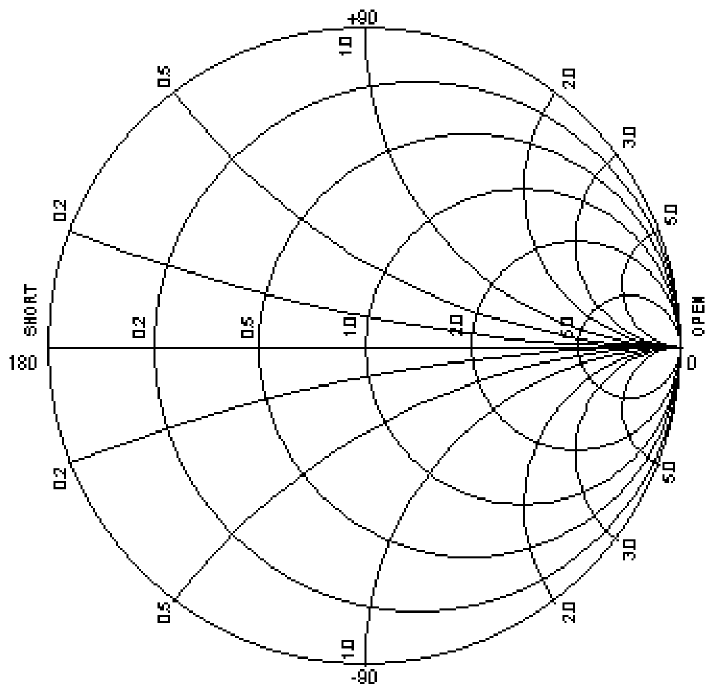
NanoVNA V2 Plus & Original NanoVNA PC Interface INSTALLATION and USERS MANUAL



December 4, 2020 – October 30, 2021

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1. What's New

The software for the V2+ series of VNAs has now been ported to support the original NanoVNA. There are two separate programs, one for each of the two VNAs. You may find the software and documents on my GitHub account:

https://github.com/joeqsmith

I also maintain a playlist on YouTube which contains various videos I have created demonstrating the VNA.

https://www.youtube.com/channel/UCsK99WXk9VhcghnAauTBsbg

The software was tested with the following firmware.

https://github.com/ttrftech/NanoVNA/releases/tag/0.8.0

An attempt was made to test Hugen79 1.0.45 NanoVNA-H_20210130.dfu which caused random errors in the data. This was found early on when I first started to look at the NanoVNA. Sadly, a year has passed, and the firmware is still unstable.

One person was attempting to use the NanoVNA H4 with firmware from DisLord. An H4 was eventually procured for test purposes. A simple regression test was running on both the latest firmware from Hugen and DisLord. Both had problems that would prevent their use. It seems one of the main justifications to run the DisLord firmware with the H4 is to allow for additional data points without having to use segmented sweeping. DisLord had released a much older version 1.0.38 which was also tested. While it has too many errors during the regression test to fully evaluate its performance, it does allow the user to try out a larger number of data points with this software. Expect to run into problems if you use an unsupported combination.

To improve the response time for segmented sweeps and peak zoom when using the original NanoVNA, the software was restructured like the V2+. The original NanoVNA supports a command to request the frequencies it is using. In my early versions of the software, I would request the frequency, then the two data sets. To speed things up, I would request only the first data set if I were using S11 along with the frequencies. Later I only requested the frequencies when I changed one of the settings that would affect it. The V2+ requires the software to calculate the frequencies. Newer versions of the software no longer support the frequency command. The original NanoVNA has always used 101 data points including the 1.08 firmware. Some new firmware is now supporting nonstandard number of data points. The number of data points is now user settable. The value can be stored into the defaults file.

With the various combinations of hardware, firmware and operating systems, it made no sense to release software for the first generation of hardware. You may wonder why release it now. There are a few reasons. First, my software has had a year to mature. While my expectations were that the new V2+ would exceed the performance of the original NanoVNA, it fell short. The design completely overlooked the need to perform narrow band measurements. While the software supported automated measurements of quartz crystals, the hardware/firmware design prevented its use.

Additionally, there have been ongoing efforts to create other software for the NanoVNAs. I have not been following their development but understand these programs have been largely adopted by the radio community. My software was not written for this group. It was designed as an engineering tool for the RF experimenter. Having other software available should help reduce the effort required to support this package.

If you are reading this, you know some time was spent documenting the software. Now that we have something in place, adding details of where the two programs deviate should take minimal effort.

Lastly, people like yourself kept asking for it.

From my own experience with the original NanoVNA, finding a stable version of firmware was always an issue. Many people were making changes to the firmware and releasing these into the public domain. Consequently, there seemed to be a focus on features that added no value when running headless. In some cases, it made the firmware less robust. To this day, I am running some very old firmware that has a fair number of problems. Even when running standalone, it is prone to lockups (requiring a power cycle), the screen will leave artifacts from a previous sweep, and maneuvering the NanoVNA's menus can cause the software to hang.

Those wanting to use this software with the original NanoVNA need to be aware that the poor quality of firmware and cloned hardware may cause a lot of wasted time. You are on your own.

Good luck

2. Documentation Update Log

Page Nos.	Amendment	SW Supported	Doc Rev	Date
All	Draft	0.10	0.04	December 5, 2020
All	Add crystal measurements and segmented sweeps	0.10	0.05	December 6, 2020
All	Add TDR, Touchstone and filter sections	0.10	0.06	December 7, 2020
All	Add calibration interpolation	0.10	0.07	December 10, 2020
All	Add offset loss to calibration. Update points when loading previous calibration. Change all frequencies to Hz and use SI units. Use standard units for RLC. Normalize all memories. Record normalized data if selected. Use common terms, Start, Stop, Port 1 & 2 Add details regarding the transfer relay.	0.10	0.08	December 11, 2020 - January 9, 2021
All	Corrections from review	0.10	0.09	January 22, 2021
All	Include specific details for the original NanoVNA. Correct scaling problem with Xtal C0 measurement. Problem was not discovered in the V2+ until after porting to the original NanoVNA.	1.00	0.10	March 13, 2021
All	Grammar corrections	1.00	0.11	March 21, 2021
All	Add troubleshooting when characterizing crystals.	1.00	0.12	March 23, 2021
All	Add sequence numbers in section 14.4. Add comment about regional settings and .INI file.	1.00	0.13	March 27, 2021 - March 31, 2021
All	Grammar corrections. Cursors now supports normalization.	1.00	0.14	April 1, 2021- April 10, 2021

	Full two port measurement menu was corrected. Added support for Polar Transmission. Add shunt through support for ESR measurements.			
All	Add details regarding ESR measurements	1.00	0.15	April 11, 2021
All	Add a software revision table. Add details about frequency table.	1.00	0.16	April 18, 2021
All	Update release table.	1.00	0.17	April 19, 2021
All	Add basic details about the changes with 2.0. Add section for PDN measurements.	2.00	0.20	June 9, 2021
All	Grammar corrections.	2.00	0.21	June 17, 2021
All	Add updates to TDR and amplifier stability.	2.00	0.23	Oct 27, 2021

3. Software Revision History

The following table provides a record of the software change history relating to versions released to the general public.

Version	Release Date	Hardware Supported	Firmware Supported	Description of Changes
1.10	4/18/2021	Original		When using segmented sweeps, segments are now concatenated while being captured. The software now displays all of the data captured rather than each segment.
1.03	4/11/2021	V2 Plus		Adds ESR measurement, Polar transmission, enhancements to full 2-port measurement display.
1.11	4/18/2021	Original		Allow programmable number of data points similar to the V2 Plus software. Allow saving to defaults. Support for Frequency command was removed in 1.09. This version allows the software to be used with firmware supporting 401 data points rather than the standard 101.
1.04	4/18/2021	V2 Plus		Fix range problem with segmented sweeps. Save the number of data points to the defaults file.
1.12	4/19/2021	Original		Remove hard coded data points during frequency change.
1.13	4/20/2021	Original		Disable data streaming when changing frequency settings. This was done as an attempt to solve a problem when using the software with the H4.
2.0	6/9/21	Original V2 Plus	Original: Custom from members at EEVBLOG	Added ability to auto center the waveform around the minimum location. Added ability to move the cursors to the maximum and minimum locations.

			V2Plus: git-20201010-86c7055 git-20201013-32077fd	Disabled sweeps before issuing shutdown. Removed support for Sweep Center/Span commands. Calculate all frequencies to simplify software, like the V2+ and other VNAs. Corrected bug in 2-port Touchstone format (used CH0 rather than CH1) Added dB delta markers. Removed the sweep flags from the receive processing. Receive processing will now be autonomous. Corrected rounding problem with step frequency. Blanked out date while the sweep parameters are being changed. When using segmented data, the software now passes the combined data to the temp storage to allow saving to Touchstone format. (Note that AppCAD does not like the quasi-log frequency sweep). Disabled sweeps while changing the frequency and remove disable from segmented sweeps. Added PDN compensation calculations. Changed the logic to retrigger and reset the nano during segmented sweeps to help support. PDN measurements. To speed up the segmented sweeps when making PDN measurements S11 is now automatically disabled. The number of segmented data points is now displayed in the status. Added phase measurement to PDN Bode plot.
2.01-.02 /	6/29/21	Original / V2 Plus		Improve the peak detection algorithm. Now using regression to solve.

2.00 - 01				
2.03 / 2.02	7/2/21	Original / V2 Plus		Allow exporting large Touchstone files when using segmented sweeps.
2.04/ 2.03	7/4/21	Original / V2 Plus		Remove overlap when using segmented log or linear sweeps which caused problems with various Touchstone viewers.
2.05	7/8/21	Original		Auto detect / handle regional settings without the need to use an INI file.
2.04	8/29/21	V2 Plus		Correct case for units. Increase the offload thread timeout. Change the font colors depending on the mode currently selected.
2.07/ 2.05	10/27/21	Original / V2 Plus		Fix order in S2P format. Add amplifier stability and gain calculations. Add polar graph magnifier. Change TDR from point slope calculation to use S-parameters to derive Z. Now requires SOL.

4. Trademarks

Intel is a registered trademark of Intel Corporation or its subsidiaries in the United States and other countries.

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5. Scope

This manual assumes the reader is PC literate and has some basic understanding of how a VNA works. It is not a learner's guide on using a VNA and offers no assistance into solving basic computer related problems.

The software is continually being developed. You may find some screen shots and features change throughout this document as a result.

The author is not an amateur radio or citizens band hobbyist. Because the software was written for my own personal use, there are many features that may be lacking or have not been completed. This is most likely due to my lack of having a use for them. Some parts of the software may be doing something totally different than what a typical user may expect. I change the software often depending on the tests I am trying to run.

This software can be viewed as an engineering tool at best. Its primary use was to extend the author's understanding of NanoVNA V2 Plus. It was never intended to be used as a general tool for radio hobbyists to tune their antennas. The software is buggy and not very robust. Even under normal conditions, expect to run into several problems if attempting to use this software. It is a very poor choice for the beginner.

This software is loosely based on a program I had written for my HP8754A, which still requires a copy of Windows XP to run. After receiving the original NanoVNA, the software was rewritten to support it while running Windows 10. It was then used as a basis for my other vintage VNAs. The real benefit is that the software has the same look and feel for all my analyzers, and it allows me to automate various experiments.

In this document, I will refer to both the NanoVNA Version 2 Plus and Version 2 Plus 4 as the V2+. As far as the software is concerned, the products are the same.

Upon receiving the V2+ and being unsuccessful with the standard software supplied with it, it made sense to support it as well. I have no need to support multiple analyzers with one software package.

This software supports the measuring and sorting of your collection of crystals in order to design your next filter. I had hoped that the new V2+ would outperform the original NanoVNA in every way but found it was not up to the task of measuring narrow band devices. To mitigate this problem, the software was ported over to support the original NanoVNA hardware.

There are a few undocumented differences between the V2+ and V2+4 that were discovered during the development of this software. The primary difference is that the V2+ appears to lockup during long data collections and requires being power cycled to recover. This was not seen with the V2+4.

6. Basic Architecture

The software was written in LabView, which is a graphical programming language. It was developed for automating tests and is well suited for this type of application. It also allows the creation of highly parallel programs which you can take advantage of with this software.

At the top level, the software has three threads. The lowest thread does nothing more than request data from the VNA, reads data from the communications port, for the V2+ performs a checksum and places the valid data into a queue. The queue is deep enough to handle any system delays that could possibility occur with the next thread.

The second thread waits for a valid entry in the queue. It pulls the entry and appends it to the data set. This thread then builds up an entire data set for one sweep. There are major differences between how the V2+ and the original NanoVNA handle the data.

The V2+ contains error checking (checksum) as well as in index while the original NanoVNA is more primitive and sends up an array of data with no index or error checking. The index is nothing more than the current sample's position in the sweep. If we are sweeping from 0.1 to 1MHz, the first sample has an index of 0. The second is 1 and so on.

Once the full data set is available, it then applies any coefficients to the data and filters it. The data is then passed onto the main thread.

The third thread is the main program which is responsible for plotting the data to the screen, recording data to disk and taking measurements. It also handles any user requests, for example, changing the sweep range.

Many of the subroutines are also processed in parallel. If you view the software in the task manager, there may be several threads running at a time.

With the release of 1.0, there are now two separate programs, one supporting the original NanoVNA's command set, the other for the V2+. A common code base is now being used. The top-level architecture and communications interface are different between the two programs. The remainder of the software is common. This should help with future development.

When running the two programs, there are a few differences. This manual provides some added details regarding them both.

7. Applicable Documents

The following specifications, standards, and handbooks form a part of this document to the extent specified herein. Unless otherwise specified, the issues of these documents are those listed.

NUMBER	TITLE/AUTHOR
1EZ43_0E	T-Check Accuracy Test for Vector Network Analyzers using a Tee-junction / Rohde&Schwarz
	Measurement of Electronic Component Impedance Using A Vector Network Analyzer / Copper Mountain Technologies
ED-11192A	Termination SMA ANNE-50+ Mini-Circuits
Note#1014, V1,10/27/04	Accurate Capacitor Inductance Extraction from S21 Measurements, Steve Weir
	Quick amplifier design with scattering parameters William H. Froehner Texas Instruments

8. Definition of Terms and Acronyms

Acronym	Definition
BW	Band Width
Cal	Calibration
CW	Continuous Wave
D	Dissipation Factor
Dec	Decade
ESR	Equivalent Series Resistance
FIFO	First In First Out
FWHH	Full Width Half Height
HPAK	Hewlett Packard Agilent Keysight
IntpCal	Interpolate Calibration
PCB	Printed Circuit Board
PDN	Power Distribution Network
Q	Quality Factor
Ref	Reference
SOLT	Short Open Load Thru (through)
TDR	Time Domain Reflectometer
Xfer	Transfer
Xtal	Crystal

9. Feature Summary

The following features are supported:

Support for the original NanoVNA and the V2+.
Supports Windows 10 (may run on OS's as early as XP).
   Requires LabView 2011 runtime engine and NIVISA.
Supports Agilent's standard coefficients.
Performs interpolation of calibration.
Generic support for add-on transfer relays.
Supports external up/down conversion.
Supports external transfer relay for full 2-port measurements.
Supports linear stage for TDR experiments.
Allows quasi logarithmic sweeps.
Bode plot for PDN measurements.
Calculate Amplifier Stability Factors.

10. Installation

Depending on what features you want to use and what peripherals are attached to your VNA, you may need to install additional drivers. The software will include an installer which contains the runtime engine only. No drivers will be included beyond NIVISA.

As of version 1.0 there are now two separate programs. One supports the original NanoVNA and the other supports the new V2+. The installer, .INI, runtime engine and VISA drivers will no longer be included. You may download these directly from NI, or just install the original release of the V2+ software. Once these are installed, copy the executable files to your directory.

10.1 Before You Begin

You will want to have all the drivers installed and make sure your PC is seeing the device before getting started. The software was tested using both the recommended Cypress as well as Microsoft's included drivers. No differences in their performance were noted.

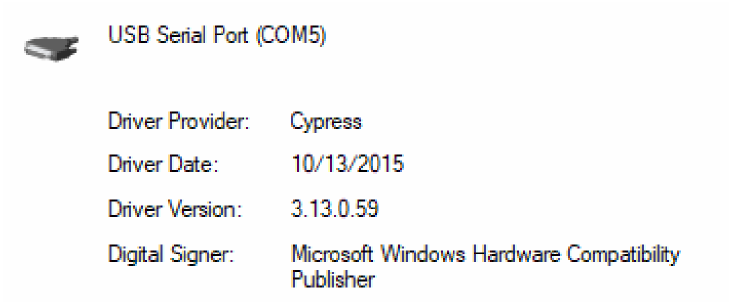


Figure 1

Figure 2

10.2 Windows Regional Settings

As of version 2.05, the regional settings for the original NanoVNA are done automatically.

If you have selected regional settings that use a comma rather than decimal point, the software will not communicate with the device. This is due to LabView expecting peripherals to handle the various separators. The NanoVNA only supports the decimal separator.

When the software is first installed it will create an .INI file. You will need add **useLocaleDecimalPt=False** to this file. The next time the program is executed, it should now use the decimal point.

If you deleted the .INI file created during the install, or manually installed the runtime engine and VISA, you can create the file using a text editor and pasting the following into it.

[NanoVNA]
server.app.propertiesEnabled=True
server.ole.enabled=True
server.tcp.paranoid=True

server.tcp.serviceName="My Computer/VI Server"
server.vi.callsEnabled=True
server.vi.propertiesEnabled=True
WebServer.TcpAccess="c+*"
WebServer.ViAccess="+*"
DebugServerEnabled=False
DebugServerWaitOnLaunch=False
useLocaleDecimalPt=False

10.3 Troubleshooting

Most of the problems seem to stem from user's inability to follow the basic instruction. Some of the more common problems are:

- Installing the EXEs and then randomly guess at which runtime is required. If they manage to find the correct one, they are unable to get the software to communicate with the device because they have not installed the correct VISA.

- Using the wrong software for the device.

- Downloading the installer and assuming the included 1.0 software is the latest available.

- Attempting to use different regional settings without changing the INI file. The NanoVNA fails to respond when the comma separator is selected.

- Trying to use an unsupported hardware / firmware combination. If you like to fiddle around reprogramming your VNA, the software is not well suited for you.

Do yourself a favor and read the readme file and manual. Of course, if you are reading this, I doubt you ran into one of above problems.

11. Button Quick Reference

The software contains quick tips. Move the mouse over the button to see a description.

Figure 3

12. Getting Started

For some of this section, the included cables, modified calibration standards and a low cost set of attenuators available from various sources will be used. The one we will be using is shown in figure 4.

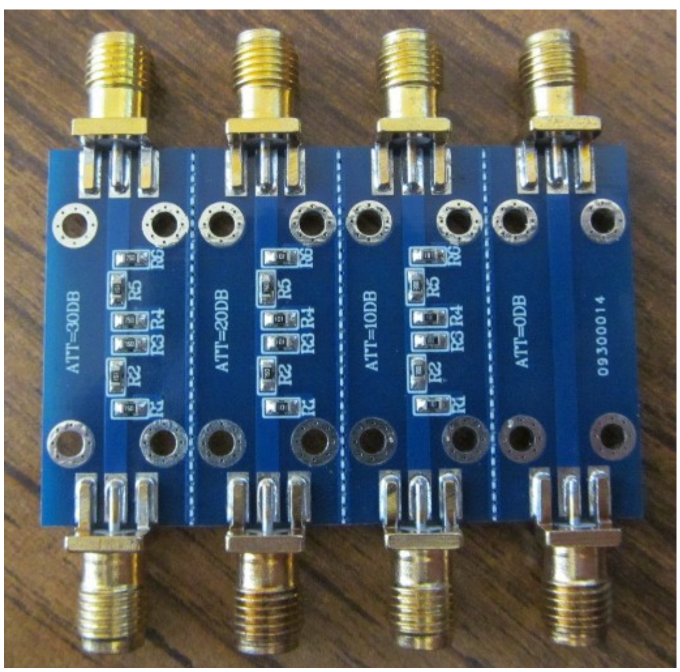


Figure 4

Features:
1.Special usage: This is a DC 4.0GHz RF Radio Frequency Fixed Attenuator.
2.The board layout is reasonable: beautiful, little current sound.
3.Uses the high quality material: stable and reliable performance.
4.Portable design: easy to install.
5.Good quality:durable to use.

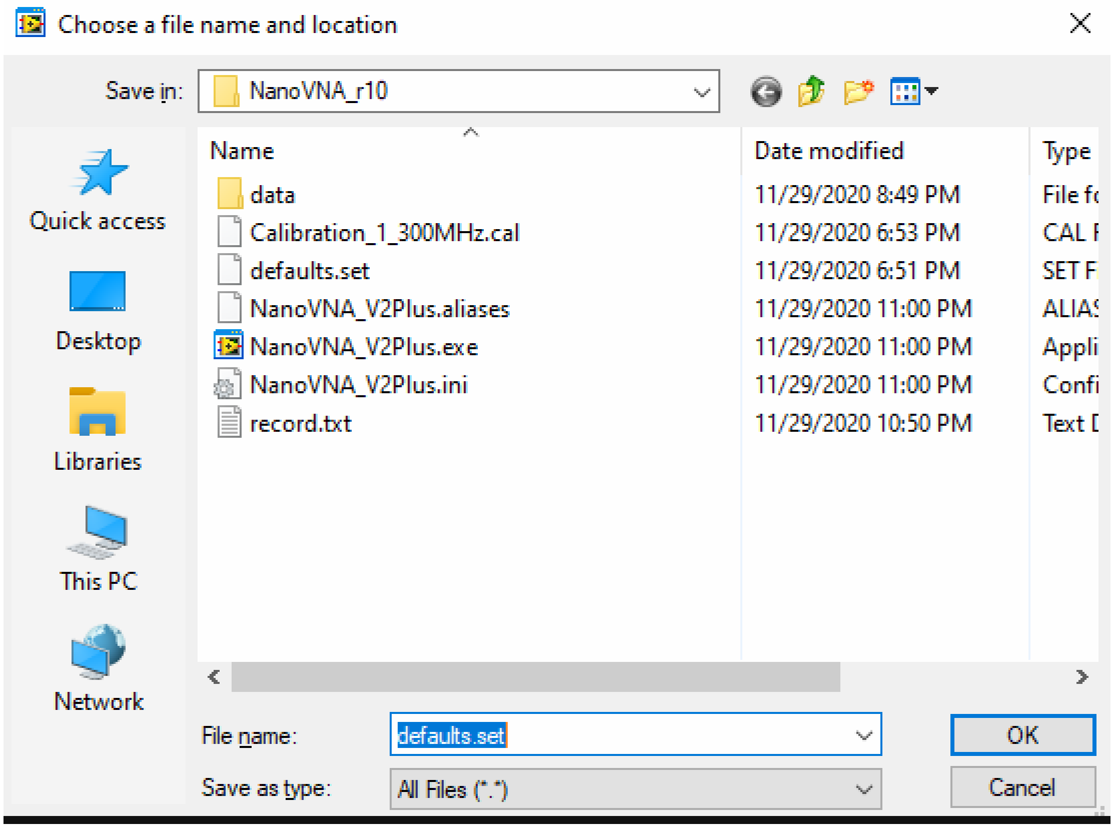
Descriptions:
1.The is a DC 4.0GHz RF Radio Frequency Fixed Attenuator Maximum power 23dBm SMA Double Female Head 0dB 10dB 20dB 30dB.
2.Compact design, easy to install.

Specifications:
Color:Green
Frequency range: DC-4.0GHz
Maximum power: 23dBm (200mW)
Standing wave ratio: 1.20
System impedance: 50
RF : SMA double female head (Outer screw inner hole)
Attenuation:

Direct: 0dB (reference)
Level 1: 10 0.8 dB
Level 2: 20 1.1 dB
Level 3: 30 1.5dB

12.1 Software Defaults

When starting the software, it will prompt you for a file that contains the default settings.



This file is not ASCII readable. It contains information about serial port settings, units, calibration standards and available peripherals. If you don't have a default setup, select cancel and the software will load with its default values.

Once the software has loaded you will be presented with the main menu (Figure 5). At this time, the software has not made any attempt to connect to the V2+ or any of the peripherals. If you do not yet have a properly configured default file, you will need to create one before attempting to do anything else with the software.

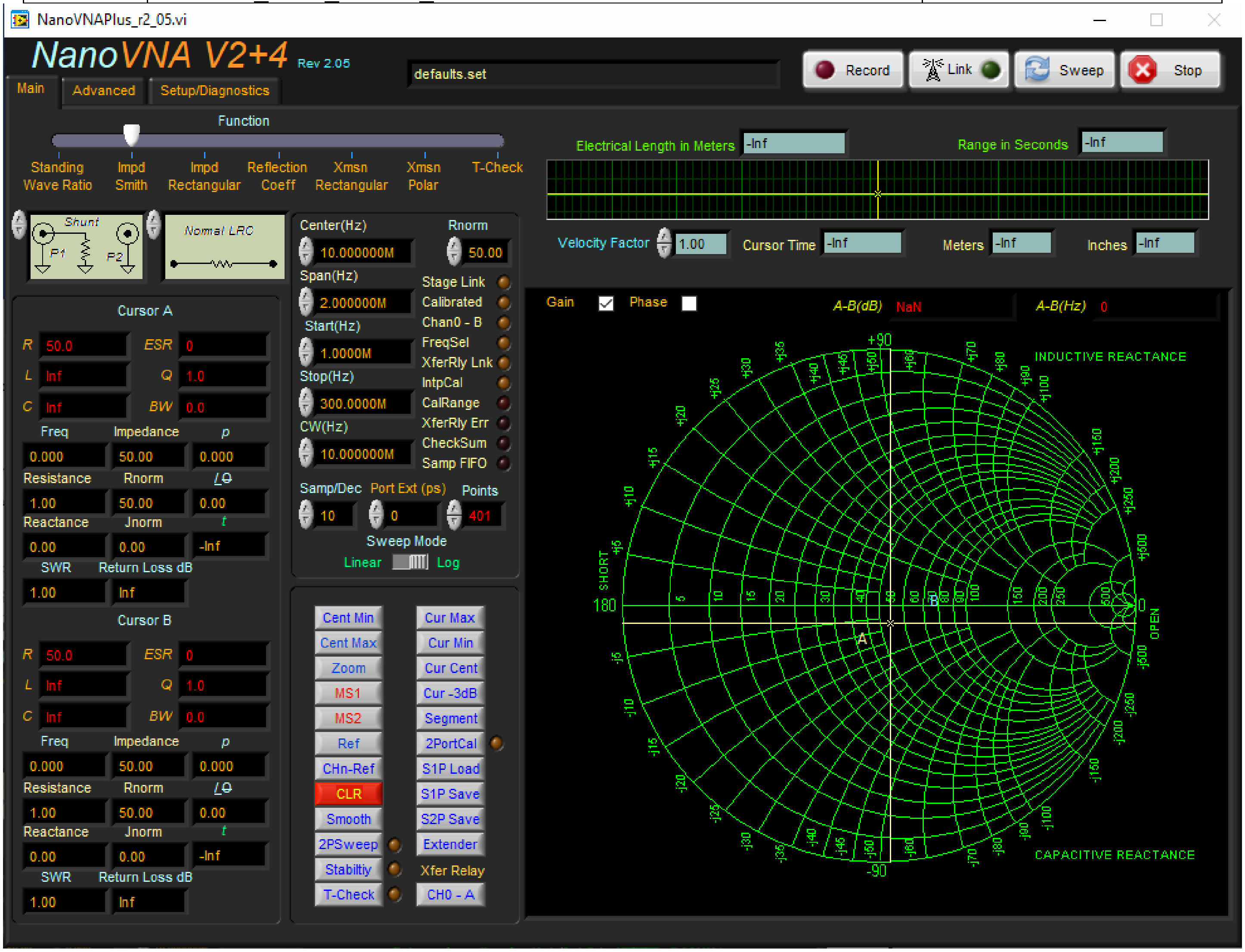
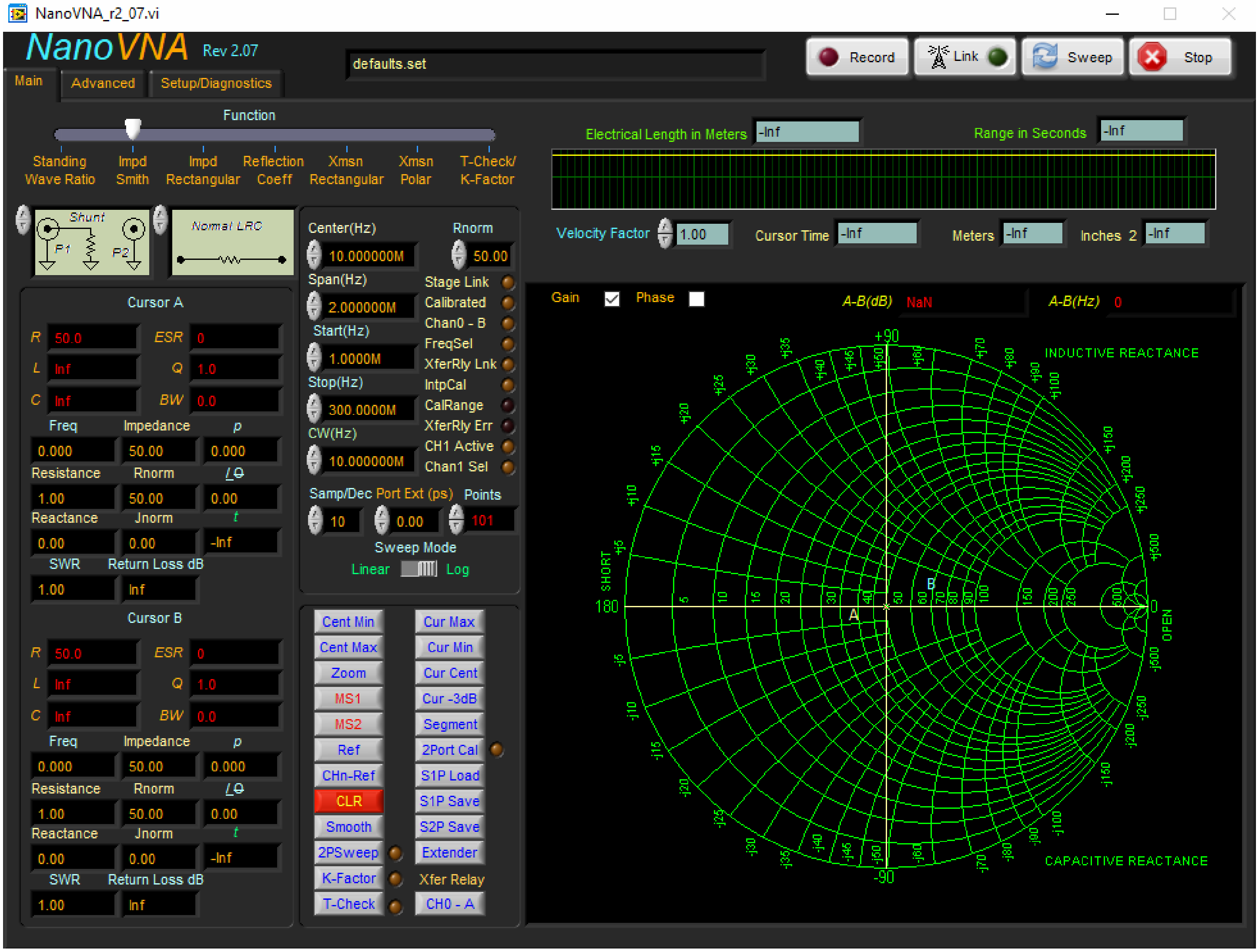


Figure 5

Looking at the main menu for the original NanoVNA (Figure 6), you can see the software is very similar. While both VNAs use the same physical layer to communicate, the original NanoVNA uses a different software layer. This goes beyond the command set. Rather than try and support multiple VNAs with a single application, the author made a clean cut of it. For the most part, these two programs drive the same.



NanoVNA_r2_07.vi
NanoVNA Rev 2.07
Main
Advanced
Setup/Diagnostics
defaults.set
Record
Link
Sweep
Stop
Function
Standing Wave Ratio
Impd Smith
Impd Rectangular
Reflection Coeff
Xmsn Rectangular
Xmsn Polar
T-Check/ K-Factor
Electrical Length in Meters
-Inf
Range in Seconds
-Inf
Velocity Factor
1.00
Cursor Time
-Inf
Meters
-Inf
Inches 2
-Inf
Shunt
P1
P2
Normal LRC
Cursor A
R
50.0
ESR
0
L
Inf
Q
1.0
C
Inf
BW
0.0
Freq
Impedance
p
0.000
50.00
0.000
Resistance
Rnorm
1.00
50.00
0.00
Reactance
Jnorm
t
0.00
0.00
-Inf
SWR
Return Loss dB
1.00
Inf
Cursor B
R
50.0
ESR
0
L
Inf
Q
1.0
C
Inf
BW
0.0
Freq
Impedance
p
0.000
50.00
0.000
Resistance
Rnorm
1.00
50.00
0.00
Reactance
Jnorm
t
0.00
0.00
-Inf
SWR
Return Loss dB
1.00
Inf
Center(Hz)
10.000000M
Rnorm
50.00
Span(Hz)
2.000000M
Start(Hz)
1.0000M
Stop(Hz)
300.0000M
CW(Hz)
10.000000M
Stage Link
Calibrated
Chan0 - B
FreqSel
XferRly Lnk
IntpCal
CalRange
XferRly Err
CH1 Active
Chan1 Sel
Samp/Dec
Port Ext (ps)
Points
10
0.00
101
Sweep Mode
Linear
Log
Cent Min
Cent Max
Zoom
MS1
MS2
Ref
CHn-Ref
CLR
Smooth
2PSweep
K-Factor
T-Check
Cur Max
Cur Min
Cur Cent
Cur -3dB
Segment
2Port Cal
S1P Load
S1P Save
S2P Save
Extender
Xfer Relay
CH0 - A
Gain
Phase
A-B(dB)
NaN
A-B(Hz)
0
INDUCTIVE REACTANCE
CAPACITIVE REACTANCE
SHORT
OPEN
+90
-90
180
0
A
B

Figure 6

12.2 Selecting the Communication Port

You will now need to setup the software. Start by selecting the Setup/Diagnostics tab (Figure 7).

Figure 7

In the upper right, select the communications port for the V2+. The BAUD rate for this device will have no effect on the transaction rates and can be ignored.

12.3 Selecting Calibration Standards

A quick word on using calibration standards. If you are familiar with HP, Agilent and Keysight (HPAK) analyzers, you may find the format familiar. This is by design. At this time the Loss and Delay coefficients for both the Load and Thru are ignored. You may also notice the software supports a port extension setting on the main page.

For the calibration standards, I suggest leaving the custom ideal standard selected. If you have characterized your standards against a known set, you may enter the data into the calibration standards tables. Scroll through the available standards with the up\down arrows. The set currently displayed is the one being used. You may create a new standard, adding as many as you like, or modify an existing set. You may also copy/paste/insert and delete standards. The entire database of standards is stored into the default file. Again, you may have more than one default file as well.

The V2+ was designed to work above 3GHz but it seems to have a fair amount of leakage (or cross coupling) between ports 1&2. Using the leakage terms can introduce noise into the reading and is normally ignored. However, it seems that without accounting for these terms with the V2+, the errors above 3GHz make the unit useless. You may manually enable these by selecting Leakage Terms. This setting is stored into the default file.

Once you have everything the way you like it, just select the SaveSetup and the software will prompt you for a file name. Use the default and select OK.

Keep in mind that you can change all of the settings at any time. You do not have to save them in order for them to take effect.

12.4 Linking to the Device

When the V2+ is powered on, the LCD will show the previous configuration.

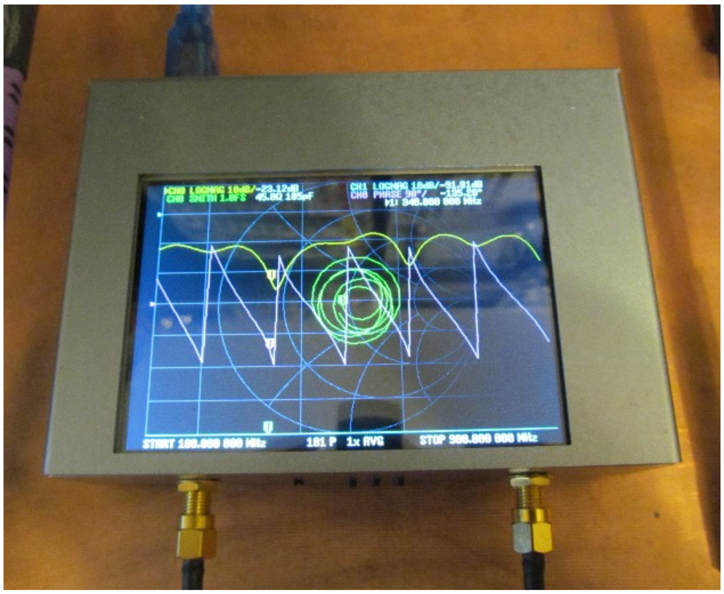


Figure 8

With the proper serial ports selected and known working, return to the main page and select Link. If the software locates the V2+, the link LED will turn green and information about the VNA will be displayed in the status bar (top center of screen, see Figure 9).

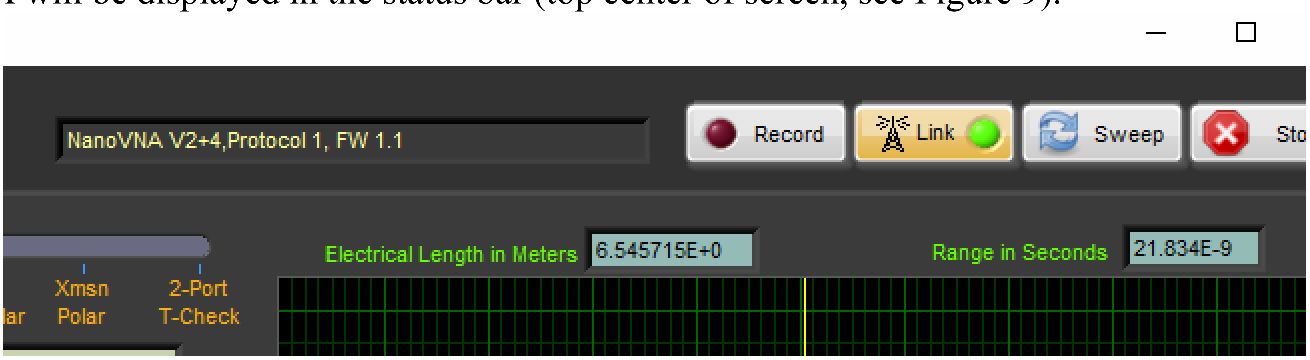


Figure 9

The Nano will display USB MODE (Figure 10). There is absolutely no use for the display when using the V2+ with the PC. As a matter of fact, the author has performed tests with the LCD completely removed, using only the main PCB.

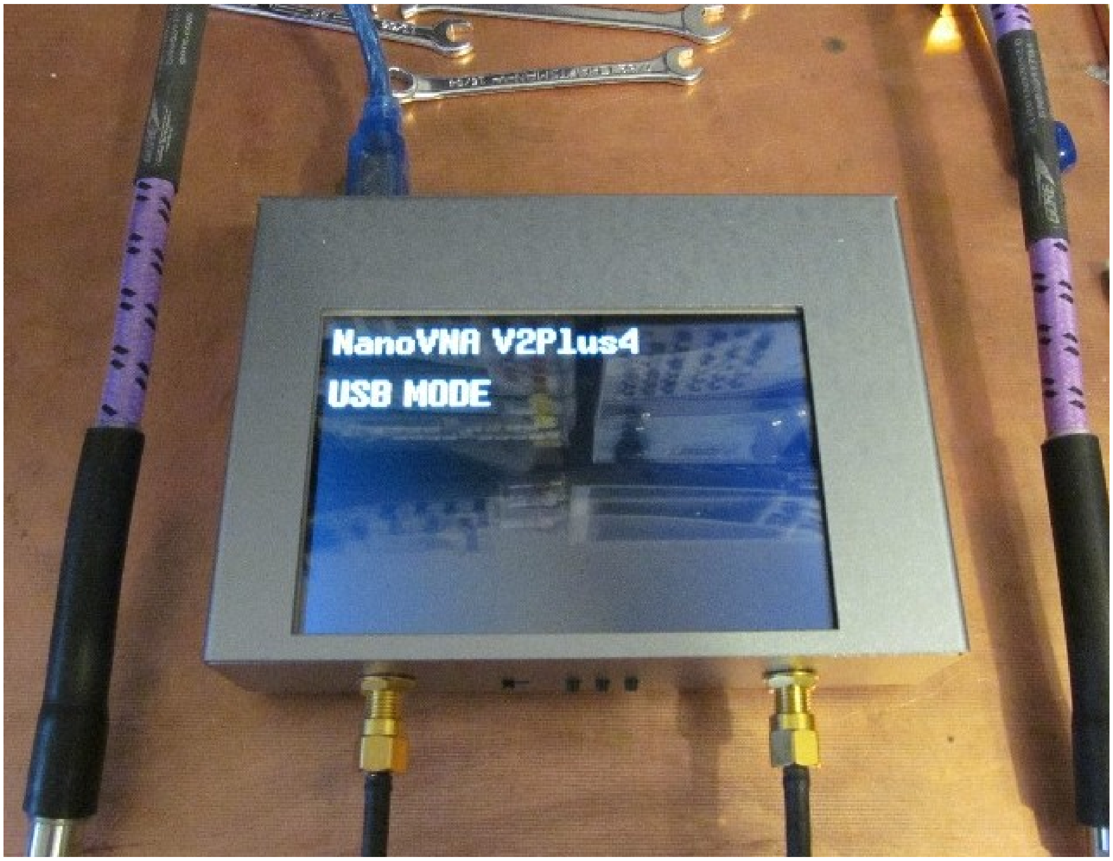


Figure 10

12.5 Displaying Data

The software will default to a center frequency of 10MHz with a 2MHz span and 201 data points (Frequency spectrum shown in Figure 11). The V2+ was programmed with these defaults when the connection was made. The V2+ is actually sweeping at this time. Select the Sweep button and the software will begin collecting data from the V2+.

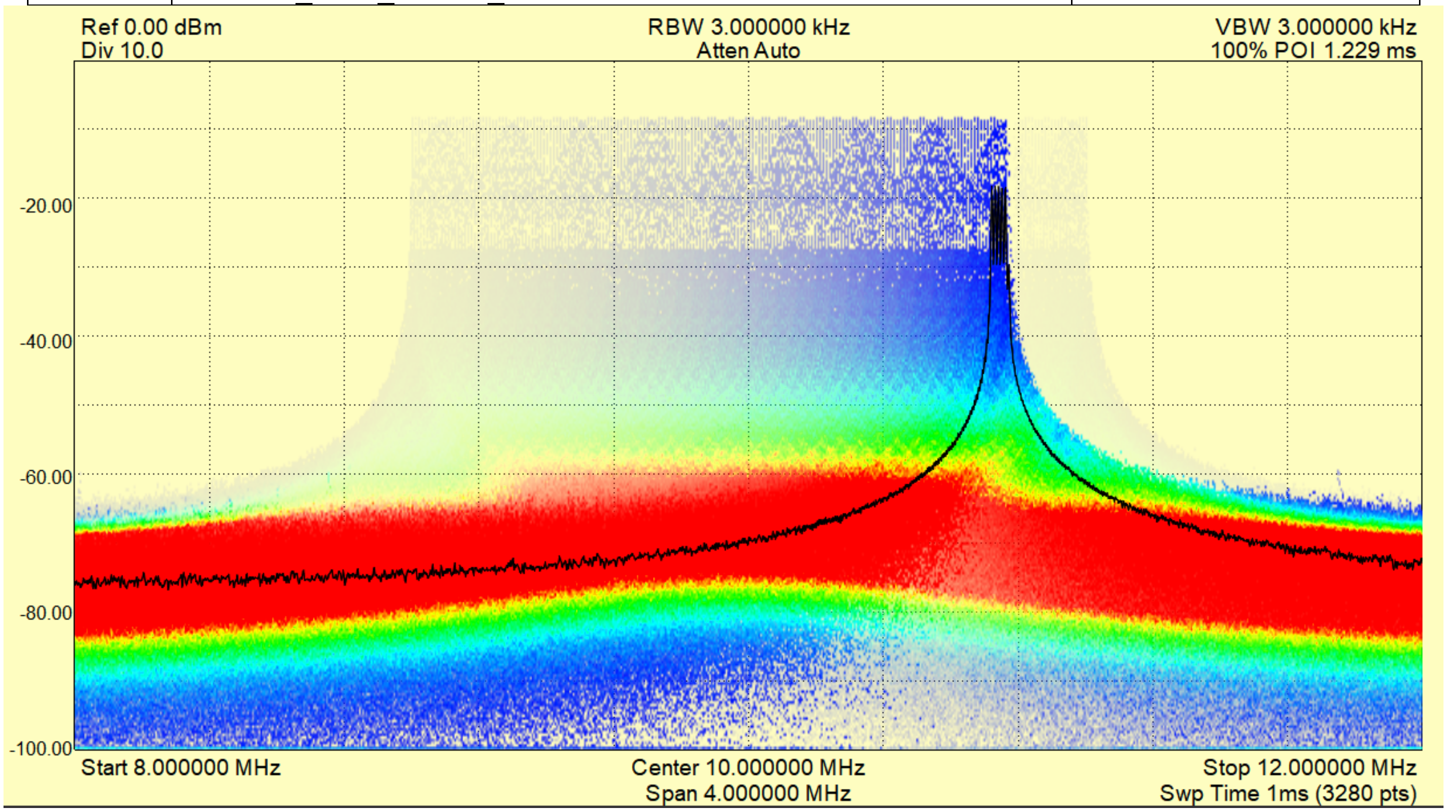


Figure 11

12.6 Normalization Example

The graph shown in Figure 12 depicts a 10dB attenuator which has been attached between Port 1&2. You can see that S11 shows very close to 50 ohms without performing any calibration.

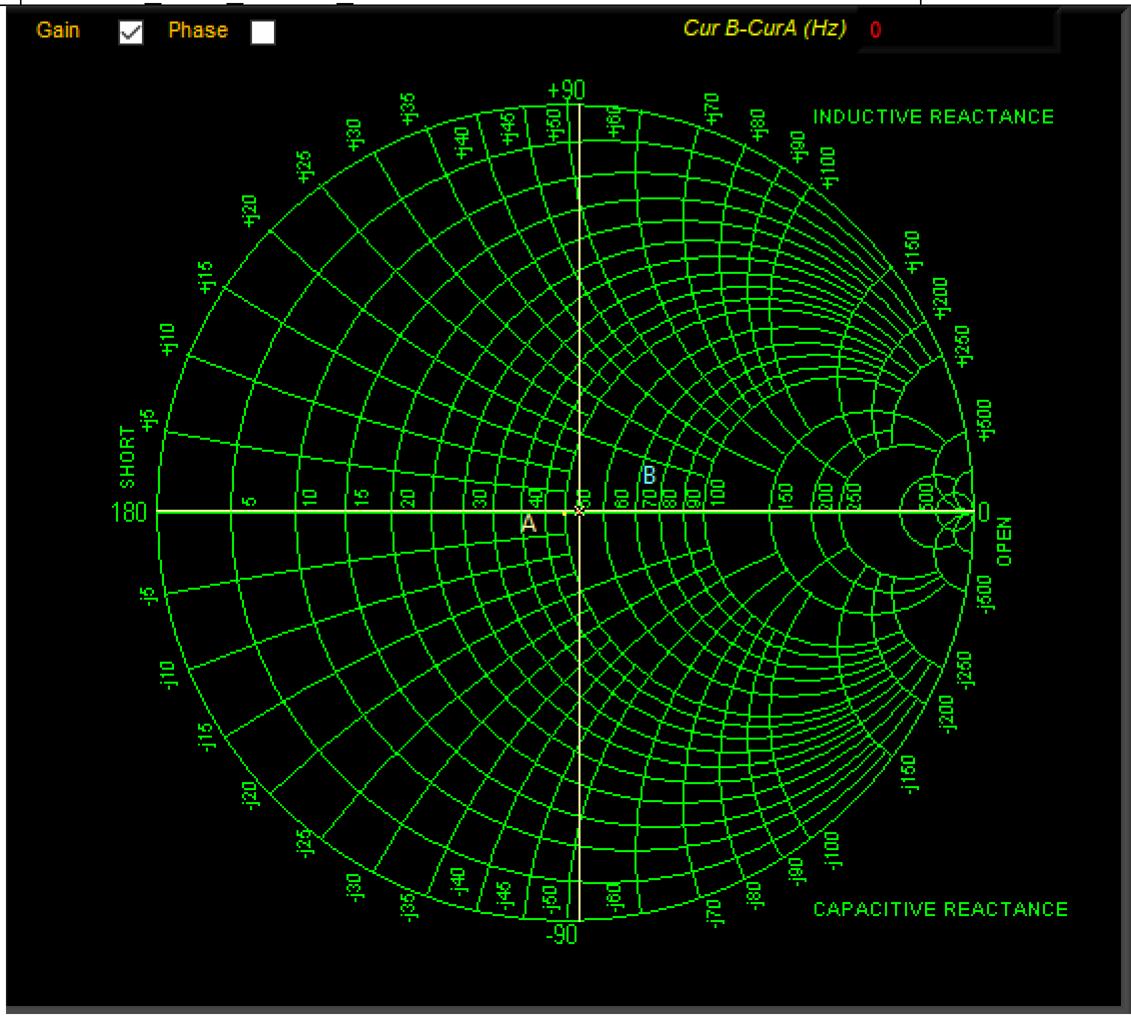


Figure 12

Now change the Stop frequency to 1GHz. The software understands SI units as well as exponents. All of the following are interpreted as 1GHz:

1000000000
1000000k
1000M
1G
1e9
1000e6

… and so on. Units are displayed in SI format. You can now see that the attenuator no longer appears to behave as a 50 ohm load (Figure 13).

NanoVNA_r10.vi
NanoVNA V2+4
Rev 0.10
Main
Advanced
Setup/Diagnostics
NanoVNA V2+4,Protocol 1, FW 1.1
Record
Link
Sweep
Stop
Function
Standing Wave Ratio
Impd Smith
Impd Rectangular
Reflection Coeff
Xmsn Rectangular
Xmsn Polar
2-Port T-Check
Electrical Length in Meters
6.545715E+0
Range in Seconds
21.834E-9
Velocity Factor
1.00
Cursor Time
13.551E-9
Meters
4.06
Inches
159.94
Cursor A
R 53.6 Ohms
L 8.53u H Q 1.0
C 2.97n F BW 1.0
Freq 1.000M
Impedance 53.60
ρ 0.035
Resistance 1.07
Rnorm 53.60
1.04
Reactance 0.00
Jnorm 0.07
-10.073
SWR 1.07
Return Loss dB 29.17
179.38
TRohms 418.858
TL H 66.67u
TC F 379.94p
Cursor B
R 53.6 Ohms
L 8.53u H Q 1.0
C 2.97n F BW 1.0
Freq 1.000M
Impedance 53.60
ρ 0.035
Resistance 1.07
Rnorm 53.60
1.04
Reactance 0.00
Jnorm 0.07
-10.073
SWR 1.07
Return Loss dB 29.17
179.38
TRohms 418.858
TL H 66.67u
TC F 379.94p
Normal LRC
Center(Hz) 10.000000M
Rnorm 50.00
Span(Hz) 2.000000M
Start(Hz) 1.0000M
Stop(Hz) 1.0000G
CW(Hz) 10.000000M
Stage Link
Calibrated
Chan0 - B
FreqSel
XferRly Lnk
IntpCal
CalRange
XferRly Err
CheckSum
Samp FIFO
Samp/Dec 10
Port Ext (ps) 0
Points 201
Sweep Mode
Linear
Log
PeakCent
Zoom
MS1
MS2
Ref
CHn-Ref
CLR
Smooth
2PSweep
T-Check
Cur Cent
Cur -3dB
Segment
2PortCal
S1P Load
S1P Save
S2P Save
Extender
Xfer Relay
CH0 - A
Gain
Phase
Cur B-CurA (Hz) 0
INDUCTIVE REACTANCE
CAPACITIVE REACTANCE
SHORT
OPEN
+90
-90
180
0

Figure 13

Select the transmission function Xmsn Rectangular. The attenuator is within 1.5dB again, keeping in mind no calibration has been performed. When the V2+ is being controlled by USB, all of the data is raw. No internal coefficients are being applied.

