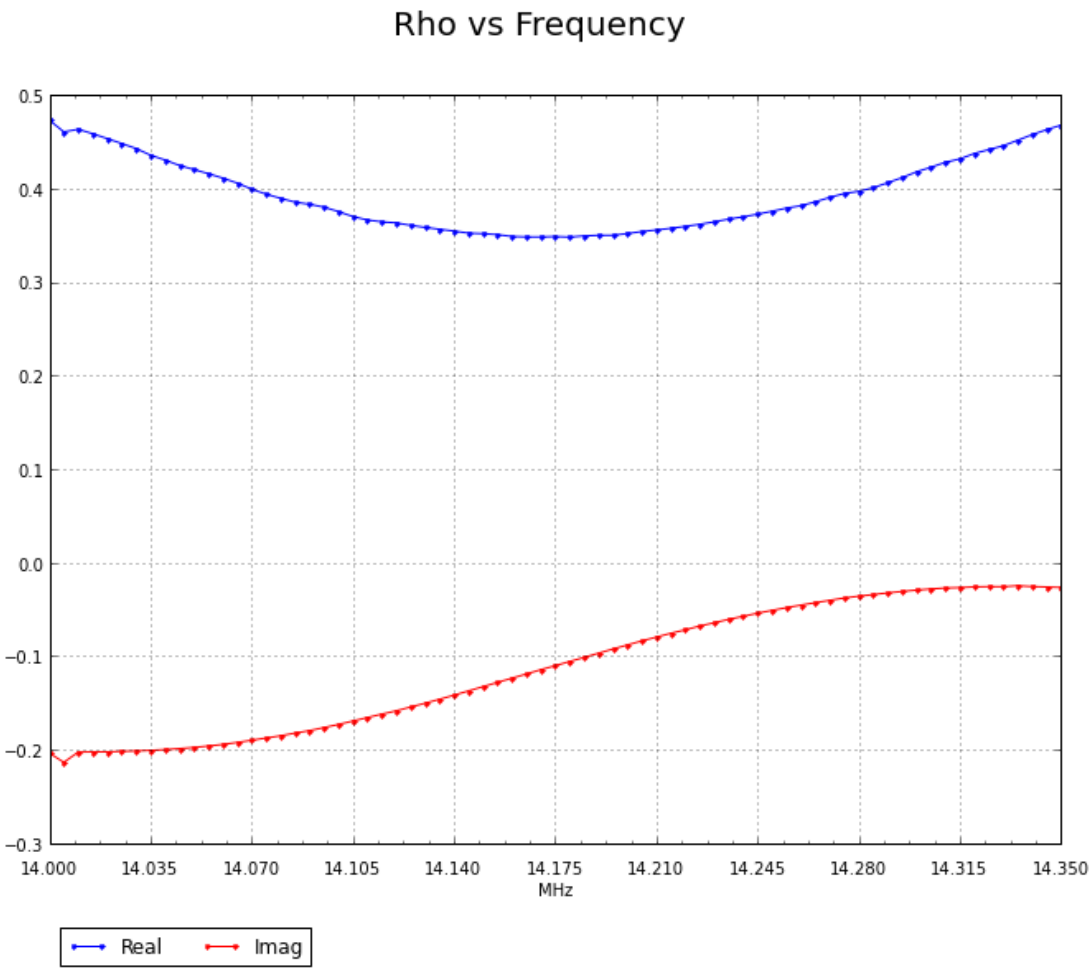
With a populated measurement object, you can create numerous plots as shown below.