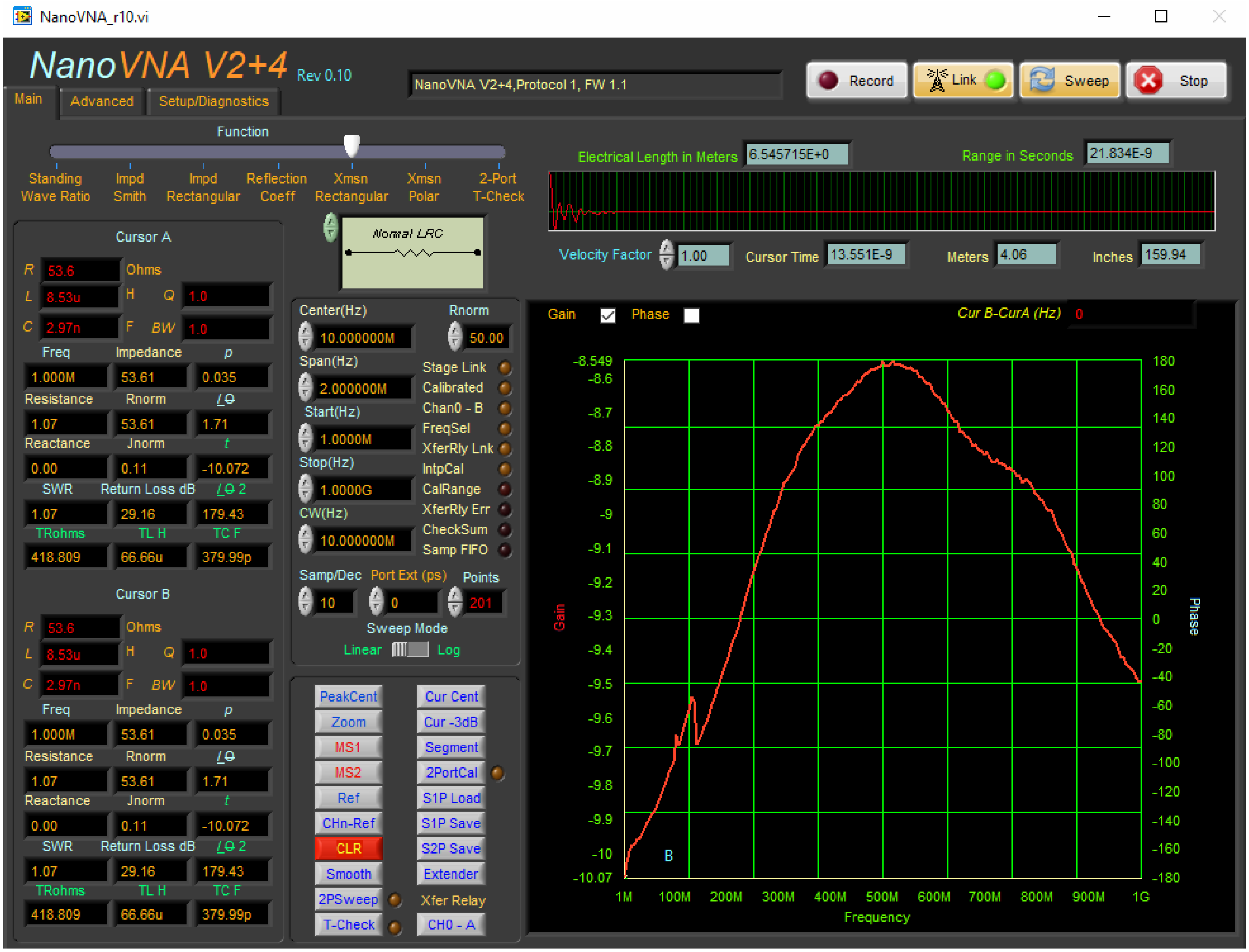


Figure 14

You can get a better idea of what this attenuator looks like simply by normalizing the data. Performing a full calibration or selecting standards is not necessary.

The first thing to do is replace the attenuator with a thru (Figure 15).

Figure 15

This would normally be 0dB but as shown, the measurement is roughly 1.3 dB higher than expected (Figure 16).

Figure 16

Select the Ref button which will temporarily store the swept data as a reference. Next select the CHn-Ref. This will cause the software to use this reference to normalize all further readings to zero. With the thru still inserted, the software now displays very close to 0dB +/-0.02dB (Figure 17).

Figure 17

Reinserting the 10dB attenuator, you can now see the software displays within 0.5dB over the entire swept range.

Figure 18

As was mentioned earlier, the V2+ exhibits a fair amount of cross talk and normalization may not always yield good results. To demonstrate this, start by changing the Stop frequency to 4GHz. Next change the start frequency to 2.5GHz. Next, deselect the Phase checkbox in the upper left corner of the graph. Now deselect the CHn-Ref to turn off the normalization and reinstall the thru.

As you can see rather than 0dB, the V2+ is displaying from -2 to -5dB (Figure 19). The waveform should be very stable.

Figure 19

As before, select the Ref followed by CHn-Ref to once again normalize the data. As shown, the data is now within +/-0.1dB over the entire 1.5GHz range (Figure 20).

Figure 20

Now install the 30dB attenuator section. You may notice that the V2+ displays something other than 30dB (Figure 21).

Figure 21

Just how much of that error is from the low cost attenuator? The cost of this set was in the order of $5. As a comparison, an 18GHz, 30dB attenuator from Midwest Microwave is shown below (Figure 22).

The data for this part looks much better. However, above 3GHz the error greatly increases.

Figure 22

To further demonstrate these errors, the thru was reinstalled and the VNA was programmed to sweep from 2.5 to 4.4GHz. The number of data points was changed from 201 to 401. A new reference was then stored. The thru was then replaced with an 18GHz, 30dB attenuator from Midwest Microwave (Figure 23).

Figure 23

Is the attenuator really this poor, or is it the V2+? Midwest isn't known for making poor products and I would expect better performance from the V2+. So what's going on? As mentioned, normalization may not always work very well.

12.7 The V2+ SOLT Standards

It's time to try and calibrate the V2+. Although I purchased the V2+ and the V2+4 with cables and standards, there are a few problems with them. The short's center conductor is locked and will turn as the nut is tightened. The thru standard doesn't have a flat. There is no way to hold it securely with your ignition wrench while you torque it.

Figure 24

The bigger problem is the return loss of the load is not very good. The following compares the load supplied with my original Nano against the two included with my V2+ VNAs, along with two Mini-Circuits ANNE-50+ terminators. Also shown as a reference, the Keysight 85033 standard load. (No standards were harmed during these measurements!!)

We can see the loads supplied with my two V2+ VNAs have a very similar performance and offer a much improved return loss over the standard that was supplied with my original Nano. However when compared with the Mini-Circuits ANNE's that were hand selected, they were not as good (Figure 25).

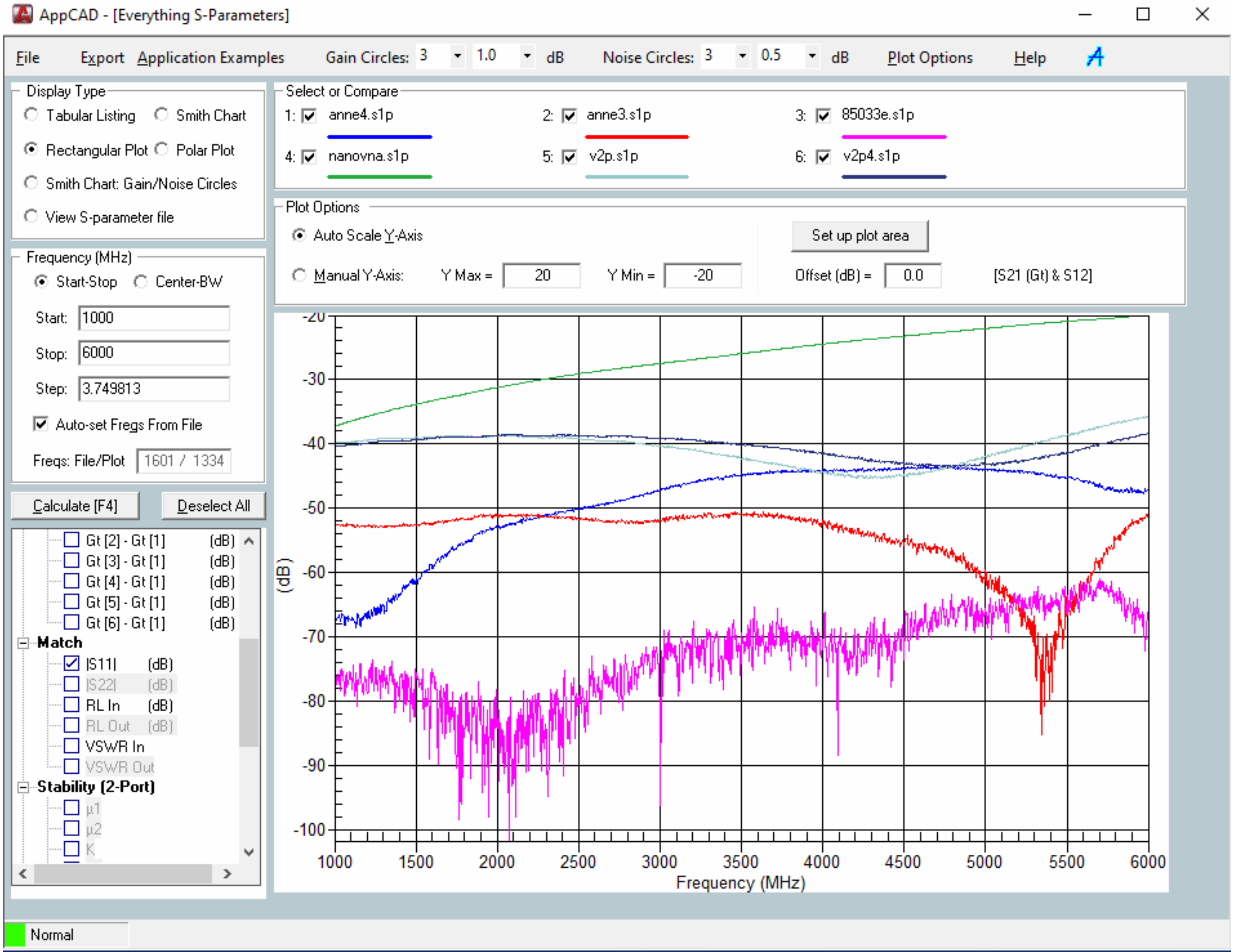


Figure 25

These two Mini-Circuit ANNE's are from a batch of seven that I purchased and sorted based on their return loss. The two shown are the best out of the group. ANNE #3 is what I use as my standard for my lab experiments. For the V2+, the original load was swapped out for ANNE #4.

Shown are some of my homemade standards using various SMT resistors for experimenting up to a GHz (Figure 26).

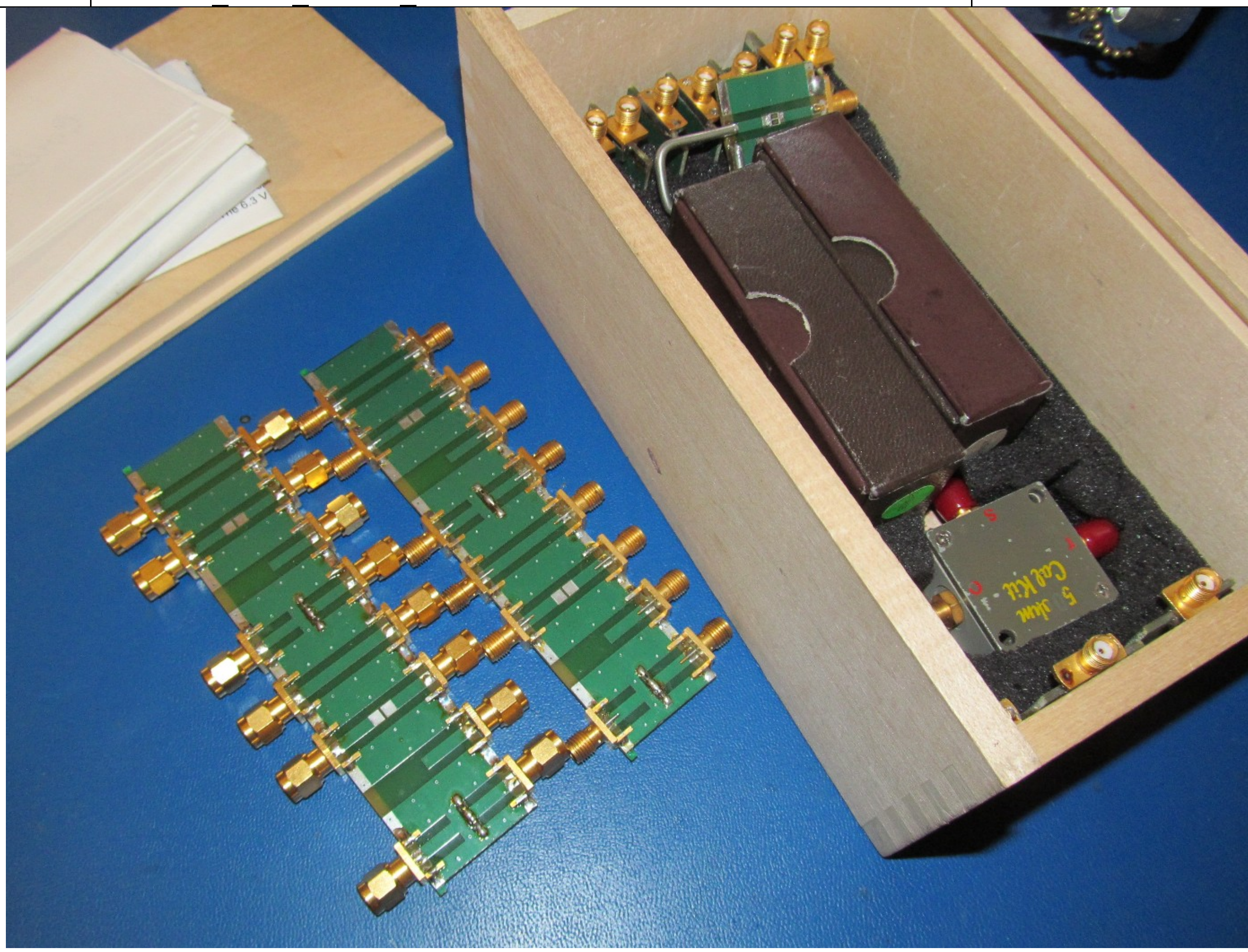


Figure 26

Attempting to make a decent load for 3GHz, good luck with that! I have attempted to make standard's for use above 1.5GHz in the past and the only thing I have accomplished is wasting time.

An attempt was made at making a set of TRL standards using some RG401 semi-ridgid coax from Fairview Microwave, PN# FM-SR250ALTN-STR (Figure 27).

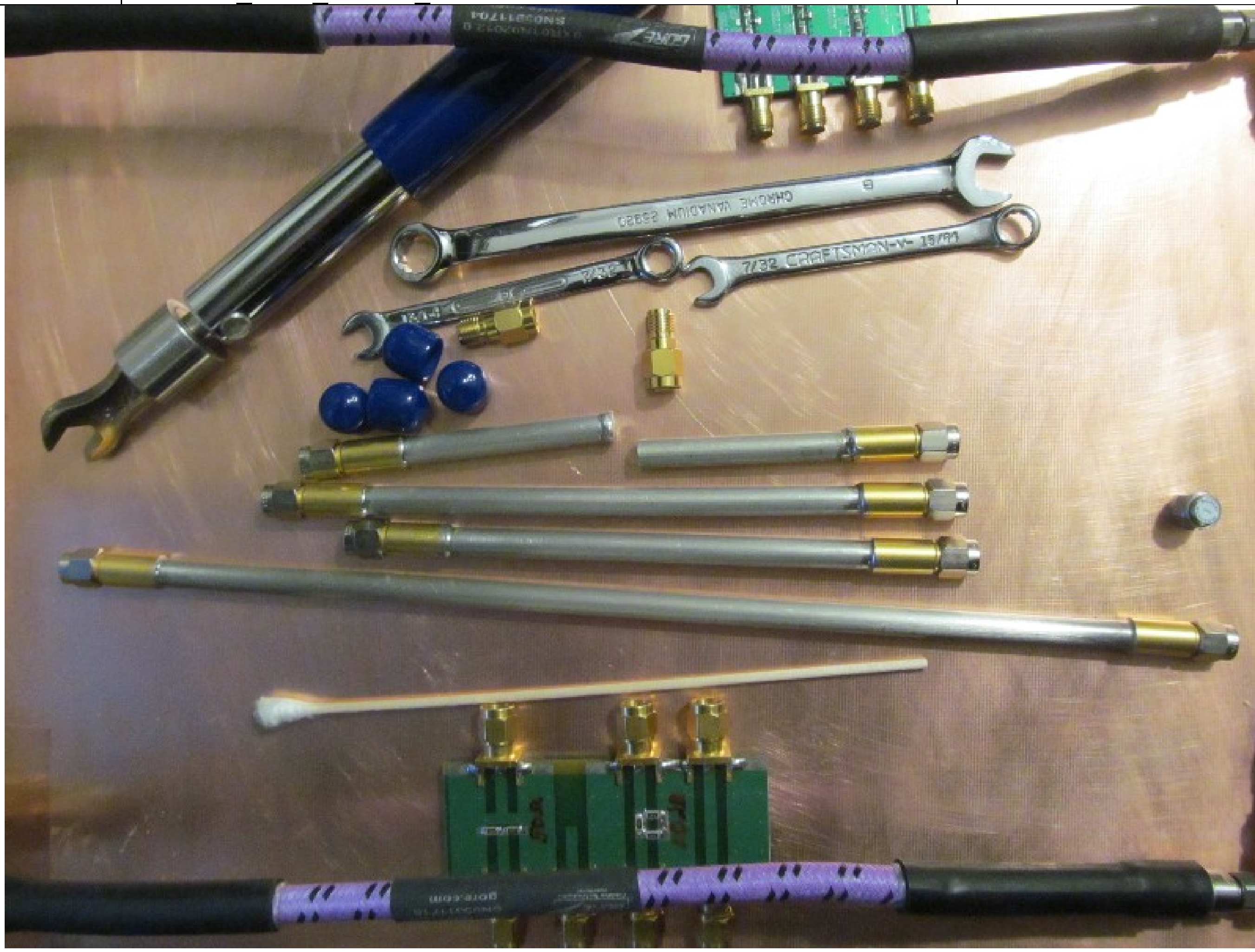


Figure 27

Figure 28 shows some of my homemade standards for experimenting in the GHz range. Toward the left are the N and SMA standards. These were characterized using a set of HPAK standards.

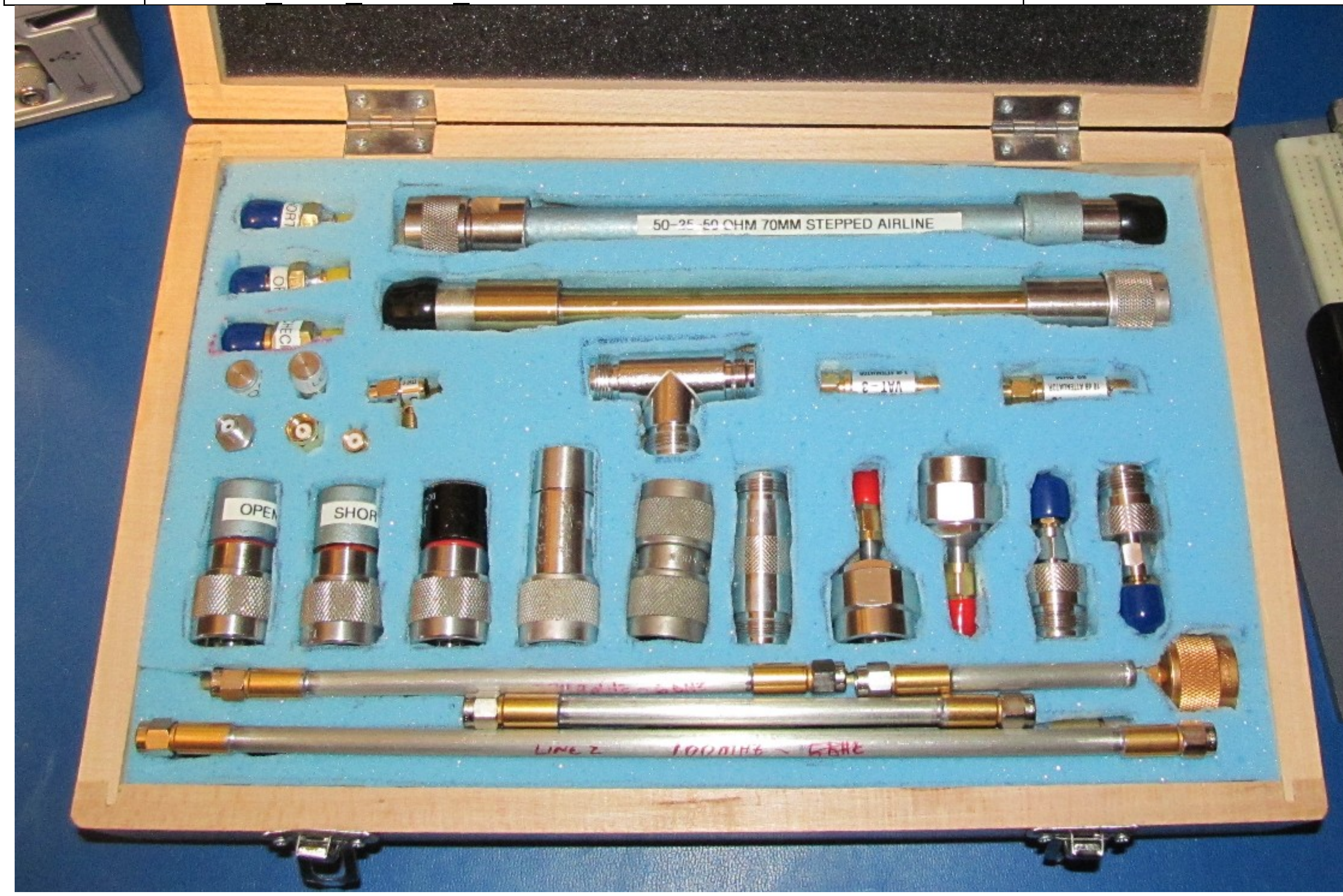
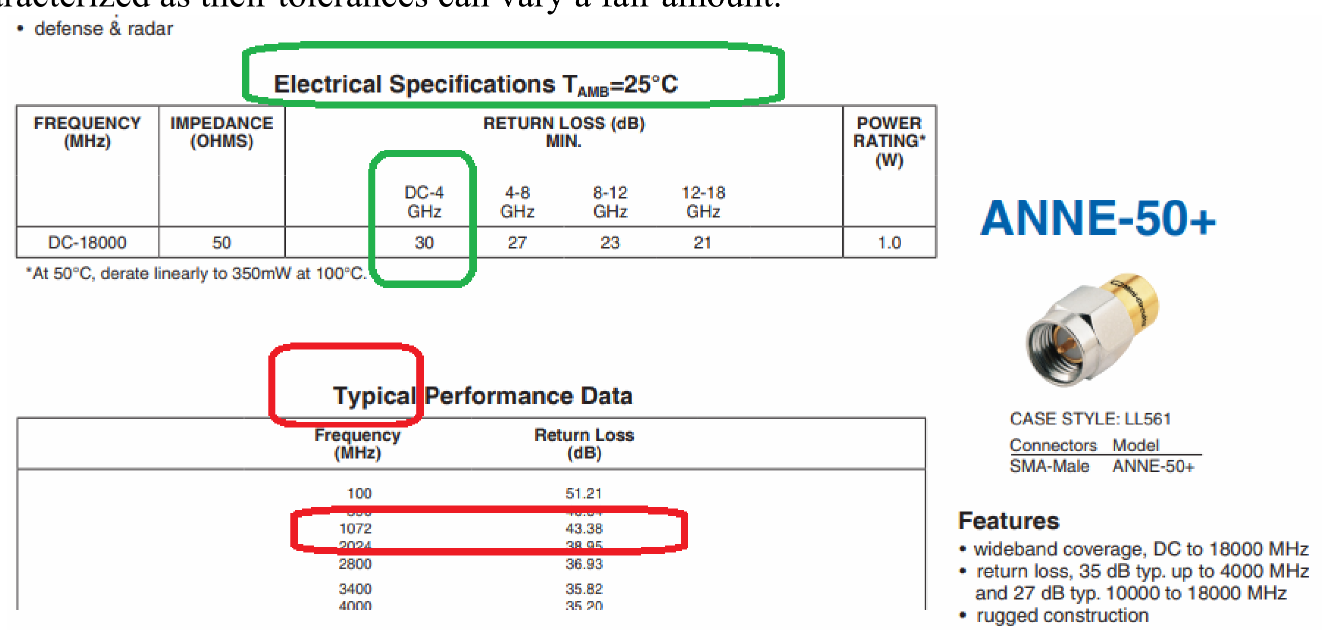


Figure 28

The N type were made from some old Narda terminators. Machining the parts for these took several attempts. The T-Check shown (upper left third down) was an improvement over the original PCB style and yields good results to around 2GHz.

Figure 29

Don't expect to go out and buy a new part from Mini-Circuits to replace yours. They need to be characterized as their tolerances can vary a fair amount.



• defense & radar

Electrical Specifications T_{AMB}=25°C

FREQUENCY (MHz)	IMPEDANCE (OHMS)	RETURN LOSS (dB) MIN. DC-4 GHz	4-8 GHz	8-12 GHz	12-18 GHz	POWER RATING* (W)
DC-18000	50	30	27	23	21	1.0

*At 50°C, derate linearly to 350mW at 100°C.

Typical Performance Data

Frequency (MHz)	Return Loss (dB)
100	51.21
1072	43.38
2024	38.95
2800	36.93
3400	35.82
4000	35.20

ANNE-50+

CASE STYLE: LL561

Connectors	Model
SMA-Male	ANNE-50+

Features
• wideband coverage, DC to 18000 MHz
• return loss, 35 dB typ. up to 4000 MHz and 27 dB typ. 10000 to 18000 MHz
• rugged construction

Figure 30

Sorting the terminators is not trivial. Shown below is one of my vintage VNAs along with a set of HP standard's that were used to characterize my homemade N standards.

Figure 31

Another set of Agilent standards used to characterize my 3.5mm set.

Figure 32

Of course these standards were never used with the NanoVNA. They are a metrology grade and demand care.

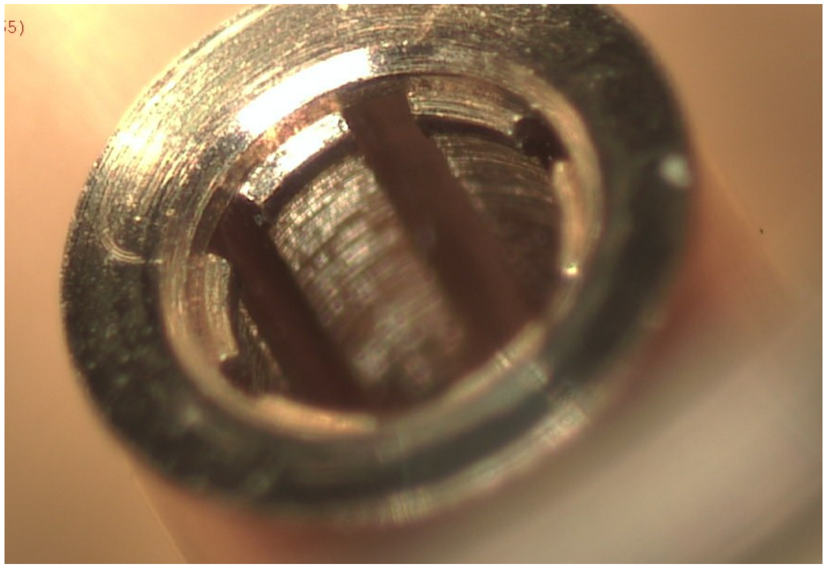


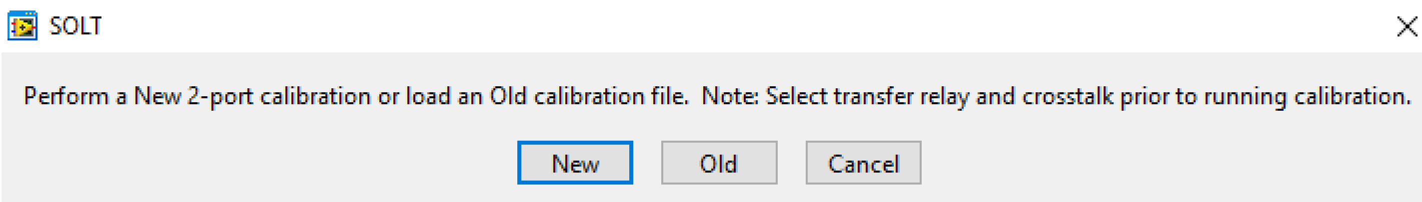
Figure 33

Shown is the new thru with a flat and ANNE included in my V2+ cal kit. On the far left it the original short. There was not enough of the center exposed to be able to hold it without twisting the center pin. I machined up a 5/16" nut from brass hex stock and soldered it to the back side (Figure 34 left). This allows a standard wrench to be used with it, a much needed improvement.

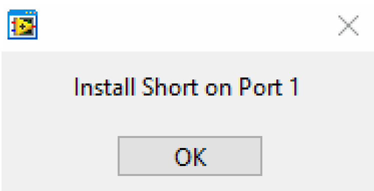
Figure 34

12.8 SOLT Calibration

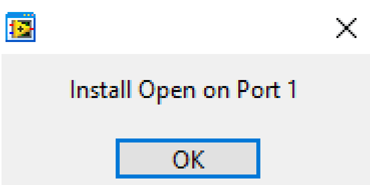
For this experiment, I used the included cables and modified calibration kit. **Select CHn-Ref to disable the normalization.** Next select the 2PortCal. You will be prompted to create a new calibration or load a previously saved one. You can have as many calibration files as you want. If you had a previously loaded calibration and you select Cancel, it will purge the current calibration.



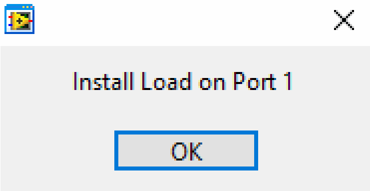
Select New. You will be prompted to insert the short on Port A (Port 1).



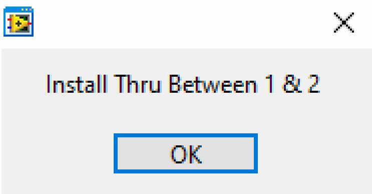
After you have it properly installed (cleaned, torqued…) go ahead and select OK. The software will prompt you to install the Open standard.



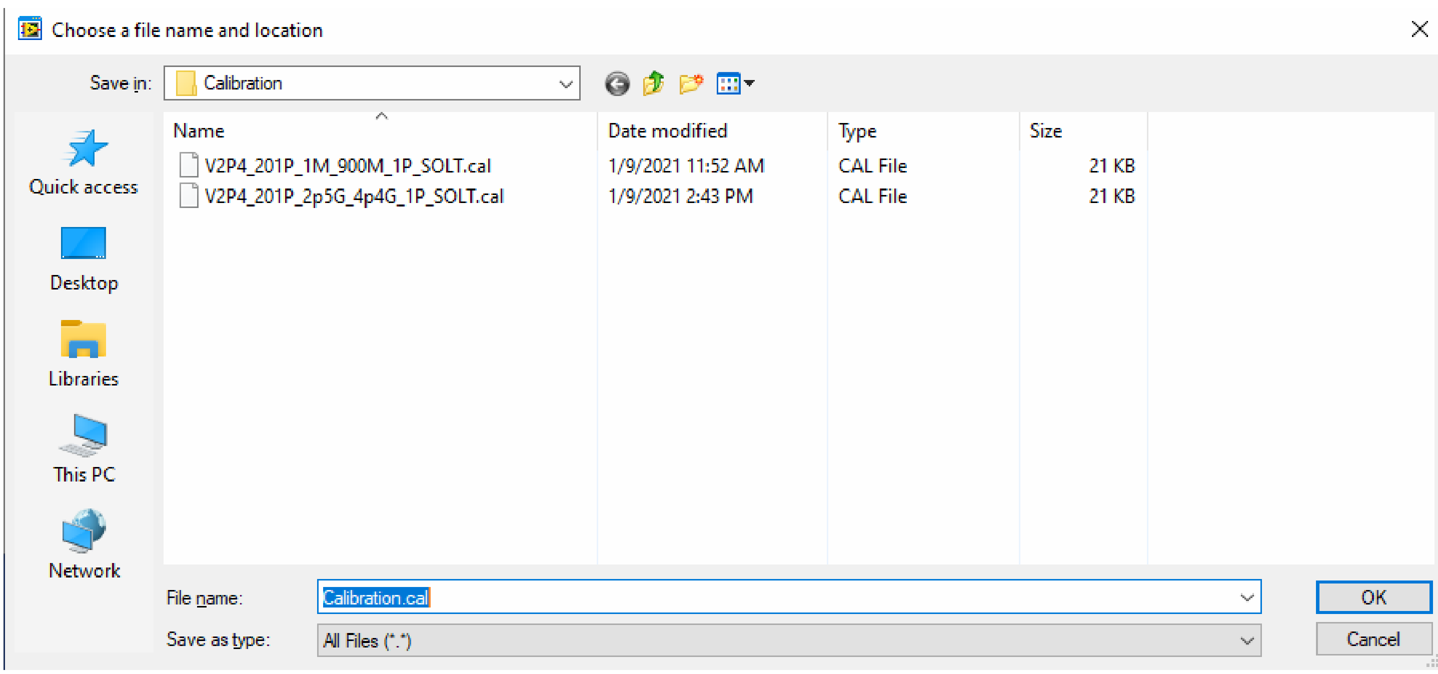
Replace the short with the open and select OK. The software will measure the crosstalk during this time and will then prompt you to install the load.



Again, select OK after installing. Now install the thru.



This software has the ability to control a transfer relay. If this option was enabled prior to selecting the calibration, you would be prompted to repeat this process for port B (2). After collecting the data, the software will ask you where you would like to save this new calibration. It defaults to Calibration.cal. I like to use descriptive names. As shown, you can see I will include the start and stop frequencies in the file name. I also keep the calibration files in a separate directory.



Select OK. With the thru still installed, select the rectangular transmission function. The software now shows the V2+ is calibrated. As we can see, with no normalization the V2+ is now showing < 0.1 dB of error (Figure 35).

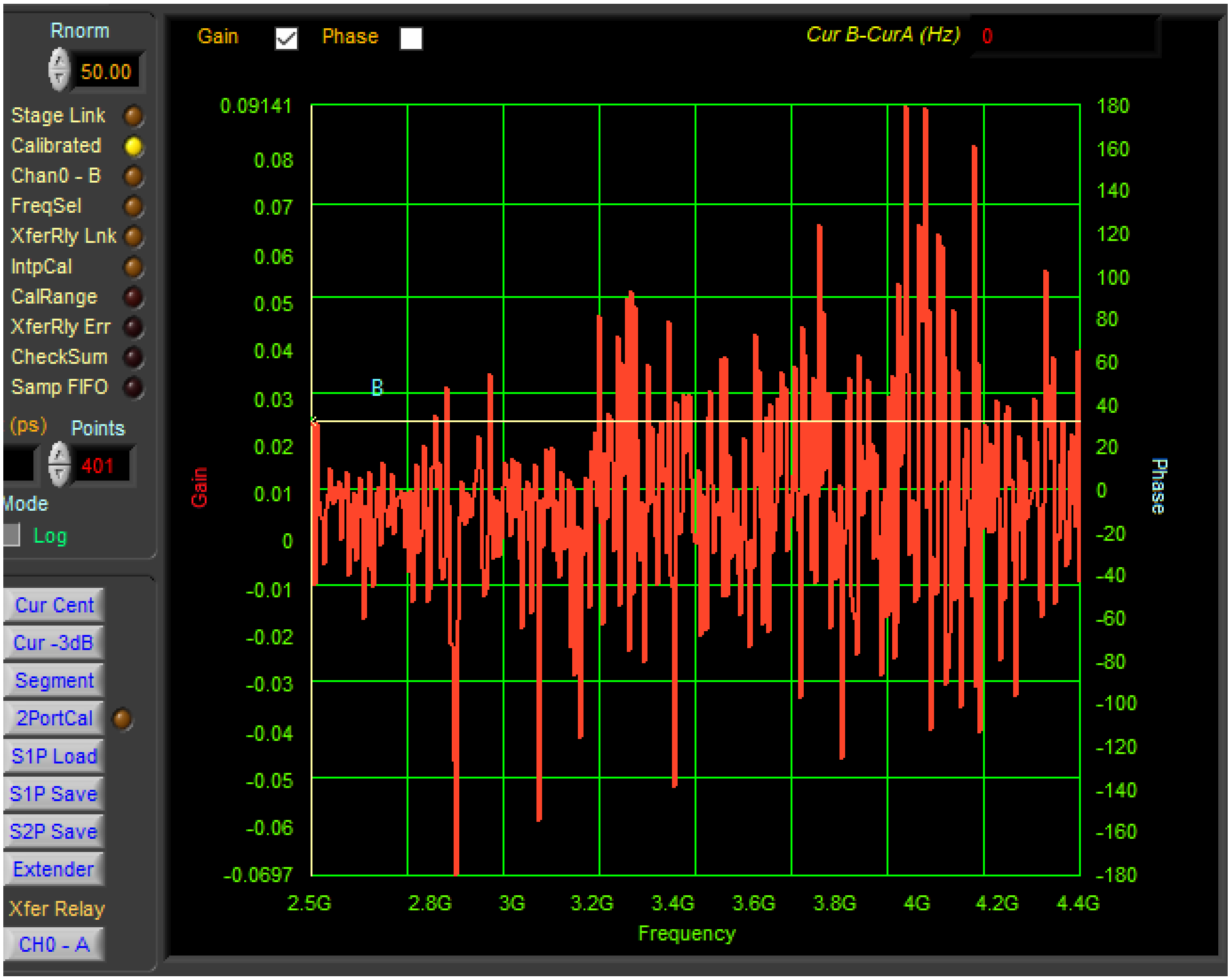


Figure 35

Next the Midwest Microwave 30dB attenuator was inserted. The data doesn't look very good but remember, I mentioned the problem with crosstalk at these higher frequencies (Figure 36).

Figure 36

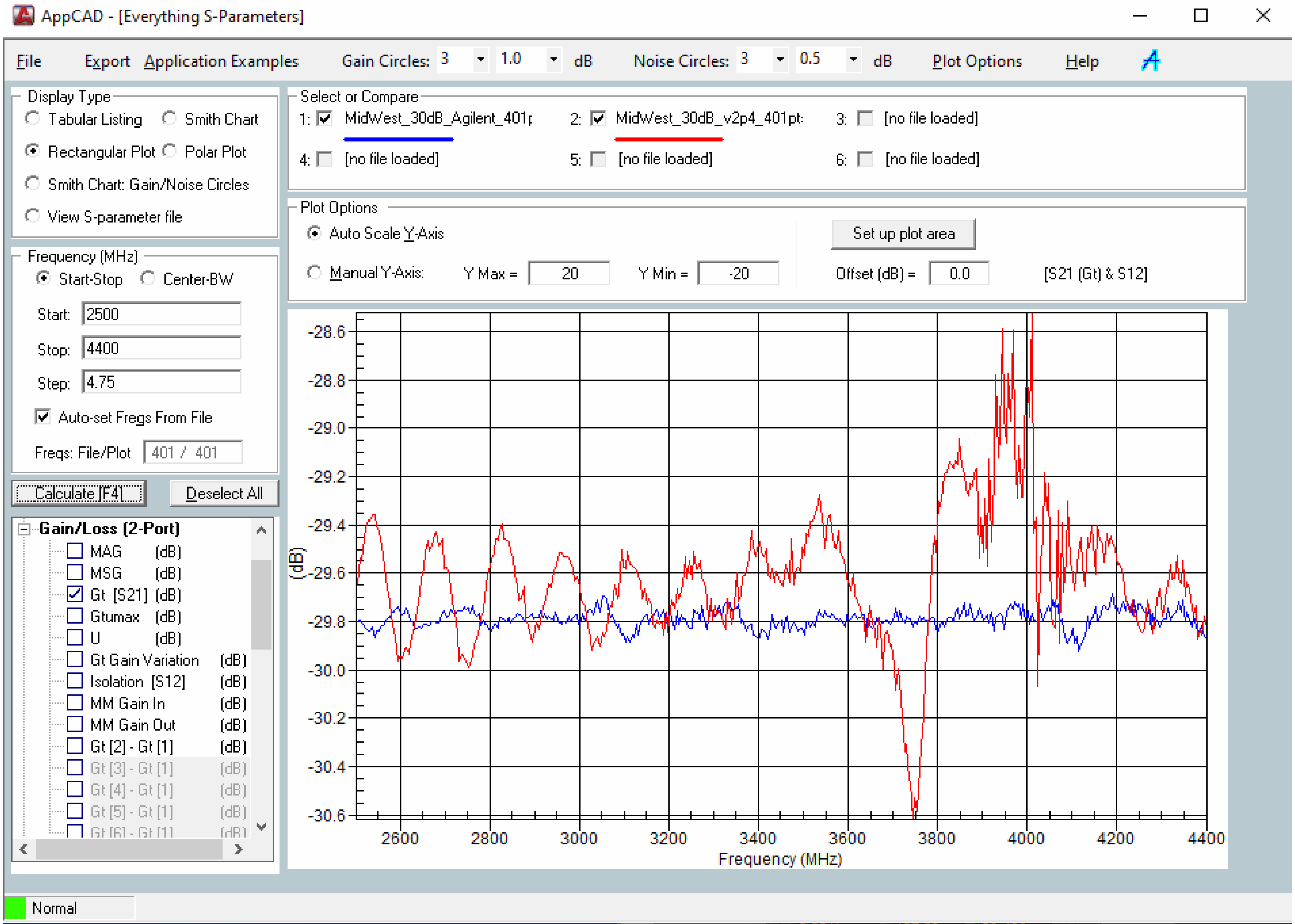
Before moving on, let's save this data to memory by selecting MS1. Select the Setup/Diagnostics menu and then select the Calibration Terms submenu. Now select the Leakage Terms checkbox (Figure 37).

Figure 37

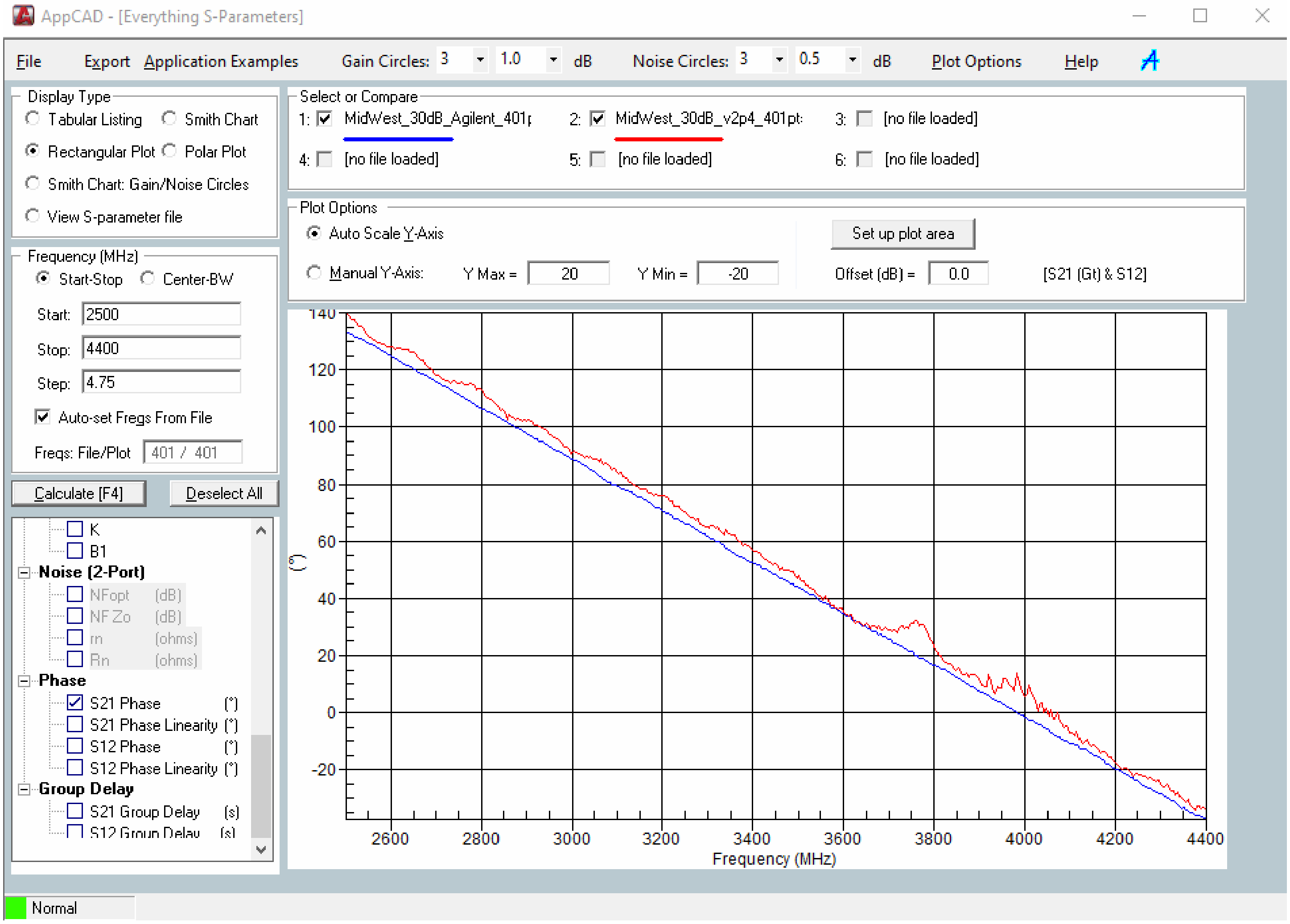
After you have selected Leakage Terms, return to the main menu. Notice the attenuator is now within 2dB all the way up to 4.4GHz (Figure 38).

Figure 38

Of course, you may be curious if this is correct or not, so here is the same attenuator shown on one of my old VNAs using my own homemade calibration kit.



AppCAD - [Everything S-Parameters]
File
Export
Application Examples
Gain Circles: 3 1.0 dB
Noise Circles: 3 0.5 dB
Plot Options
Help
Display Type
Tabular Listing
Smith Chart
Rectangular Plot
Polar Plot
Smith Chart: Gain/Noise Circles
View S-parameter file
Frequency (MHz)
Start-Stop
Center-BW
Start: 2500
Stop: 4400
Step: 4.75
Auto-set Freqs From File
Freqs: File/Plot 401 / 401
Calculate [F4]
Deselect All
Gain/Loss (2-Port)
MAG (dB)
MSG (dB)
Gt [S21] (dB)
Gtumax (dB)
U (dB)
Gt Gain Variation (dB)
Isolation [S12] (dB)
MM Gain In (dB)
MM Gain Out (dB)
Gt [2] - Gt [1] (dB)
Gt [3] - Gt [1] (dB)
Gt [4] - Gt [1] (dB)
Gt [5] - Gt [1] (dB)
Select or Compare
1: MidWest_30dB_Agilent_401
2: MidWest_30dB_v2p4_401pt
3: [no file loaded]
4: [no file loaded]
5: [no file loaded]
6: [no file loaded]
Plot Options
Auto Scale Y-Axis
Set up plot area
Manual Y-Axis:
Y Max = 20
Y Min = -20
Offset (dB) = 0.0
[S21 (Gt) & S12]
(dB)
-28.6
-28.8
-29.0
-29.2
-29.4
-29.6
-29.8
-30.0
-30.2
-30.4
-30.6
2600
2800
3000
3200
3400
3600
3800
4000
4200
4400
Frequency (MHz)
Normal



Now install the low cost 30dB attenuator. It's not much better but again, it's a $5 part and rated for 4GHz with a 1.5dB flatness. The author purchased two different versions of these low cost attenuators. One of them performed much closer to the claimed specification (Figure 39).

Figure 39

12.9 Interpolation

The software will now perform an interpolation of the calibration data if the frequency is changed rather that requiring a new calibration be performed. This is done automatically if the frequency bounds have changed by more than 20KHz. The new frequency range must be within the range that the unit was calibrated. If for example we set the start and stop frequencies to 1 and 300MHz, then perform a calibration. We can now change the start and stop to anything within that range. For example, we can change the start to 20MHz and you will not have to recalibrate. The software will activate the IntpCal indicator to let you know it is using interpolation (Figure 40).

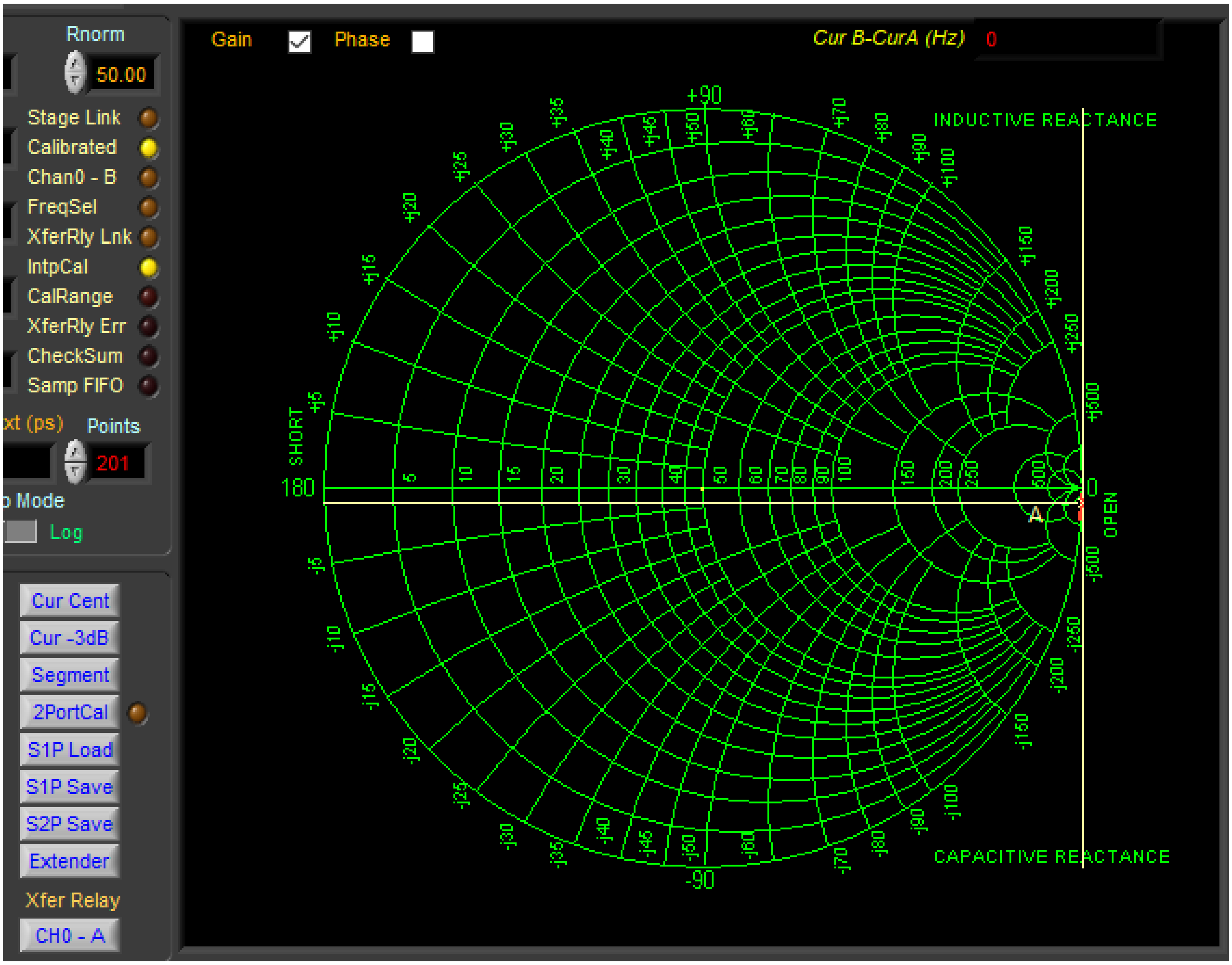
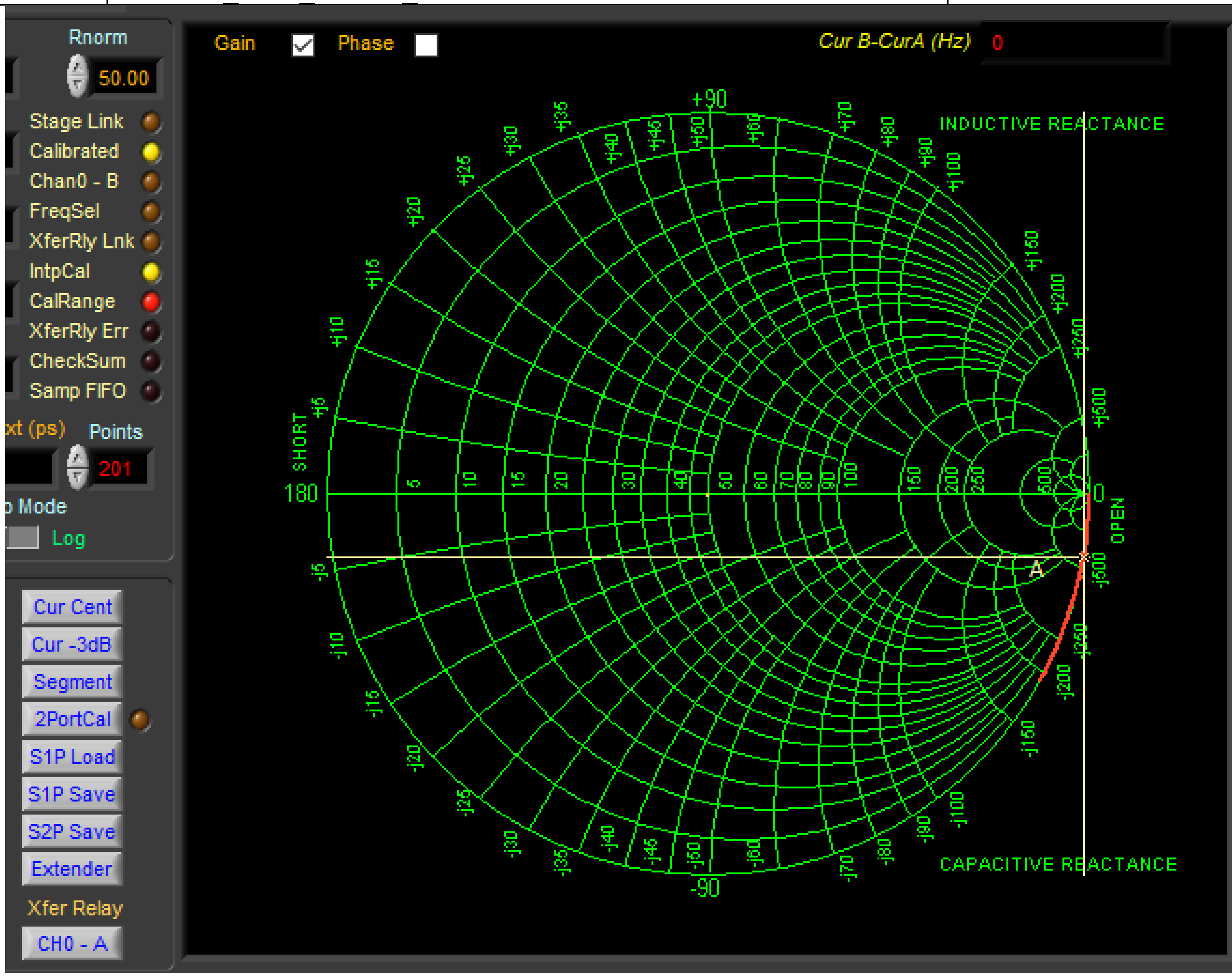


Figure 40

If you change the start to within 20KHz of the frequency the unit was calibrated, the IntpCal indicator will turn off along with interpolation. If you do go outside of the calibrated range, the software will activate the CalRange error as shown in Figure 41.



Rnorm
50.00
Stage Link
Calibrated
Chan0 - B
FreqSel
XferRly Lnk
IntpCal
CalRange
XferRly Err
CheckSum
Samp FIFO
xt (ps)
Points
201
o Mode
Log
Cur Cent
Cur -3dB
Segment
2PortCal
S1P Load
S1P Save
S2P Save
Extender
Xfer Relay
CH0 - A
Gain
Phase
Cur B-CurA (Hz)
0
INDUCTIVE REACTANCE
CAPACITIVE REACTANCE
SHORT
OPEN
180
+90
-90
A

Figure 41

13. Using Memories

The software has three memories that may be used to temporarily store and overlay waveforms. The Ref and CHn-Ref is a special memory that is used to normalize the data. MS1&2 have no math function associated with them.

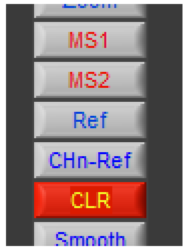


Figure 42

Store the current waveform by selecting one of the two buttons, MS1 or 2. The waveform will be immediately displayed. In the following two different waveforms have been saved.

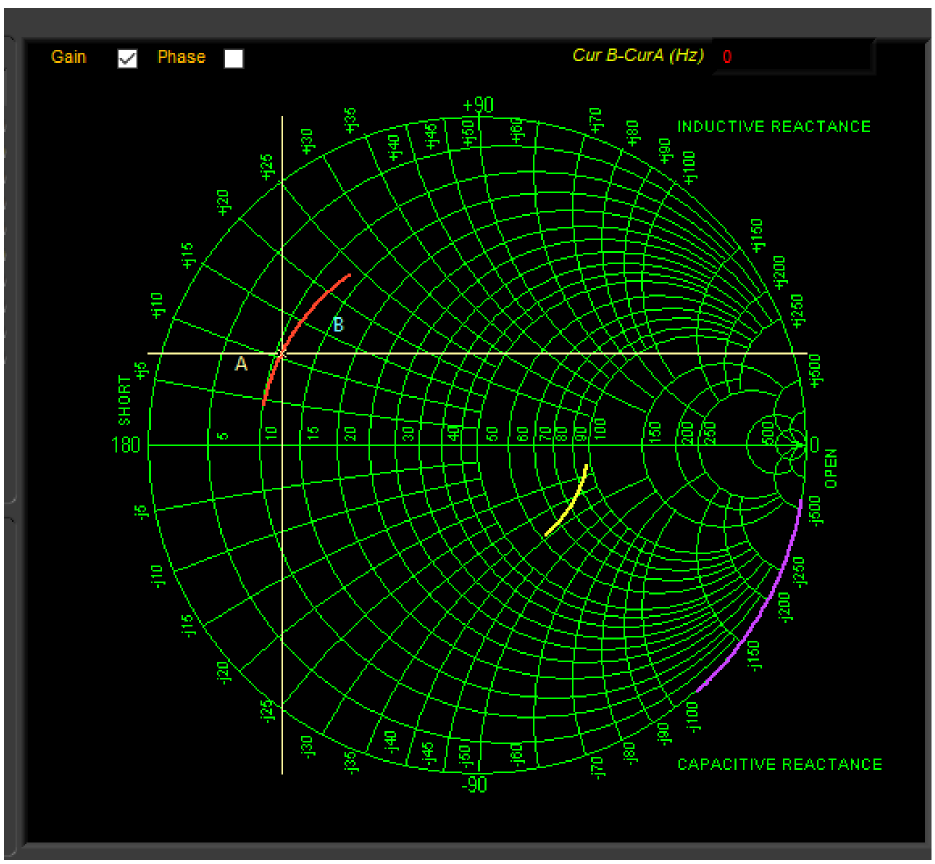


Figure 43

The memories will work for both polar and rectangular measurements. Here I have installed a manual step attenuator (Figure 44).

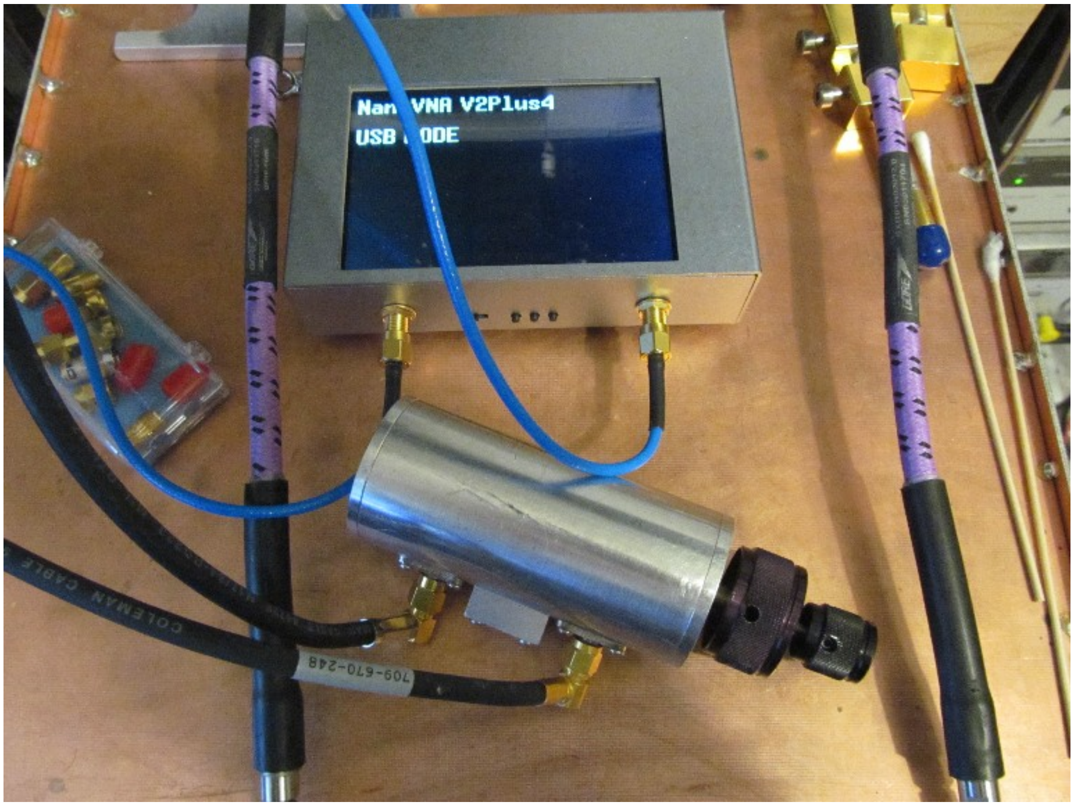


Figure 44

I have saved 0dB into Mem1 and 10dB into Mem2. The attenuator was then set to 20dB.

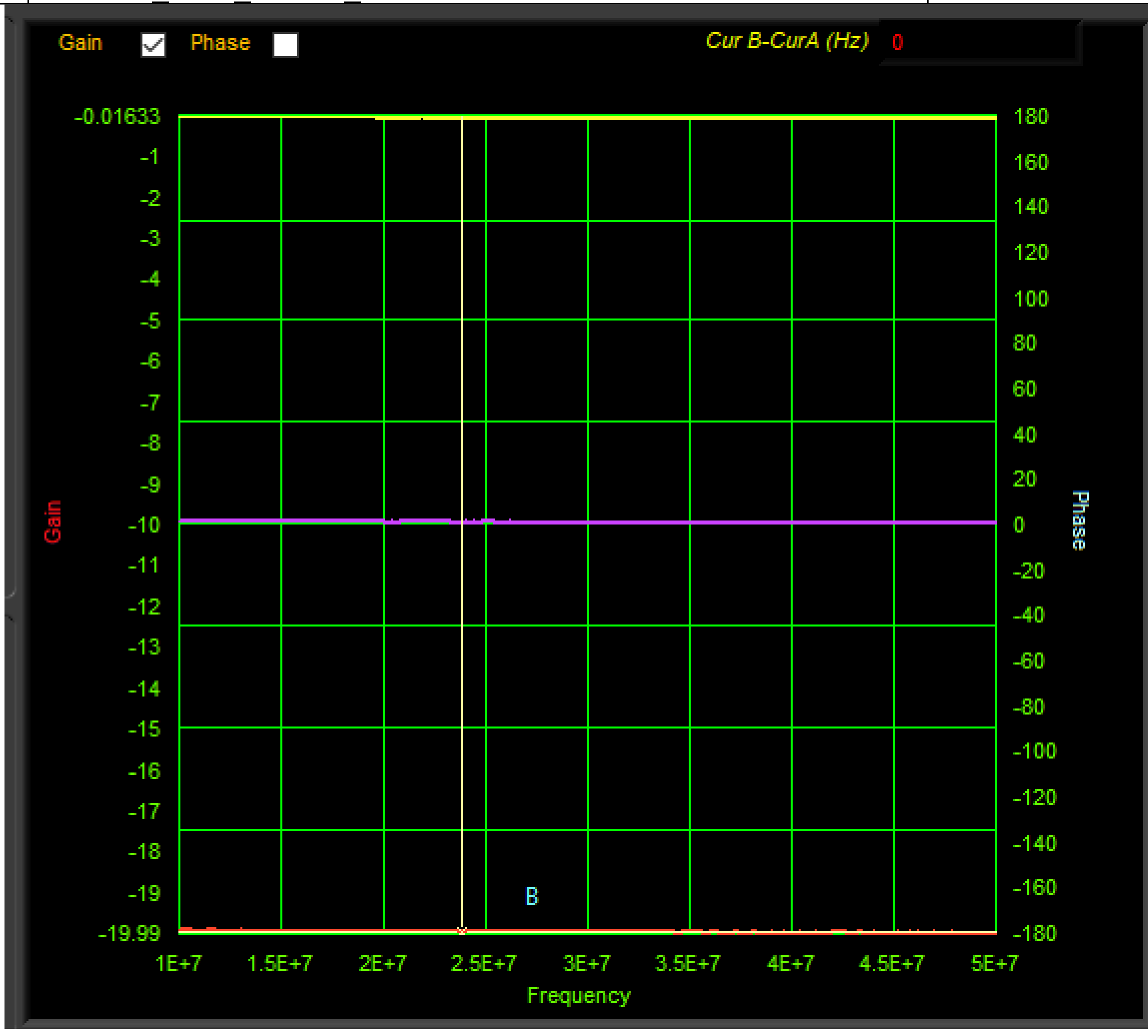

Gain
Phase
Cur B-CurA (Hz)
0
-0.01633
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-19.99
180
160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
-120
-140
-160
-180
B
1E+7
1.5E+7
2E+7
2.5E+7
3E+7
3.5E+7
4E+7
4.5E+7
5E+7
Frequency

Figure 45

If the Ref is selected, it will save 20dB as the reference. If CHn-Ref is selected, the software will apply the reference to the current sweep as well as the saved data in each memory.

Note, as of 1.08 (original NanoVNA) and 1.03 (V2 Plus), the software now applies the normalized data to the cursor readouts as well.

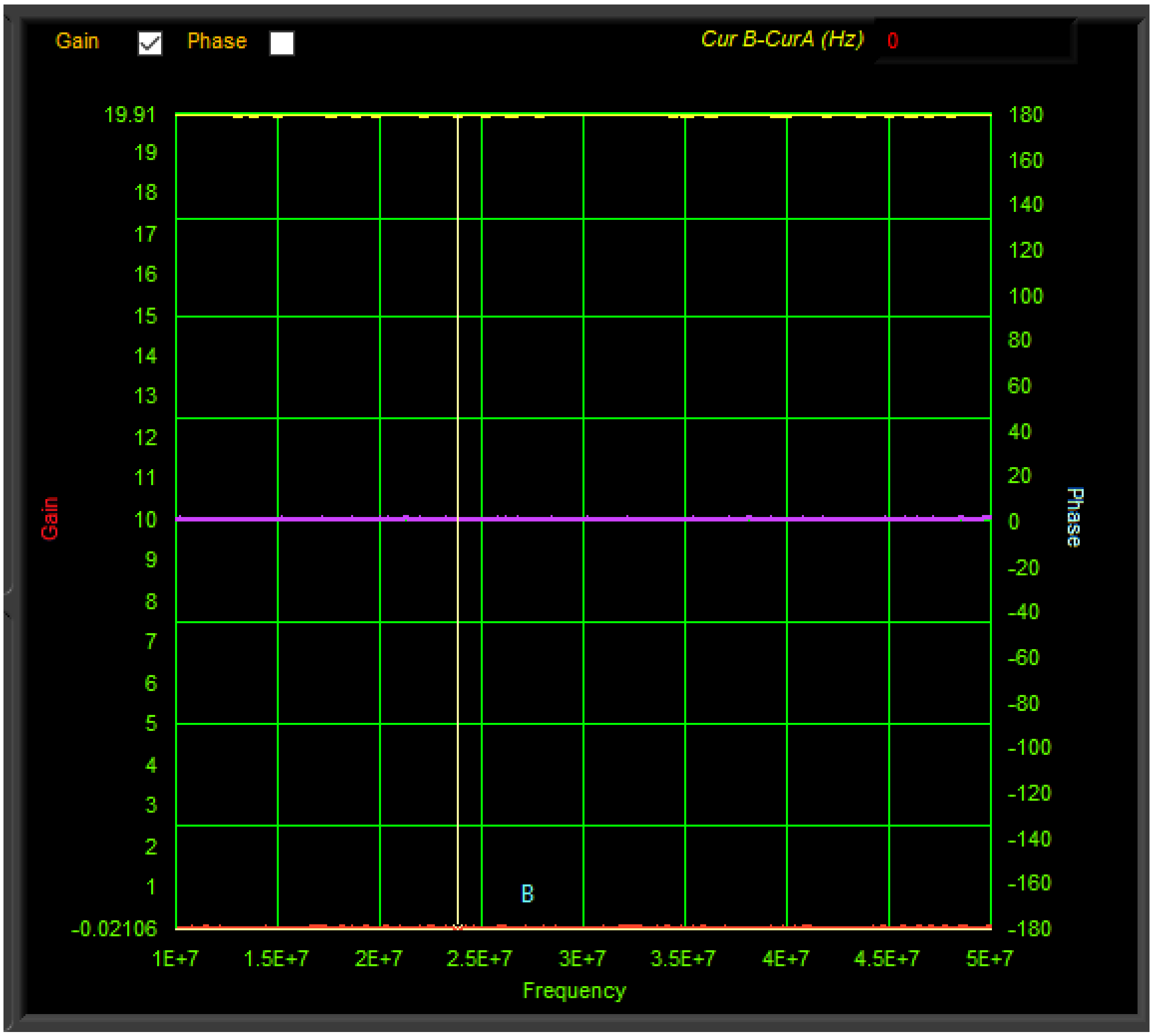


Figure 46

Selecting the clear button will erase all three memories and turn them off. You do not have to erase a memory before storing a new waveform. Pressing one of the memory keys will always overwrite the previously stored waveform.

14. Recording Multiple Sweeps to Disk

The software has the ability to record the swept data to disk. Once you have the VNA setup, select the Record button. You will be prompted to enter a filename.

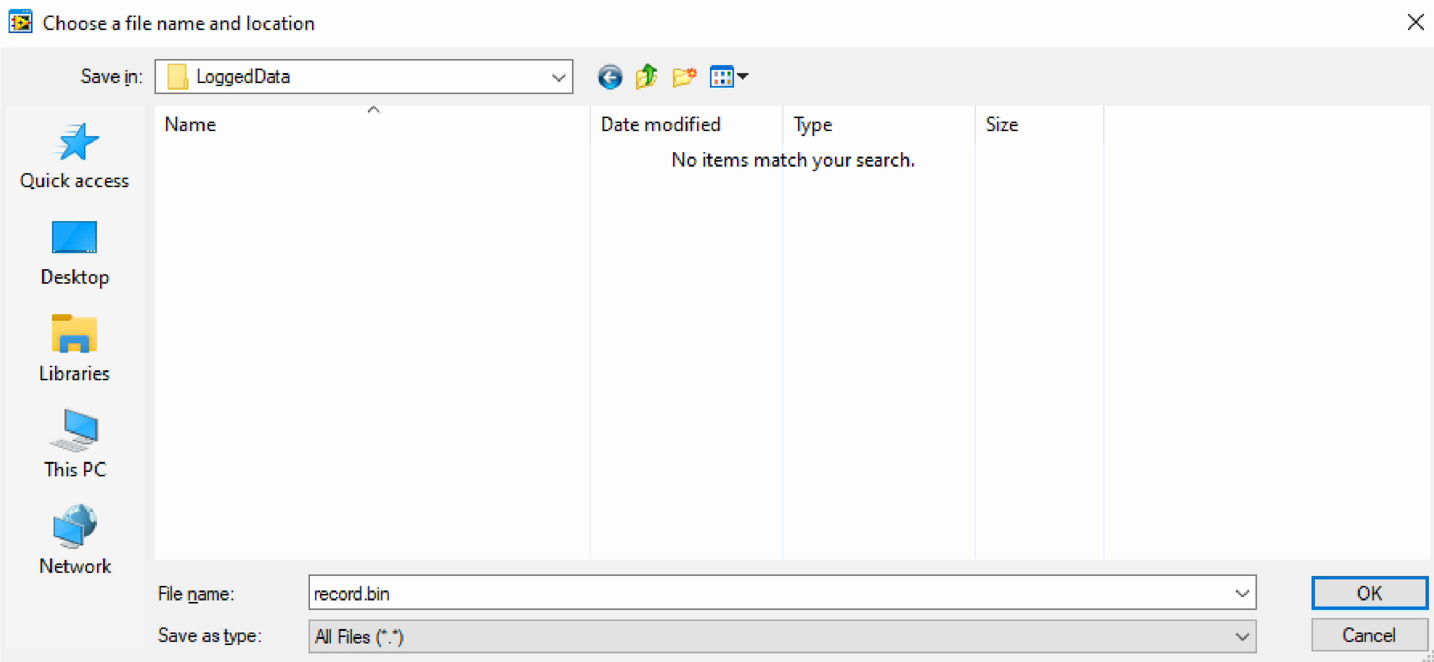


Figure 47

The software will immediately begin recording all of the corrected S-parameters. Selecting standards, performing a calibration, changing the port extension, using normalize and enabling filters will all have an effect on the recorded data.

The author has found the V2+ (not the +4 model) to be very unreliable when running for extended times. The NanoVNA itself appears to lockup and will require a power cycle to clear it. The +4 model does not appear to have this problem. You need to be aware of this if you are attempting to run a long term study.

Figure 48

Once you have finished recording your data, just select Record again to stop the collection.

14.1 Post Processing

Selecting the Advanced tab followed by the Surface tab will bring up the following menu.

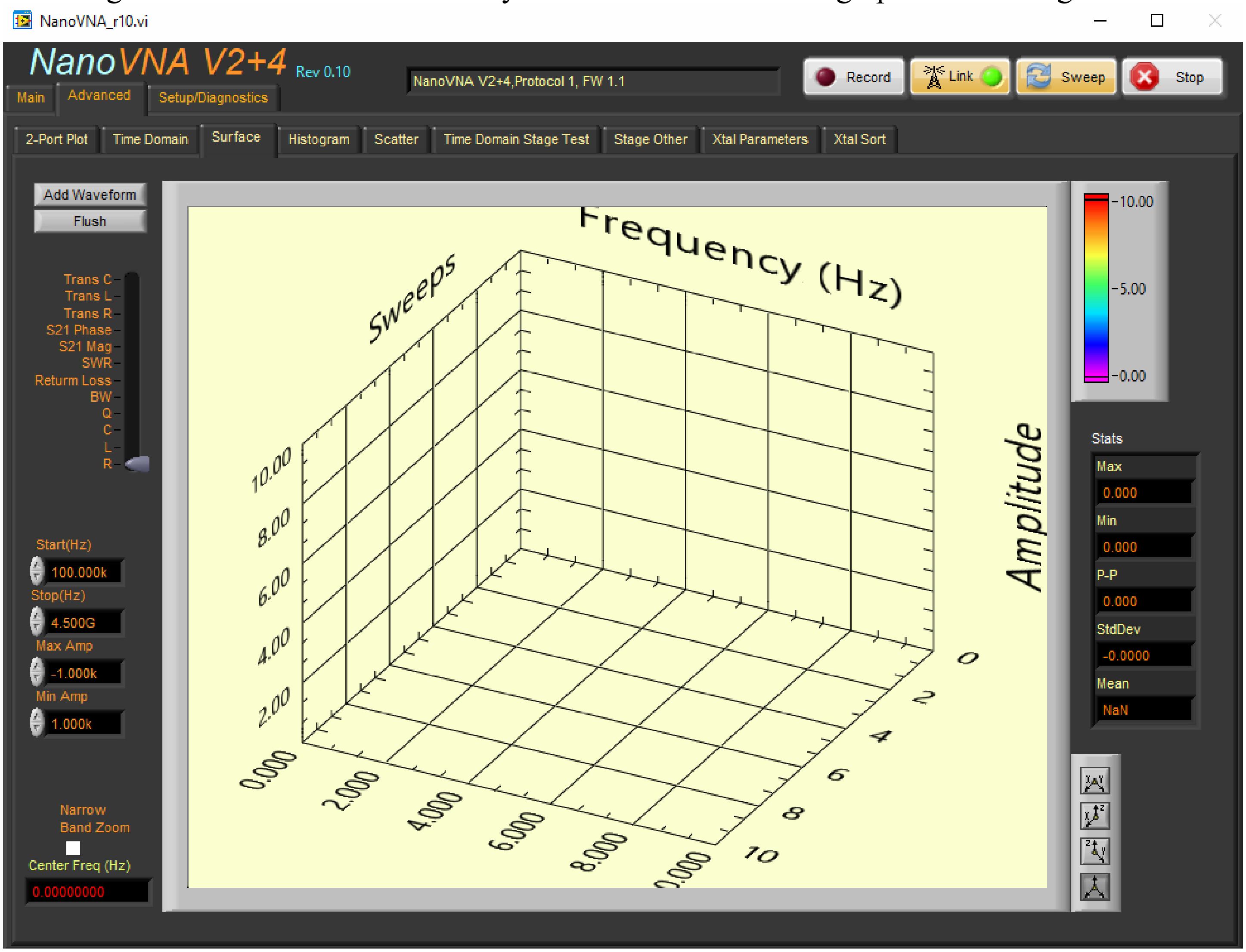


Figure 49

You may now select your file by selecting Add Waveform. You will be prompted for a file name. Note there is now a file named record.txt which is the file just created.

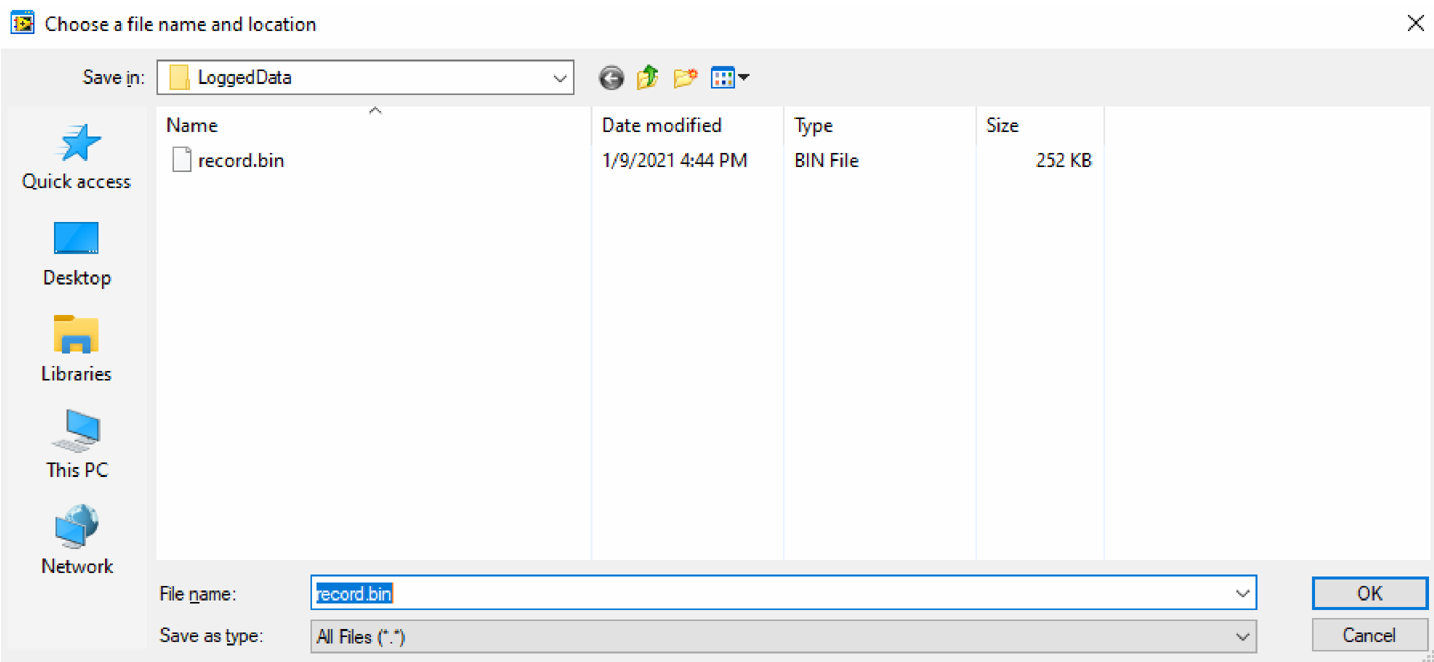


Figure 50

Once the file has been loaded, you may use the slider on the left to select the parameter you would like to view.

IMPORTANT!!!!

This file is not ASCII formatted! The default names were changed to .bin to reflect being a binary file. Currently, Touchstone is the only ASCII formatted file type supported for swept data.

Selecting Flush will purge the memory.

In some cases you will want to view very narrow band data. The Narrow Band Zoom feature allows rescaling the graph around the center frequency. You may also use the Start, Stop, Max and Min amplitudes to change the displayed range of the graph.

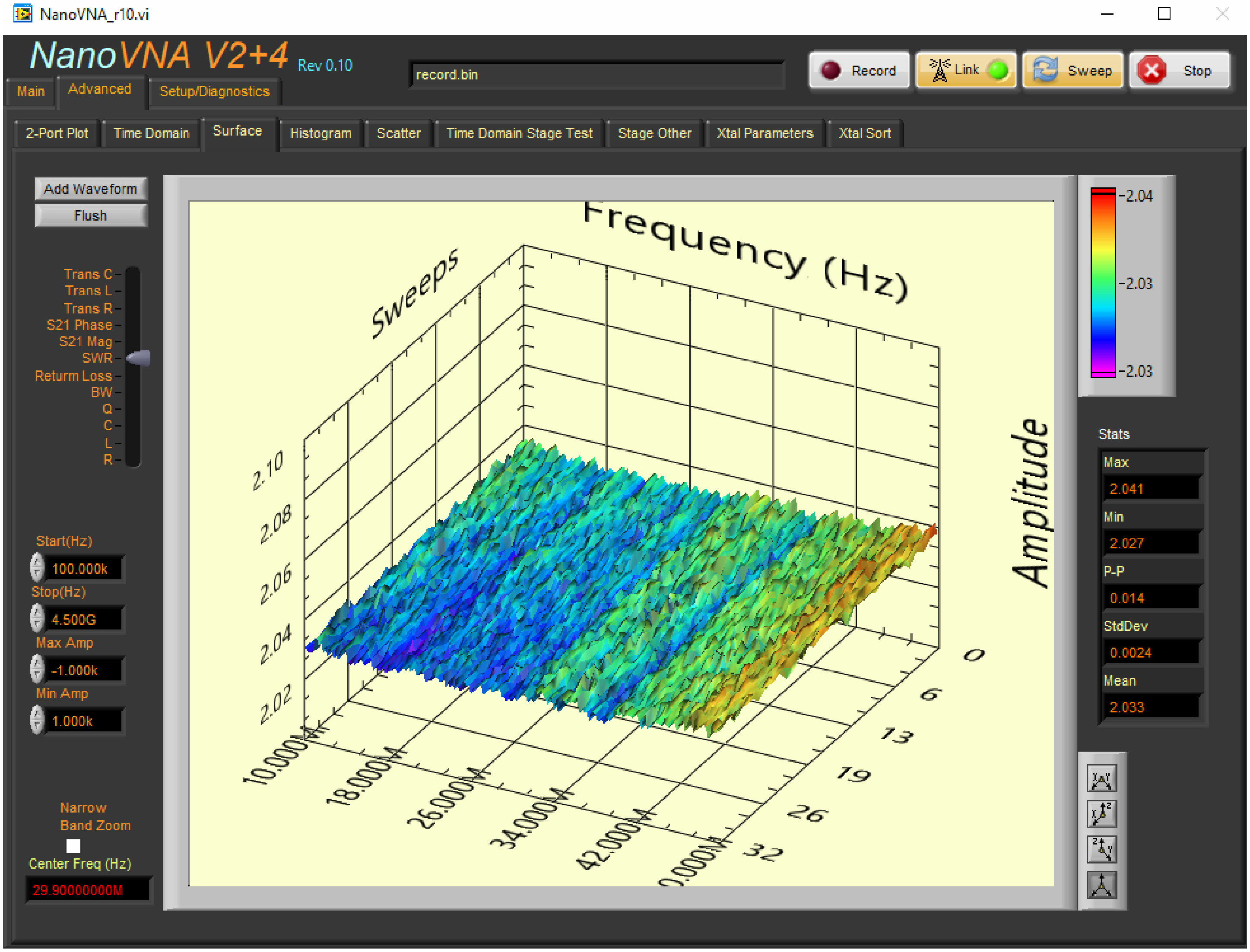


Figure 51

14.2 Histograms and Scattering Diagrams

You may also display the histogram for the selected data.

NanoVNA_r10.vi
NanoVNA V2+4
Rev 0.10
Main
Advanced
Setup/Diagnostics
record.bin
Record
Link
Sweep
Stop
2-Port Plot
Time Domain
Surface
Histogram
Scatter
Time Domain Stage Test
Stage Other
Xtal Parameters
Xtal Sort
Probability Samp
100
Samples
Measured Value

Figure 52

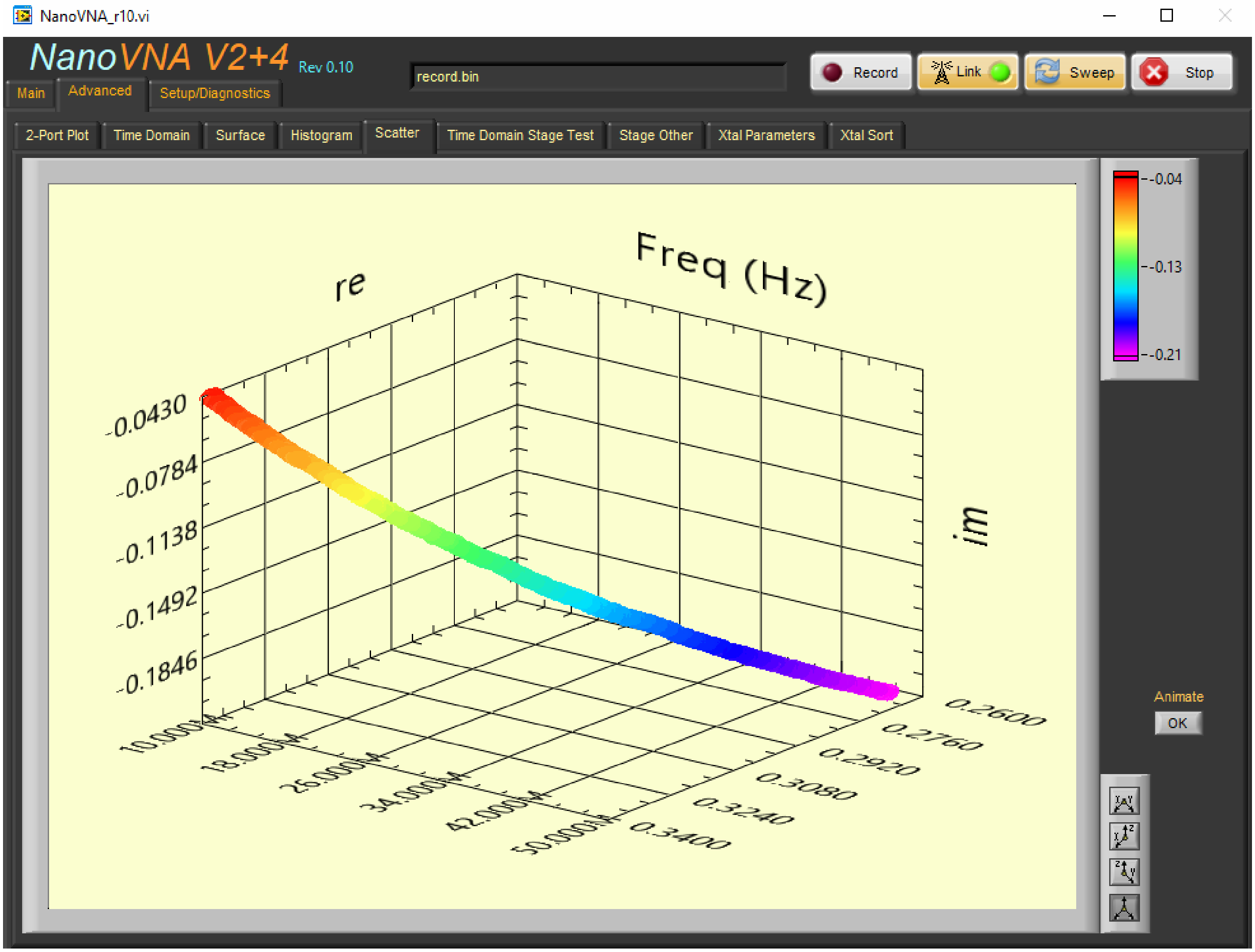


Figure 53

15. Narrow Band Measurements

&$#&%$#%^!!!!!!!!!!!!!!!

While the original NanoVNA did a very nice job making narrow band measurements, sadly the V2+ is not able to make these same measurements. The various features have been included but do not expect them to provide any useful data.

15.1 Segmented Sweeps

Segmented sweep was originally added to the NanoVNA software to provide a means of creating high resolution Touchstone files that could be used to generate SPICE models. The original NanoVNA supported a fixed 101 data points for a given sweep range. Segmented sweeps provided a way to work around this limitation. The resolution was really only limited by how long the user wanted to wait and the hardware's minimum step size.

The V2+'s firmware supports more than enough data to make these measurements without the need for segmentation.

15.1.1 Linear / Log Sweep

When using segments, you may select either linear or logarithmic sweeps. Linear is fairly straight forward. For log sweeps, the software computes the step size for each segment based on the samples per decade. While not a true log sweep in the sense, it does allow collecting a higher number of data points for lower frequencies.

15.1.2 Setting up the Segmented Mode

Assuming you are running a linear sweep, set Fspan to the frequency range of each segment. The step size is the span divided by the number of data points selected.

Next, set the start (Fmin) and stop (Fmax) to the range of frequencies you would like to sweep.

IMPORTANT!!!!
There is an order to selecting the data. The software will always program the V2+ to the last setting you made. If you change Fcenter, the software will use the center and span to calculate the new range. If you change Fmin, the software will use the min (start) and max (stop) to calculate the range. If you were to program the min and max first, then change the span, the V2+'s start and stop would change.
Also, changing the number of points will cause the software to recalculate the sweep range based on the min (start) and max (stop).

Using the defaults, the software will start by sweeping from 1MHz to 3MHz, with 201 data points. It will then continue to the next segment.

By attaching a 12MHz 5 pole LP filter, you can see that the resolution in the lower frequencies is poor. I have changed the span from 2MHz to 50MHz.

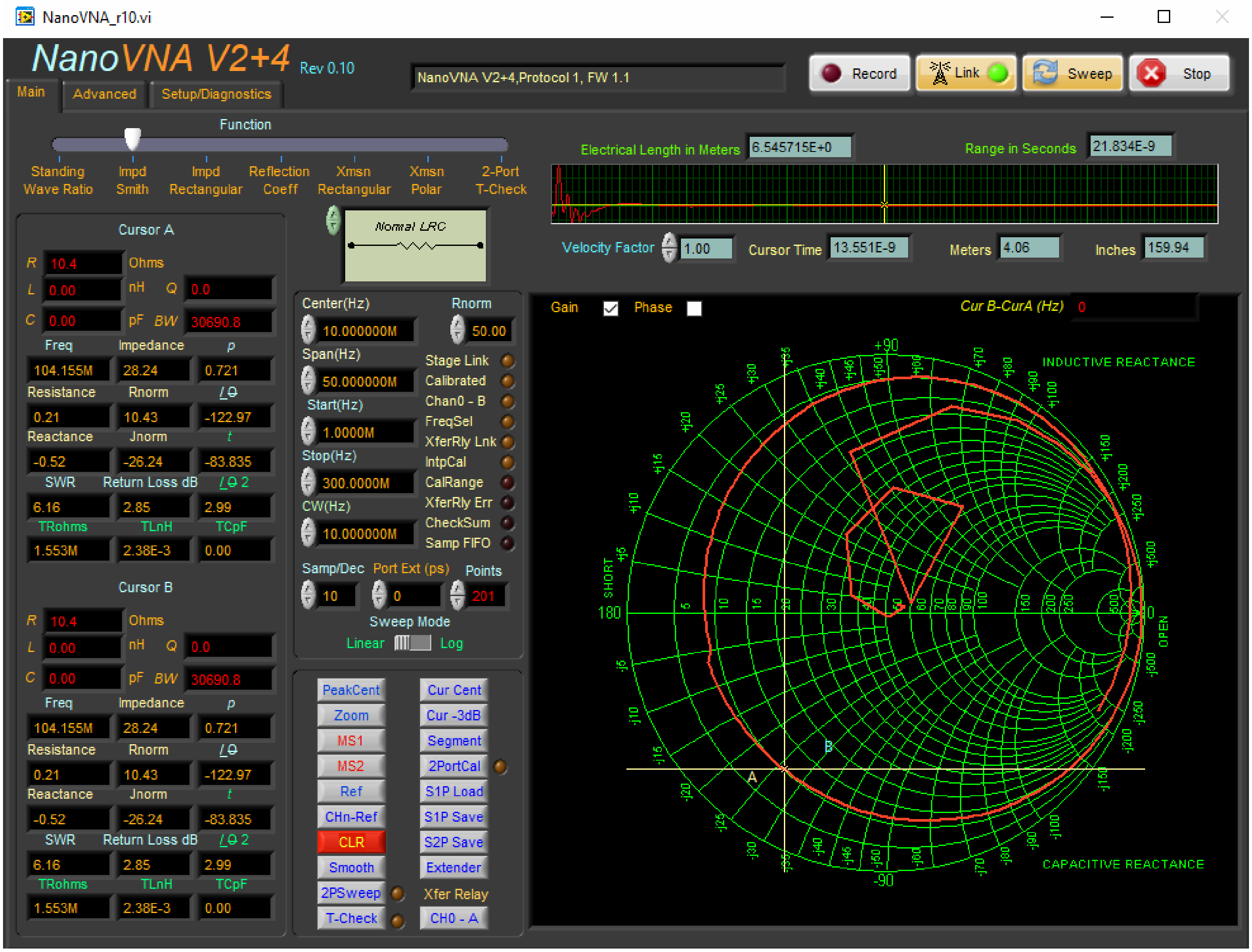


Figure 54

Selecting Segment, and increasing from 201 points to 1005 points allows for more detail.

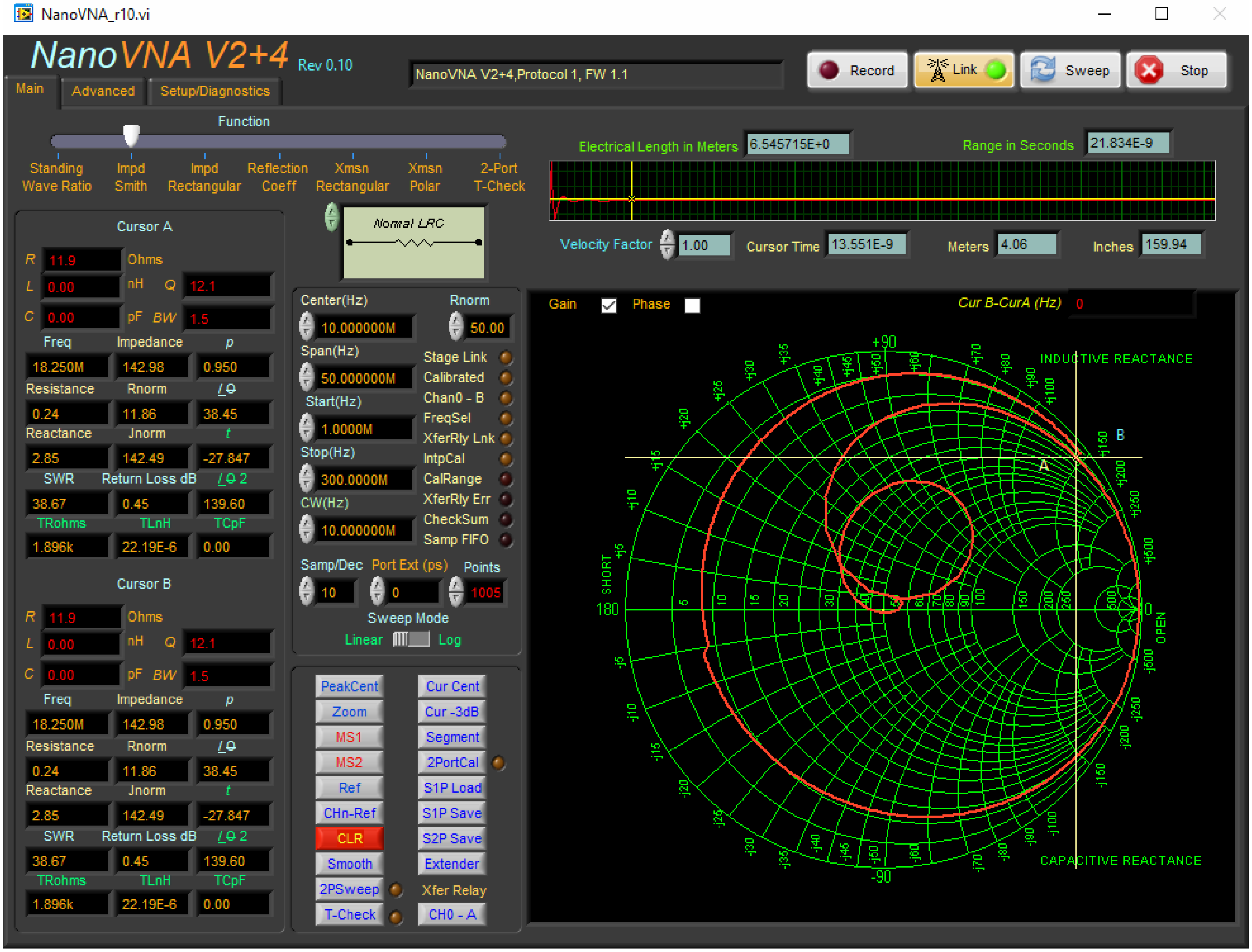
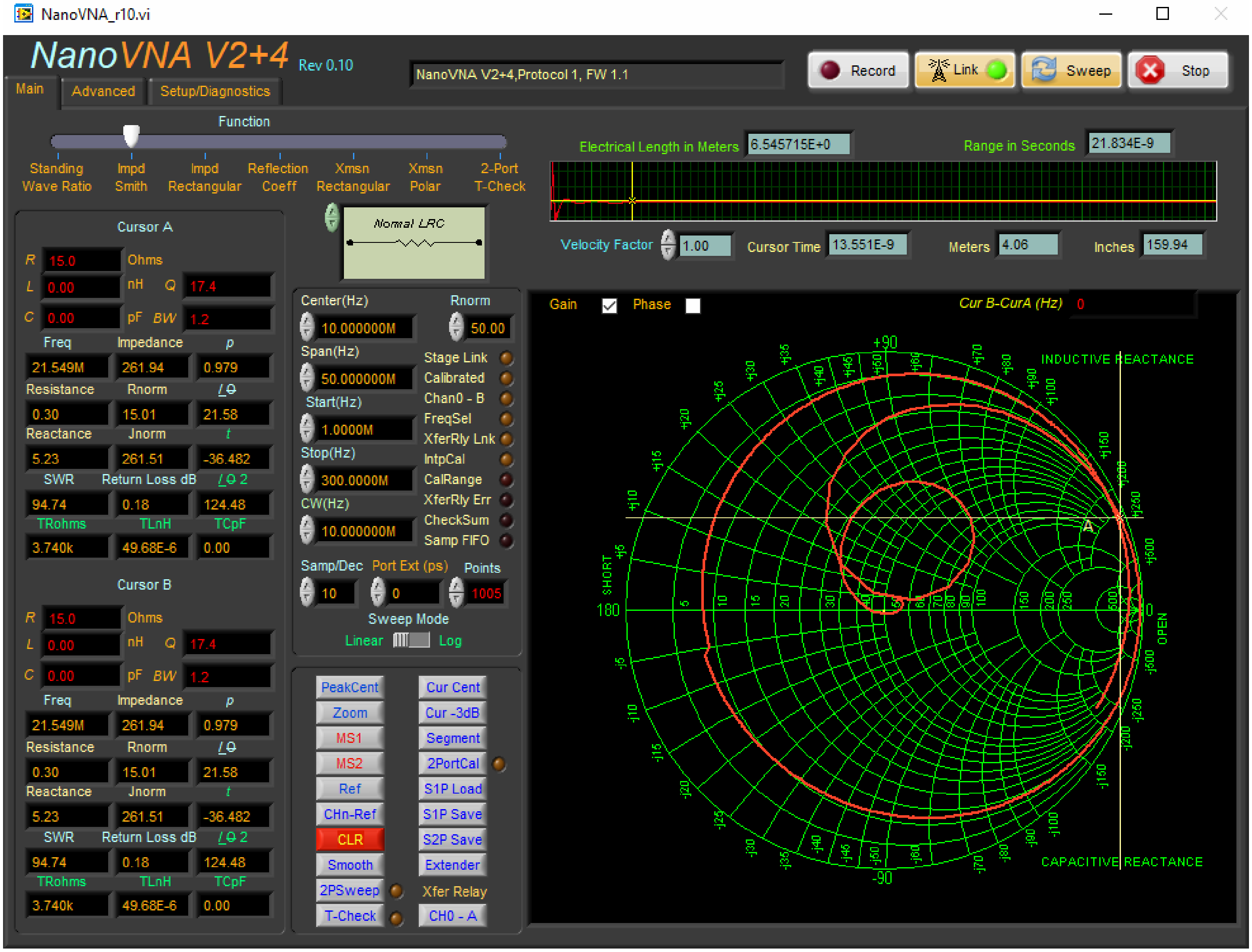


Figure 55

The software currently supports up to 1600 data points. Changing the number of points to 1005 the V2+ will send the same amount of data with a normal sweep.

As shown in Figure 56 when compared with Figure 55, the only difference between the segmented and the normal sweep modes is the sweep time for the normal mode is roughly 4.4 seconds (Figure 57).