In[7]:
```
## The basic plot
m.Plot()
```



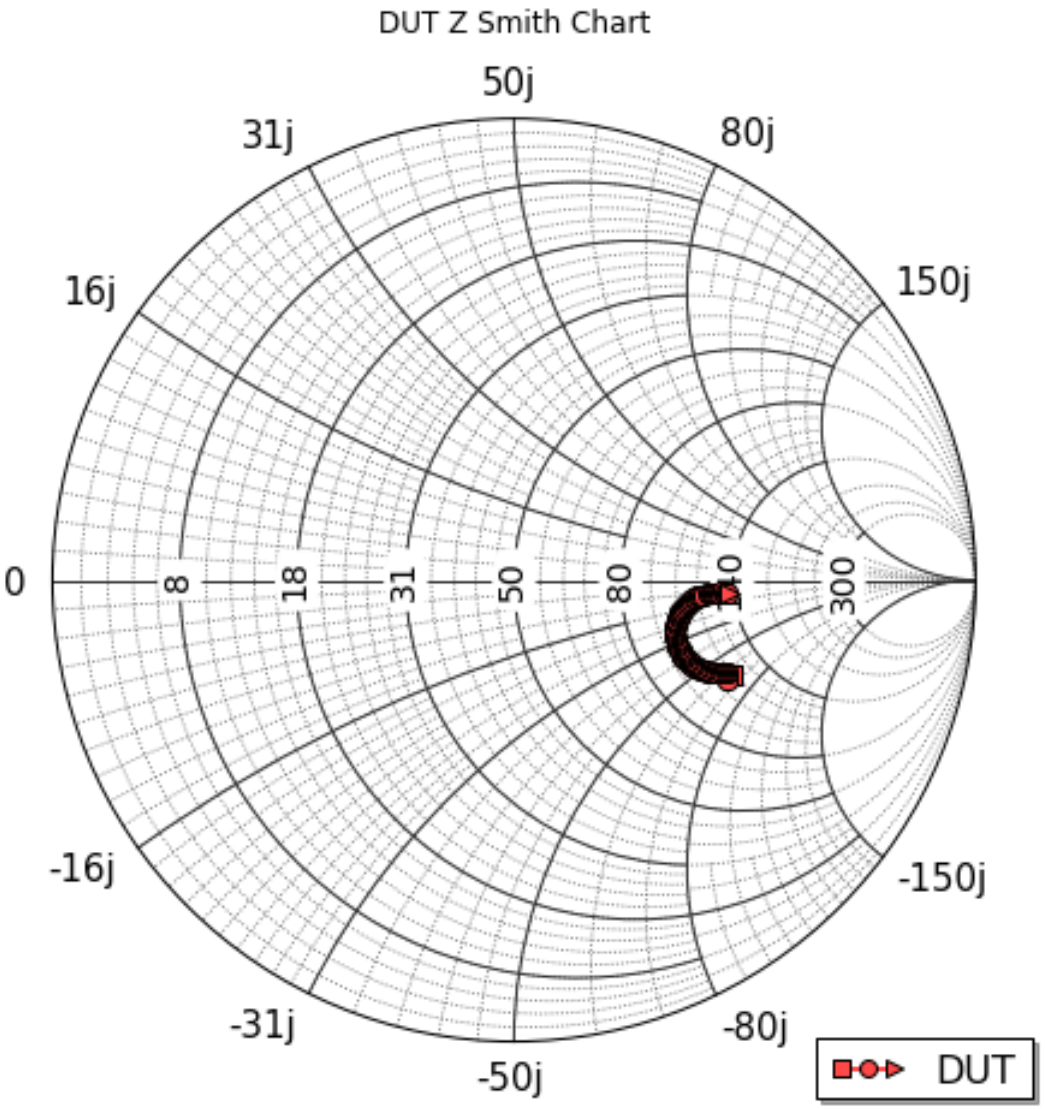
In[8]:
```
## Return loss and Rho
m.PlotRL()
m.PlotRho()
```


Return Loss vs Frequency
9.0
8.5
8.0
7.5
7.0
6.5
6.0
5.5
dB
14.000
14.035
14.070
14.105
14.140
14.175
14.210
14.245
14.280
14.315
14.350
MHz
RL



See `help(m)` or the `Measurement.py` for a complete list of plots possible. If your installed matplotlib version is >=1.2, you can also generate a Smith chart.

In[9]:
```
## Create a Smith Chart
m.PlotSmithChart()
```



See the measurement notebook file for more details on measurement objects. Since PySDRVNA integrates with C arrays, it is best to exit cleanly with the following code.

In[25]:
```
## Exit cleanly
vna.Exit()
```