NanoVNA_r10.vi
NanoVNA V2+4
Rev 0.10
NanoVNA V2+4,Protocol 1, FW 1.1
Record
Link
Sweep
Stop
Main
Advanced
Setup/Diagnostics
Function
Standing Wave Ratio
Impd Smith
Impd Rectangular
Reflection Coeff
Xmsn Rectangular
Xmsn Polar
2-Port T-Check
Electrical Length in Meters
6.545715E+0
Range in Seconds
21.834E-9
Velocity Factor
1.00
Cursor Time
13.551E-9
Meters
4.06
Inches
159.94
Normal LRC
Cursor A
Cursor B
Ohms
Freq
Impedance
Resistance
Rnorm
Reactance
Jnorm
SWR
Return Loss dB
TRohms
TLnH
TCpF
Center(Hz)
10.000000M
Rnorm
50.00
Span(Hz)
50.000000M
Start(Hz)
1.0000M
Stop(Hz)
300.0000M
CW(Hz)
10.000000M
Stage Link
Calibrated
Chan0 - B
FreqSel
XferRly Lnk
IntpCal
CalRange
XferRly Err
CheckSum
Samp FIFO
Samp/Dec
Port Ext (ps)
Points
Sweep Mode
Linear
Log
PeakCent
Zoom
MS1
MS2
Ref
CHn-Ref
CLR
Smooth
2PSweep
T-Check
Cur Cent
Cur -3dB
Segment
2PortCal
S1P Load
S1P Save
S2P Save
Extender
Xfer Relay
CH0 - A
Gain
Phase
Cur B-CurA (Hz)
INDUCTIVE REACTANCE
CAPACITIVE REACTANCE
SHORT
OPEN

Figure 56

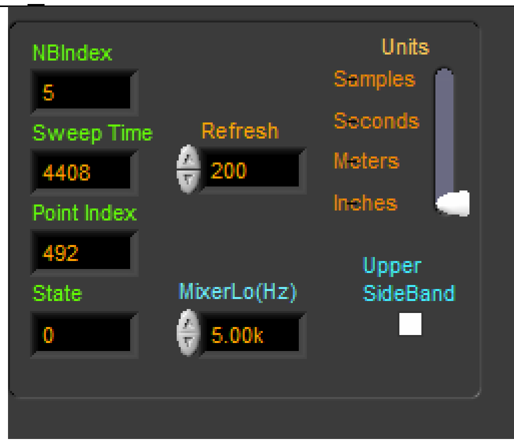


Figure 57

15.2 Measuring Crystals

While the original NanoVNA made these measurements fairly accurately compared with the author's other VNAs and various test equipment, the V2+ lacks the ability to perform any narrowband measurements. This section of the document has been included only to provide details explaining (showing) how the software works. Do not expect to make use of these specific modes unless an improved V2+ that is software compatible with the current versions is released. To mitigate this problem, I suggest the original NanoVNA be procured.

The following table from CopperMountain shows the equations for the three types of impedance measurements. For these measurements, we will be looking at the crystals series impedance.

1	$Z_0 \cdot \frac{1+S_{11}}{1-S_{11}}$	$\Delta Z^{\max} = \frac{2Z_0 \cdot \lvert \Delta S_{11}^{\max} \rvert}{\lvert 1-S_{11} \rvert^2}$, $\lvert \Delta S_{11}^{\max} \rvert = \lvert D \rvert + \lvert R-1 \rvert \cdot \lvert S_{11} \rvert + \lvert M \rvert \cdot \lvert S_{11} \rvert^2$	2.5 Ohm to 1 kOhm
2	$\frac{Z_0}{2} \cdot \frac{S_{21}}{1-S_{21}}$	$\Delta Z^{\max} = \frac{Z_0 \cdot \lvert \Delta S_{21}^{\max} \rvert}{2 \cdot \lvert 1-S_{21} \rvert^2}$, $\lvert \Delta S_{21}^{\max} \rvert = (\lvert T-1 \rvert + \lvert M \rvert + \lvert L \rvert) \cdot \lvert S_{21} \rvert + \lvert X \rvert$	1 mOhm to 100 Ohm
3	$2Z_0 \cdot \frac{1-S_{21}}{S_{21}}$	$\Delta Z_3^{\max} = \frac{2Z_0 \cdot \lvert \Delta S_{21}^{\max} \rvert}{\lvert S_{21} \rvert^2}$, $\lvert \Delta S_{21}^{\max} \rvert = \lvert T-1 \rvert \cdot \lvert S_{21} \rvert + \lvert X \rvert$	8 Ohm to 100 kOhm

Figure 58

15.3 Test Fixture

To make these measurements, a custom test fixture was created. This is nothing more than two 3dB attenuators and two five-turn bifilar transformers wound with Teflon wire. I used some cores I had on hand. These are toroids with a 12.7mm dia, 6.35mm height and a 2.4mm thickness. I suspect these were made by TDK or Fair-Rite. This fixture works fairly well for measuring crystals in the range of 2-30MHz.

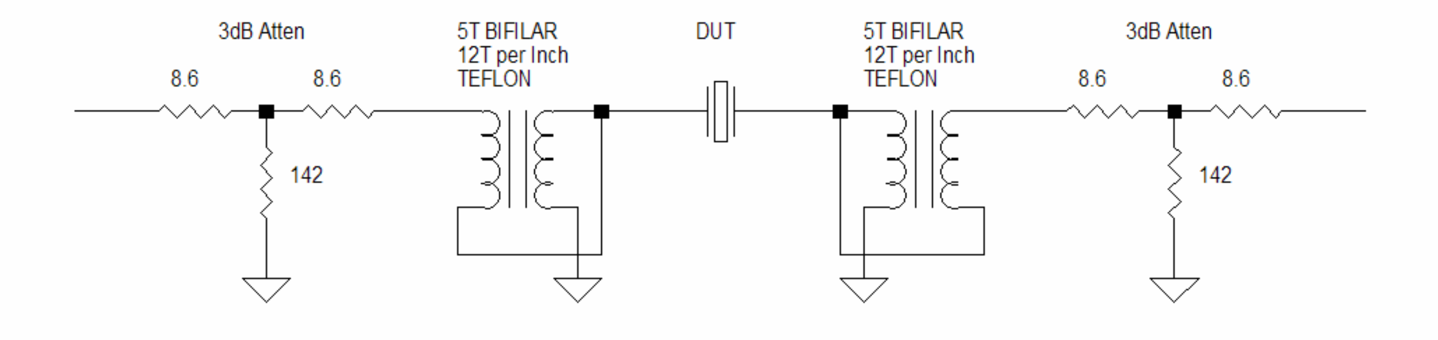


Figure 59

The standards along with the fixture are shown below. The copper block and connector is just a heatsink for soldering these.

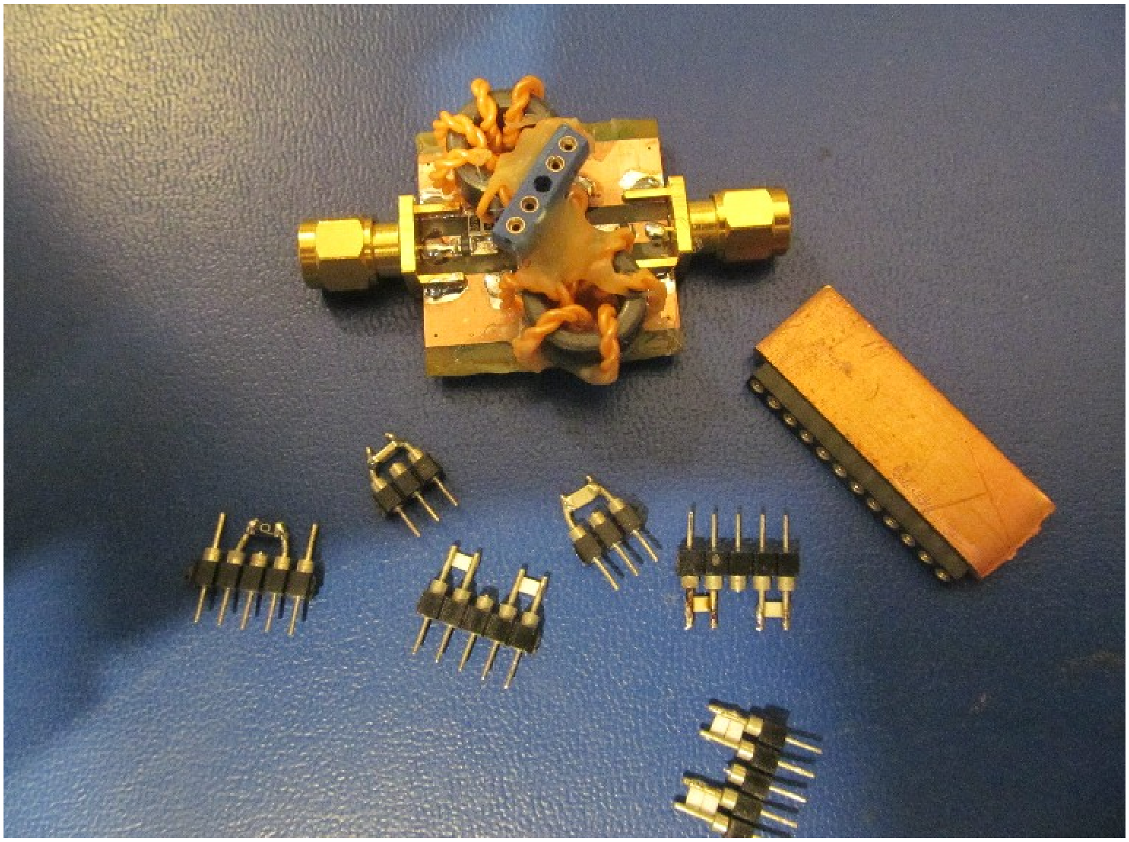


Figure 60

15.4 Example of Measuring a Crystal

The basic steps when characterizing quartz crystals is as follows:

1. Insert fixture
2. Set the Center frequency to roughly the value of the Xtal and set the span to 100KHz
3. Install short standard into Xtal socket
4. Select Ref, followed by CHn-Ref (Should now measure 0dB)
5. Remove short and insert Xtal to test
6. Select Zoom. The software will zoom into the peak and set the span to 500Hz
7. Select Advanced, Xtal Parameters
8. Make sure that the Fixture type is set to 4:1 (unchecked)
9. Select CO Cap and wait for TrC measurement to complete
10. Right mouse click on the center graph and select Clear data
11. Wait for the crystal to become temperature stable
12. Fill out the Serial number, Brand and Model of the device
13. Select Save Data (This will write one record to the file you select)
14. Replace the crystal and repeat steps 10-14 for each crystal to characterize.

Note that no calibration is required as normalization is used.

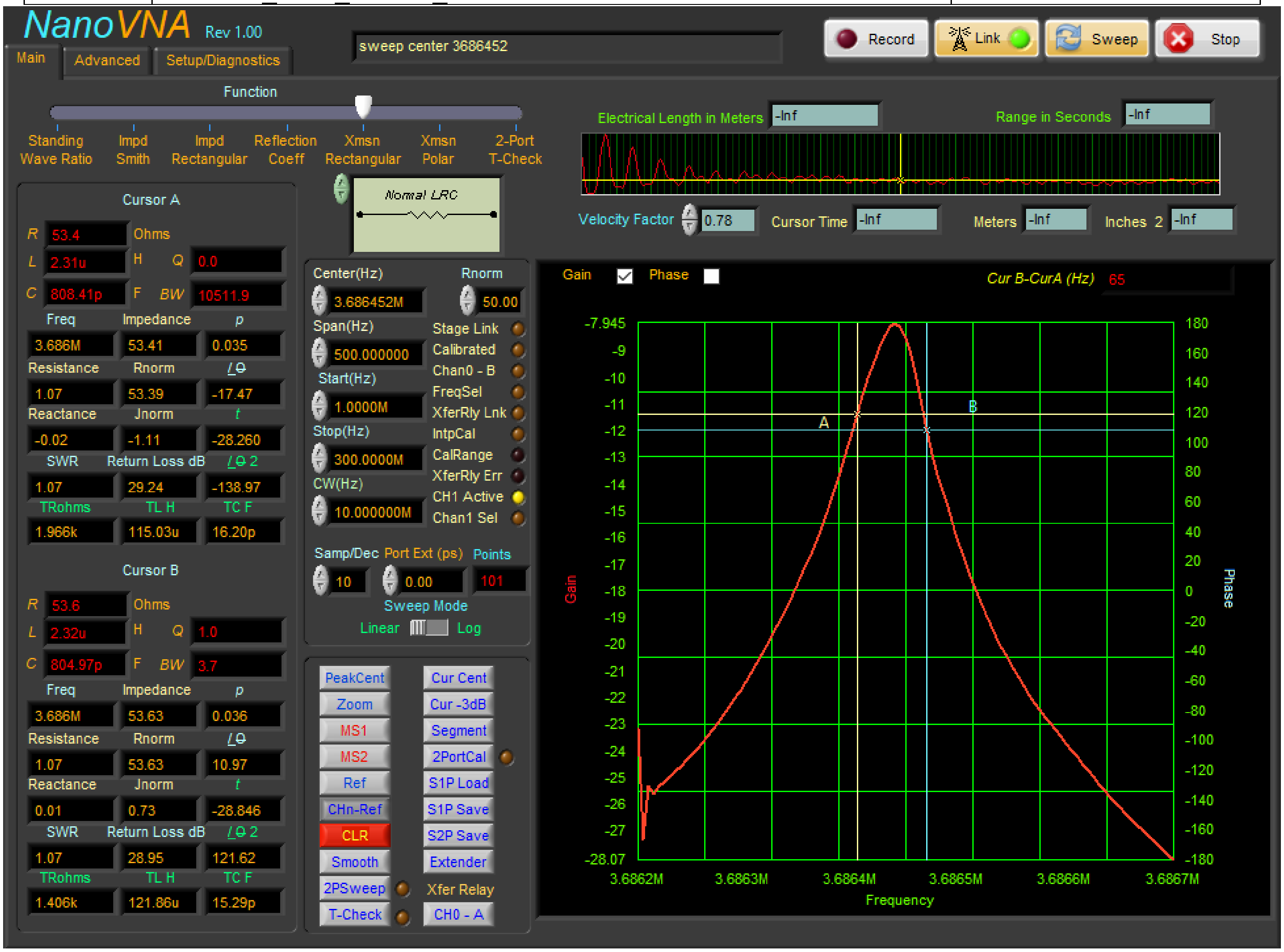
For this example I used a 3.6864MHz crystal from Fox, series 0368S. Start by installing the fixture and a short in place of a crystal. Set the function to Xmsn Rectangular. Set the center frequencies to 3.7MHz (roughly in the center of the crystals you plan to characterize).

When using the original NanoVNA, you should not use the internal calibration for any measurements. Rather you can reset the calibration from the Nano's menu and then store that to settings 0. When the unit is powered up, it will always be cleared. Of course the software does not care if the Nano is calibrated or not and it does support loading the internal calibrations for those who need this feature. Again, think engineering tool.

Notice without the calibration, the original NanoVNA will display roughly -17dB.

Figure 61

Select the Ref button to store this as your reference. Now select CHn-Ref. The software will now display 0dB. Next install the crystal you want to characterize and select Zoom. The software will automatically zoom into the peak and center it. Once finished, you can set the cursors to the 3dB points by selecting Cur-3dB.



NanoVNA Rev 1.00
Main
Advanced
Setup/Diagnostics
sweep center 3686452
Record
Link
Sweep
Stop
Function
Standing Wave Ratio
Impd Smith
Impd Rectangular
Reflection Coeff
Xmsn Rectangular
Xmsn Polar
2-Port T-Check
Normal LRC
Electrical Length in Meters
Range in Seconds
Velocity Factor
0.78
Cursor Time
Meters
Inches 2
Cursor A
Cursor B
Center(Hz)
3.686452M
Rnorm
50.00
Span(Hz)
500.000000
Start(Hz)
1.0000M
Stop(Hz)
300.0000M
CW(Hz)
10.000000M
Stage Link
Calibrated
Chan0 - B
FreqSel
XferRly Lnk
IntpCal
CalRange
XferRly Err
CH1 Active
Chan1 Sel
Samp/Dec
Port Ext (ps)
Points
Sweep Mode
Linear
Log
PeakCent
Cur Cent
Zoom
Cur -3dB
MS1
Segment
MS2
2PortCal
Ref
S1P Load
CHn-Ref
S1P Save
CLR
S2P Save
Smooth
Extender
2PSweep
Xfer Relay
T-Check
CH0 - A
Gain
Phase
Cur B-CurA (Hz)
65
Frequency

Figure 62

If using the V2+, when adjusting the start and stop frequencies (or span) to zoom into this area, you begin to see a problem. Normally, you would expect this to be a very smooth curve but the limitation of the V2+ is already causing problems.

Figure 63

Notice the steps in the V2+'s data as we continue to zoom into the peak.

Figure 64

For a reference: Figure 65 shows the same model/brand crystal and test fixture attached to one of my old network analyzers. The original NanoVNA compares closely to the results obtained with this instrument.

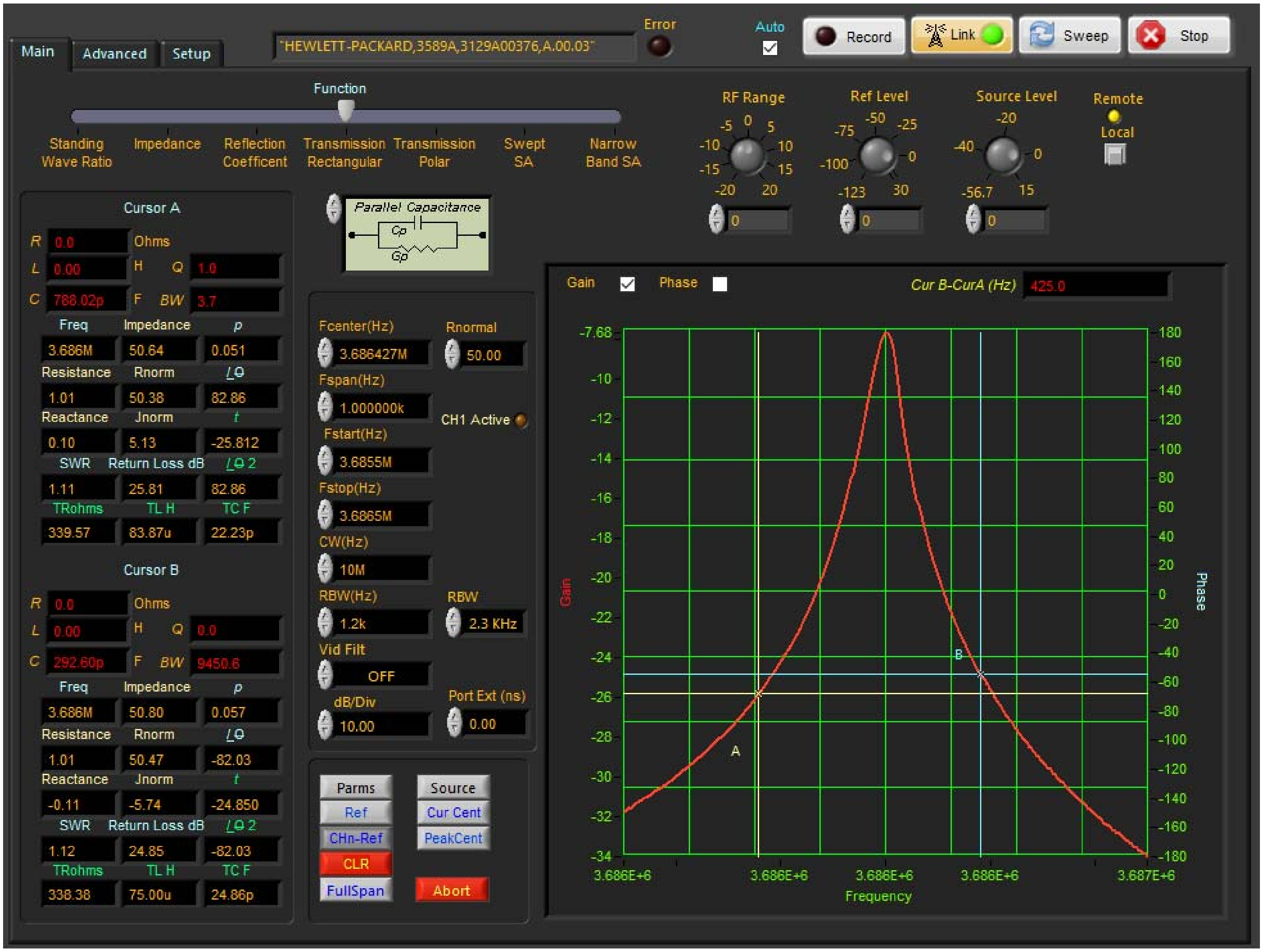


Figure 65

Next select the Advanced tab followed by Xtal Parameters. If you right click on the center graph, you can select clear data. Allow the temperature to stabilize. This may take more than a minute depending on your procedure.

We can see this by monitoring the Series Frequency. I suggest not handling the crystals with your hands to avoid the effects of your body temperature. The NanoVNA is more than sensitive enough to detect very small changes in the crystal. As the part starts to become stable you will see a peak in the histogram.

Figure 66

Once the crystal is stable, selecting the C0 button will cause the software to automatically make this measurement. As noted, I have built up various standard for this fixture. One standard has a 5.6, 10 and 100pF capacitors. These are placed in the fixture rather than the crystals to validate the setup.

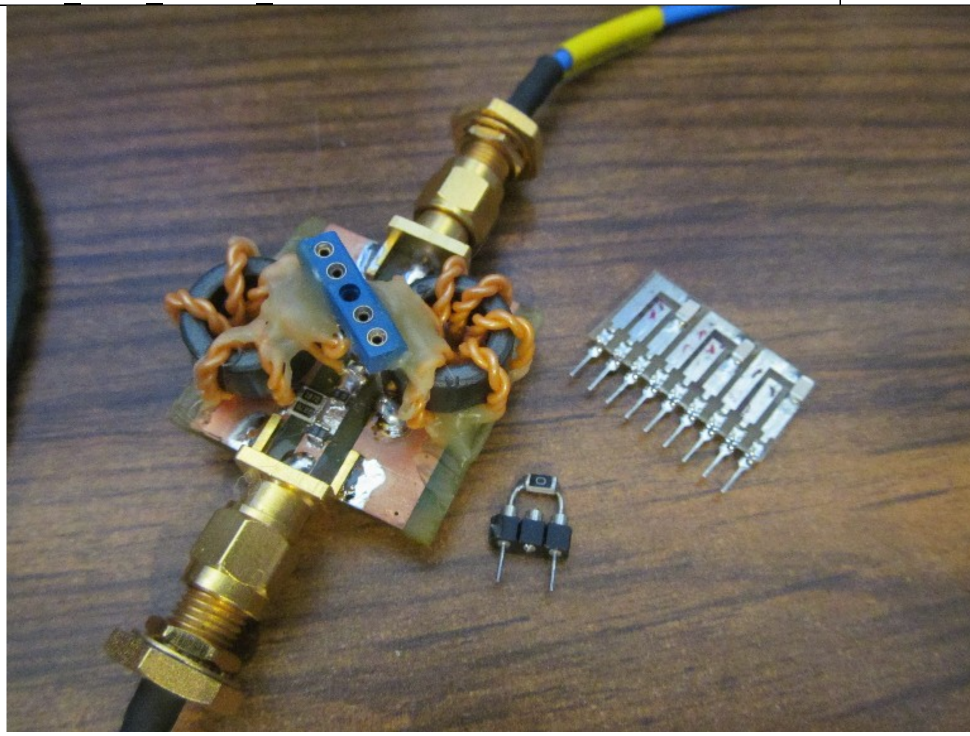


Figure 67

As you can see, the NanoVNA has calculated a value of 4.159pF for C0. Note the dip in the frequency. The software reprograms the VNA to 500KHz to make this measurement. Currently this is fixed. Obviously this assumes you are not characterizing crystals with a resonance near the test frequency.

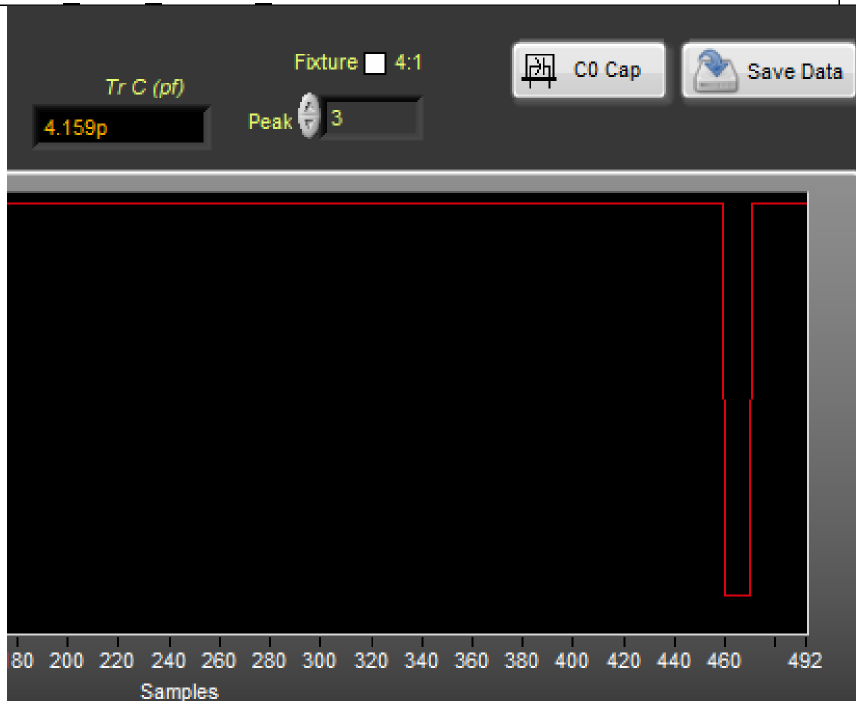


Figure 68

A simple RLC meter can also be used to validate the results. 70fF, close enough….

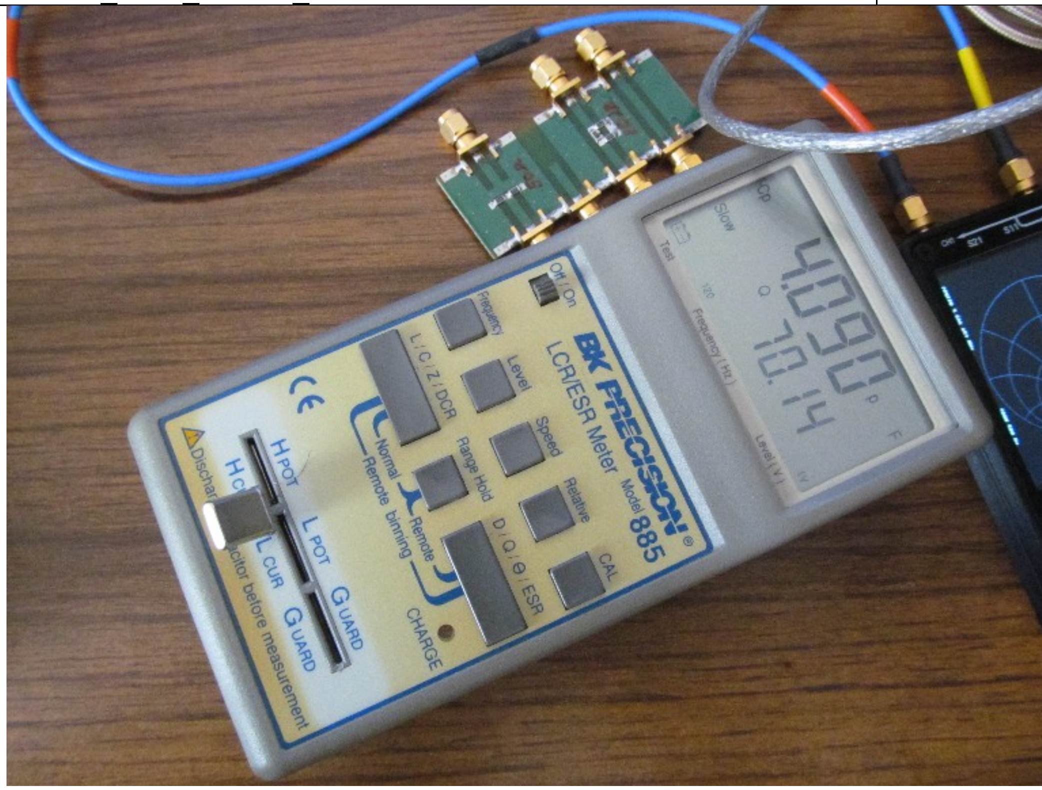


Figure 69

You may now clear the series frequency graph. Allowing the system to run, you will get a feel for the noise.

The software has made all the measurements and you can enter a serial number, brand and model that will be stored with the data.

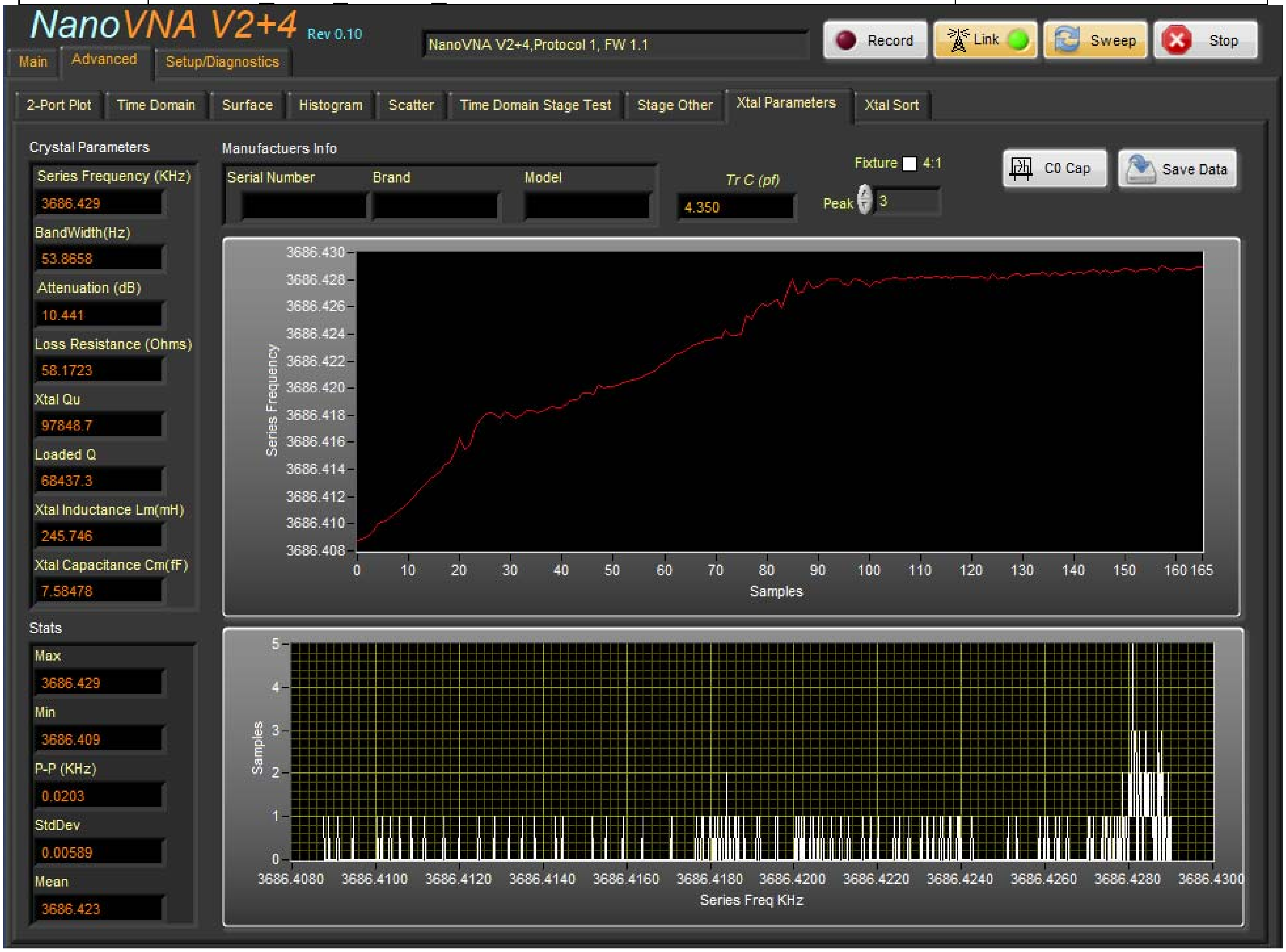


Figure 70

Select Save Data and you will be prompted for a file name. It's best to name the file with a meaningful description.

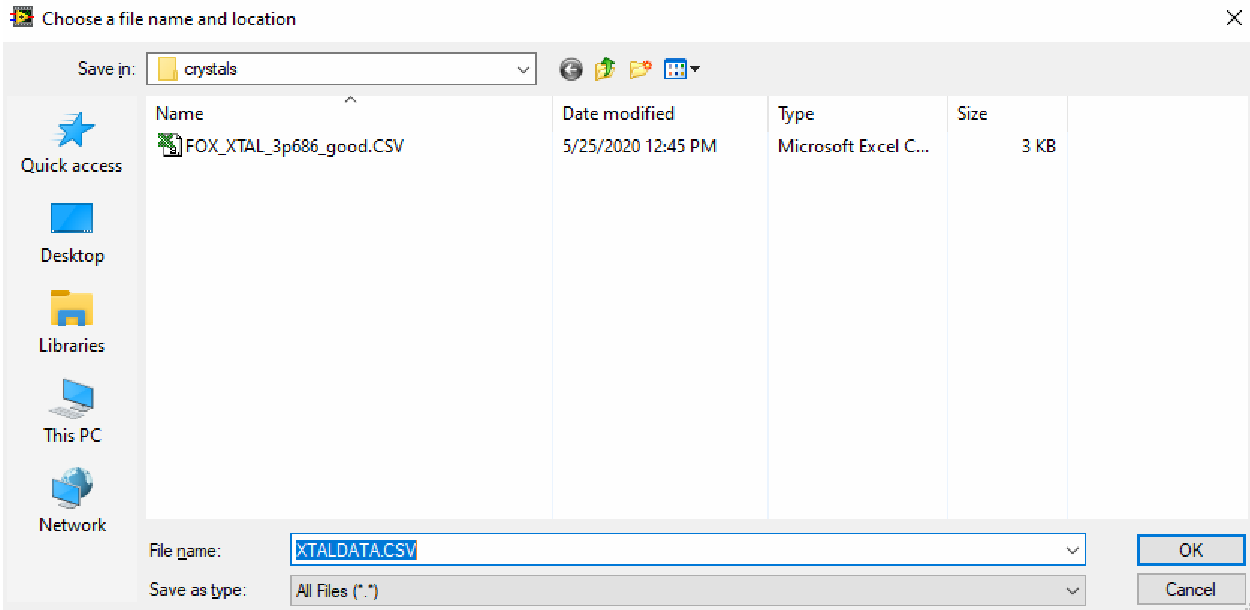


Figure 71

Selecting Xtal Sort tab will allow you to sort the data you have collected. Select the SortData button and you will be asked to select the file name to sort. For this example, I used data collected from the original NanoVNA.

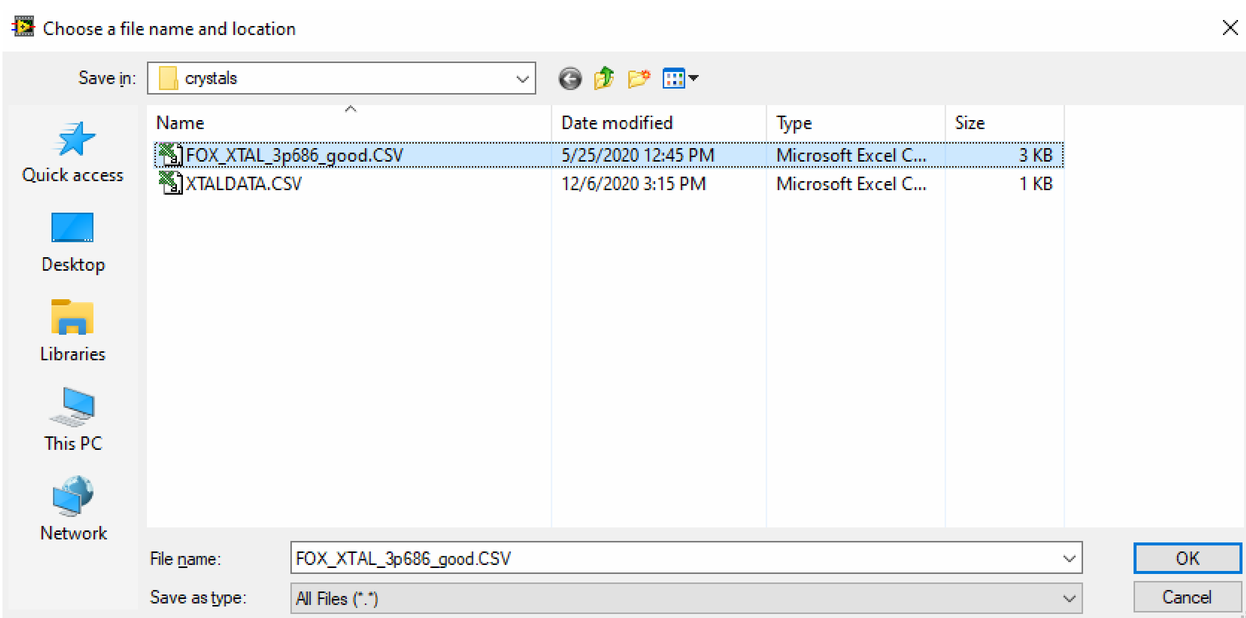


Figure 72

The crystal data will be presented in table format. You may then select the number of poles for the filter you are designing and the software will highlight the closest match.

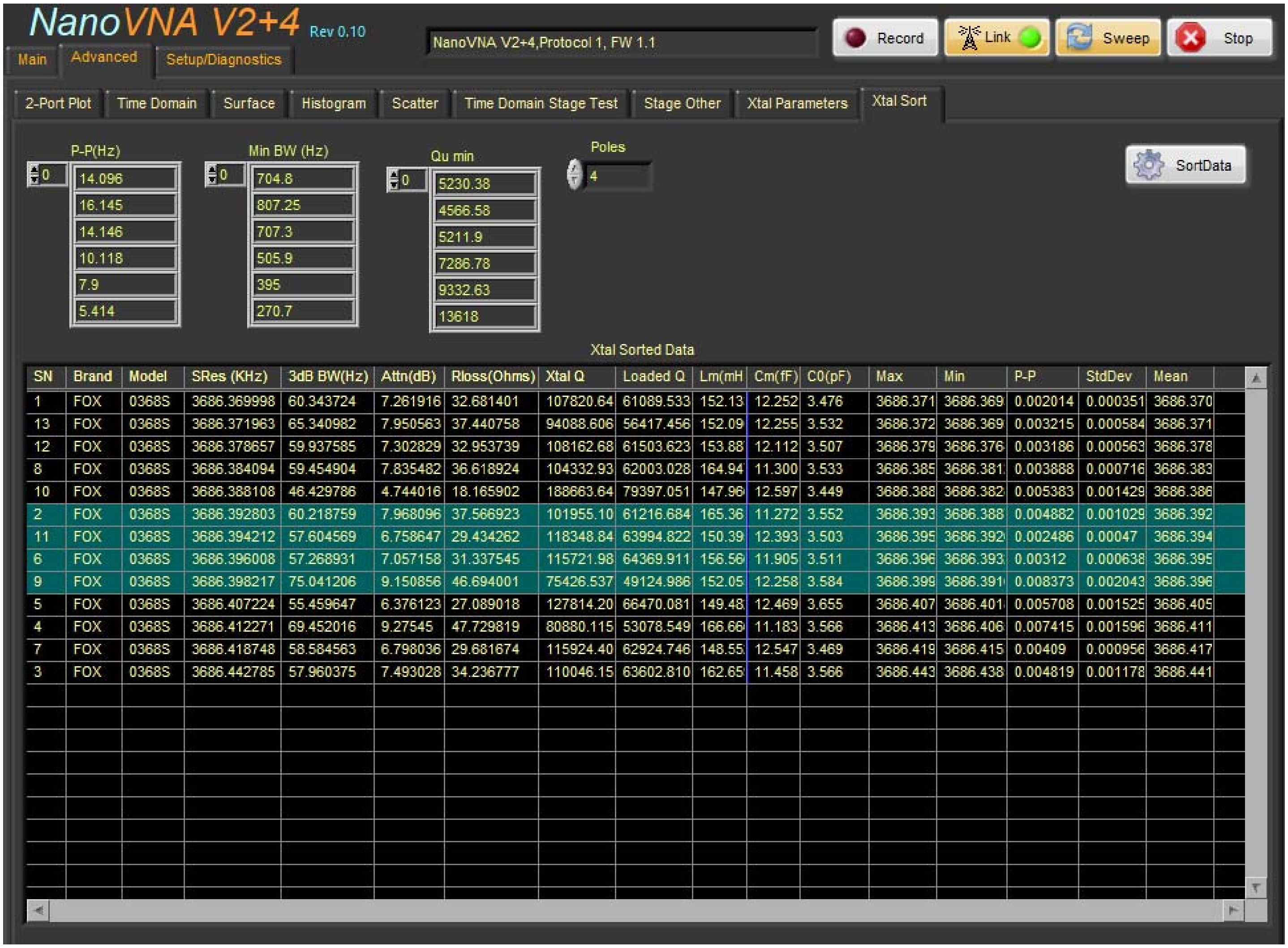
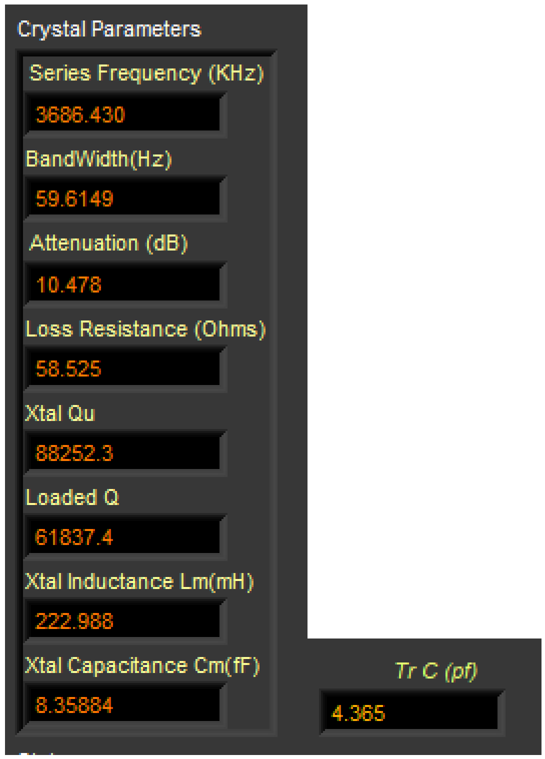


Figure 73

When this data is compared with that we just measured, the series frequency and bandwidth are good, the attenuation is about 3dB off. The measured loss resistance is more than 20 ohms high. Lm, Cm and C0 are not even close. The author owns a few old VNAs that are more than capable of making this measurement and the data collected with the original Nano is very close to what I get with the other systems, using the same test jig.



SN	Brand	Model	SRes (KHz)	3dB BW(Hz)	Attn(dB)	Rloss(Ohms)	Xtal Q	Loaded Q	Lm(mH	Cm(fF)	C0(pF)
1	FOX	0368S	3686.369998	60.343724	7.261916	32.681401	107820.64	61089.533	152.13	12.252	3.476
13	FOX	0368S	3686.371963	65.340982	7.950563	37.440758	94088.606	56417.456	152.09	12.255	3.532
12	FOX	0368S	3686.378657	59.937585	7.302829	32.953739	108162.68	61503.623	153.88	12.112	3.507
8	FOX	0368S	3686.384094	59.454904	7.835482	36.618924	104332.93	62003.028	164.94	11.300	3.533
10	FOX	0368S	3686.388108	46.429786	4.744016	18.165902	188663.64	79397.051	147.96	12.597	3.449
2	FOX	0368S	3686.392803	60.218759	7.968096	37.566923	101955.10	61216.684	165.36	11.272	3.552
11	FOX	0368S	3686.394212	57.604569	6.758647	29.434262	118348.84	63994.822	150.39	12.393	3.503
6	FOX	0368S	3686.396008	57.268931	7.057158	31.337545	115721.98	64369.911	156.56	11.905	3.511
9	FOX	0368S	3686.398217	75.041206	9.150856	46.694001	75426.537	49124.986	152.05	12.258	3.584
5	FOX	0368S	3686.407224	55.459647	6.376123	27.089018	127814.20	66470.081	149.48	12.469	3.655
4	FOX	0368S	3686.412271	69.452016	9.27545	47.729819	80880.115	53078.549	166.66	11.183	3.566
7	FOX	0368S	3686.418748	58.584563	6.798036	29.681674	115924.40	62924.746	148.55	12.547	3.469
3	FOX	0368S	3686.442785	57.960375	7.493028	34.236777	110046.15	63602.810	162.65	11.458	3.566

Figure 74

So while it may be interesting for some to play with this feature, it really offers no value at this time when using the V2+4. You must use the original NanoVNA when using the software to make these measurements.

15.5 Problems while characterizing crystals

From testing, it is apparent that the firmware for the NanoVNA is anything but stable. It is strongly recommended that you start by loading the identical firmware that the software was tested with. The following random spikes were a result from running an untested version of firmware.

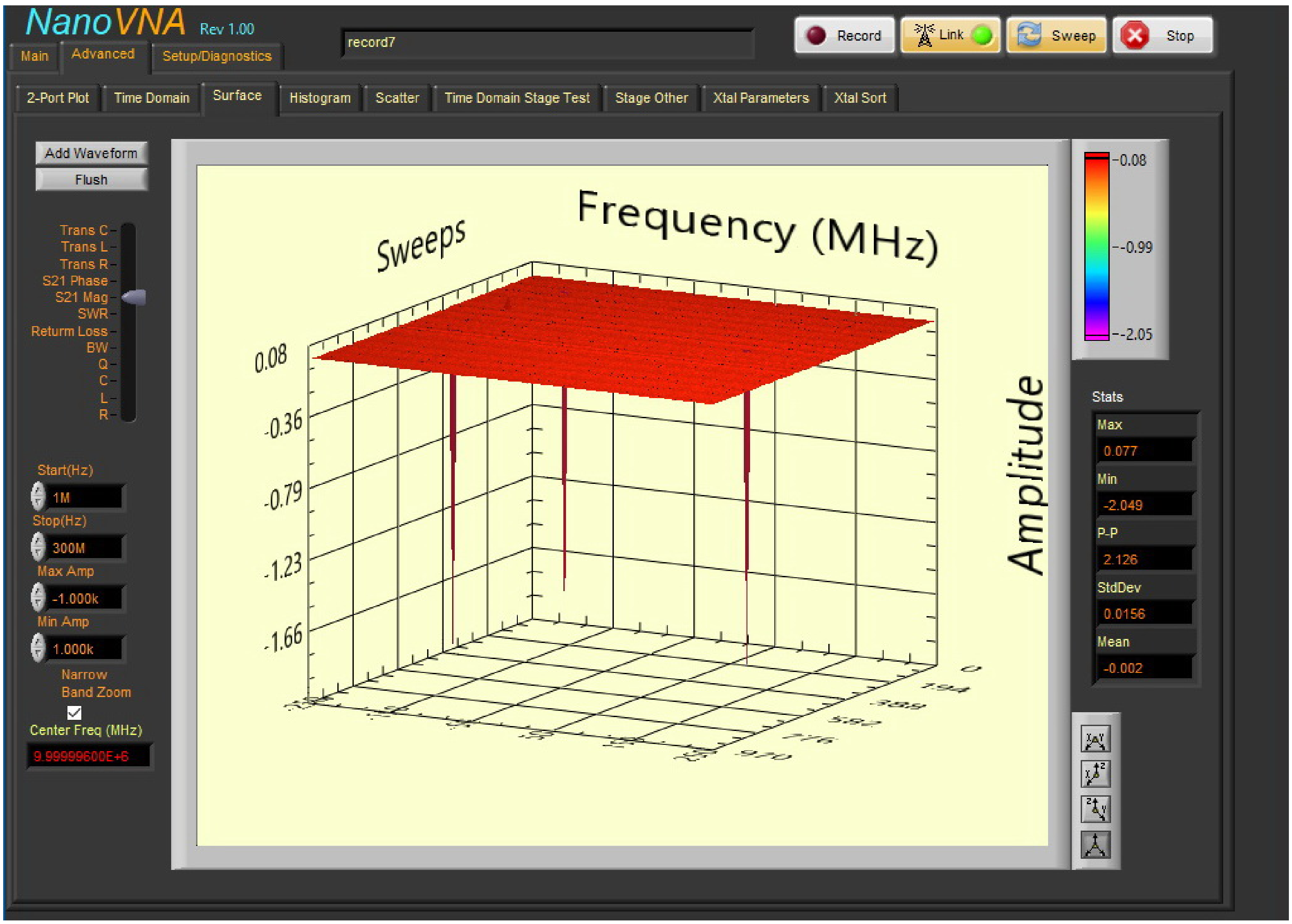


Figure 75

It should be obvious that running the same firmware removes a lot of questions and may save you a lot of time.

Start by selecting the Xmsn Rectangular from the Main menu. With your short installed in place of the crystal, it should read well within 0.1dB after normalization (Figure 76). Make sure you understand the difference between the Nano's internal calibration and the software's.

Figure 76

Assuming that the gain and noise look good, select Record and let it run for 10 minutes or more. Press Record again to turn off the recording. Select Advanced, Surface, Add Waveform and then load the file you saved the data to. Next select Narrow Band Zoom and select S21 Mag. You should have << 0.1dB noise P-P. Notice after touching the setup there is a drop in the signal, but is still within 0.045dB P-P (Figure 77).

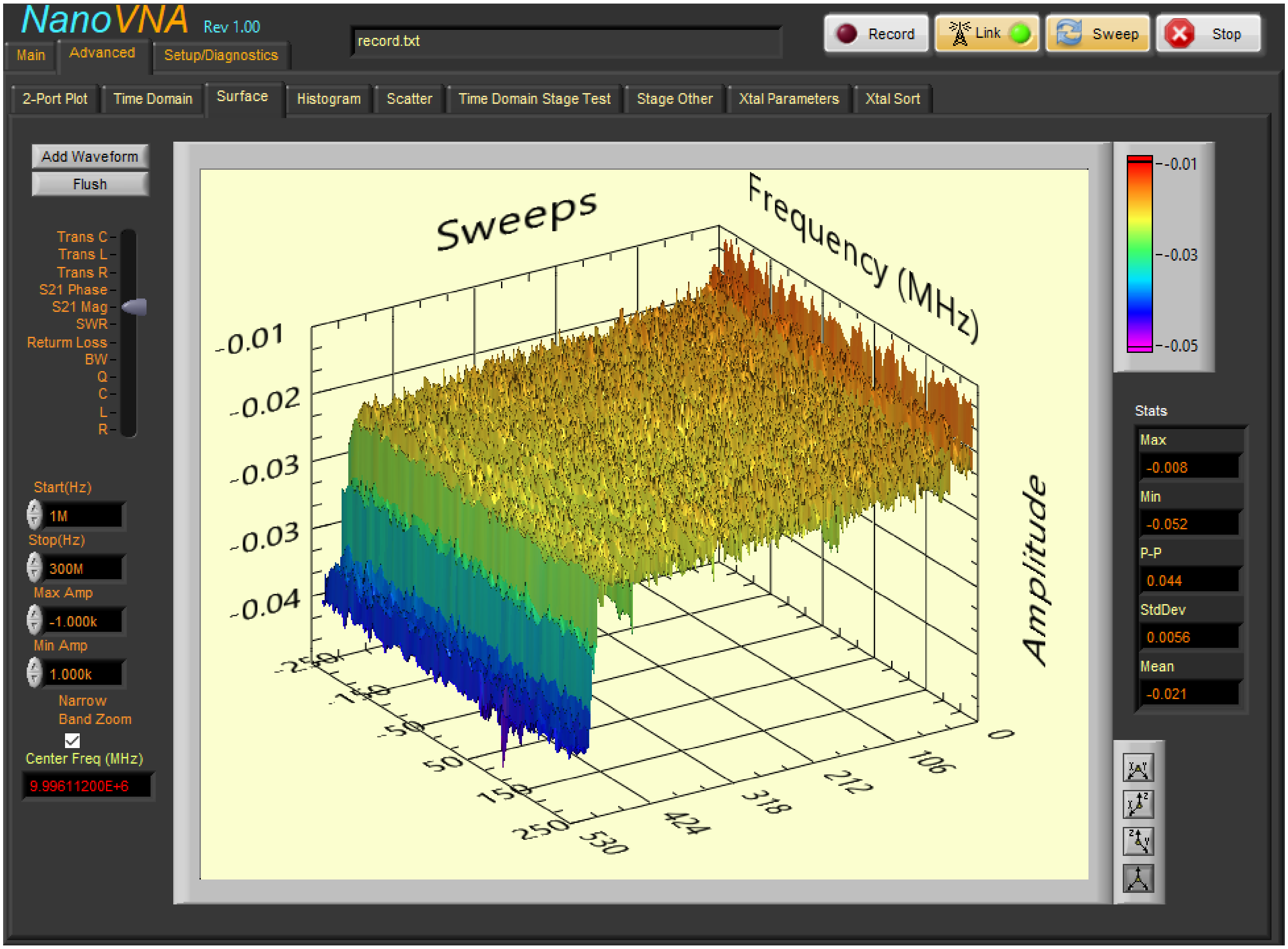


Figure 77

Assuming you are not seeing a problem up to this point, select the Main menu (you should still be seeing << 0.1dB) and swap out the short for one of your crystals. You should see a VERY smooth curve (Figure 78). The peak is the Attenuation. This is typically between 2 and 10dB.

Figure 78

Select Record and save the data to a new file. Let it run for another 10 minutes or more. Don't touch anything and stay away from the fixture. If you have a lot of air flow in the room, my standard practice is the beach towel. Make a note of the temperature if you plan to try and reproduce the test or are collecting the data over long periods of time. 100ppm/degC with even a 2 degree shift and a 10MHz is easily detected.

Select Record again to stop the recording. Select Surface and select Flush. Now select Add Waveform. Looking at both S21 Mag/Phase, they should be void of any spurs (Figures 79&80).

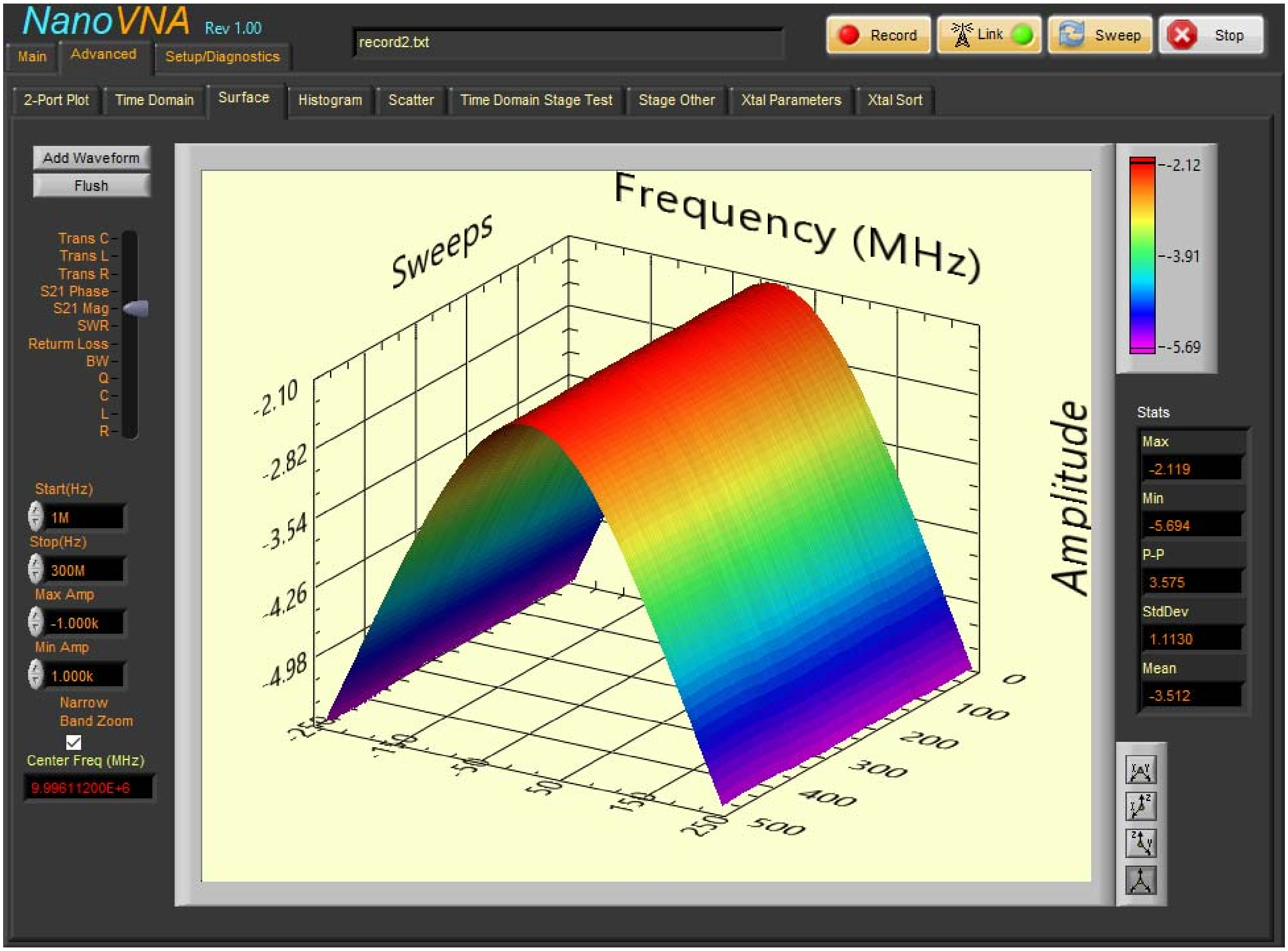


Figure 79

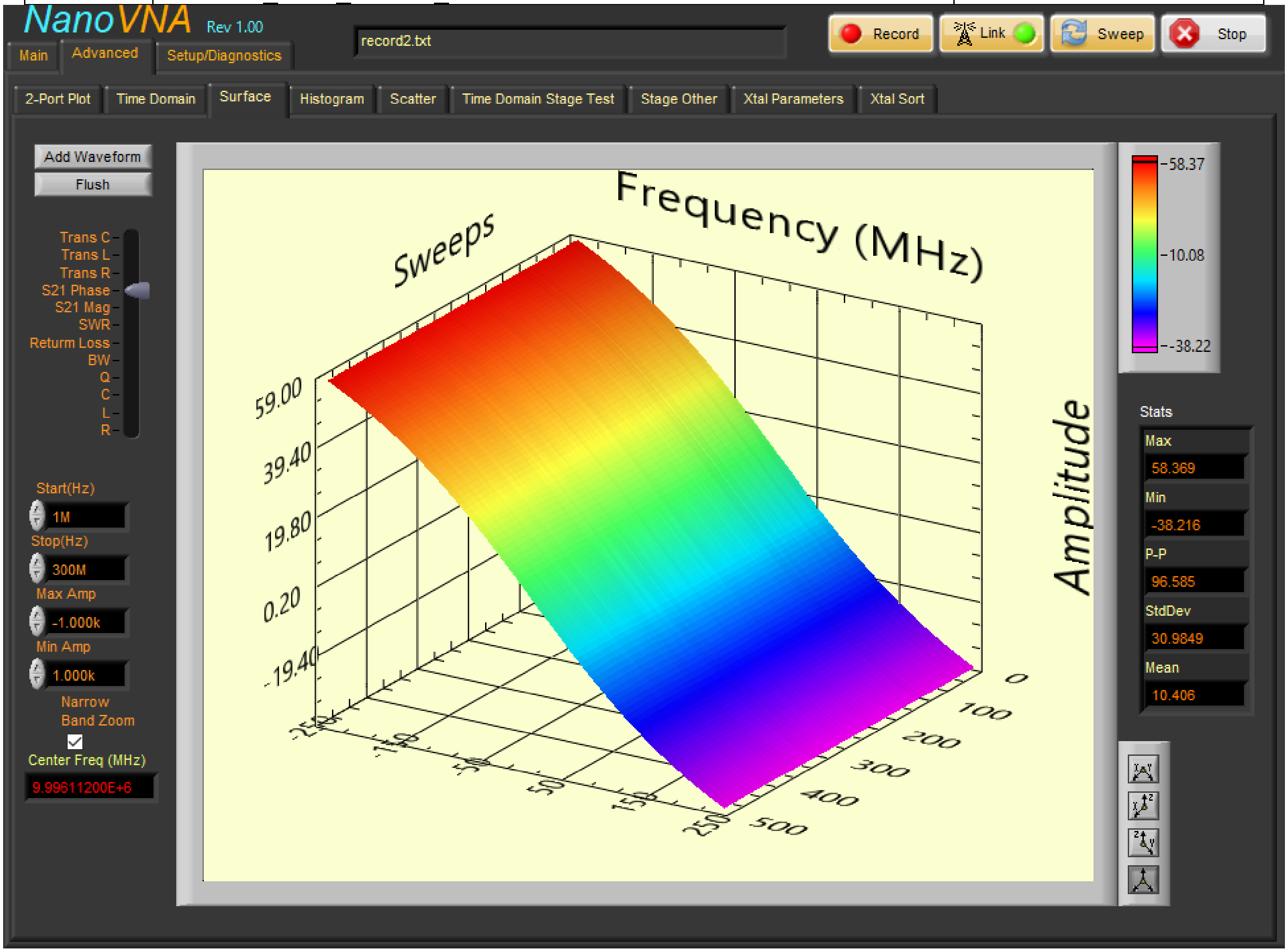


Figure 80

Next validate that the C0 measurement is working. If you don't have a good RLC meter, I suggest installing a known capacitor. Maybe a few values ranging from 2 to 20pF. Depending what you have for parts, their tolerances can be pretty wide. Just make sure that the numbers are in the ballpark and you should be fine. If you insert a 100pF capacitor and it reads 50pF, something is obviously wrong. Try another capacitor. The following shows data collected from the author's original NanoVNA, a handheld DMM and two RLC meters. All values are in pF.

NanoVNA	Fluke 189	BK RLC	BK RLC
2.095	2	1.8	1.88
2.901	3	2.8	2.758

5.098	5	5.1	5.096
6.15	6	6.1	6.133
10.132	10	10.4	10.43
21.319	22	22.2	22.28

16. Filtering the Swept Data

The software includes a filter which acts on the corrected data before it is processed by the main loop. The same filter is used for all of the S-parameters. The filter is enabled by selecting the Smooth button.

17. Touchstone Files

Touchstone format is an industry standard, allowing you to compare data from various test equipment. I use AppCad's built-in viewer for this. I also use it with SPICE as a way to create models for RF circuits.

The software supports both single and two port formats. If you select a 2-port file and you do not have a transfer relay installed, the software will replicate the same data for both ports. This still may be useful for comparing data.

One thing I should mention is that AppCad requires the same number of points in all the Touchstone files. If you plan to use this tool, make sure your NanoVNA is configured the same as your other equipment.

18. Time Domain Measurements

Shown below is a home made Beatty standard made from an old microwave air line attenuator and some brass tubing. The step is 70mm long.

Figure 81

The Beatty standard is attached to port 1. The Beatty standard is then terminated to 50 ohms. The frequency range is set from 100kHz to 4.4GHz. For this example, the instrument has been calibrated.

IMPORTANT!!!!

Older versions of the software used the Beatty standard for the impedance reference. The software would perform a simple point slope calculation to determine unknown values. This was done to avoid having to perform the SOL calibration. Newer versions of the software use S-parameters to calculate Z. At this time, the author has no plans to revert back to using the point slope technique.

The time domain data can be seen towards the upper right. The first negative going peak is the first discontinuity caused from the Beatty standard's step in the brass tubing thickness. The second positive peak is where the tubing necks back down to 50 ohms. The distance between these two peaks is the length of your standard.

Figure 82

While this view is fine for longer cable measurements, you can select the Advanced tab followed by Time Domain which will provide an easier to read graph.

Figure 83

The software will calculate the FWHH automatically. We can see it is displaying 70.785mm. Under Setup, the units are set to Meters.

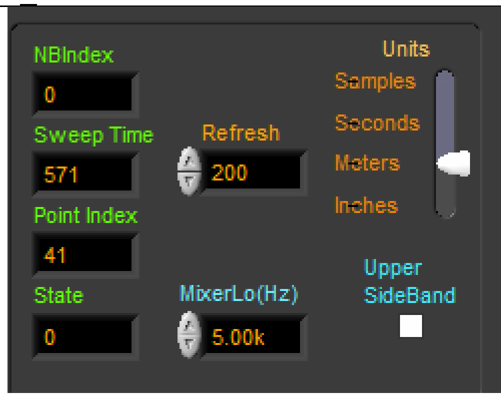
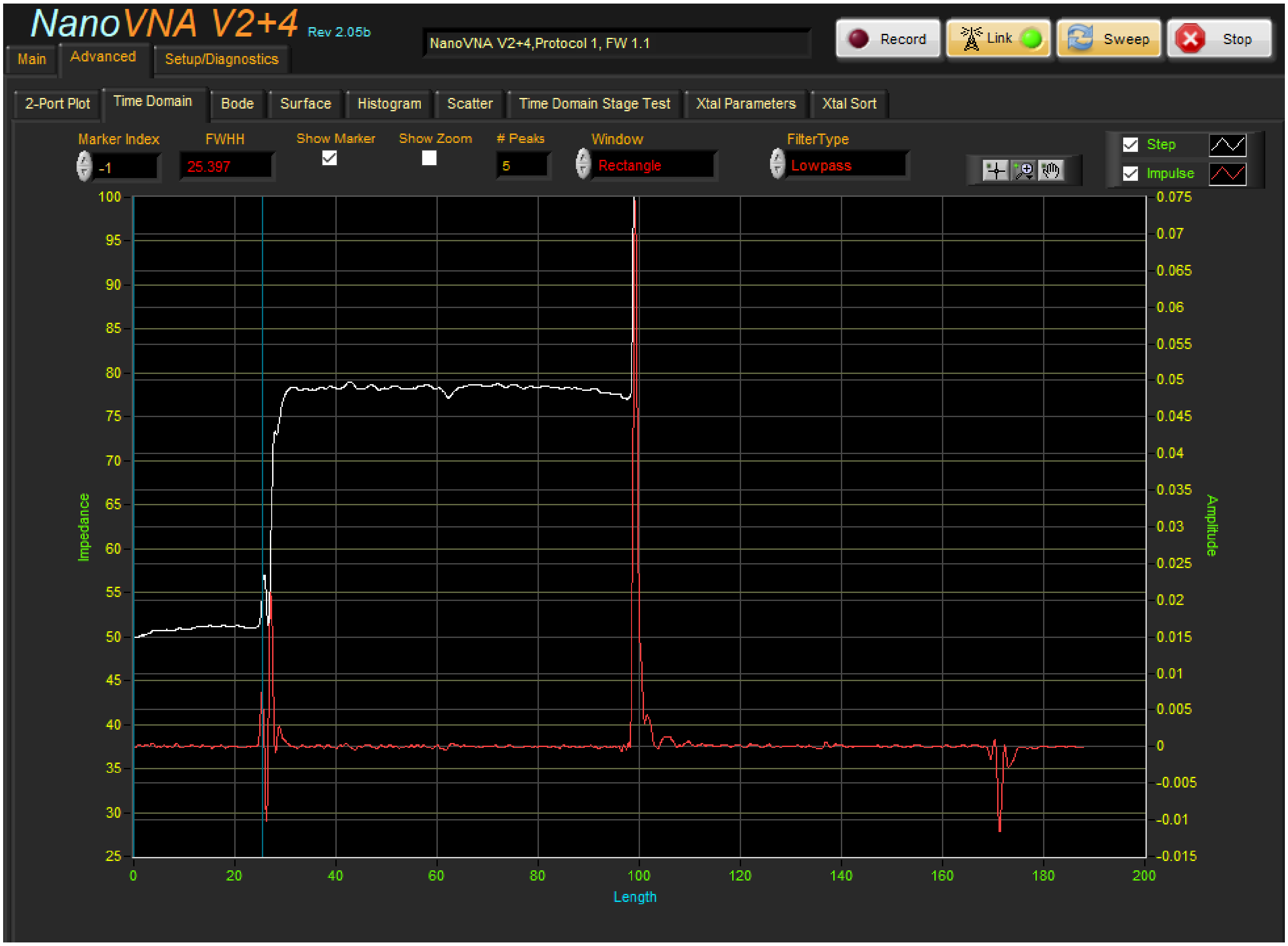


Figure 84

Two sections of coax were attached to Port 1. The two sections were placed in series with a BNC to BNC adapter. The first section of coax is RG58C/U which is 50 ohms. The second section is RG59U which is 75 ohms. Note that the end of the coax is an open.



18.1 Linear Stage

The software supports a linear stage, or slide. This is a ball screw driven from a stepper motor. The software supports the M-Drive series motors using a standard communications port.

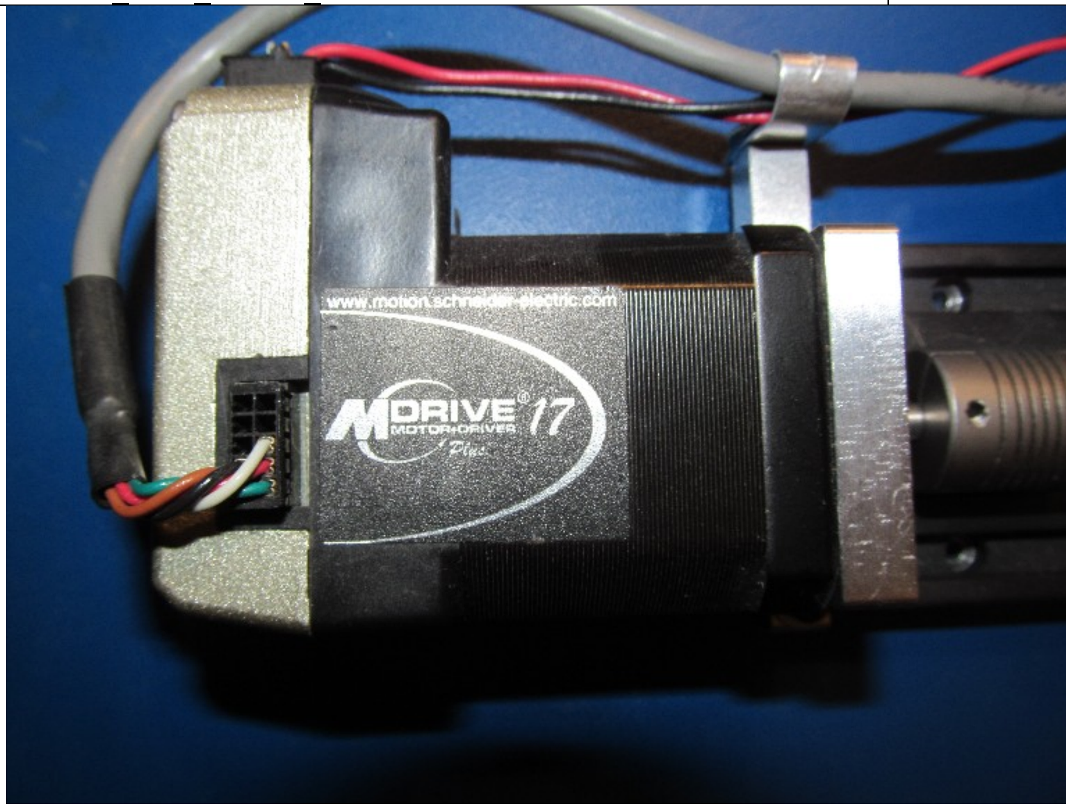


Figure 85

You will need to select the correct communications port and select the Stage checkbox to enable use of the slide. There is also a separate tab to set the motor parameters.

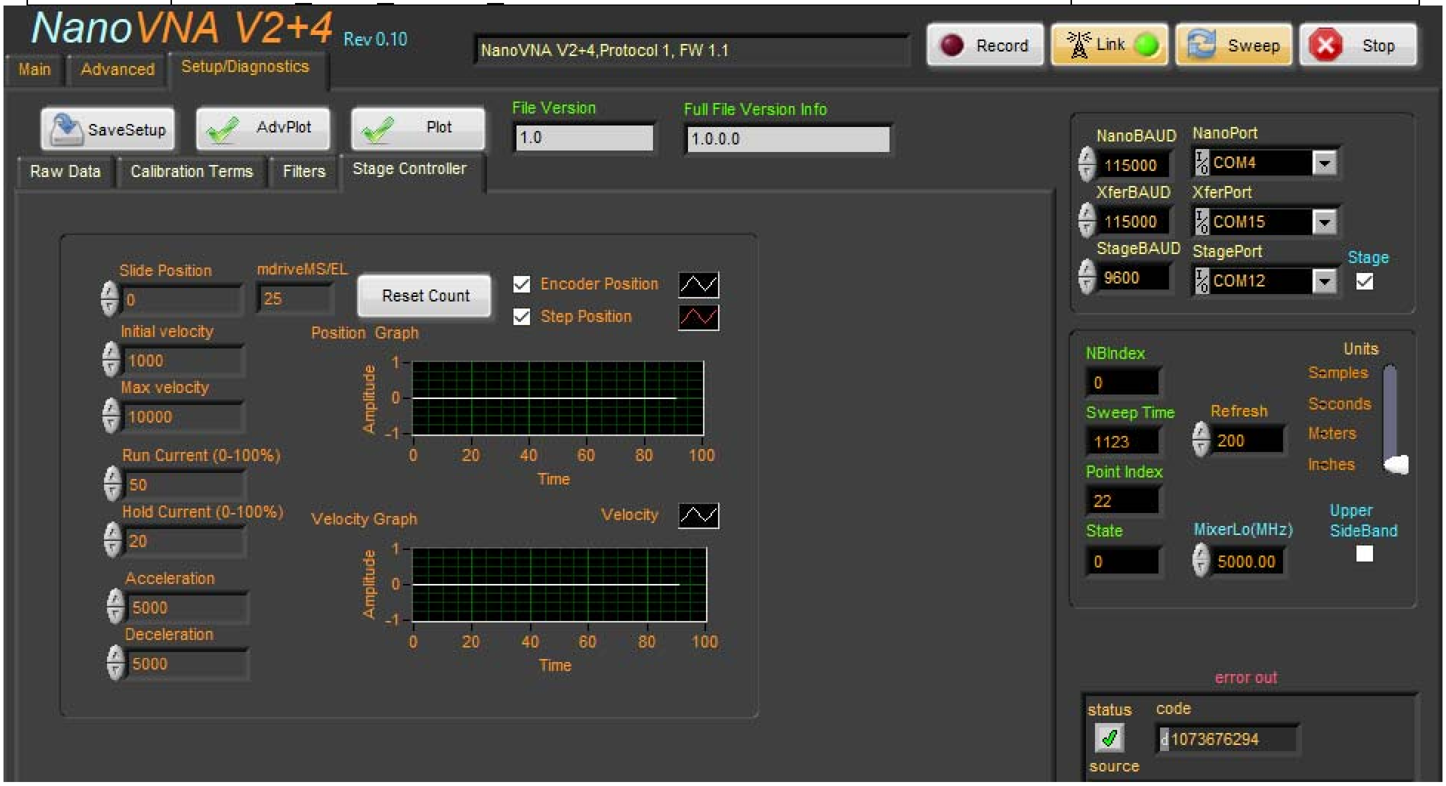


Figure 86

Attached to the slide is a homemade section of airline made from brass tubing. This setup allows you to change the length of the transmission line fairly precisely.

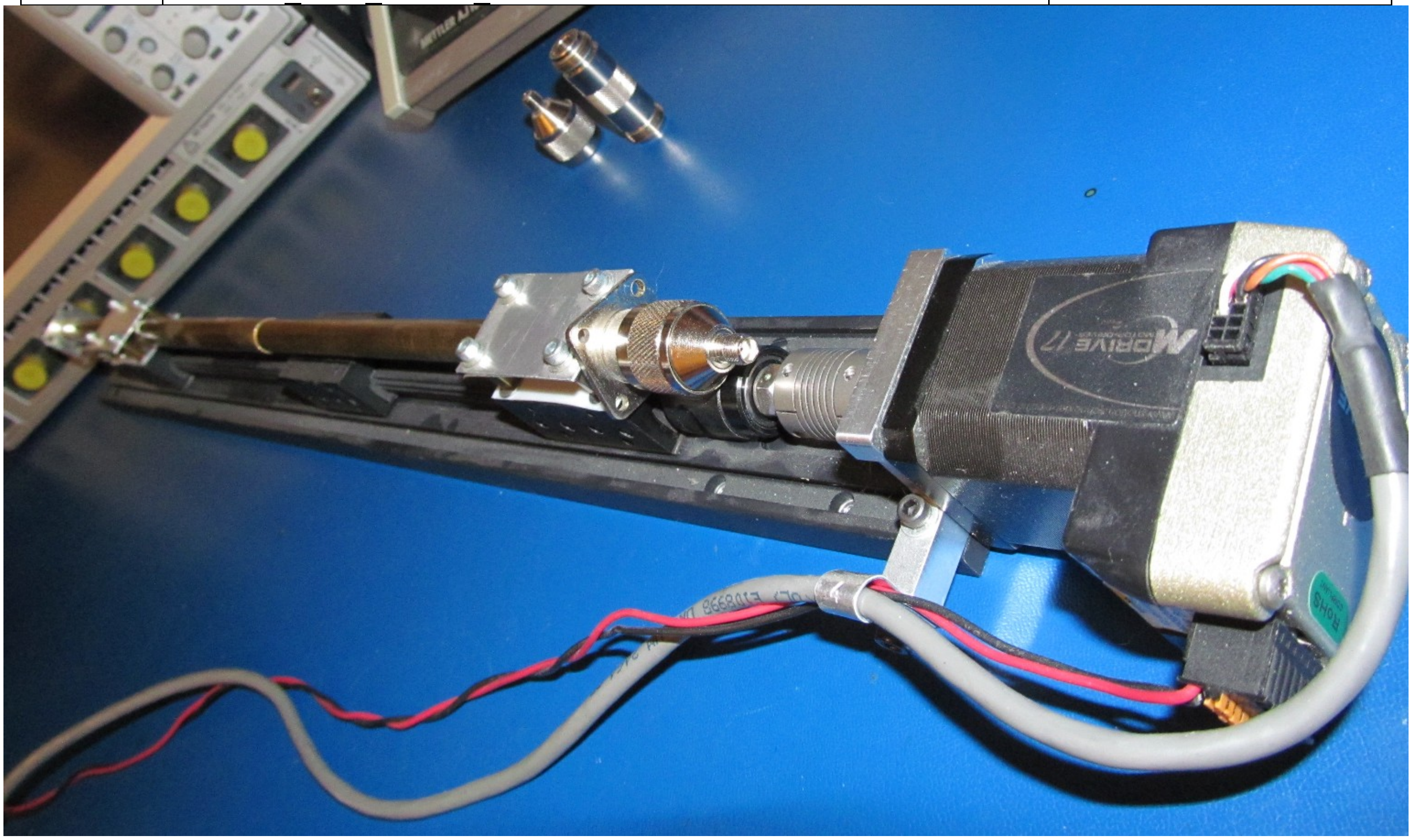


Figure 87

Shown below, the slide is attached to the V2+.   One end of the coax is left open.

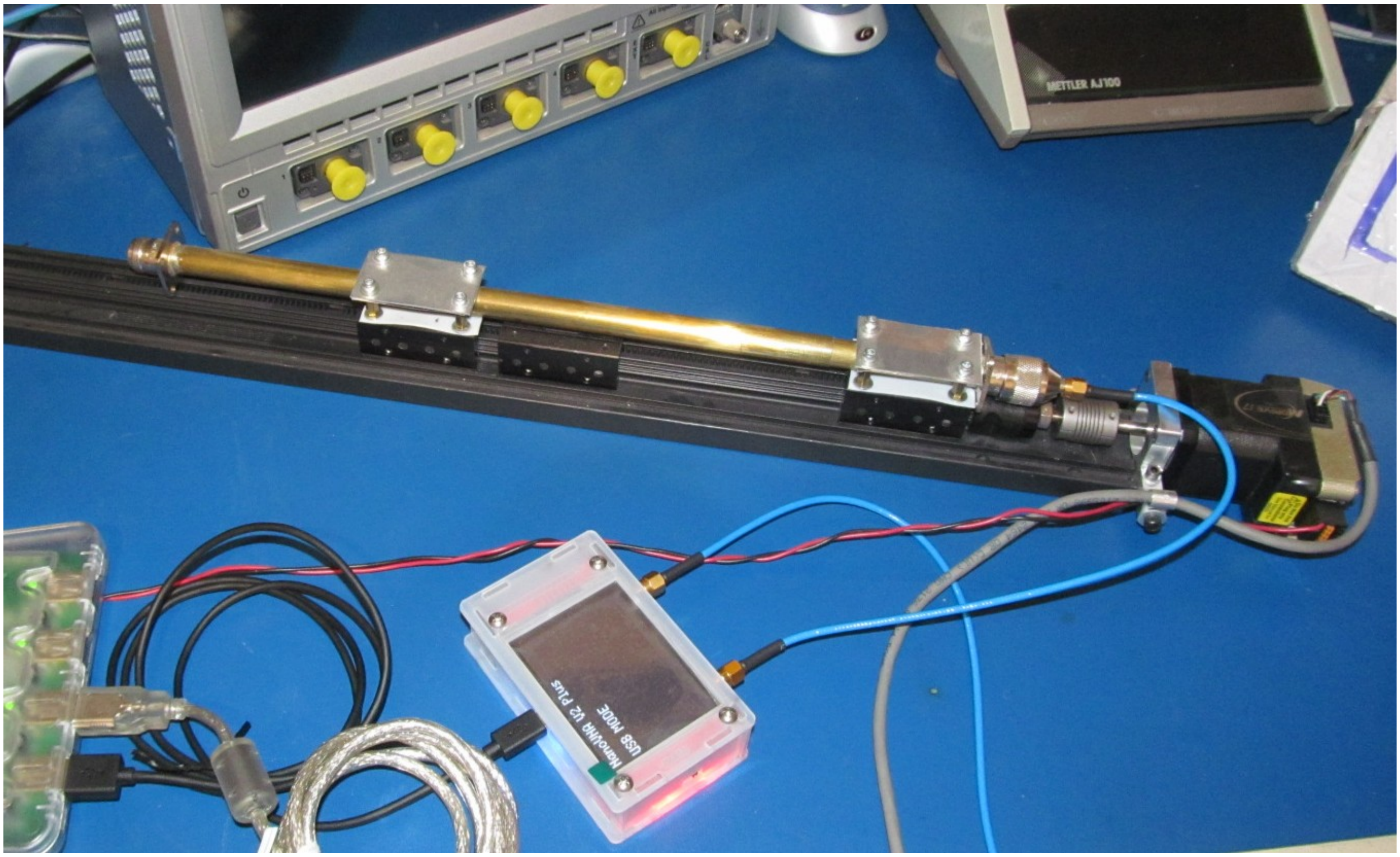


Figure 88

To run a sweep using the stage, select the Advanced tab followed by Time Domain Stage Test. Towards the upper left, you may set the number of steps per unit length.   My slide will travel 0.100" with 2048 steps. As shown, we are moving the slide 200 unit lengths of 0.025" each. The average step size the V2+ measured was 0.0249".   There is a bit of noise. Looking at the center histogram, you can see the noise has a somewhat Gaussian shape. It's very possible this is a limitation of the stage using the homemade airline.

Figure 89

19. Integrating a Transfer Relay

The software supports adding an external transfer relay. The author has attempted to construct some low cost units based on GaAs and relay technologies for experimenting with the NanoVNA. Their performance was very poor.

Figure 90

Note that there are 6 ports total on the two homemade transfer relays. These provide bias-Ts for each of the two ports.

The left most relay is an old Transco device. It was designed for operation to 18GHz and is well suited for this task.

The software really doesn't care what type of transfer relay is attached. It uses a common USB – TTL adapter from FTDI. The RTS signal is used to select the state of the relay and the CTS is used to monitor it's status. The communications port is selected in the Setup/Diagnostics page using the XferPort. Again, the BAUD rate has no effect. The selected port is saved as part of the defaults. Shown is the FTDI cable attached to the Transco controller.

Figure 91

19.1 Manually Controlling the Transfer Relay

With the correct communications port selected, the next time Link is selected, the software will check for the presence of the port. There is no other check beyond it finding a valid port number. If found the XferRly Lnk indicator (found on the main page), will become active.

You can manually change the state of the relay by selecting the CH0-A switch on the front panel. Once selected, the Chan0-B indicator will become active. If the relay does not change states, the XferRly Err indicator will become active.

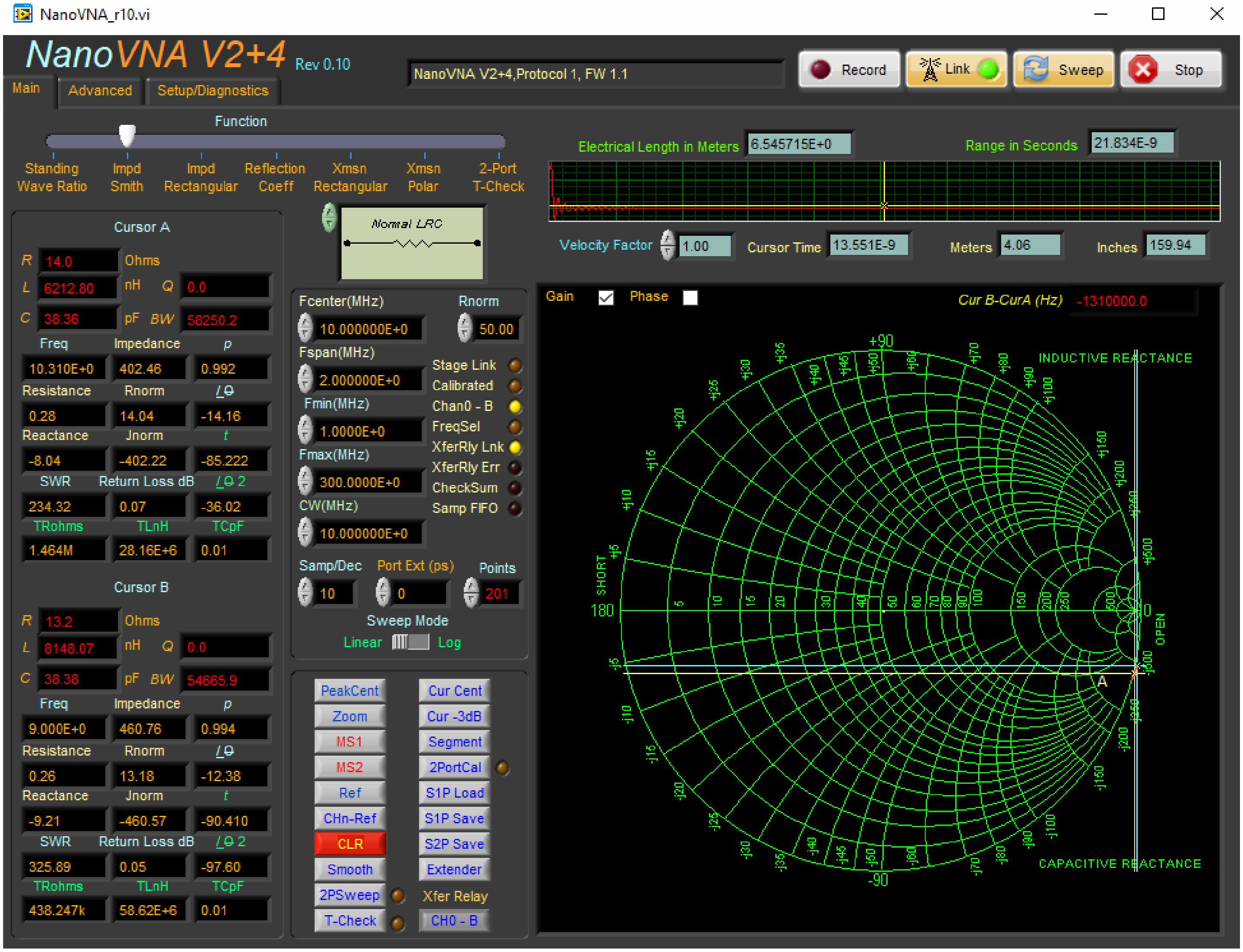


Figure 92

19.2 Full 2-Port Calibration

Once the transfer relay is inserted, selecting a 2PortCal will now walk you through a full 2-Port calibration. You will be prompted to insert the SOL standards on each port rather than just Port1.

Once calibrated, you should see very little difference measuring between the two ports. In the following a parallel LC circuit was installed first on Port1. The data was stored into MS1 and then the circuit was moved to Port2. Notice the two are basically identical.

Figure 93

19.3 T-Check Testing 2 port calibration

The software supports using a T-Check as a means to ensure the calibration is valid. The T-Check is nothing more than a T with the stub terminated. For this example I'm using some homemade standards and T-Check to help remove any errors due to the fixtures. This is very doable at these low frequencies.

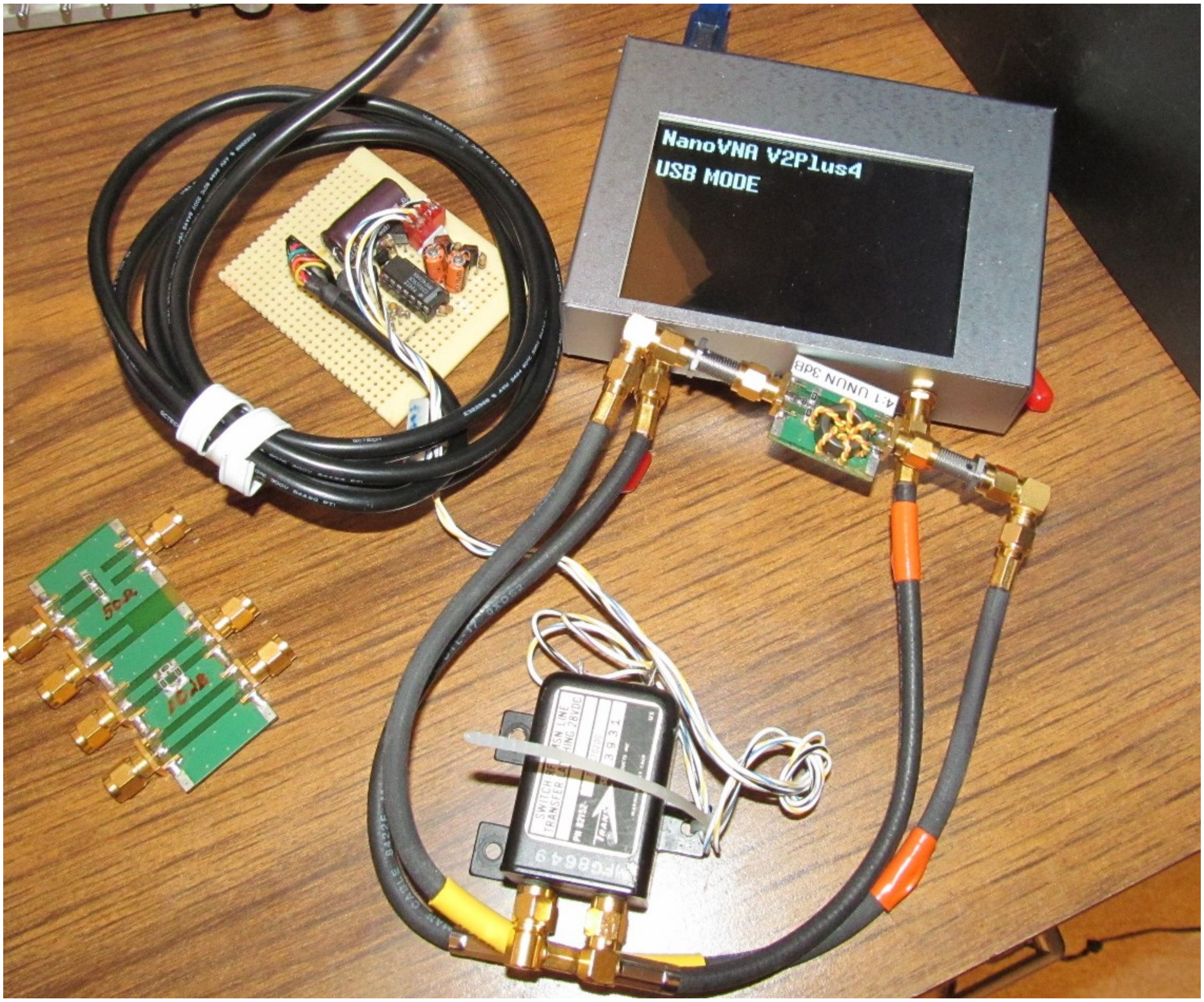


Figure 94

Once installed, you should see something close to 25 ohms as seen here. Again saving a channel and then changing the state of the transfer relay should show very little difference.

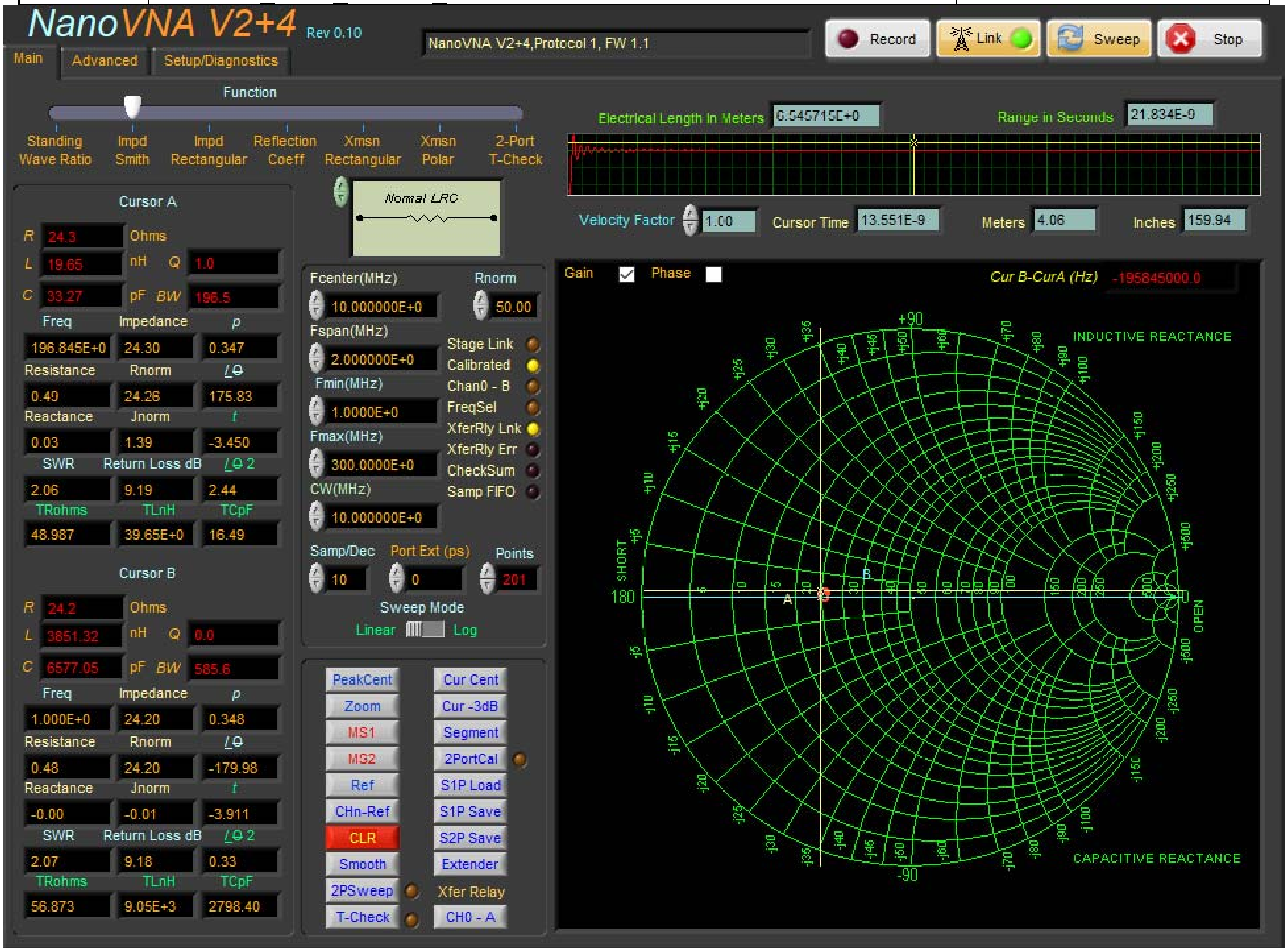
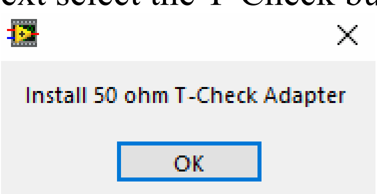


Figure 95

Next select the T-Check button. You will be prompted to install the T-Check adapter.



Select OK after you have everything ready. The software will then select the 2-Port T-Check function. You can also manually select it at anytime. It will then run through a series of sweeps while automatically programming the transfer relay.

Once complete, you should see a graph similar to the following example. Plot should center around 100%. Deviations of +/-10% are minor. You should not see more than +/-15% (115 - 85%).

Figure 96

19.4 2-Port Sweep

To run a 2-Port sweep, select the 2PSweep button. The software will sweep then automatically change the state of the transfer relay before collecting a second sweep. Once complete, it will turn off the 2PSweep indicator and change the transfer relay back to the original state.

The transfer relay is controlled by the state of the RTS pin. When RTS is de-asserted, Port 1 and 2 of the VNA will route to Ports 1 and 2 of the transfer relay. When RTS is asserted, Port 1 and 2 of the VNA will route to Ports 2 and 1 of the transfer relay. The software expects the transfer relay to always assert the CTS pin, or it will set the transfer relay error (XferRly Err).

The software will store Port 1 data to memory 1 and Port 2 data to memory 2. Here a short has been applied to Port 1 of the transfer relay and Port 2 is left open.

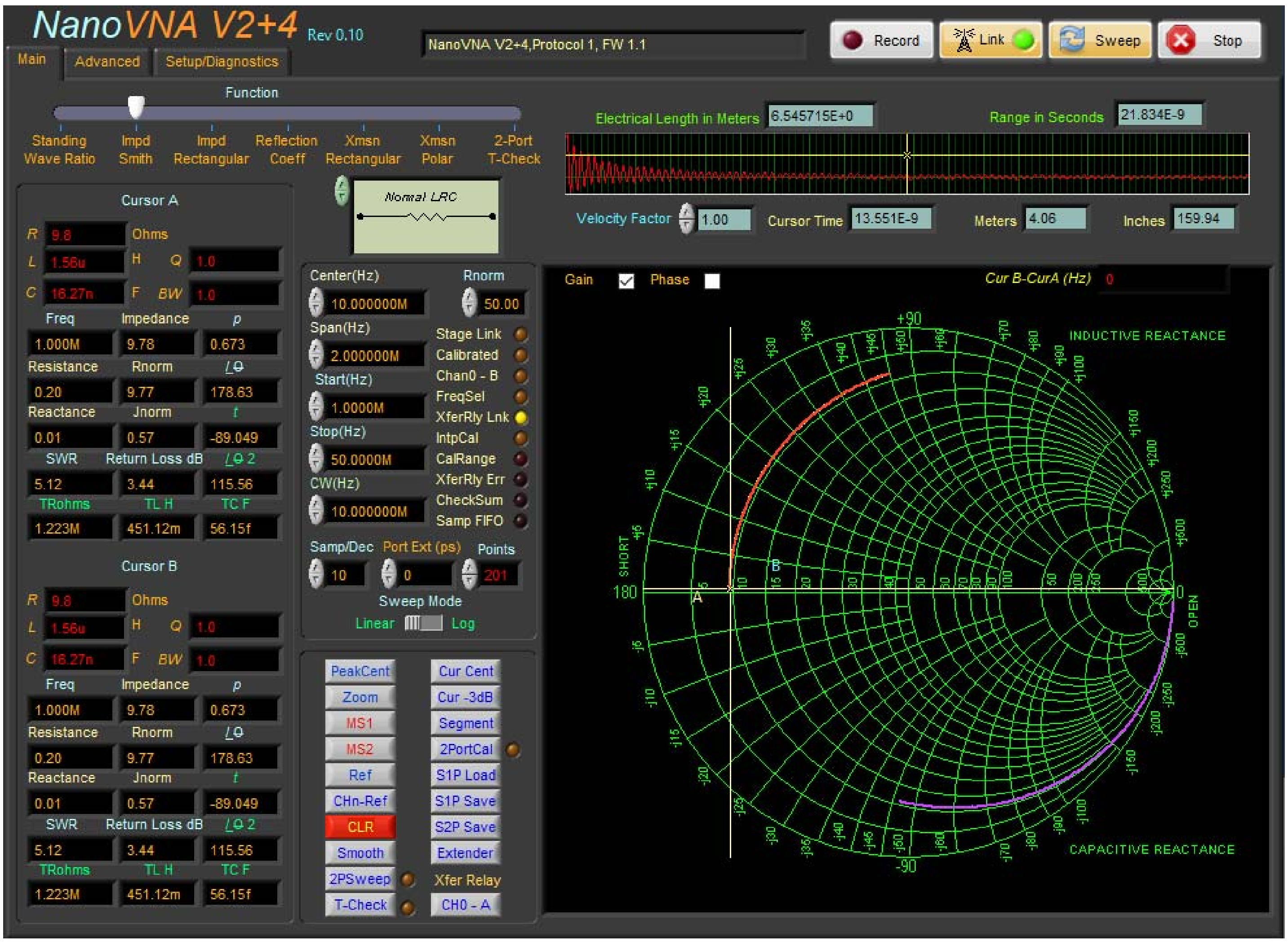


Figure 97

Select the Advanced tab and then the 2-Port Plot to view all of the data on a single page.

Note, as of 1.08 (original NanoVNA) and 1.03 (V2 Plus), the 2-Port plot has changed to support more common measurements. Polar displays for S21 & S12 were added. The size of the Smith charts was increased to make them easier to view. SWR was removed. The readouts will track the cursors. Moving any one cursor will cause the others to track.

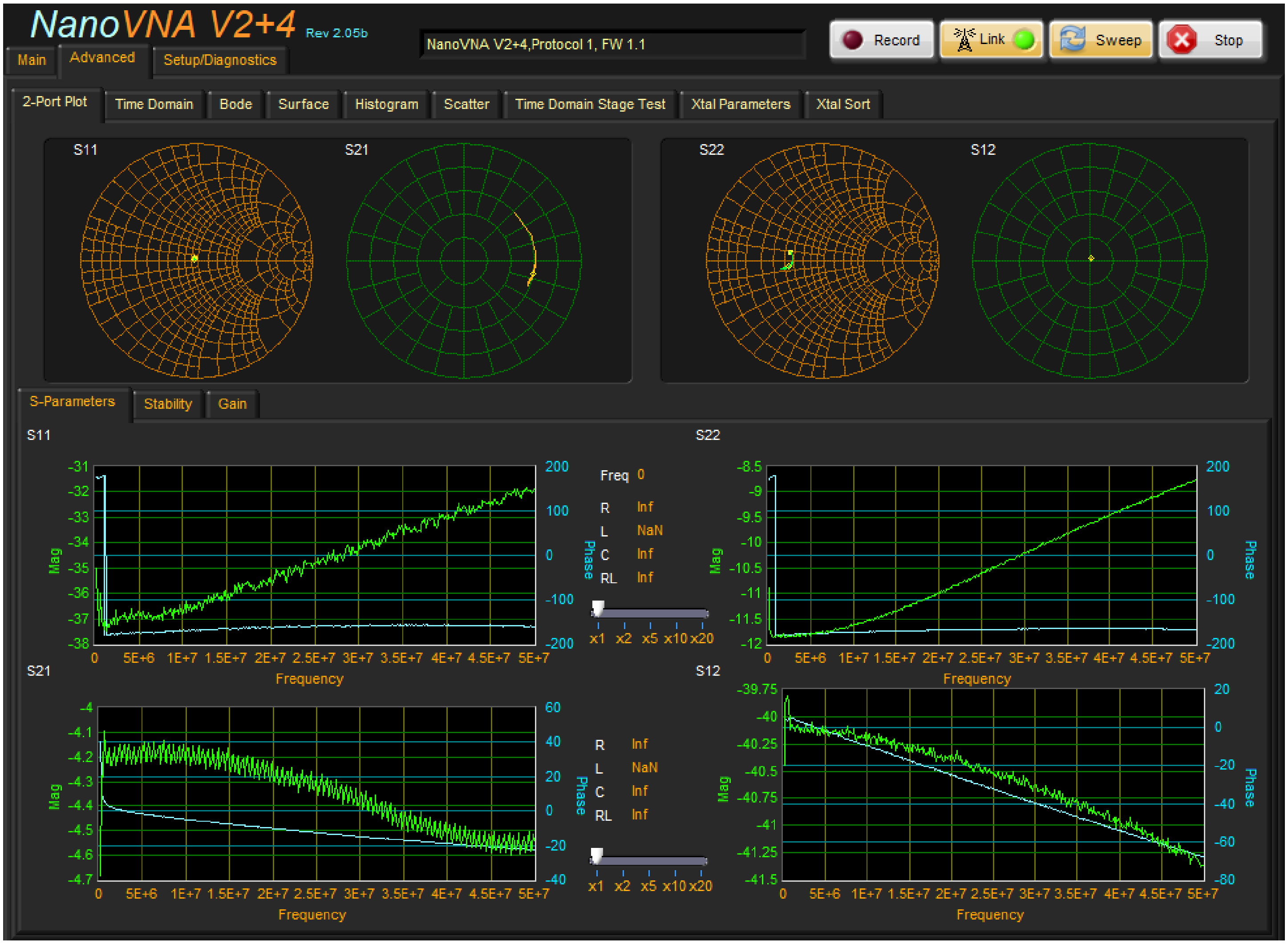


Figure 98

19.5 Transco PN# 82152-70070200 Driver

The Transco relay requires 24V and is a latching type relay. A simple DC-DC converter was designed using a 7400 gate that boosts the USB voltage to 24V and charges a large capacitor. This capacitor holds the charge needed to drive the relay.

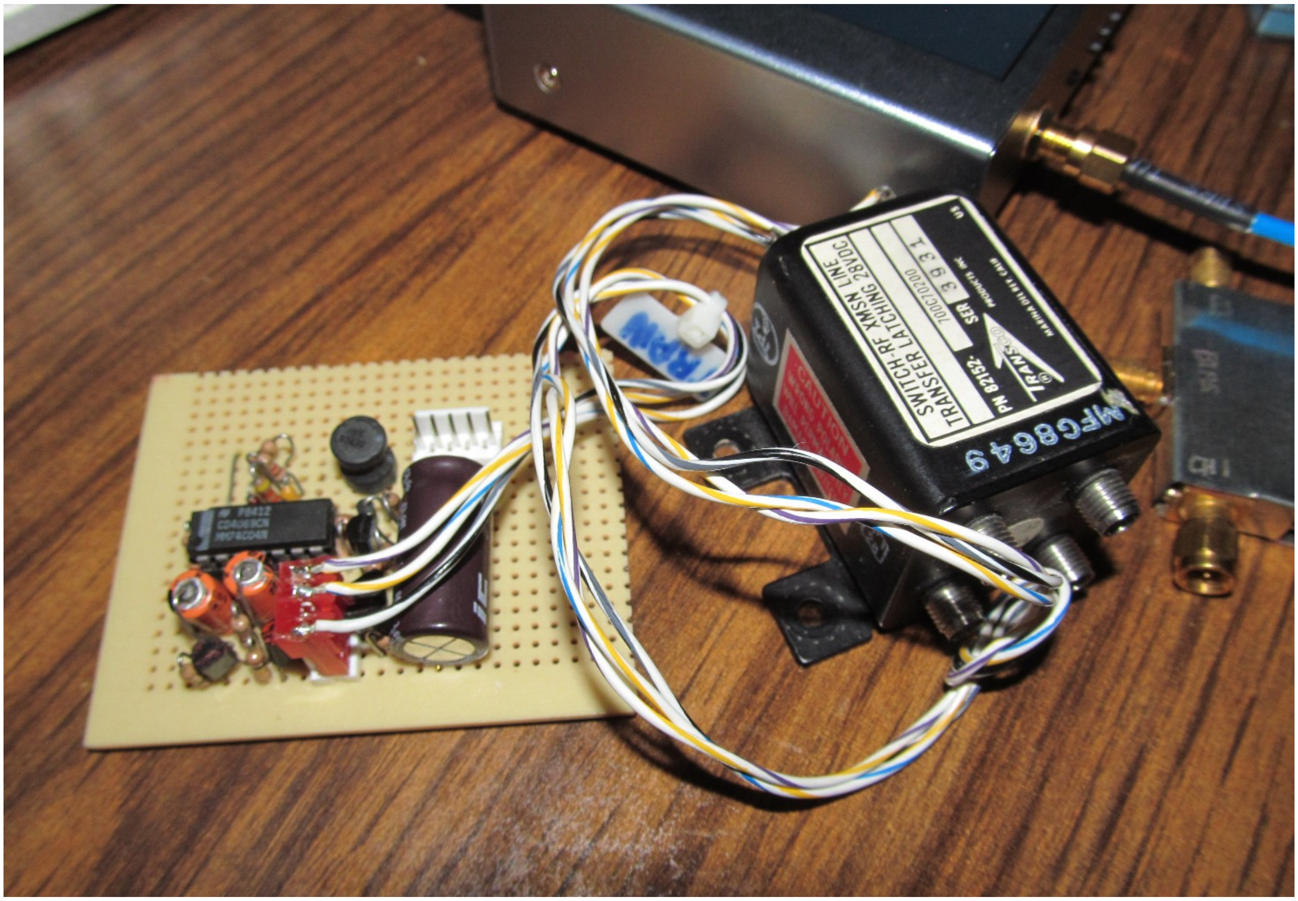


Figure 99

Figure 93 shows the DC-DC converter made from a 7404 hex inverter. The two remaining gates are used to buffer the signals to drive the relay coils. This is not meant as a reference to base your own design from. Rather this is what I put together with what I had on hand.

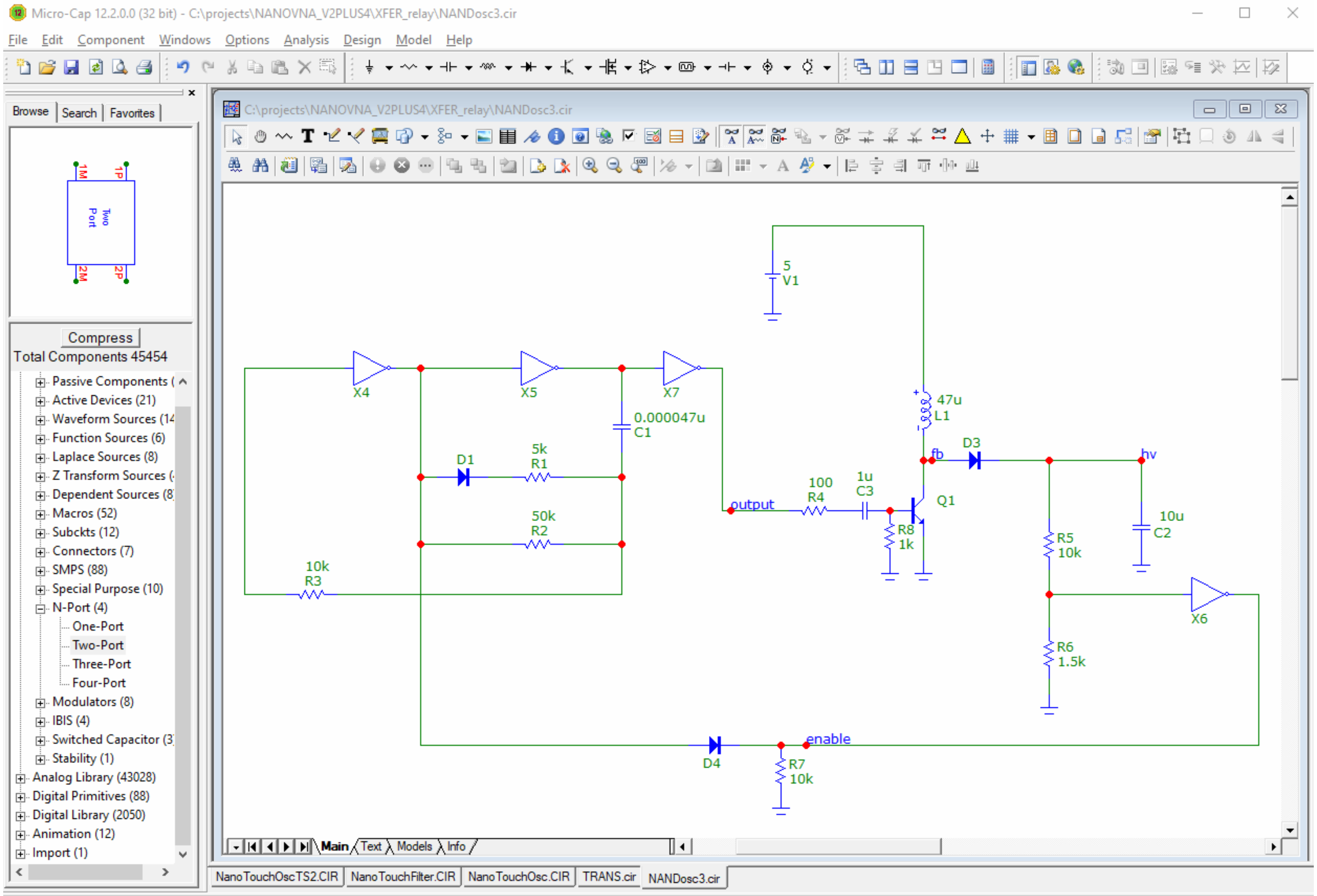
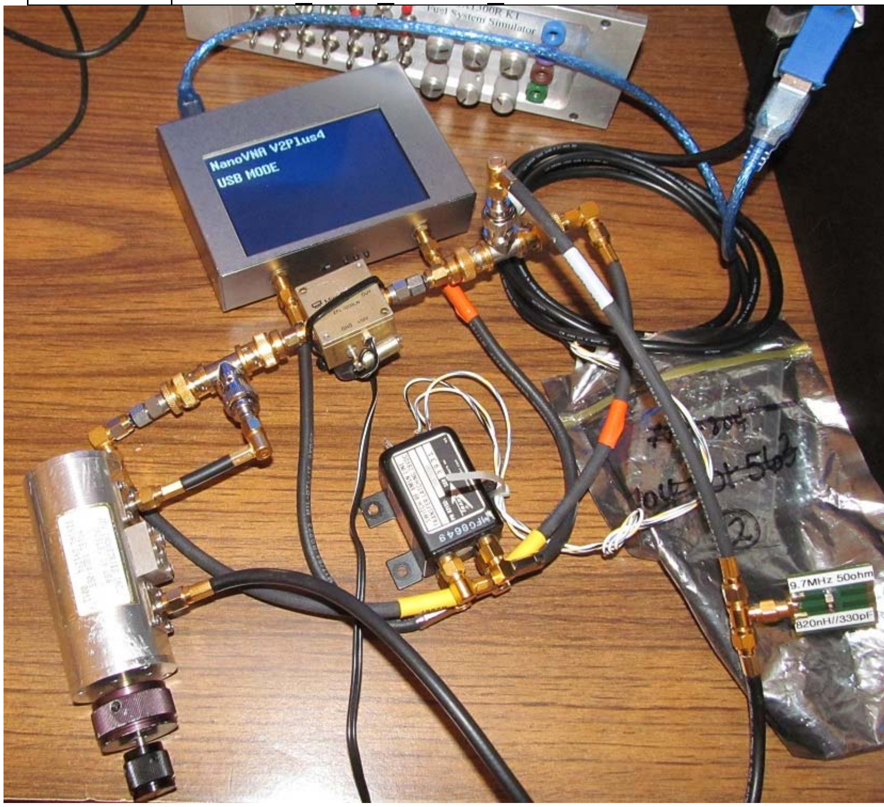


Figure 100

20. Amplifier Stability / Gain

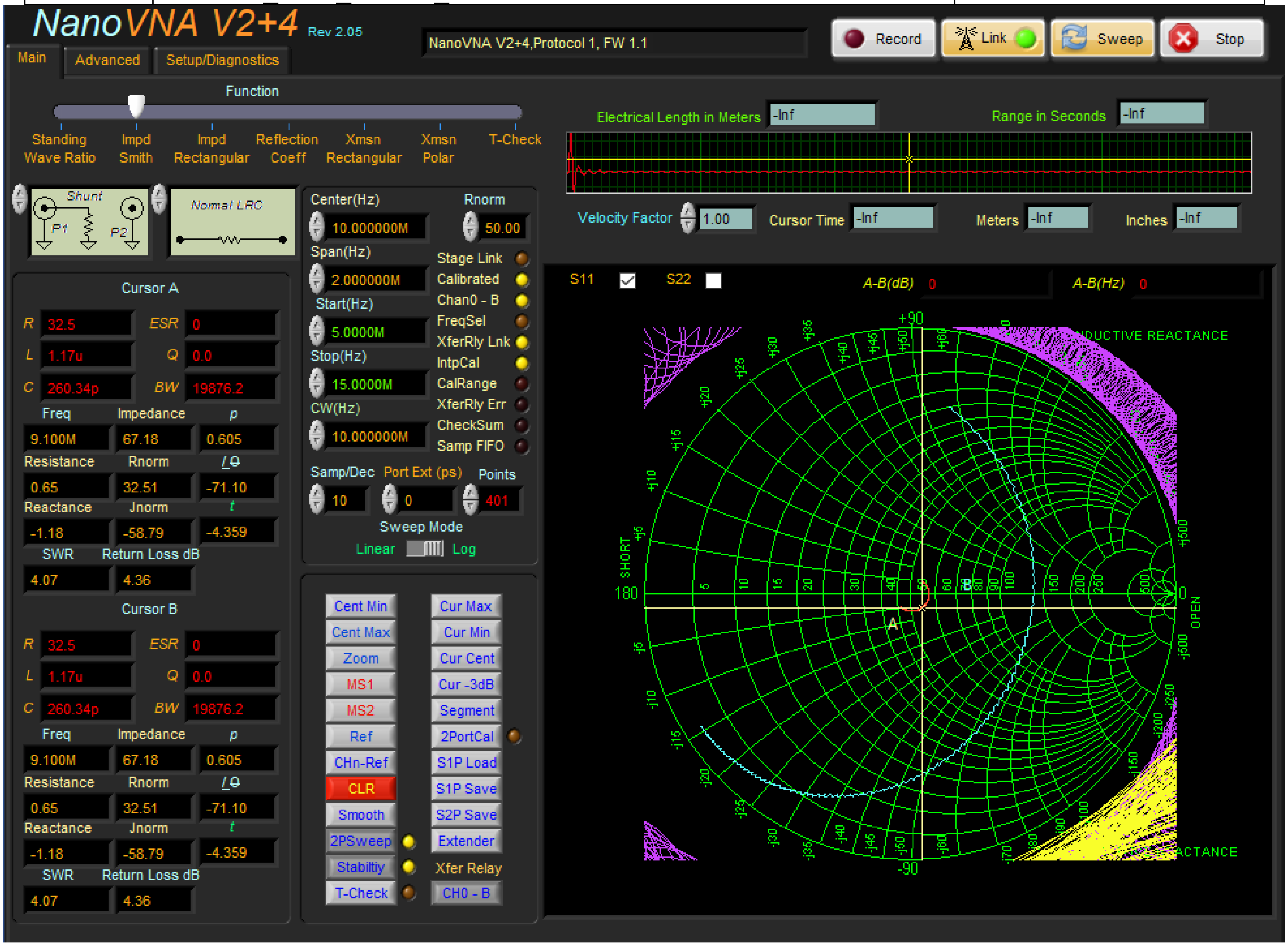
Having the ability to determine all four S-parameters allows us to perform other more complex measurements such as investigating an RF amplifier's stability. This subject is outside of the scope of this document to cover in any detail. It is up to the reader to do their own research on this topic. There are several free papers available on the internet.

For the following examples, we will be using Mini-Circuits ZFL-1000N amplifier along witj various fixed attenuators. Note that two T's are used to connect a step attenuator that will provide the feedback.

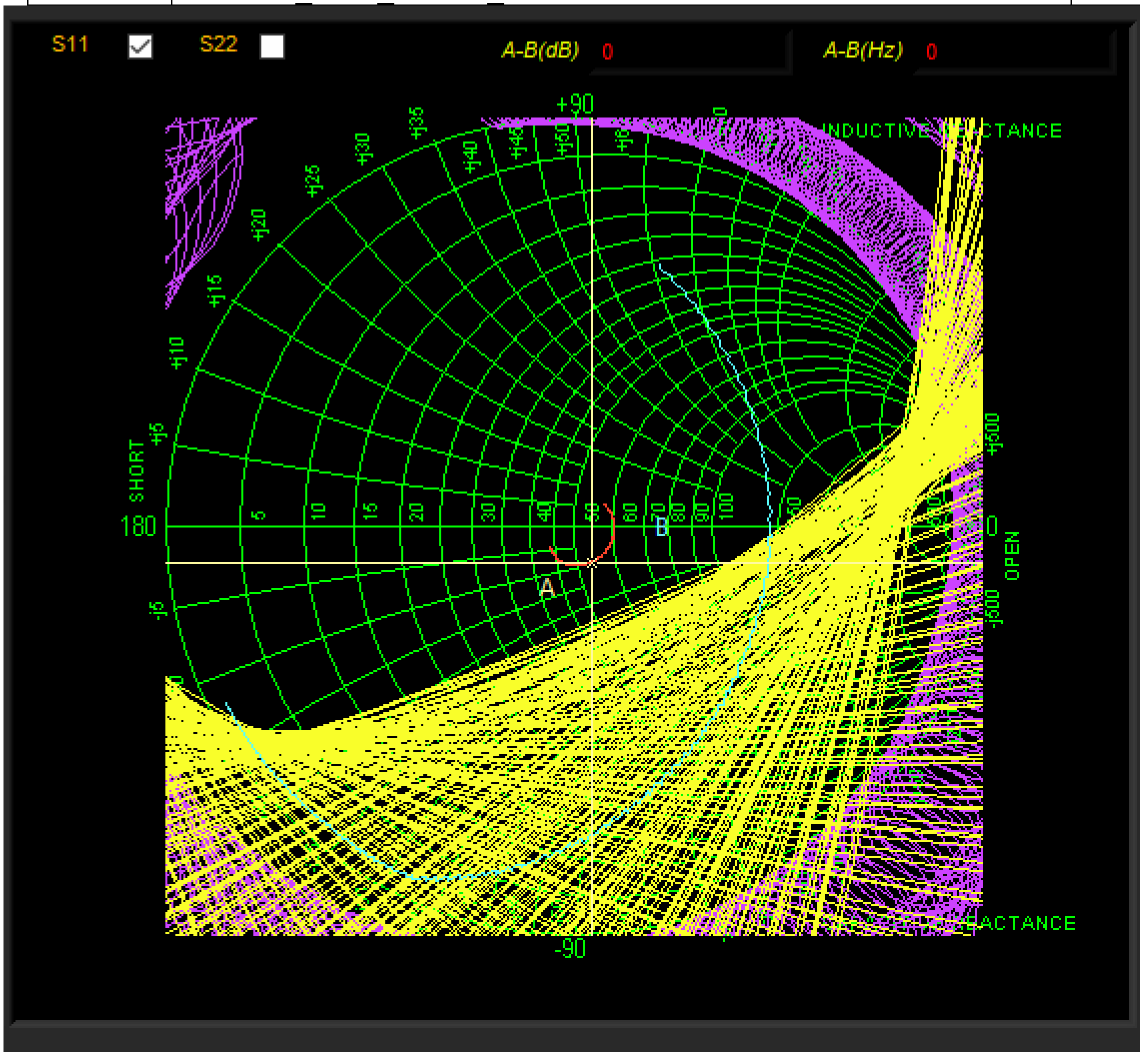


20.1 Stability Circles, Main Plot

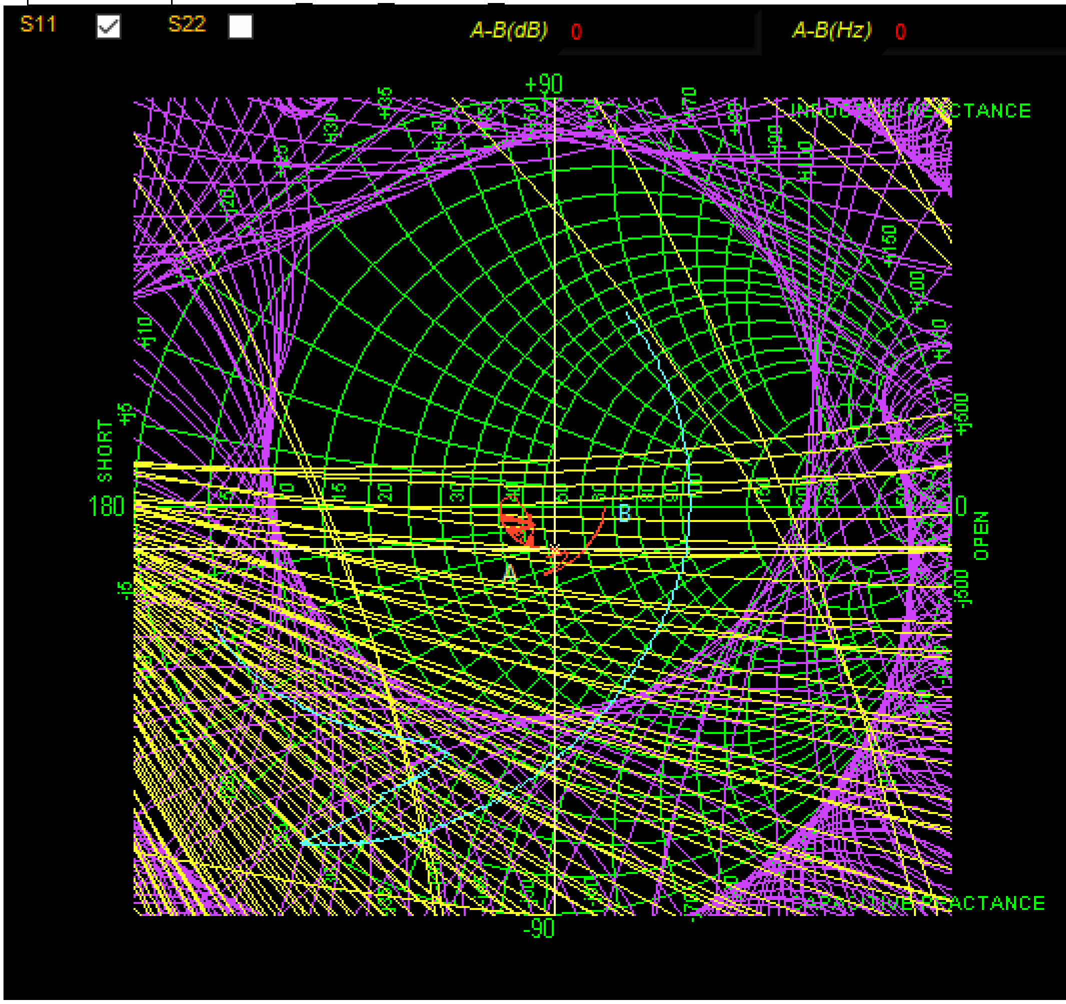
The software can display the family of standard stability circles on the main graph by selecting first the 2PSweep then the Stability buttons. The source circles are displayed in Yellow and the load in Purple.



Notice the effect of increasing the feedback has on the stability circles.

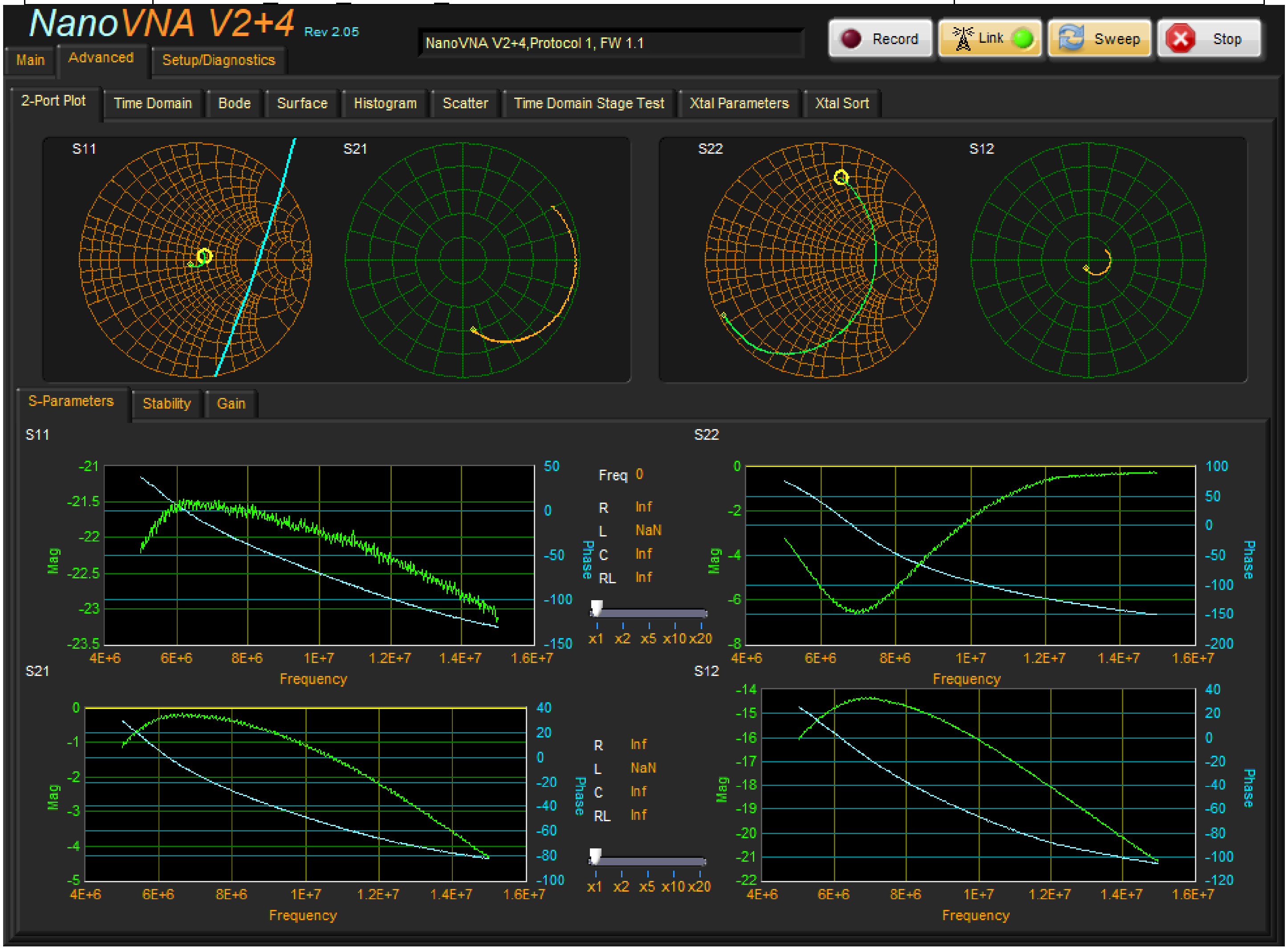


And increasing the feedback even further.



By selecting the Advanced 2-Port Plot, the software provides addition details about the stability of our test setup. When selected, we are presented with graphs showing all four S-parameters. Phase plot magnifiers have been added, similar to the one on the main screens polar plot.

Note the additional two tabs for Stability and Gain.



Selecting the Stability tab, we are presented with the various stability factors.

The stability circles along with the various stability factors are selected by moving the cursor.

20.2 K

John Rollet's stability factor

$$= \frac{1-|S_{11}|^2-|S_{22}|^2+|\Delta|^2}{2|S_{21}S_{12}|}$$

20.3 Delta

$$= S_{11}S_{22} - S_{12}S_{21}$$

20.4 B1

$$= 1 + |S_{11}|^2 - |S_{22}|^2 - |\Delta|^2$$

20.5 U

Unilateral Figure of merit

$$= \frac{|S_{11}||S_{21}||S_{12}||S_{22}|}{(1-|S_{11}|^2)(1-|S_{22}|^2)}$$

20.6 Mu

Edwards-Sinsky' stability factor

$$= \frac{1 - |S_{11}|^2}{|S_{22} - \Delta S_{11}^*| + |S_{12}S_{21}|}$$

20.7 Stability Circles, 2-Port Plot

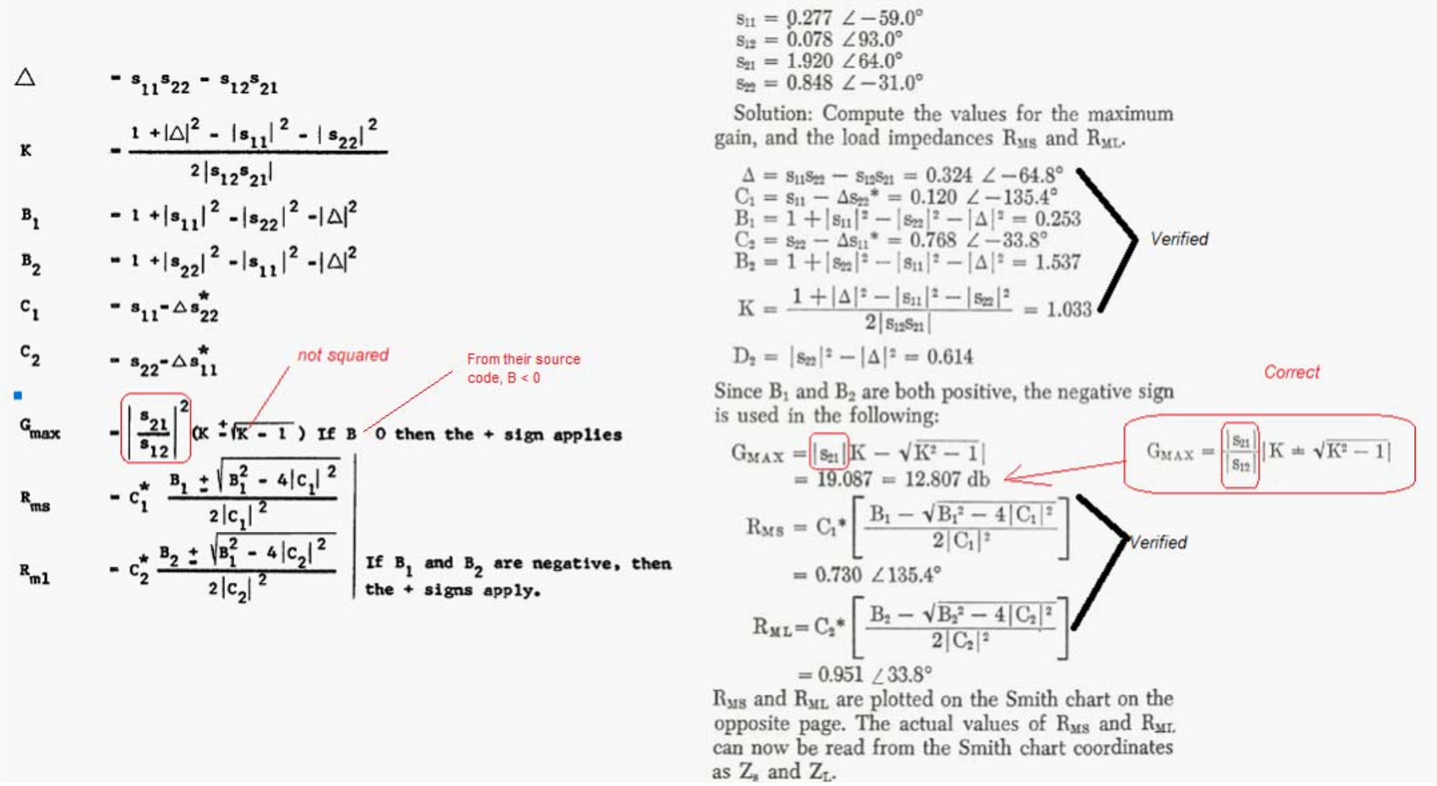
Looking at the stability circles, the Blue represent the standard circles while the Yellow are the mapping circles.

Notice as we move the cursor to the unstable region.

20.8 Amplifier Gain, Gmax

The software is also able to plot the amplifier's gain as shown.

One problem when reading on-line papers is to be aware of errors. Below are showing two different papers, both incorrect but with different errors. The correct equation for Gmax is also shown.



$\Delta = s_{11}s_{22} - s_{12}s_{21}$

$K = \dfrac{1 + |\Delta|^2 - |s_{11}|^2 - |s_{22}|^2}{2|s_{12}s_{21}|}$

$B_1 = 1 + |s_{11}|^2 - |s_{22}|^2 - |\Delta|^2$

$B_2 = 1 + |s_{22}|^2 - |s_{11}|^2 - |\Delta|^2$

$C_1 = s_{11} - \Delta s_{22}^*$

$C_2 = s_{22} - \Delta s_{11}^*$

$G_{max} = \left|\dfrac{s_{21}}{s_{12}}\right|^2 (K \pm \sqrt{K - 1})$ If B 0 then the + sign applies

$R_{ms} = C_1^* \dfrac{B_1 \pm \sqrt{B_1^2 - 4|C_1|^2}}{2|C_1|^2}$

$R_{ml} = C_2^* \dfrac{B_2 \pm \sqrt{B_1^2 - 4|C_2|^2}}{2|C_2|^2}$

If B_1 and B_2 are negative, then the + signs apply.

not squared

From their source code, B < 0

$s_{11} = 0.277 \angle -59.0°$
$s_{12} = 0.078 \angle 93.0°$
$s_{21} = 1.920 \angle 64.0°$
$s_{22} = 0.848 \angle -31.0°$

Solution: Compute the values for the maximum gain, and the load impedances R_{MS} and R_{ML}.

$\Delta = s_{11}s_{22} - s_{12}s_{21} = 0.324 \angle -64.8°$
$C_1 = s_{11} - \Delta s_{22}^* = 0.120 \angle -135.4°$
$B_1 = 1 + |s_{11}|^2 - |s_{22}|^2 - |\Delta|^2 = 0.253$
$C_2 = s_{22} - \Delta s_{11}^* = 0.768 \angle -33.8°$
$B_2 = 1 + |s_{22}|^2 - |s_{11}|^2 - |\Delta|^2 = 1.537$

$K = \dfrac{1 + |\Delta|^2 - |s_{11}|^2 - |s_{22}|^2}{2|s_{12}s_{21}|} = 1.033$

Verified

$D_2 = |s_{22}|^2 - |\Delta|^2 = 0.614$

Since B_1 and B_2 are both positive, the negative sign is used in the following:

$G_{MAX} = |s_{21}||K - \sqrt{K^2 - 1}|$
$= 19.087 = 12.807$ db

Correct

$G_{MAX} = \left|\dfrac{s_{21}}{s_{12}}\right| |K \pm \sqrt{K^2 - 1}|$

$R_{MS} = C_1^* \left[\dfrac{B_1 - \sqrt{B_1^2 - 4|C_1|^2}}{2|C_1|^2}\right]$
$= 0.730 \angle 135.4°$

$R_{ML} = C_2^* \left[\dfrac{B_2 - \sqrt{B_2^2 - 4|C_2|^2}}{2|C_2|^2}\right]$
$= 0.951 \angle 33.8°$

Verified

R_{MS} and R_{ML} are plotted on the Smith chart on the opposite page. The actual values of R_{MS} and R_{ML} can now be read from the Smith chart coordinates as Z_s and Z_L.

21. Up/Down conversion

The software supports adding an external up / down converter to extend the frequency range.

22. Equivalent Series Resistance ESR

The software supports directly measuring a capacitors ESR using the shunt through method. ESR is measured at the capacitor's resonance.

Figure 101 showing three different capacitors.   Lower valleys represent lower ESR values.

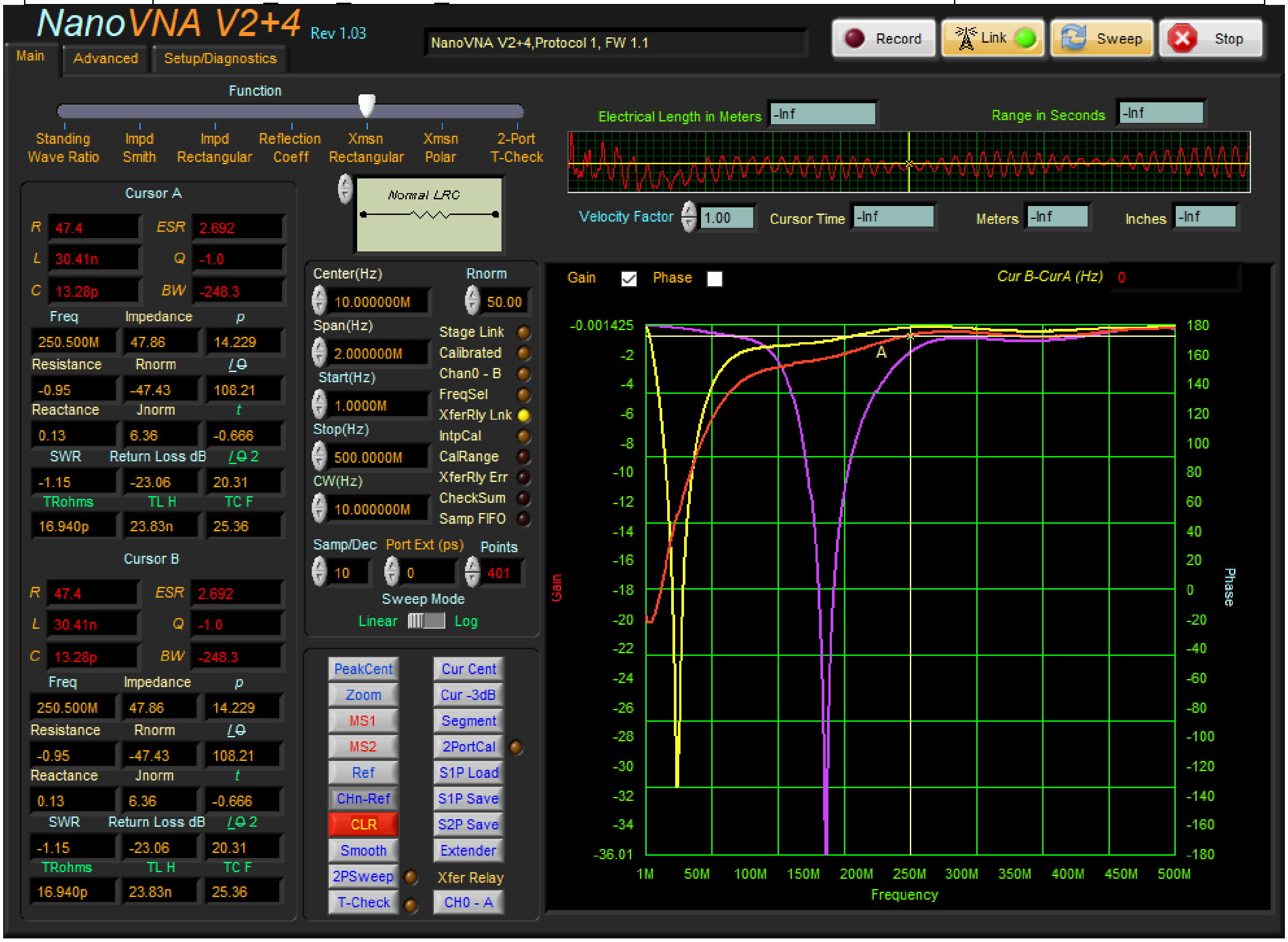


Figure 101

Figure 102 shows a typical RF capacitor mounted to a test board. Also shown are two different resistive test boards, one consisting of two 0.050-ohm resistors in parallel, the other with a single 0.100 ohm resistor. These boards are used to verify our results. A third board is also shown which has two capacitors mounted in series to double the ESR reading.

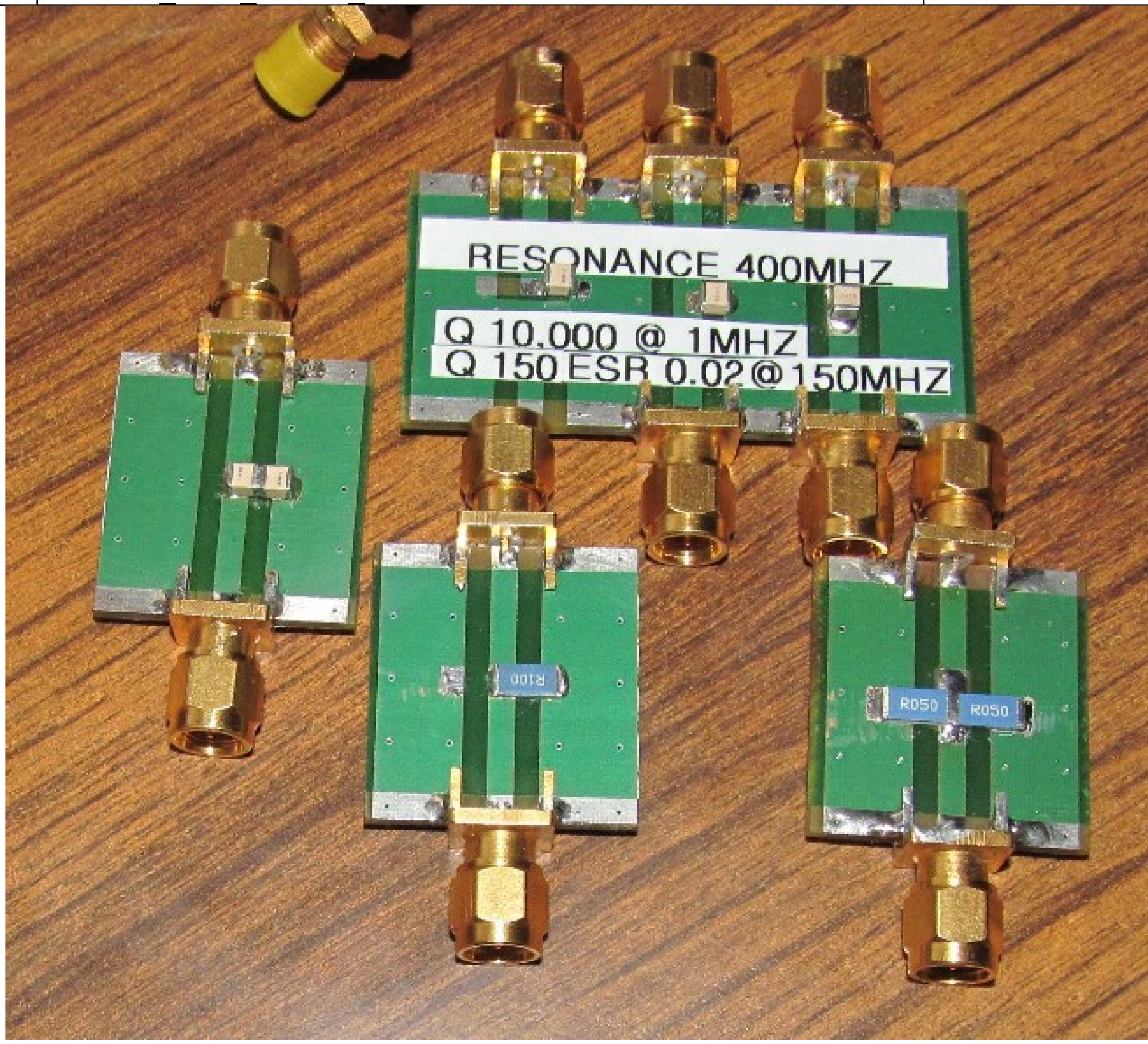
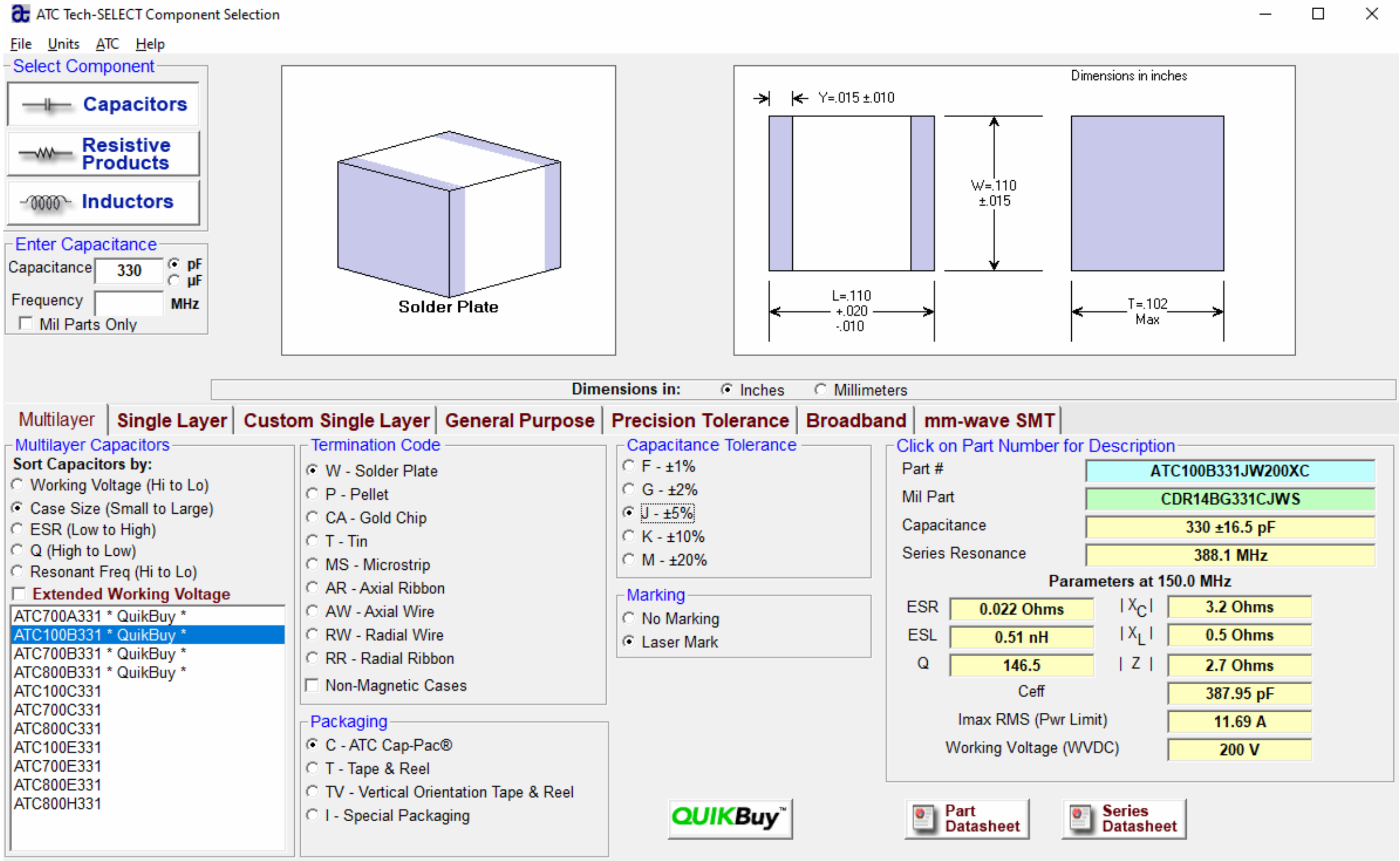


Figure 102

Figures 103 & 104 show the data sheet for the capacitor we want to characterize. Note this part has an ESR of less than 0.050 ohms.



ATC Tech-SELECT Component Selection
File Units ATC Help
Select Component
Capacitors
Resistive Products
Inductors
Enter Capacitance
Capacitance 330 pF µF
Frequency MHz
Mil Parts Only
Solder Plate
Dimensions in inches
Y=.015±.010
W=.110 ±.015
L=.110 +.020 -.010
T=.102 Max
Dimensions in: Inches Millimeters
Multilayer
Single Layer
Custom Single Layer
General Purpose
Precision Tolerance
Broadband
mm-wave SMT
Multilayer Capacitors
Sort Capacitors by:
Working Voltage (Hi to Lo)
Case Size (Small to Large)
ESR (Low to High)
Q (High to Low)
Resonant Freq (Hi to Lo)
Extended Working Voltage
ATC700A331 * QuikBuy *
ATC100B331 * QuikBuy *
ATC700B331 * QuikBuy *
ATC800B331 * QuikBuy *
ATC100C331
ATC700C331
ATC800C331
ATC100E331
ATC700E331
ATC800E331
ATC800H331
Termination Code
W - Solder Plate
P - Pellet
CA - Gold Chip
T - Tin
MS - Microstrip
AR - Axial Ribbon
AW - Axial Wire
RW - Radial Wire
RR - Radial Ribbon
Non-Magnetic Cases
Packaging
C - ATC Cap-Pac®
T - Tape & Reel
TV - Vertical Orientation Tape & Reel
I - Special Packaging
Capacitance Tolerance
F - ±1%
G - ±2%
J - ±5%
K - ±10%
M - ±20%
Marking
No Marking
Laser Mark
Click on Part Number for Description
Part # ATC100B331JW200XC
Mil Part CDR14BG331CJWS
Capacitance 330 ±16.5 pF
Series Resonance 388.1 MHz
Parameters at 150.0 MHz
ESR 0.022 Ohms
ESL 0.51 nH
Q 146.5
|XC| 3.2 Ohms
|XL| 0.5 Ohms
|Z| 2.7 Ohms
Ceff 387.95 pF
Imax RMS (Pwr Limit) 11.69 A
Working Voltage (WVDC) 200 V
QUIKBuy
Part Datasheet
Series Datasheet

Figure 103

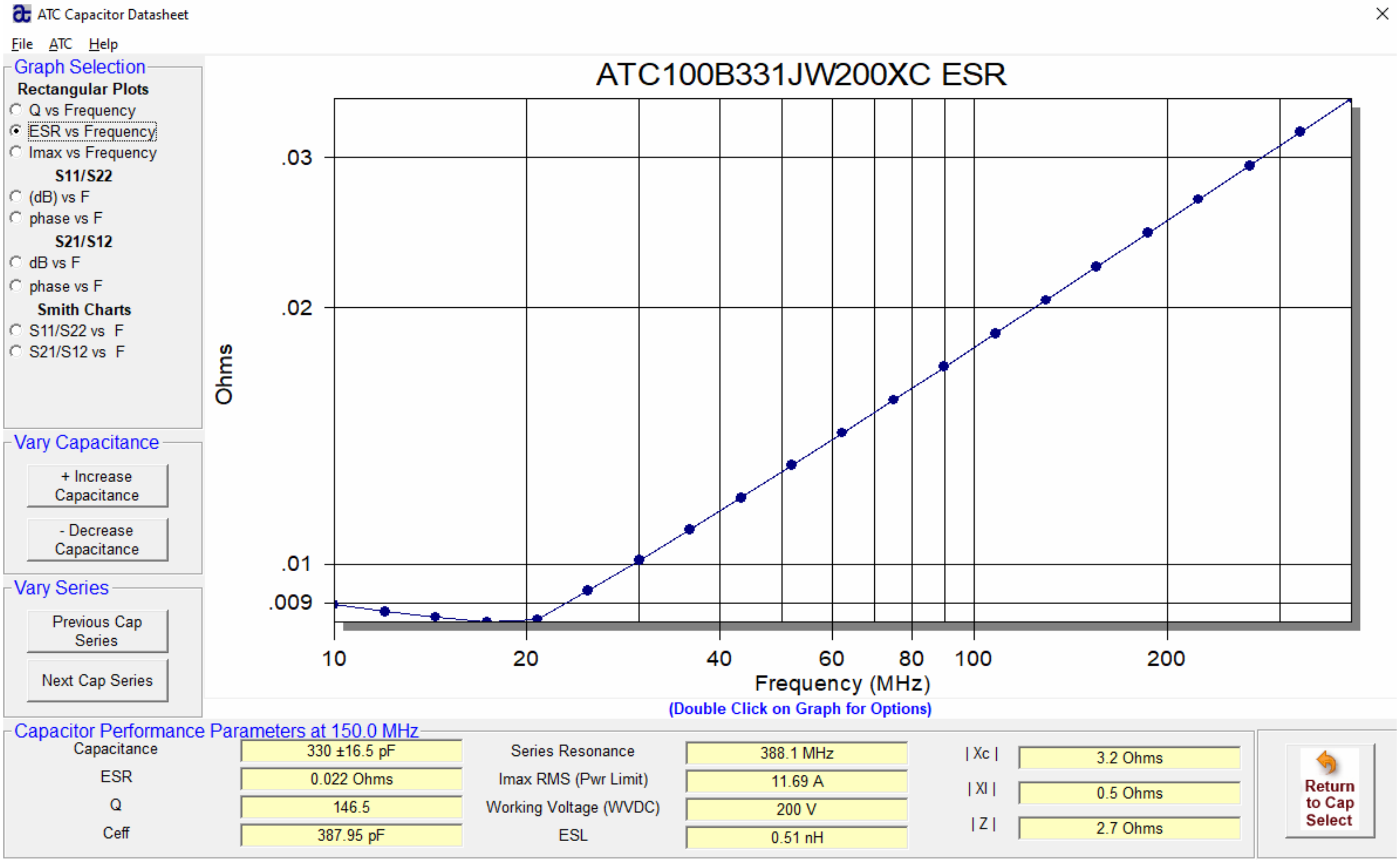


Figure 104

Connecting this part to the RLC meter (figure 105), we can see it measures 120 ohms. The meter is randomly measuring from -200 ohms to +200 ohms. Reading the manual, this meter was not designed to measure capacitors with such low capacitance and ESR. This is where the VNA can be helpful. Of course, the VNA can have problems as well. Using the shunt through method will inherently cause a ground loop that you may need to deal with. You may also require attenuators to improve the match from the VNA to the fixture. There are several papers available on this subject for those wanting to do additional research.

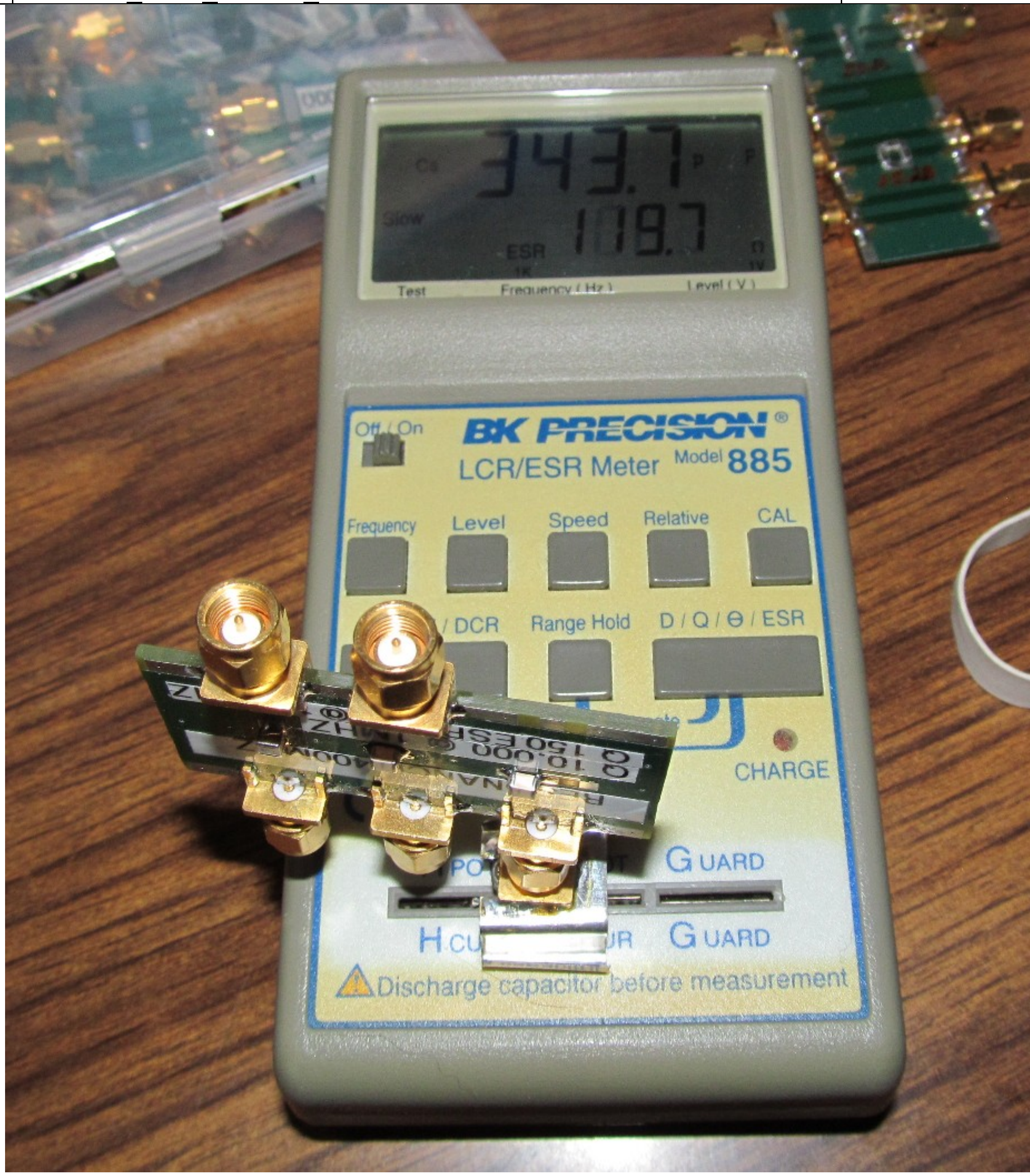


Figure 105

Figure 106 shows are test capacitor installed. Note the resonance is roughly 250MHz and VNA is measuring an ESR of 0.032 ohms.

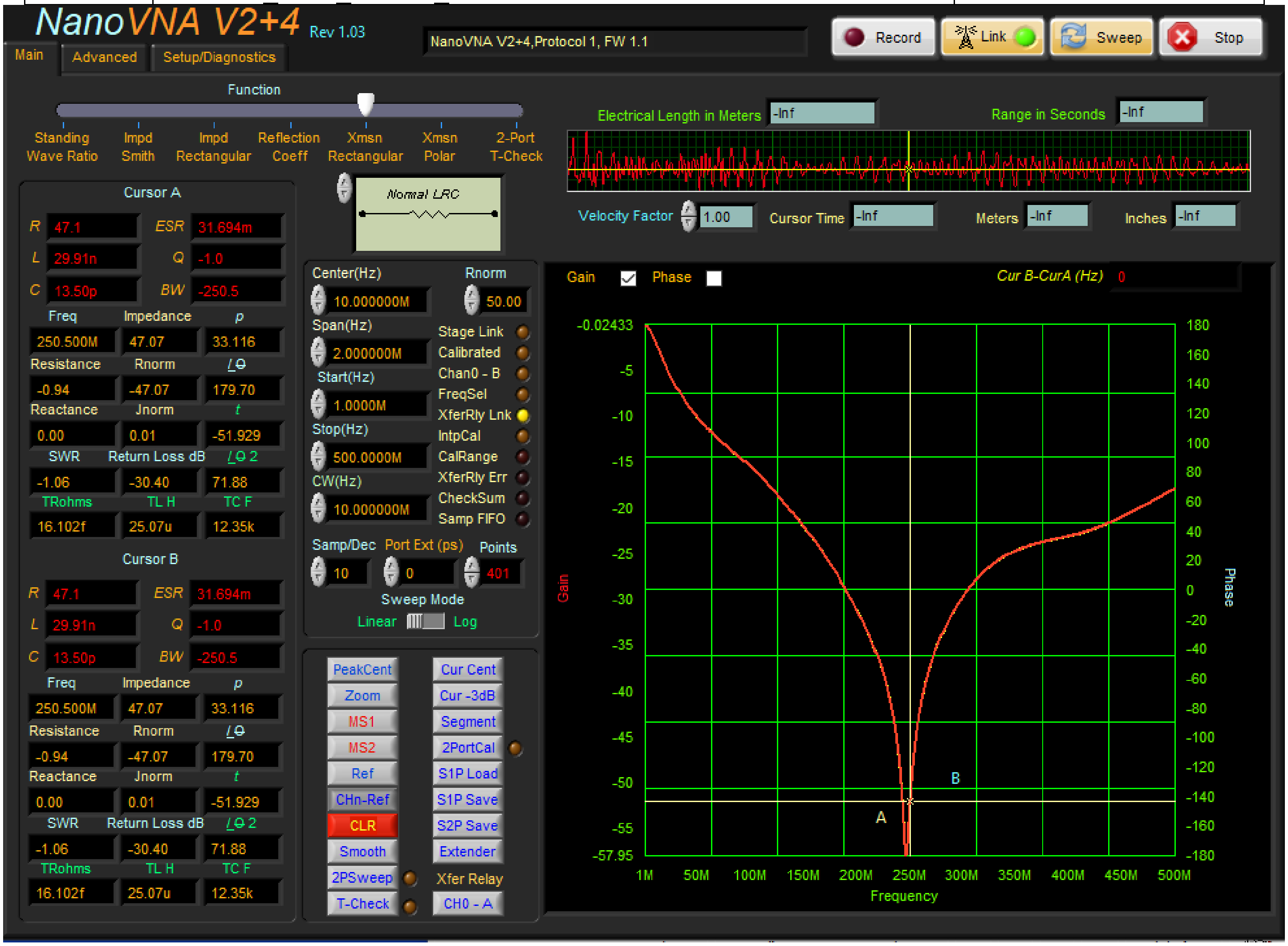


Figure 106

Going back to the datasheets, we can draw a line up from 250MHz and note that the ESR should be roughly 0.028 ohms. Close enough…

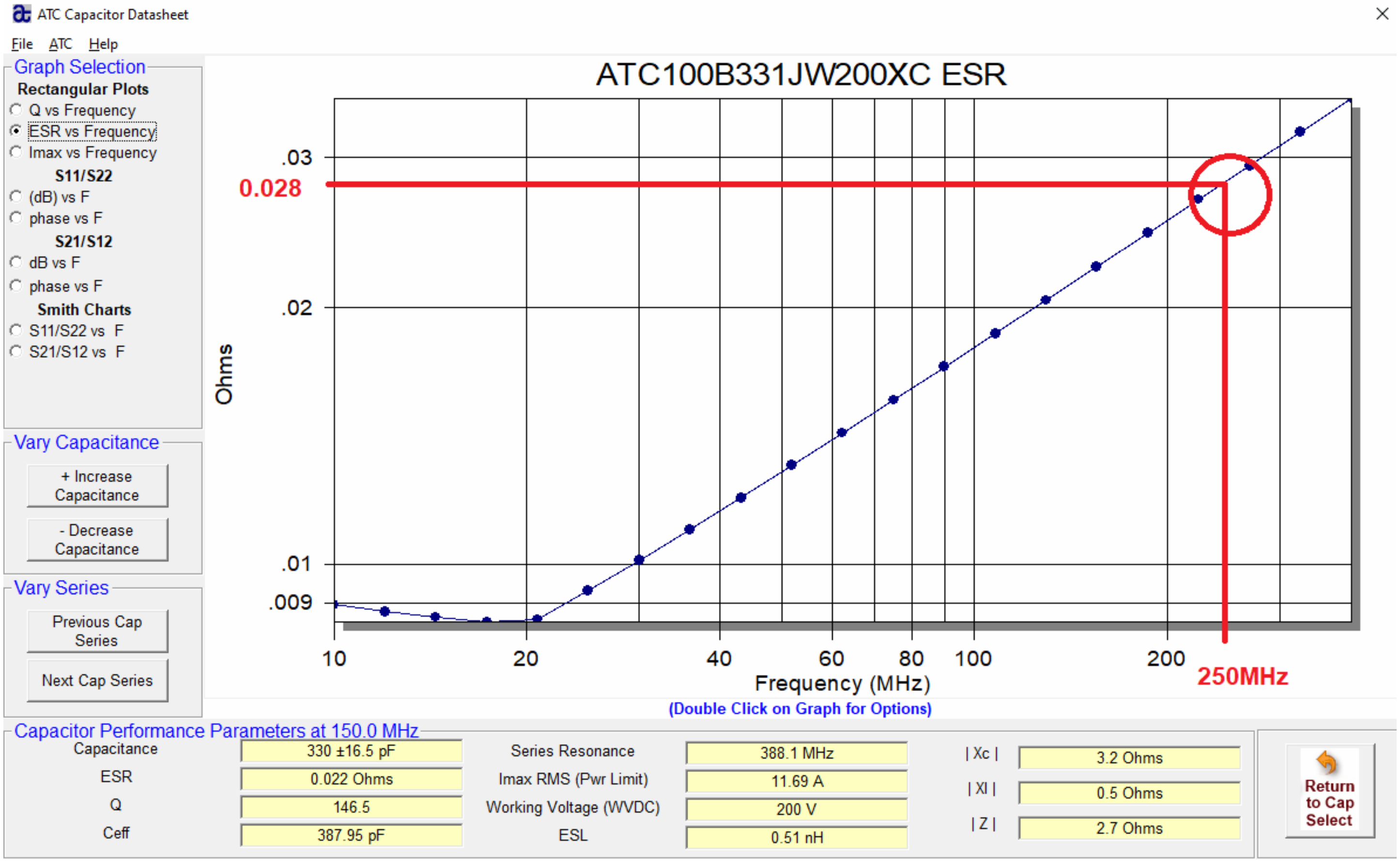


Figure 107

23. Changes to 2.0

Some of the changes with 2.0 are:

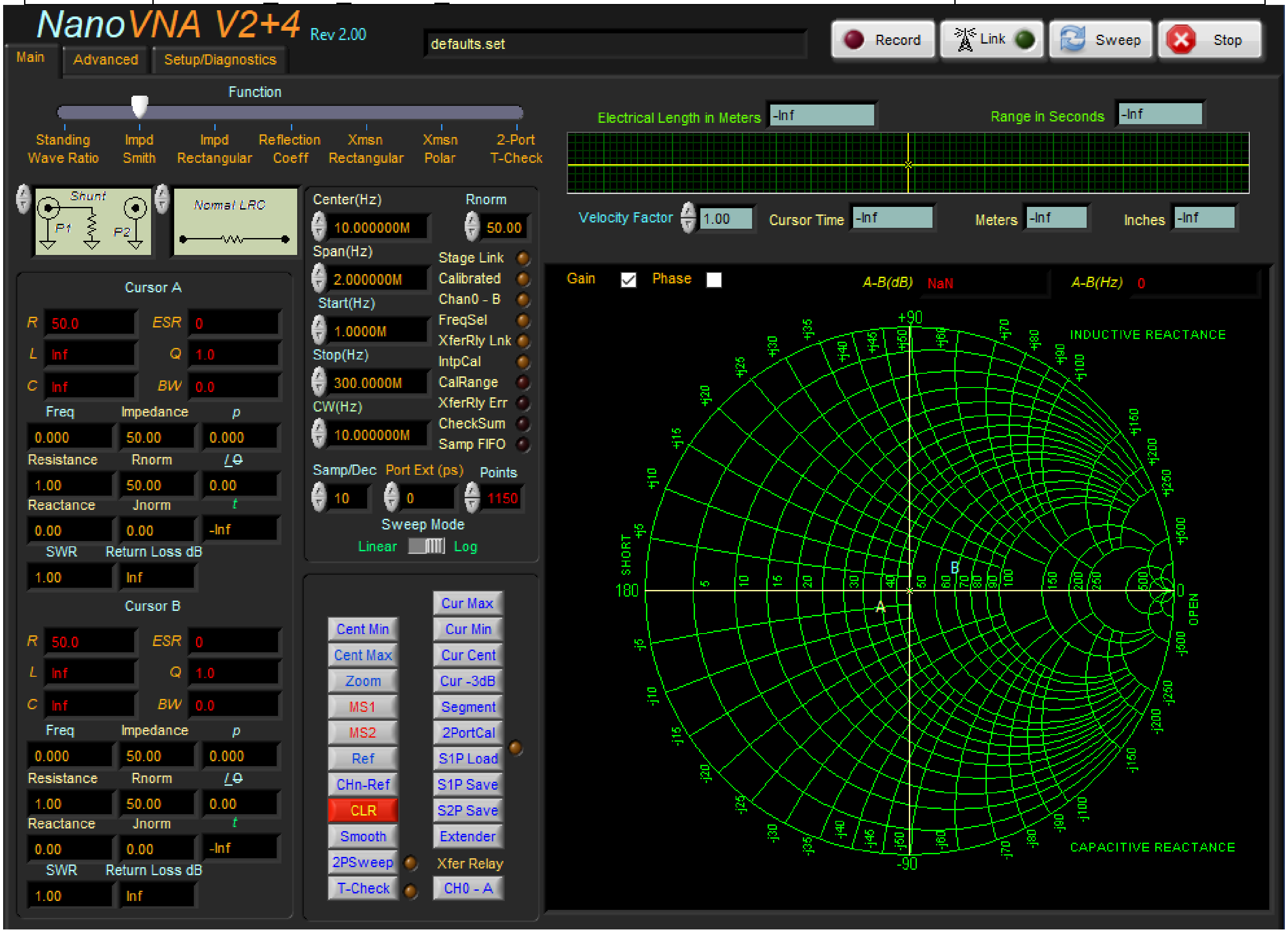
- Readouts are now more generic and correspond to the measurement type selected.
- Auto center the waveform at the minimum and maximum.
- Auto move the cursors to the min and max.
- Add delta dB for cursors.
- Correct bug with 2 port Touchstone.
- Correct bug when saving segmented data to Touchstone (AppCAD does not handle the odd spacing when using quasi log sweeps).
- Display the number data points when using segmented sweeps to the status box.

- Update the display with the segmented data as it is being collected rather than at the end as with previous versions.
- Blank out the display after changing the frequency range. This was done for cosmetic reasons only to avoid displaying partially updated data sets.
- Reduce commands used to interface with the firmware (now like V2Plus4).
- Add Bode plot for PDN analysis.

The Bode plot supports the following:

- Auto detect peaks and valleys and provide readouts for each.
- Calculate capacitor compensation values.
- Performs conversions to ohms and dB ohms.
- Improve the data collection (faster and easier to setup and use).
- Plot gain, phase, ohms and dB ohms.

The following shows the new main menu. Notice that some of the cursor readouts have been removed. These were only used when making thru measurements. You may now select the measurement type (shunt, series and shunt thru) and the readout will change accordingly. The measurement type is automatically selected when changing the Function. For example, if S11 is selected, the shunt measurement is also active. You may override this setting. One reason to do this would be when looking at S21 which defaults to thru, you may want to select the shunt thru measurement instead.



Additional buttons have been added to allow faster manipulation of the waveform and cursors.

When using the software with the original NanoVNA, the software now calculates a start and stop frequency for any changes made to the Center, Span, Start or Stop. This was done to simplify the software and make it more compatible with the V2+4. It also improves the update rates when using the Zoom and Segmented sweep.

When using the software with the original NanoVNA, you may now select the number of data points. This value is stored into the defaults file. Some newer firmware/hardware supports additional data points. The original software would issue the Frequency command when connecting to the original NanoVNA and any time a setting was changed. This made setting the value transparent to the user. This command is no longer supported to make the software more generic.

24. PDN Measurements

The most significant change to the software was the addition of a Bode plot which may be used to measure a Power Distribution Network. This document will not cover details about how to design a PDN. It will instead explain the basics on how to use the software to make such a measurement. There is a lot of free material on this subject available and I strongly suggest you use these resources.

24.1 What You Need to Get Started

When making measurements, it would be ideal to use frequencies below 20kHz. Some firmware for the original NanoVNA does support lower frequencies however it appears the performance falls off below 20KHz. The V2+4 is limited to even higher frequencies. You should not expect to get the same level of performance from a VNA costing under $200 including cables and standards and you will with a name brand lab grade instrument. If you are only considering the PDN measurements from a learning perspective, you should be fine. Otherwise, open that wallet and buy some better equipment!

In order to measure the PDN, we will be using the shunt thru method. There is a ground loop between the two ports that will cause an error in the measurement when working at lower frequencies. As we start to work at higher frequencies, this error will become less as the cable losses will dominate. One way to break this ground loop is to use a common mode transformer between the DUT and port 2.

PDN measurements are tested with the board both powered on and off. The PDN may very well have voltages higher than what would damage the VNA. One way to work around this problem is by introducing a DC block on the connection points to the DUT.

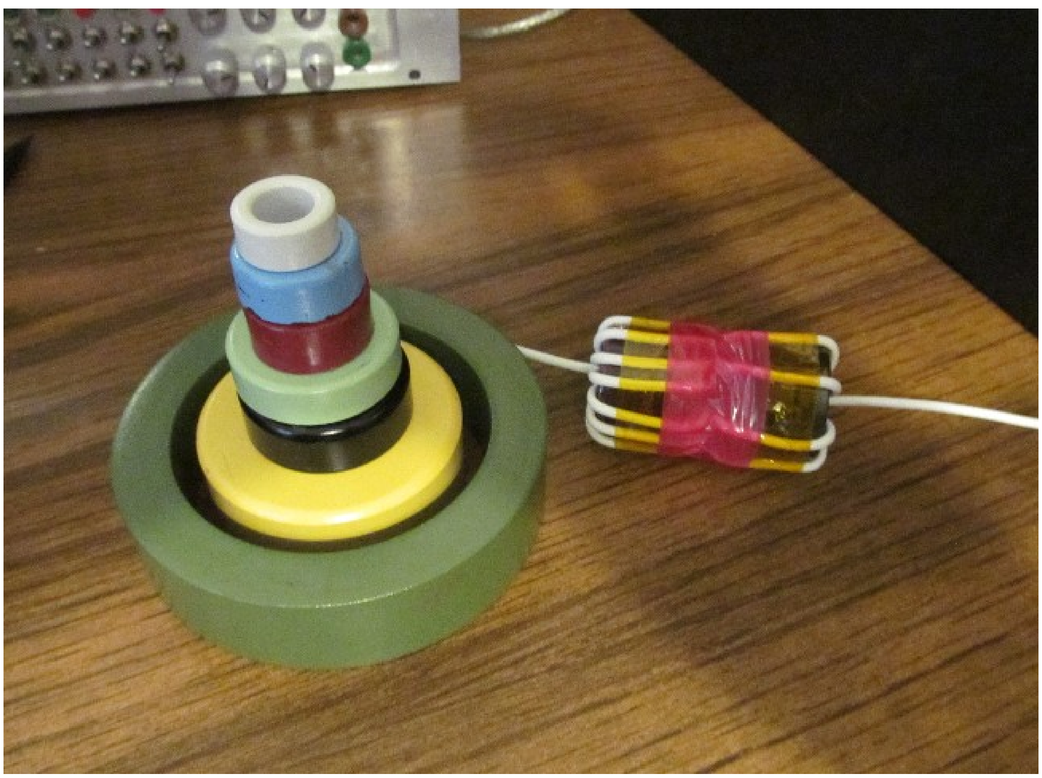
You will also need additional cables and probes. For the purpose of these examples, we will be using coax soldered directly to the DUT or plugged into a breadboard.

24.2 Common Mode Transformer

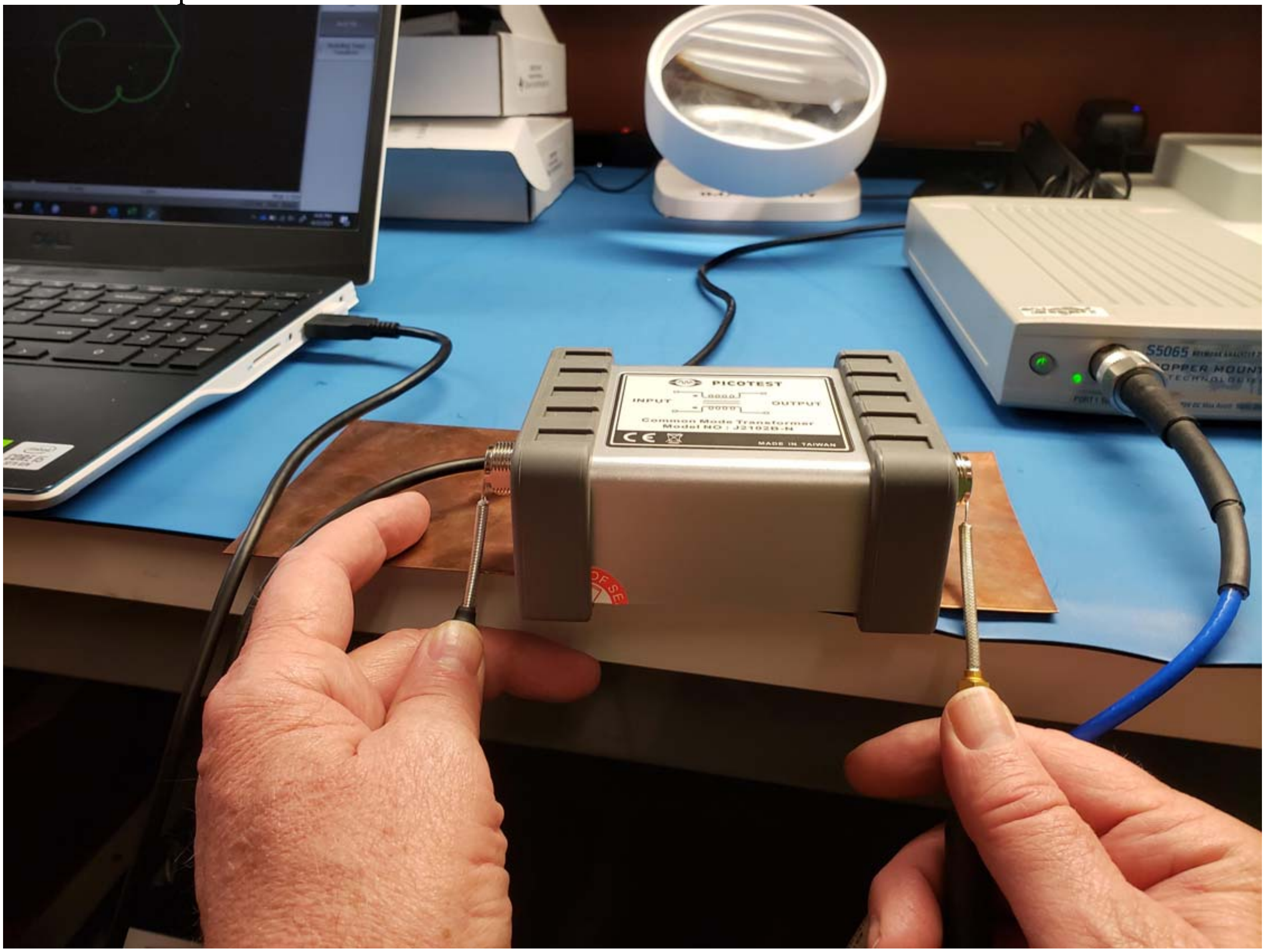
When making very low impedance measurements using the shunt thru method, there will be an inherent ground loop formed between ports 1 & 2. This ground loop will cause errors in the readings and must be considered. One way to reduce the error is by inserting a common mode transformer between the device we are testing and port 2 of the VNA. The transformer must have a very wide bandwidth and low loss. To maintain 50 ohms, they will be a coaxial type. PicoTest produces such a transformer (PN# J2102B) but the cost may exceed the typical hobbyist's budget.

Brian Walker of Copper Mountain Technologies had access to the J2102B and was kind enough to provide the S-parameters for it which included measuring its common mode loss. Brian has published a paper about this subject that I highly recommend reading. BIG thanks to Brian for this help.

I have collected a fair number of toroidal cores over the years of various sizes and materials. Attempting to make a transformer using the parts that were on-hand, I was unable to achieve performance comparable with the Picotest J2102B. One of the early transformers may be seen to the right. Note that this transformer was made using different types of core materials.

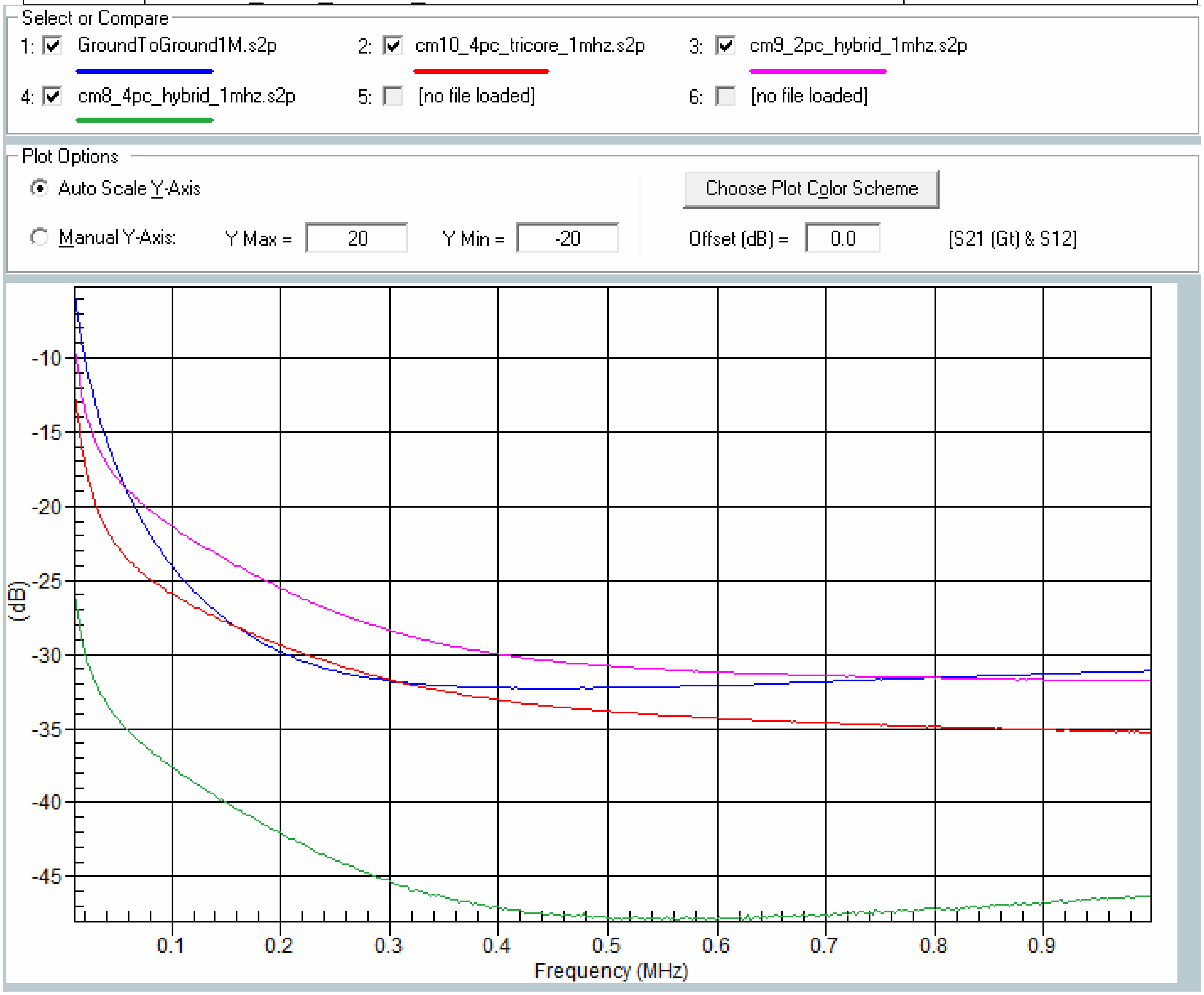


Measuring the common mode performance, Brian had measured across the transformer's shield as I would expect.

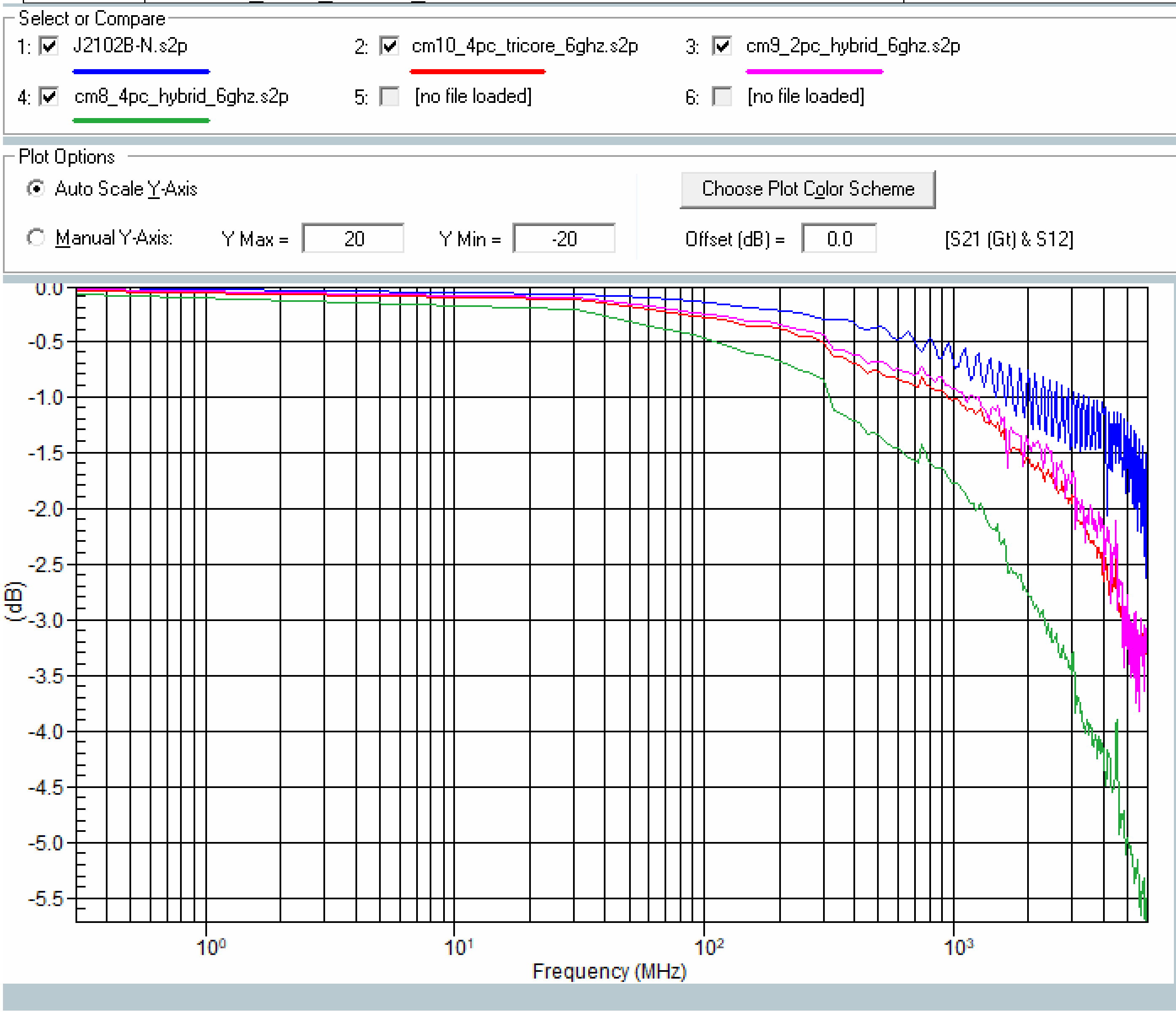


I had reached out to Steve Sandler at Picotest to see if I could understand the data shown on their website, but I was never able to get a clear answer. I had been doing something like Brian, soldering the coax's braid to a couple of BNCs connected to the VNA but later made adapters.

To improve the transformer, some better materials were purchased. My 8th attempt which was one of the more promising designs, was based on a mix of nanocrystalline and Mn-Zn cores. Looking at the following plots, GroundToGround (Blue) is the common mode data supplied by Brian. CM8 (Green) was my 8th attempt at a home-made transformer.

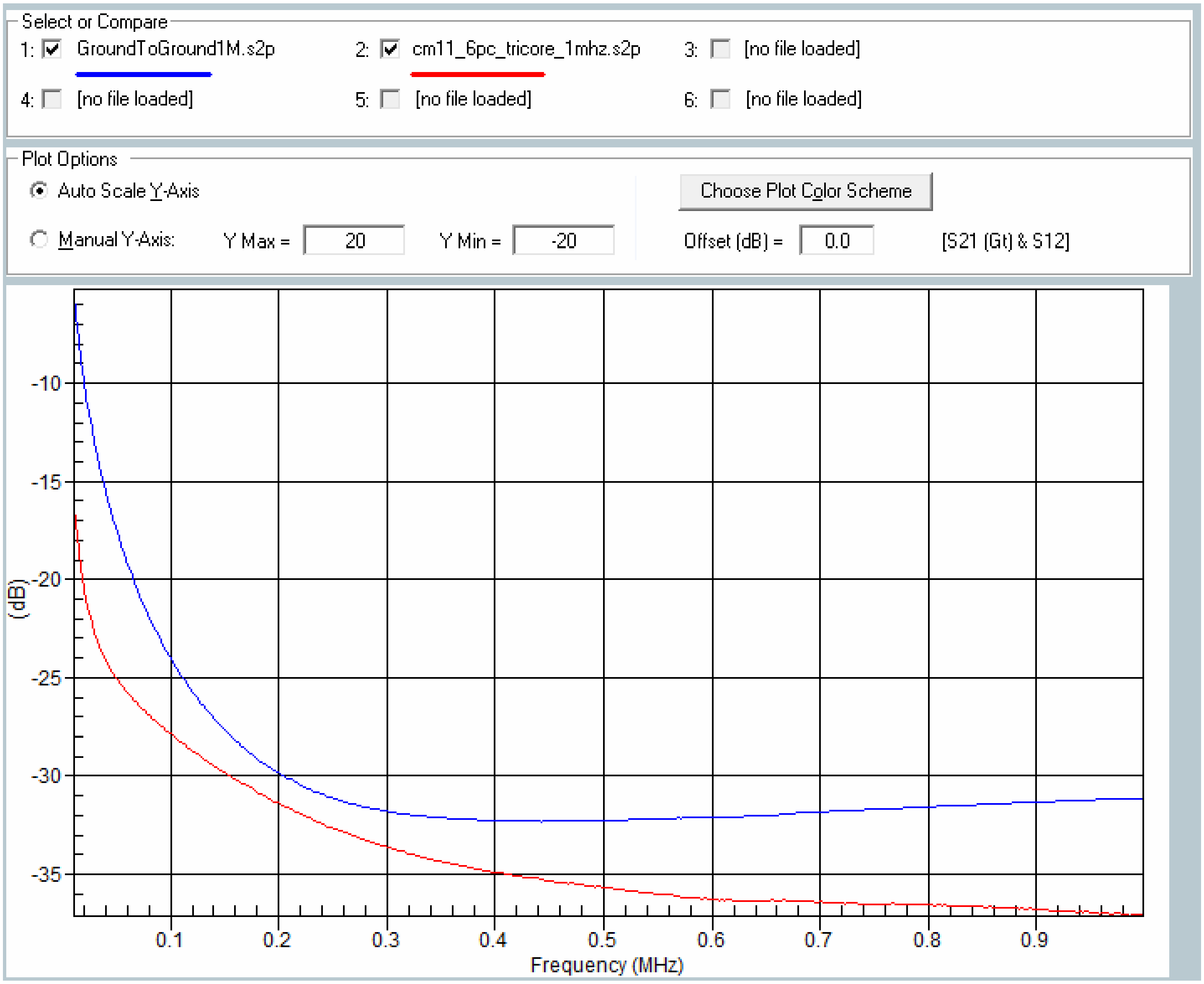


The common mode performance looks good but the loss at 6GHz is very poor. It appears that the Picotest transformer has a worse 50-ohm match, but we can use that to our advantage.

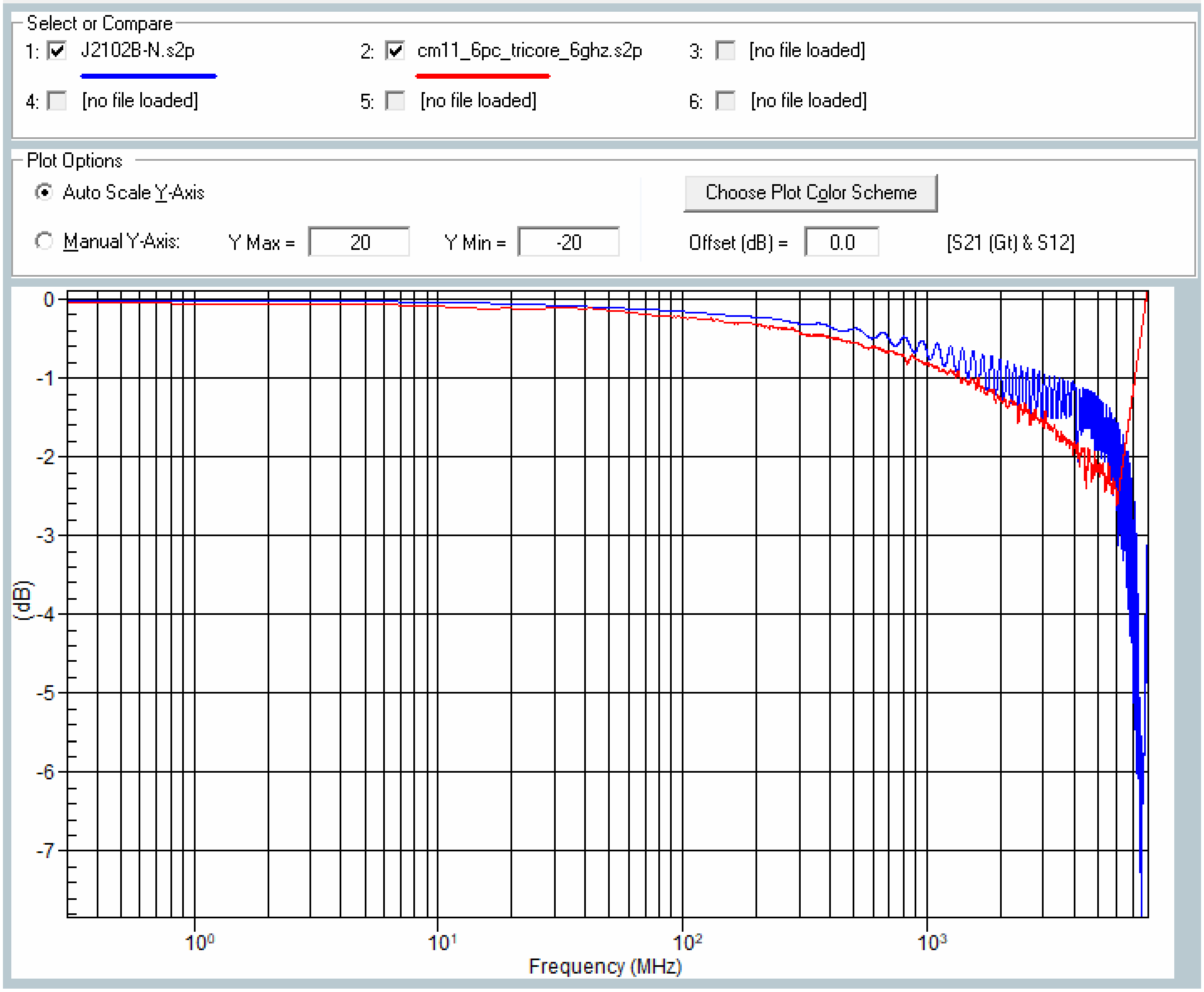


We can use the data Brian provided to make a guess at what coax was used in the Picotest transformer along with the length. My 8th attempt used a more coax to achieve better common mode. It is a tradeoff. The next two attempts (CM9&10) have lower losses, but their common mode is not as good.

One last attempt was made to improve the homemade transformer and another set of cores were ordered. The following plots compare the 11th attempt against the Picotest. Brian's VNA is capable of running at much higher frequencies (advantage of working for Copper Mountain) so I have included the extended loss data.



Select or Compare
1: GroundToGround1M.s2p
2: cm11_6pc_tricore_1mhz.s2p
3: [no file loaded]
4: [no file loaded]
5: [no file loaded]
6: [no file loaded]
Plot Options
Auto Scale Y-Axis
Choose Plot Color Scheme
Manual Y-Axis:
Y Max = 20
Y Min = -20
Offset (dB) = 0.0
[S21 (Gt) & S12]
-10
-15
-20
-25
-30
-35
(dB)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Frequency (MHz)



The common mode performance for our home-made transformer is better than the Picotest and the loss seems to be on par. Because transformer #8 has such good common mode performance and the loss is acceptable at 2.4GHz, I decided to build up final versions of each design.

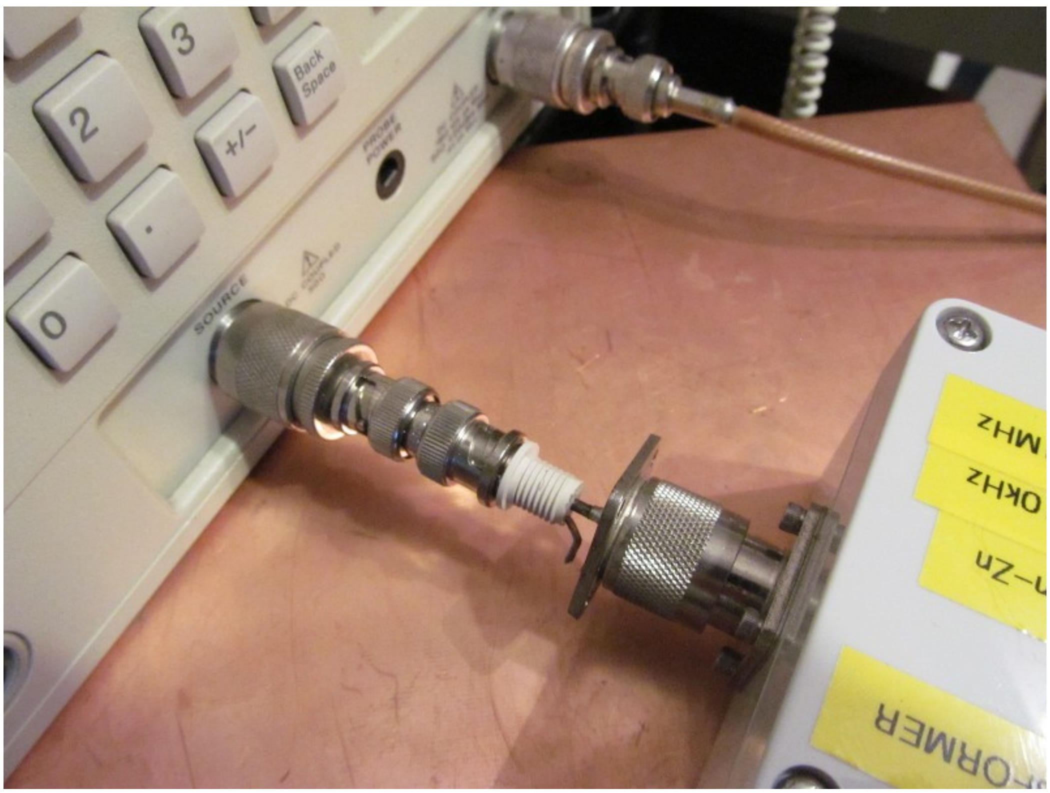
@ 100Hz; 25dB @ 10kHz
100kHz; 45dB @ 1MHz
50 OHMS
-3dB @ > 6GHz
COMMON MODE TRANSFORMER

COMMON MODE TRANSFORMER
-3dB @ 2.4GHZ
NANOCRYSTALLINE/Mn-Zn
3.2dB @ 100Hz; 25dB @ 10kHz
37dB @ 100kHz; 45dB @ 1MHz
50 OHMS
COMMON MODE TRANSFORMER
-3dB @ > 6GHz
1kHz -2.5dB 10kHz -17.5dB
100kHz -27dB 1MHz -37.5dB
NANOCRYSTALLINE / Mn-Zn

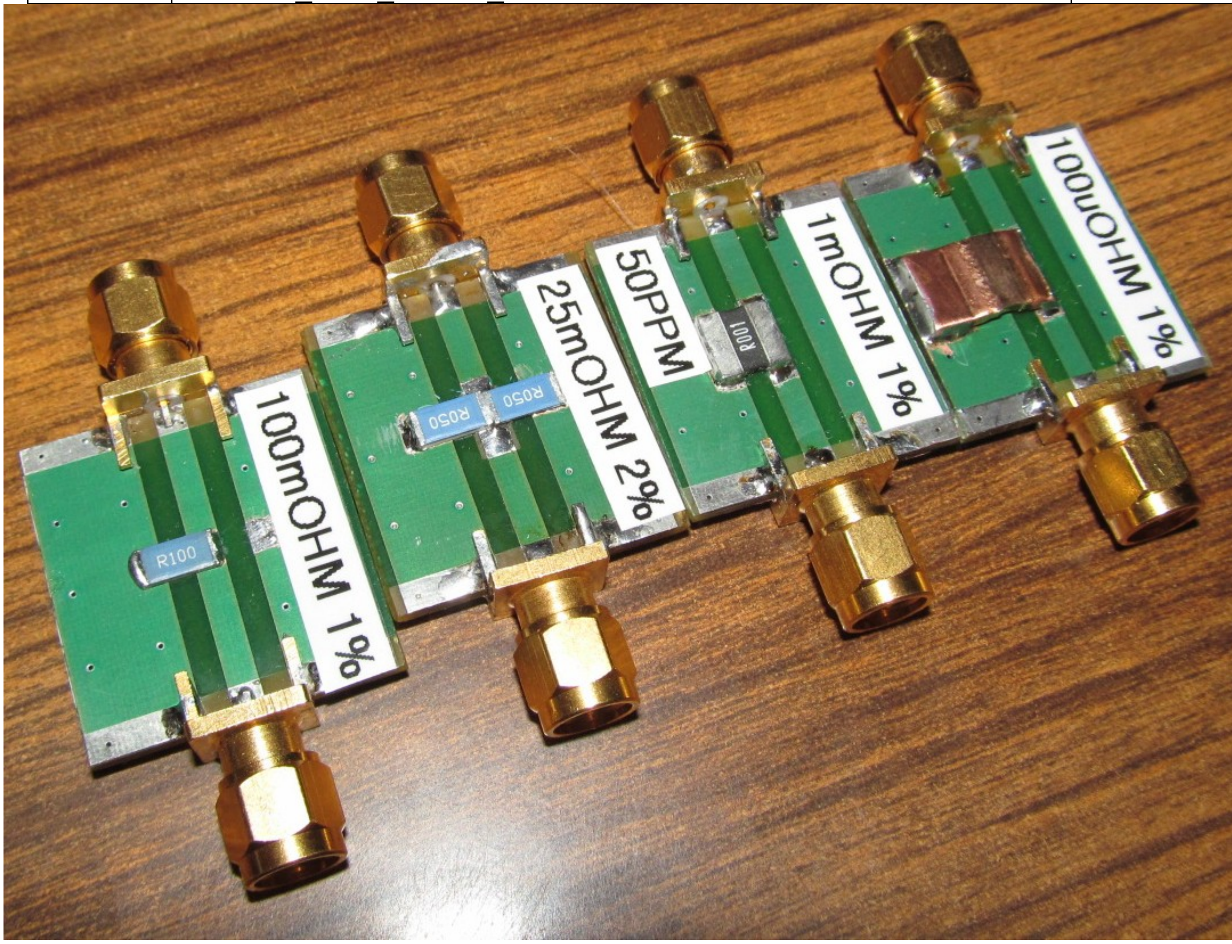
Most of the cost for these two transformers was the connectors. The nanocrystalline cores came next, followed by the box, then the Mn-Zn cores, hardware and coax. The transformer on the right was about $200, more than half of that was connectors.

24.3 Testing the Homemade Transformers

Initially I started out using N style connectors for transformer #8 but later changed to SMA to try and reduce the costs. Shown below, measuring the common mode performance of #8 w/ N style connectors.



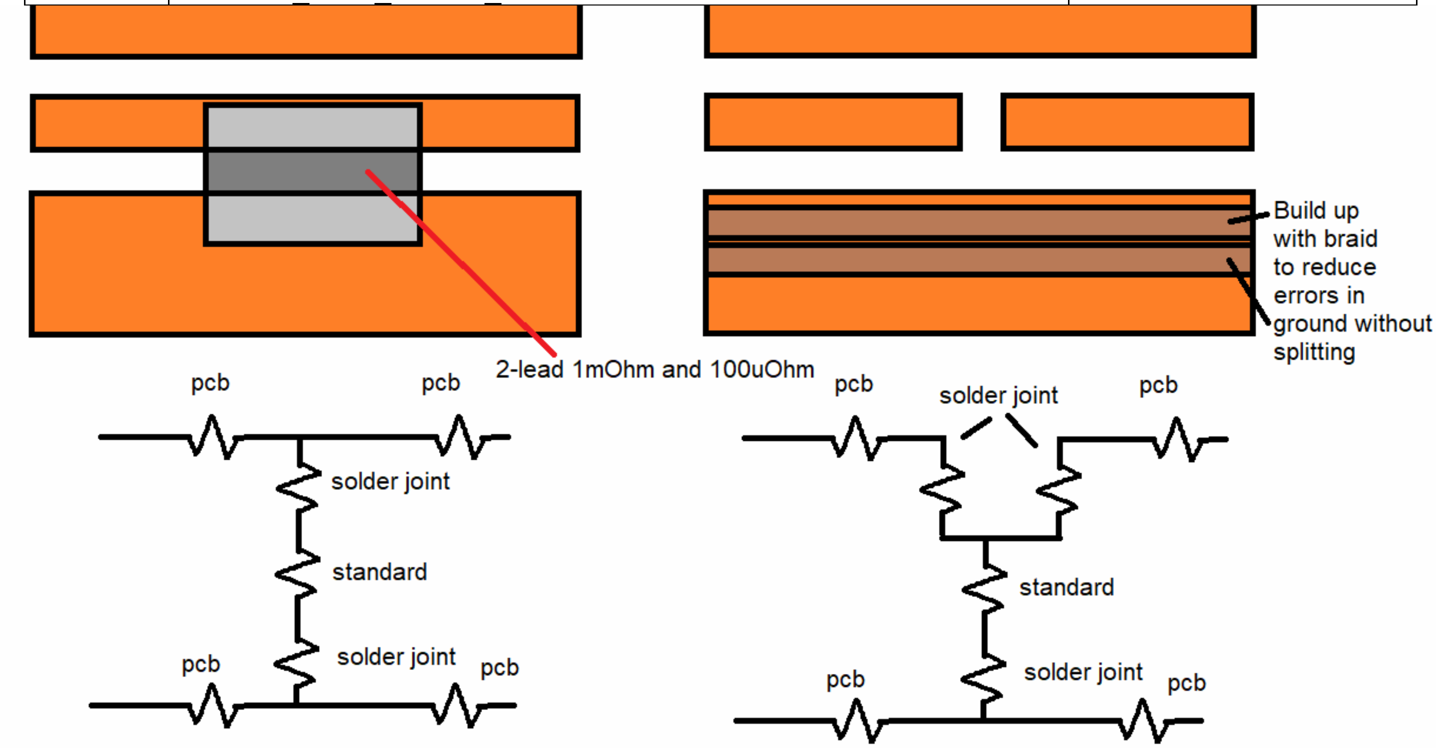
Four different resistors were mounted on test boards to use as standards.



The resistors were then measured both with and without the transformer inserted. We can see that there is a major improvement in our measurement when using the transformer, however the errors of the 1mOhm and 100uOhm devices are not at all close.

VNA/PNA	Test Freq	Resistor	Direct (dB)	Direct (Ohms)	%Error	Xform (dB)	Xform (Ohms)	%Error
VNA	2.5k	0.1	-47.76	0.102735621	2.735621	-48.04	0.099463661	0.536339
VNA	2.5k	0.025	-59.15	0.027600644	10.40258	-59.96	0.025140651	0.562606
VNA	2.5k	0.001	-77.95	0.003165884	216.5884	-85.63	0.001307563	30.75633
VNA	2.5k	0.0001	-80.82	0.00227499	2174.99	-98.92	0.000283103	183.1033

The problem is obviously the PCB but there are limits to how to improve it without expending a lot of effort. I decided to try cutting the trace and adding layers of copper to the ground plane to reduce the losses as shown.



Shown below is the 1mOhm standard after mods. Both boards were then coated with dope.

Using a power supply and a couple of meters, at DC I measured the following:

1mOhm: Measured 0.9870A @ 1.0120mV or 1.025mOhms.
100uOhm: Measured 1.8929A @ 189.0uV or 99.85uhms.

The standards were then tested again using our transformer.

With the changes to the standards, the error was now in the 5% range.

VNA/PNA	Test Freq	Resistor	Direct (dB)	Direct (Ohms)	%Error	Xform (dB)	Xform (Ohms)	%Error	Xform (dB)	Xform (Ohms)	%Error
VNA	2.5kHz	0.1	-47.76	0.102735621	2.735621	-48.04	0.099463661	0.536339			
VNA	2.5kHz	0.025	-59.15	0.027600644	10.40258	-59.96	0.025140651	0.562606	-60.05	0.02488124	0.4750389
VNA	2.5kHz	0.001	-77.95	0.003165884	216.5884	-85.63	0.001307563	30.75633	-88.43	0.000947232	5.2767777
VNA	2.5kHz	0.0001	-80.82	0.00227499	2174.99	-98.92	0.000283103	183.1033	-107.55	0.000104819	4.8194387

24.4 DC Blocks

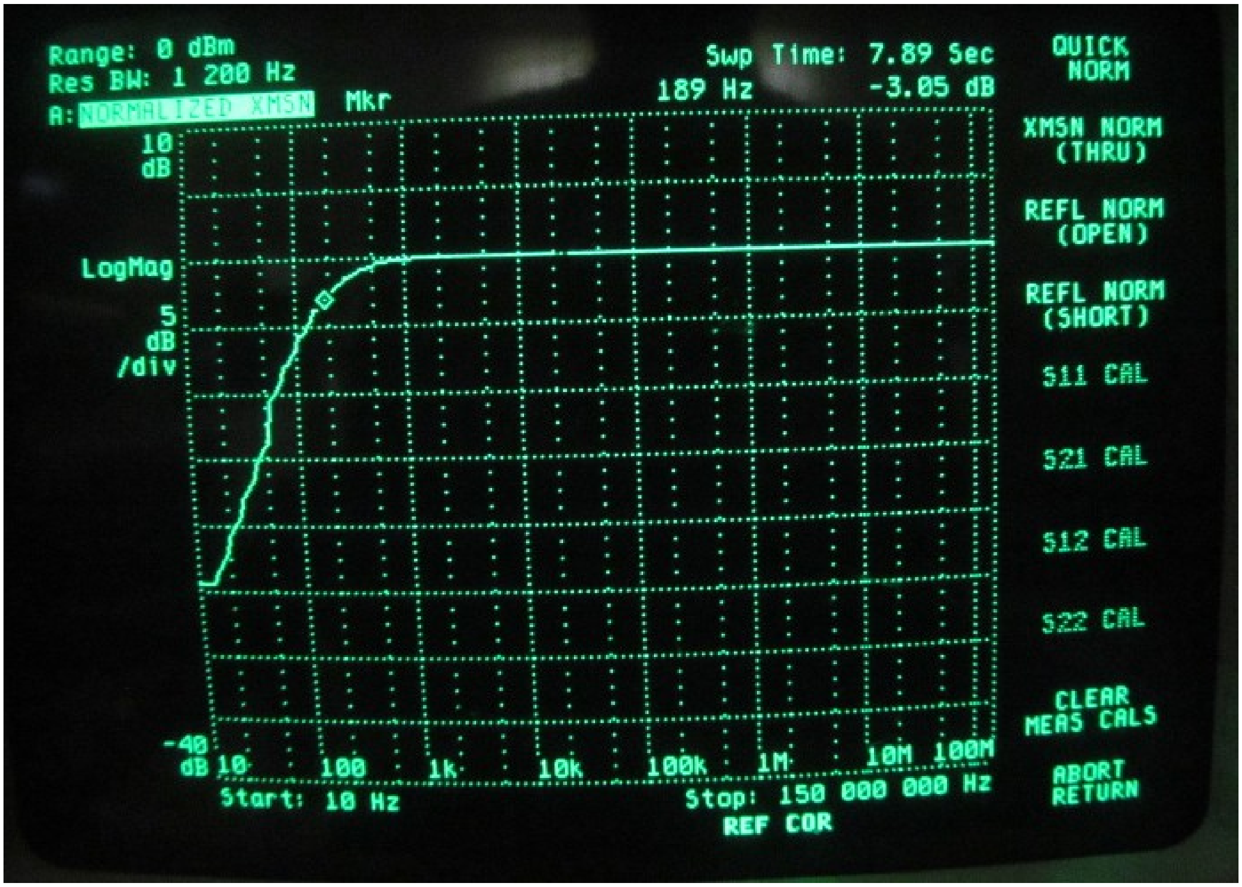
Of course, looking at resistors directly with the VNA is fine but we want to look at the power rails for a circuit. Normally we will want to look at them when they are powered both off and on. It is VERY possible that these voltages will damage the VNA. We are only interested in the AC component and can install a capacitor to block the DC.

Warning! If you are reading this, I will assume your smart enough to know that at very high frequencies the capacitors impedance is very low. When you turn on the supply, it could have a very sharp transition that could very well blow right though the DC block and damage your VNA! Make sure you understand what it is that you are doing BEFORE you randomly start trying things. The NanoVNAs are low cost and damaging one is not the end of the world but if you are working with a $250,000 instrument, your boss may end your career if you take out their VNA being stupid. You have been warned.

Picotest offers the P2130A DC block. These are rated for 500Hz to 8GHz and have a 50V rating. Once again, the cost for a couple of these (remember the VNA has two ports, and both are susceptible) may exceed the hobbyist's budget. While Mini-circuits and others offer blocks at reasonable prices, you may find it difficult to located ones with decent performance at low frequencies. For our PDN measurements we want to at least get below 20kHz, if not lower.

Once again, we will make our own. While the capacitance of a ceramic device will be greatly affected by the voltage, using stable parts (COG, NPO vs X7R) may not be needed and would certainly be difficult to obtain. I assembled these using a couple of X7R 50V parts mounted between two SMA connectors using a Teflon spacer.

Looking at the low frequency response, the 3dB point for our homemade blocks is roughly 200Hz. This is more than adequate for our use. The HP3589A which is being used for these low frequency measurements is limited to 150MHz.



In order to determine how the block behaves at higher frequencies, it was attached to the Agilent PNA and swept to 6HGz. Notice that a flavor of the same software runs on the PNA. It has since been updated to version 2.0 as well.

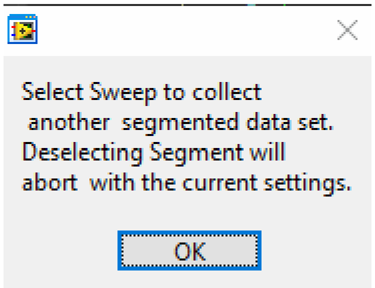
24.5 Using Quasi Log Segmented Sweeps

Looking at a typical PDN, the information we are interested in is feature rich at lower frequencies. We would really like to have a log sweep but sadly this feature is not yet available with these low cost VNAs. To work around this, early on I had created a quasi-Log sweep. When combined with segmented sweep, the NanoVNA can collect a fair amount of data in a reasonable time.

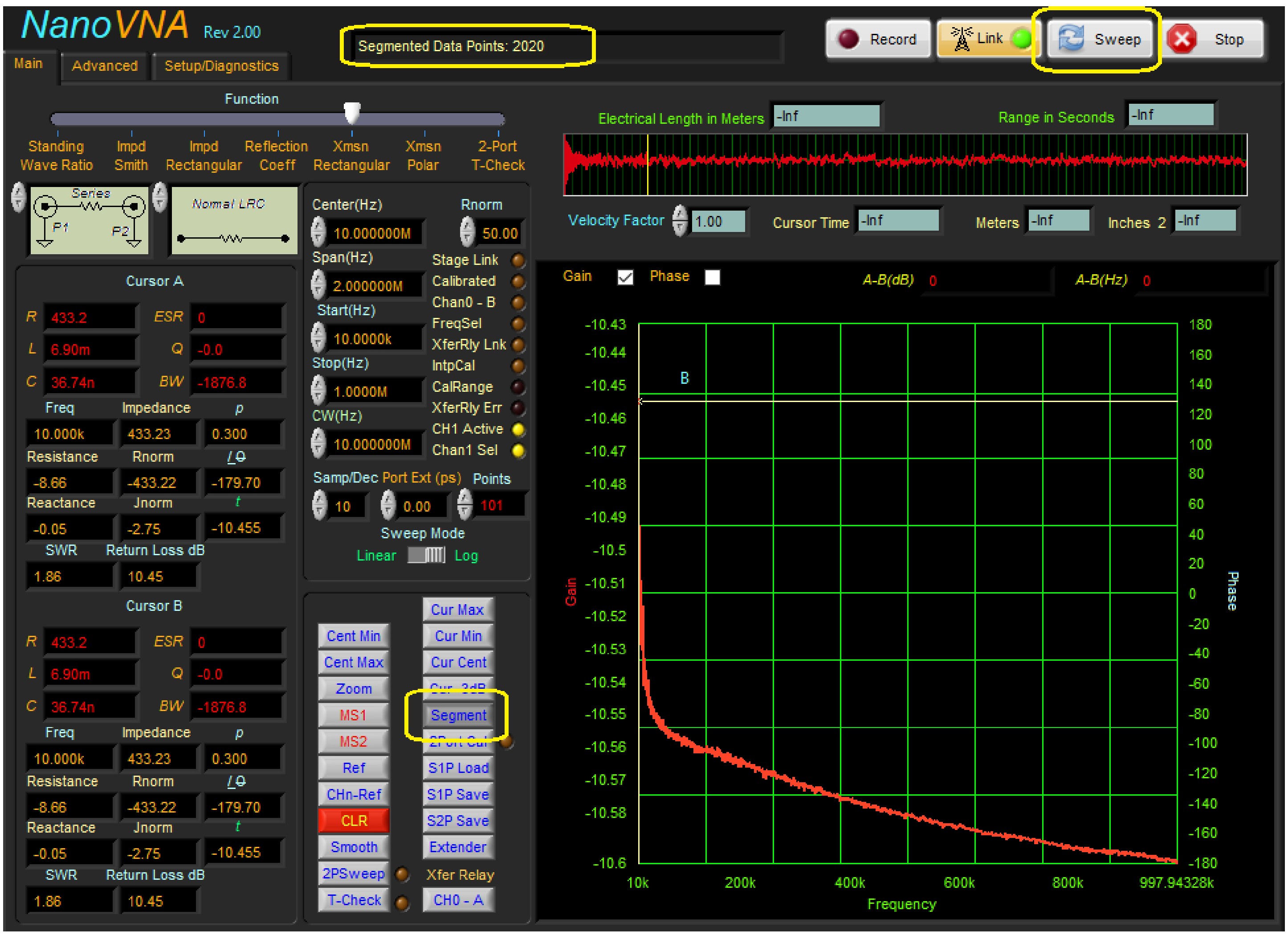
To use the log rather than the linear sweep mode, set the samples per decade rather than the Span to the resolution you want. The default is 10 which is normally more than enough. Set the start and stop frequency. Normally, you will want to run down to 10KHz if possible. Some firmware/hardware combinations will not support going this low. It is assumed if you are attempting to make these measurements, you know what your VNA is capable of. From my own testing, newer hardware and firmware may not be your best choice. For the upper frequency, hey, it is your design…. For these examples, we will be testing at low frequencies only. Finally, select the Xmsn Rectangular function.

24.6 Calibration

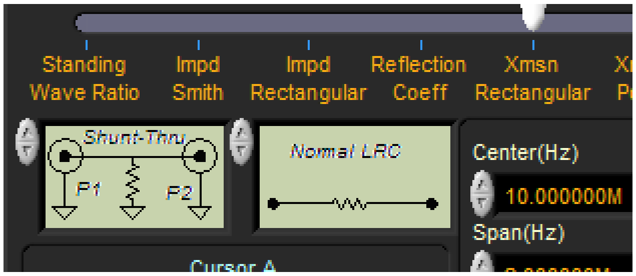
While you could go though a full calibration, just to get a quick idea how the system performs I recommend using the normalization. Insert a thru and select Sweep. Now select the Segment button. Using the above settings, the software will now perform a quasi-log sweep from 10kHz to 1MHz. Once complete, the following message will be displayed. Select OK.



Notice that the sweep has been disabled and the number of data points collected are shown in the status at the top of the menu. With my NanoVNA, uncalibrated it read about 11dB. Select the Ref button then CHn-Ref to save this data as the reference.



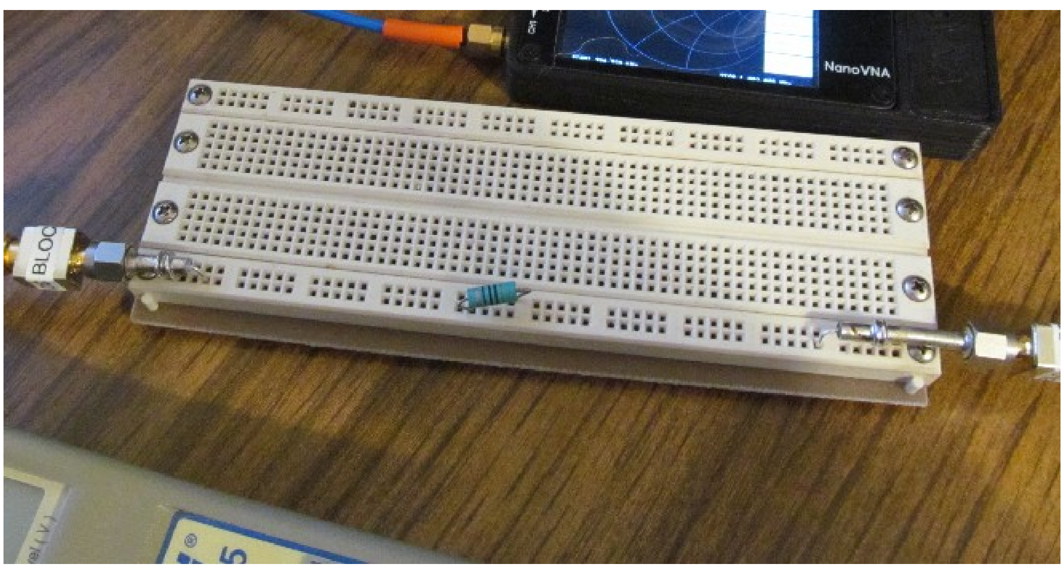
Select the Shunt-Thru measurement. All the readouts will now show the proper values for this measurement type.



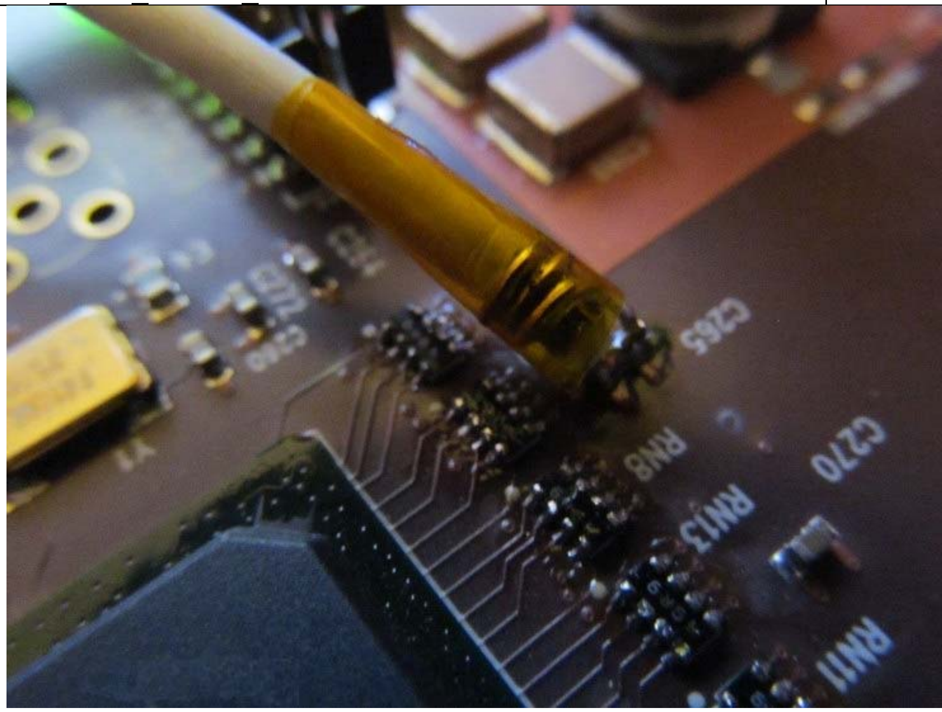
You are now ready to attach your device and make a measurement.

24.7 Attaching to the Target

Connecting to your PDN will require some sort of probing method. Normally you will want to calibrate out any errors caused by your probes. In the following, two sections of ridged coax are attached to two ends of a breadboard that will simulate our PDN.

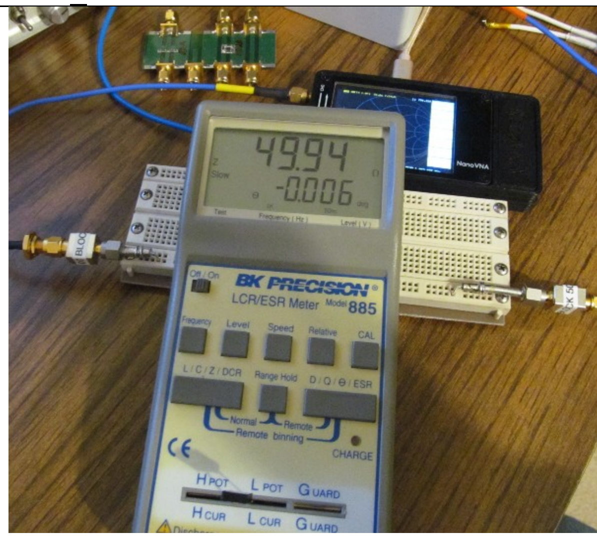


You may want to make up some short lengths of coax that could be soldered to directly to your board. In the following the coax is soldered across on of the bypass capacitors.



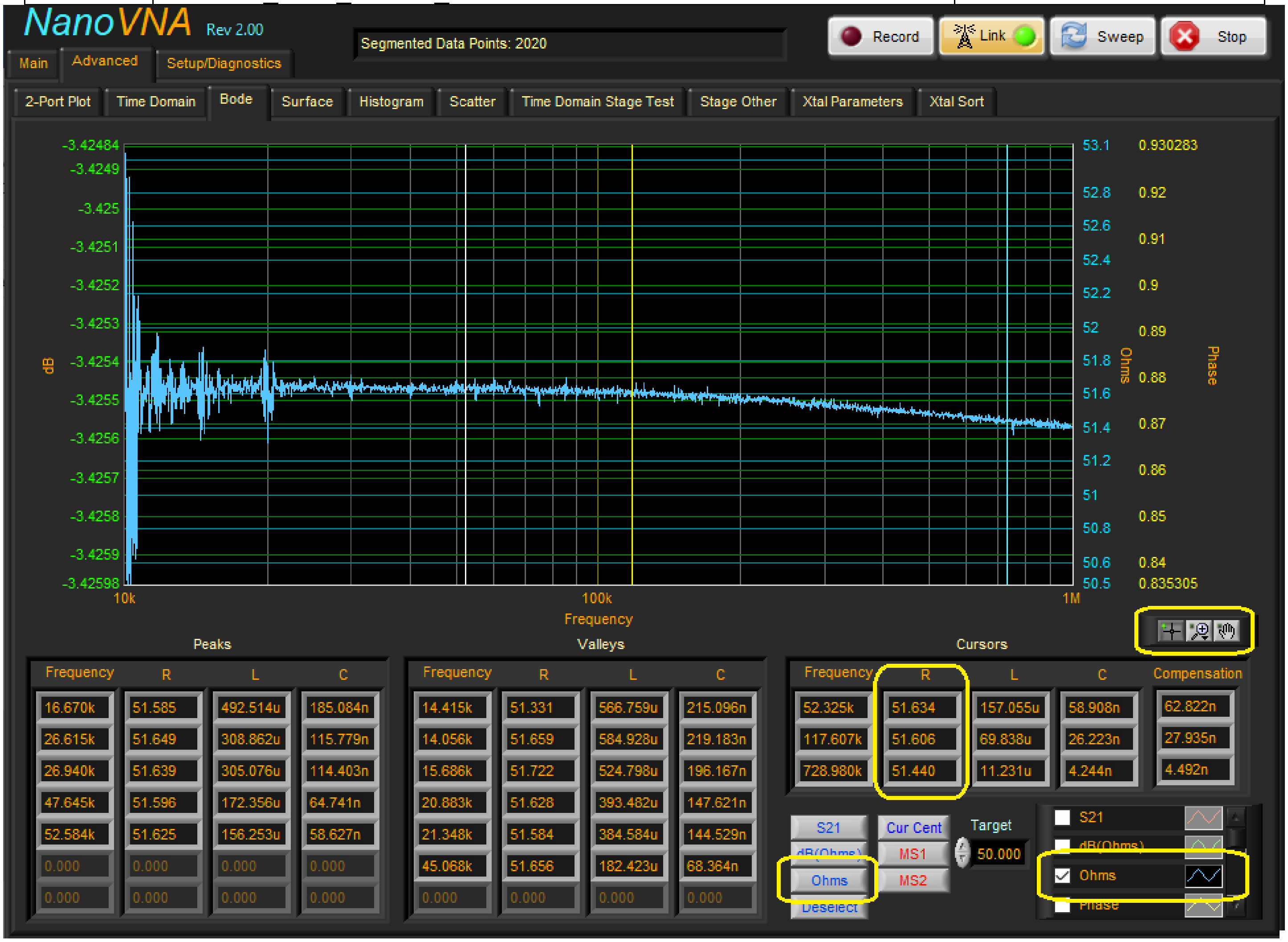
24.8 Making a Measurement

It is better to start with some basic parts that we can measure by other means. For this example, we will attempt to measure a 50ohm resistor by placing it across the power plane of a breadboard as shown.

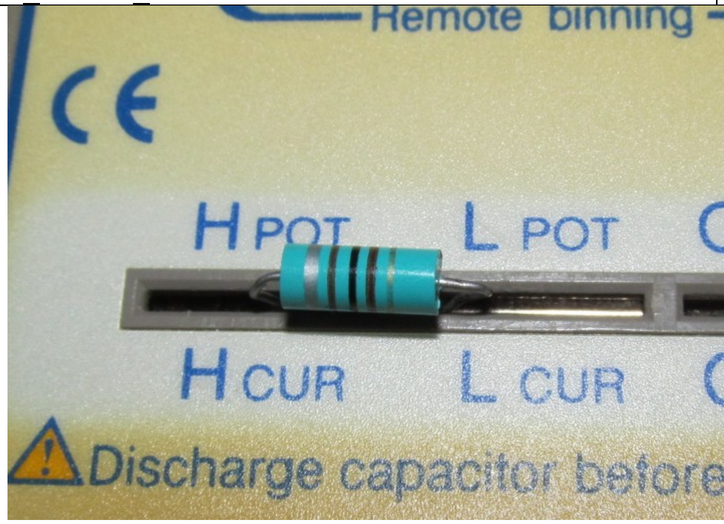


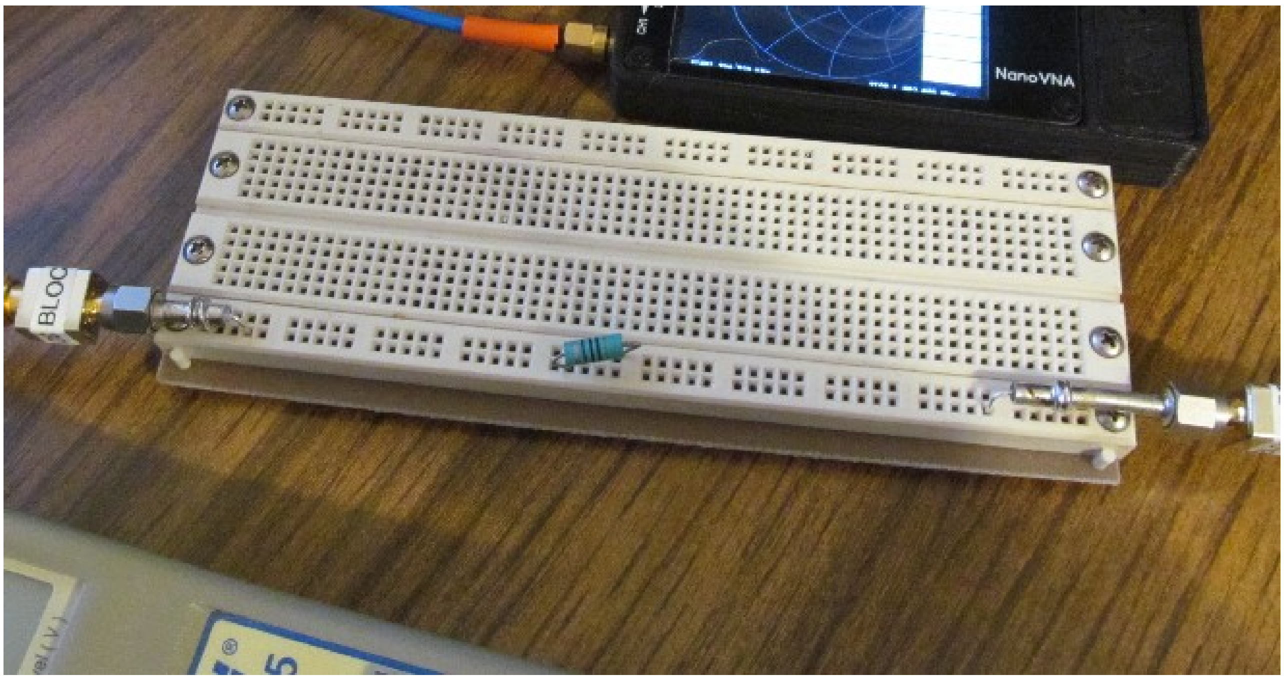
Select the Advanced tab followed by Bode and press Sweep.

Selecting Ohms will perform the conversion. We can see the resistor is well behaved up to 1MHz. The Bode plot has three cursor measurements and will automatically measure the peaks and valleys as well.



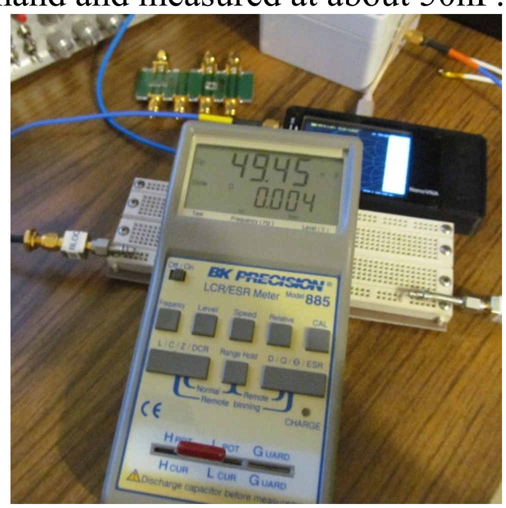
Let us try something a little more complex than a resistor. Here we have a 100uH inductor that we will use in place of our 50-ohm resistor.



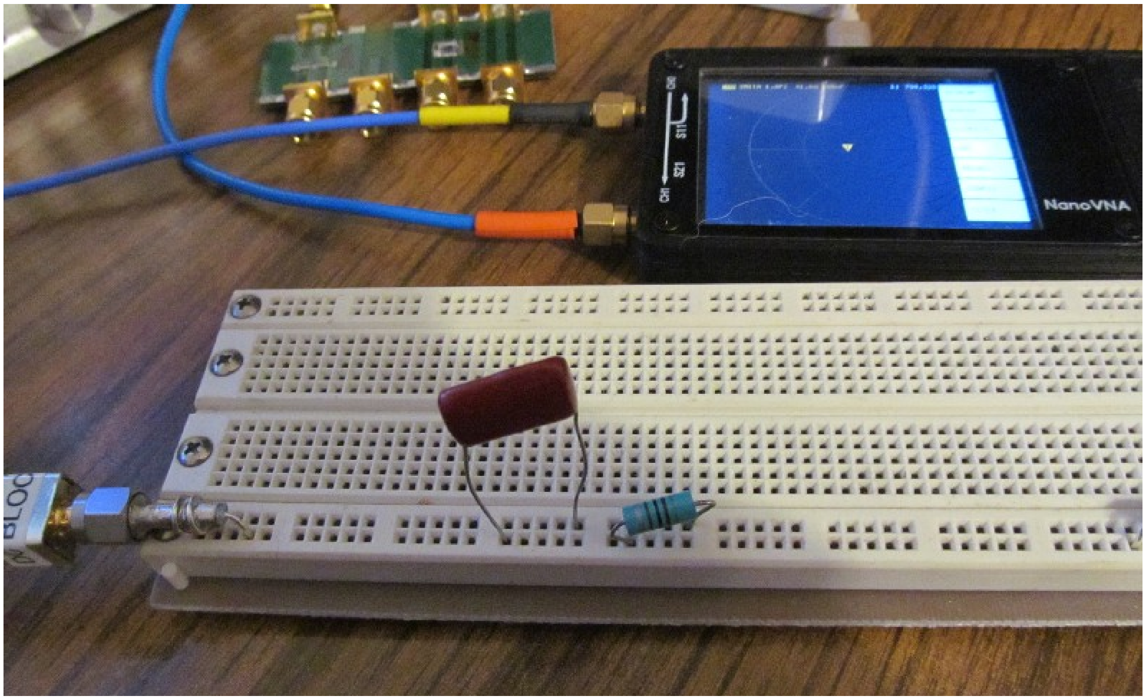


Leave the software settings the same with a target impedance of 50 ohms. Select the Sweep button. The software measures a 100uH inductor and for a target of 50 ohms, it displays that a 50nF capacitor (C = L/Z^2) is required to compensate this network.

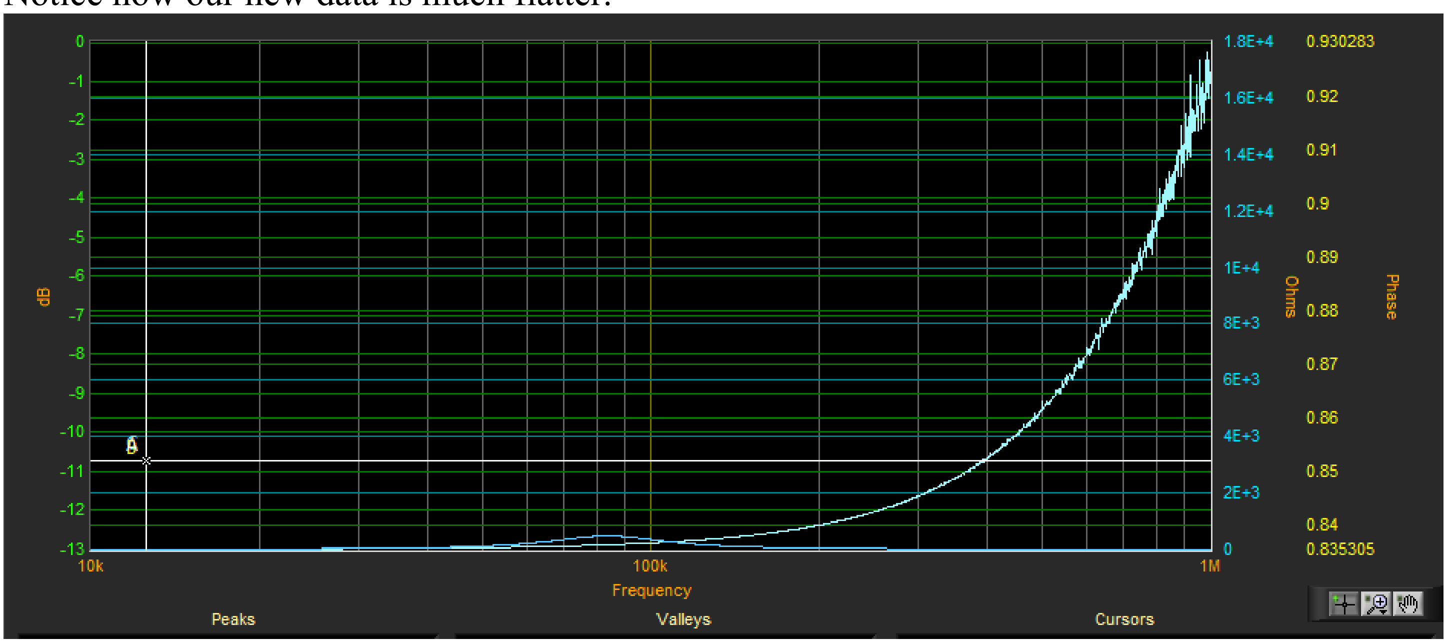
A 47nF film capacitor was on-hand and measured at about 50nF.



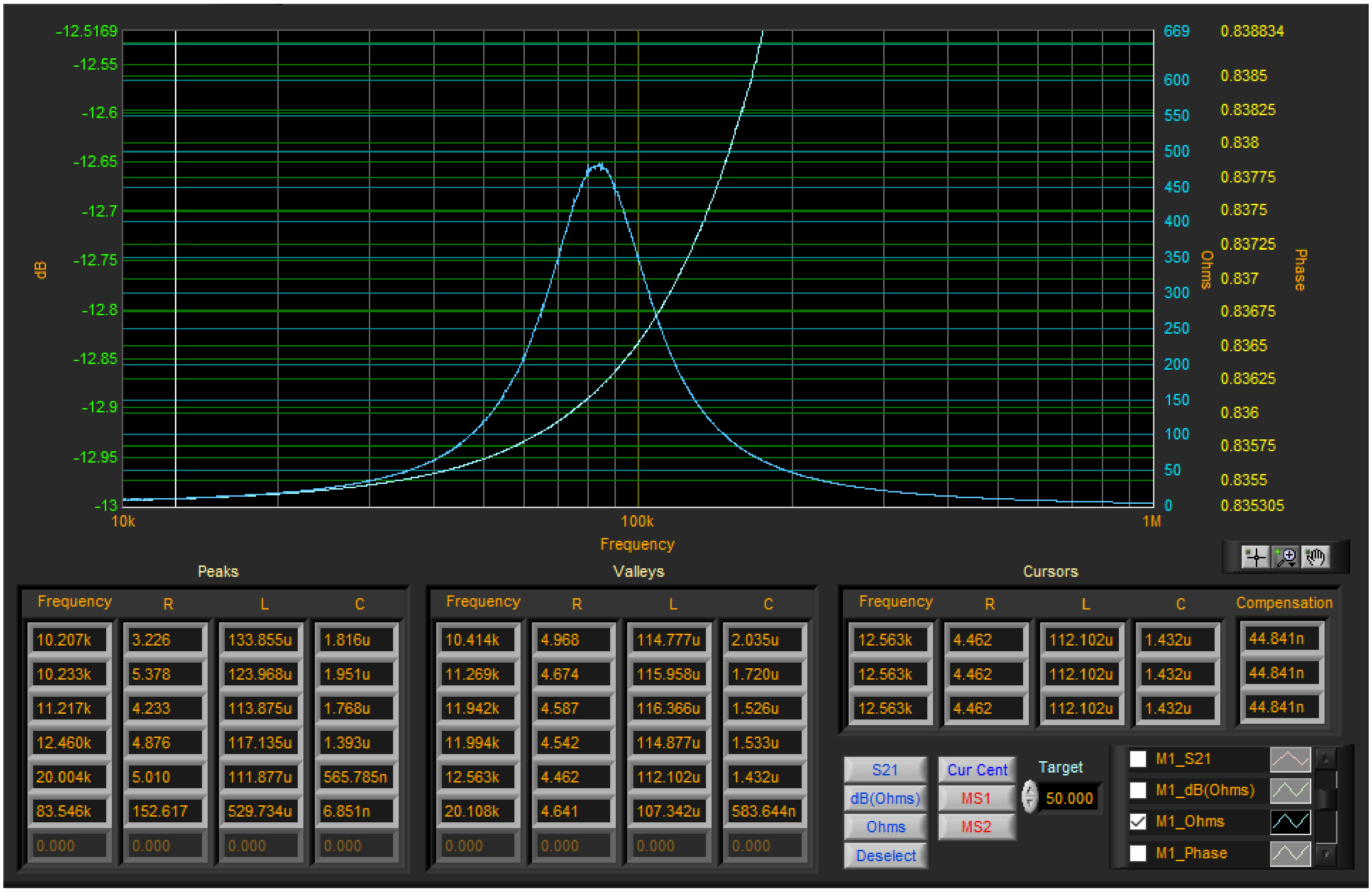
The capacitor was then placed in parallel with our inductor compensate for the effects. Before starting another sweep, select MS1 to save the current sweep. Now go ahead and select the Sweep button again.



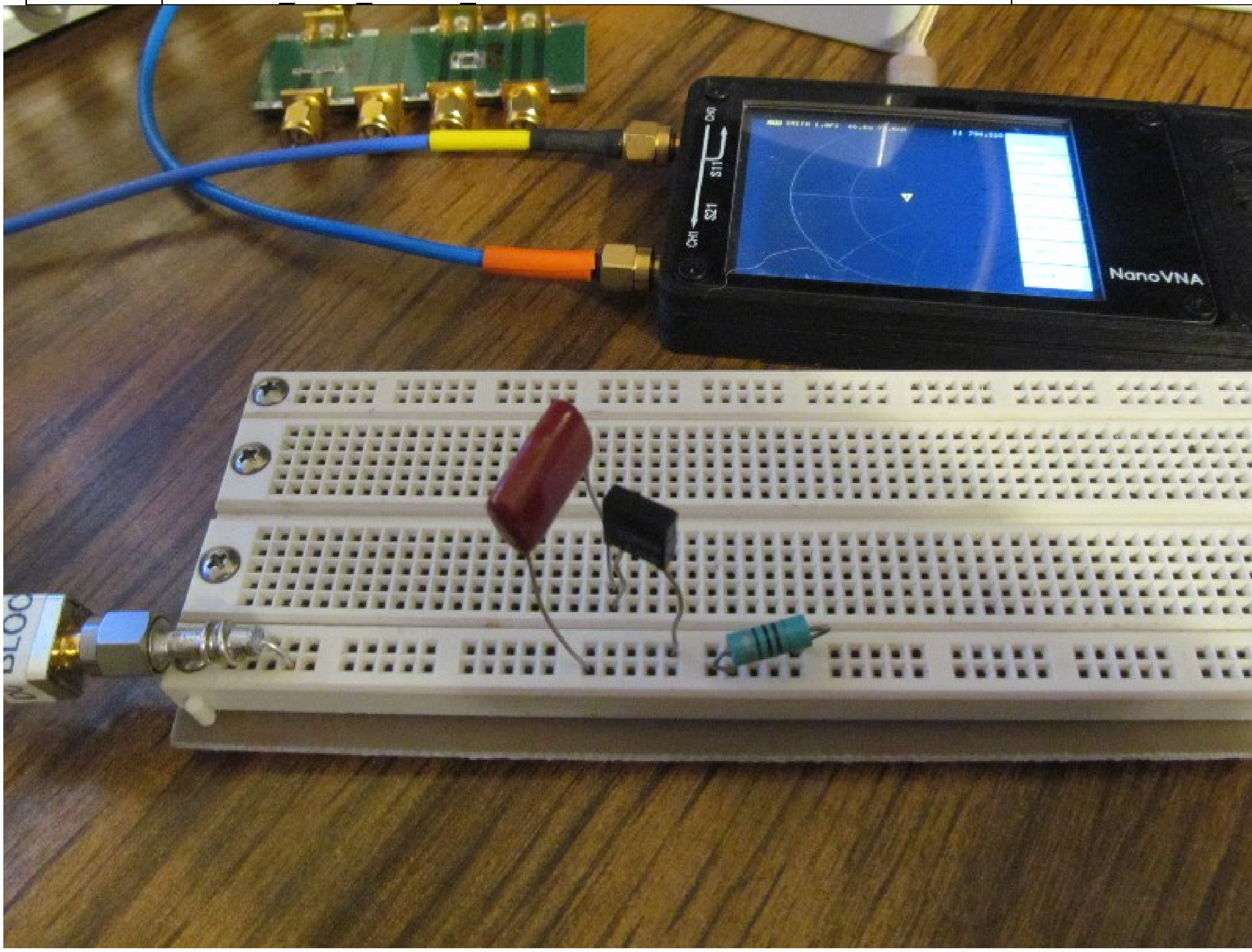
Notice how our new data is much flatter.



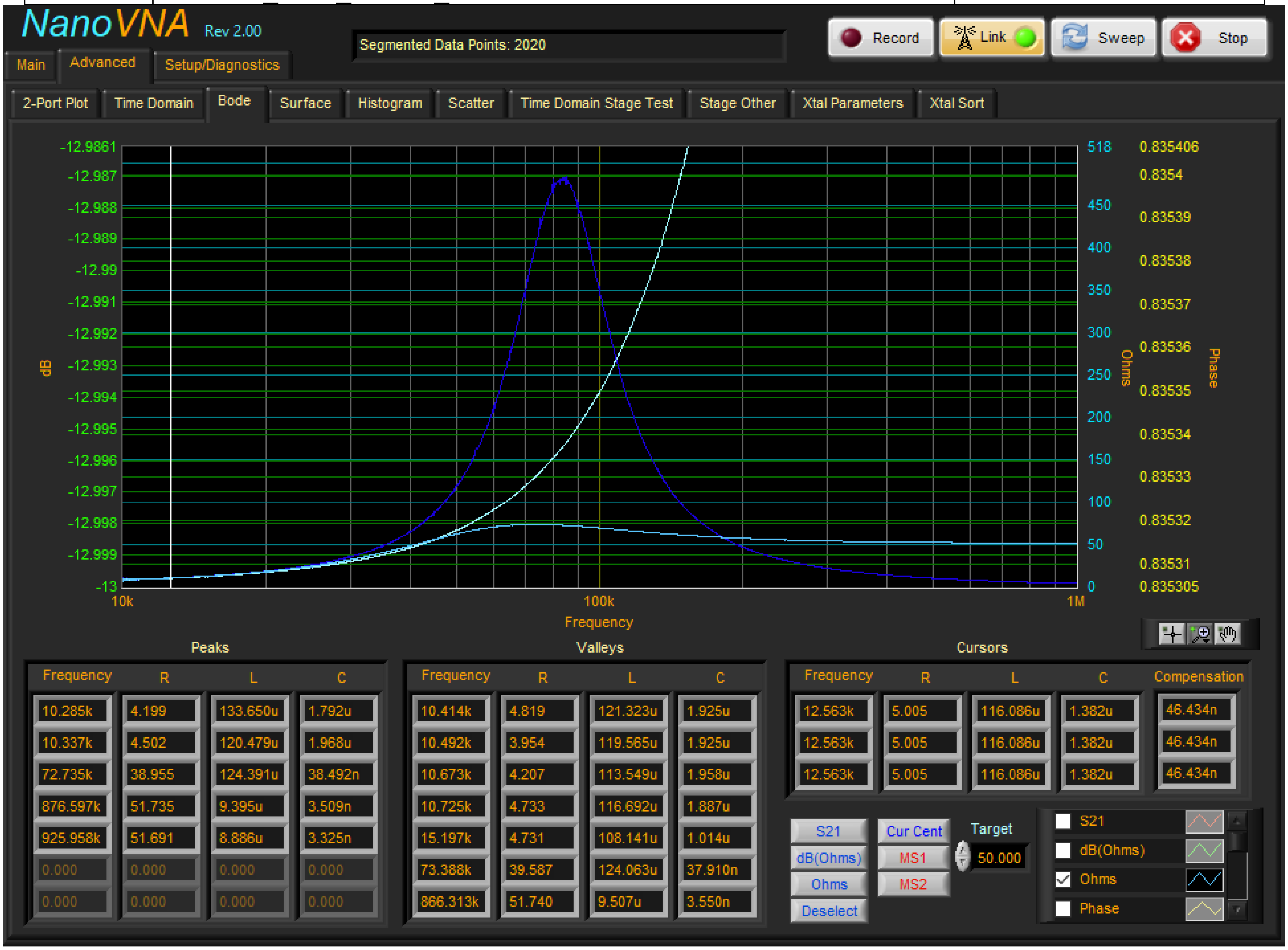
However, when we zoom into this area, we can see that it peaks at about 450 ohms! That is a long way from the 50 ohms we targeted. What is wrong?



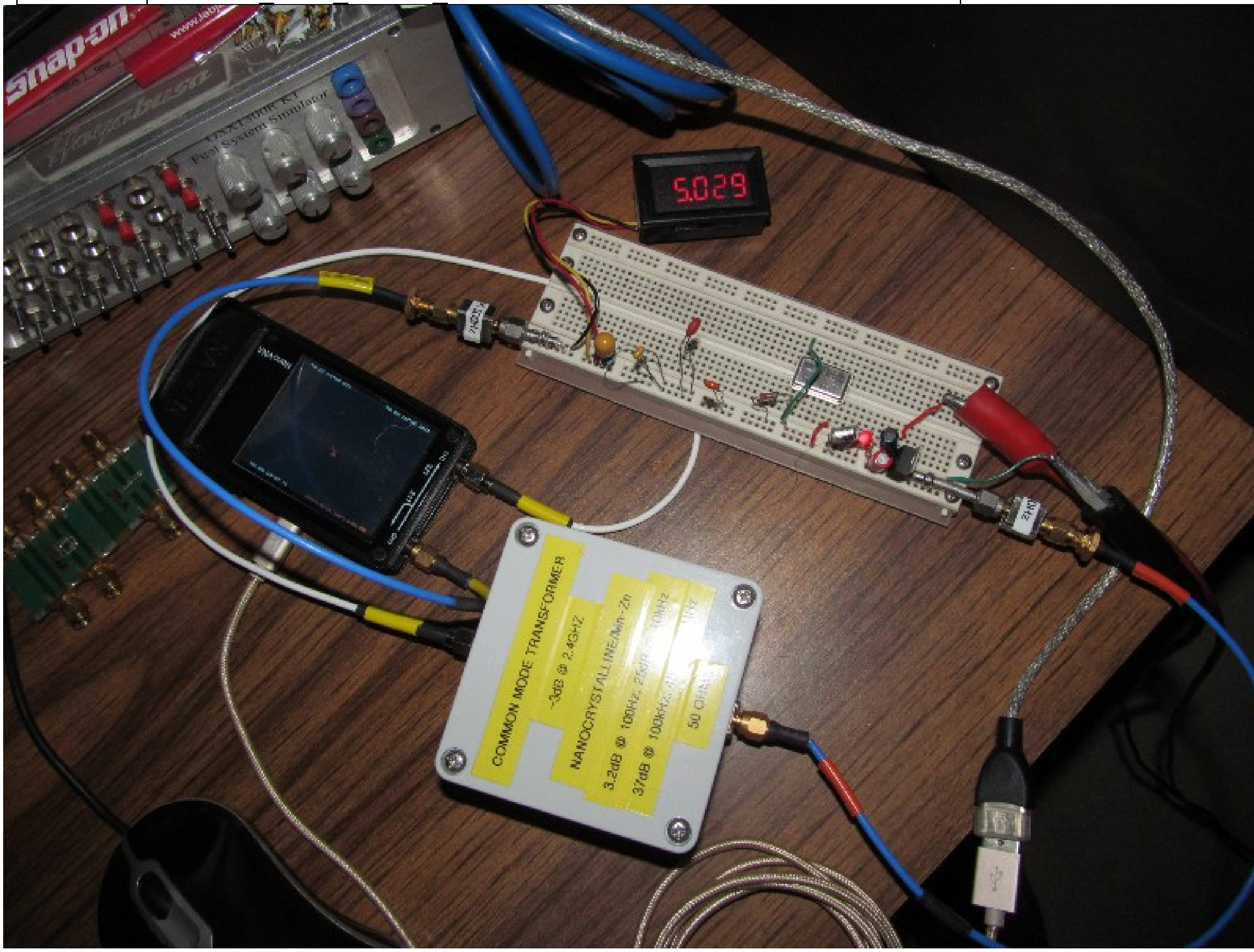
Those of you who design PDNs will know that the capacitors ESR plays a big role. When selecting a capacitor, we need to select one that has an ESR equal to the target impedance. Our film capacitor has a much lower ESR, but we can add our 50 ohm resistor in series with the capacitor to increase it as shown.



Select MS2 to again save our last dataset and then start a new sweep. Notice now how flat the impedance is. The name of the game when it comes to PDN analysis.

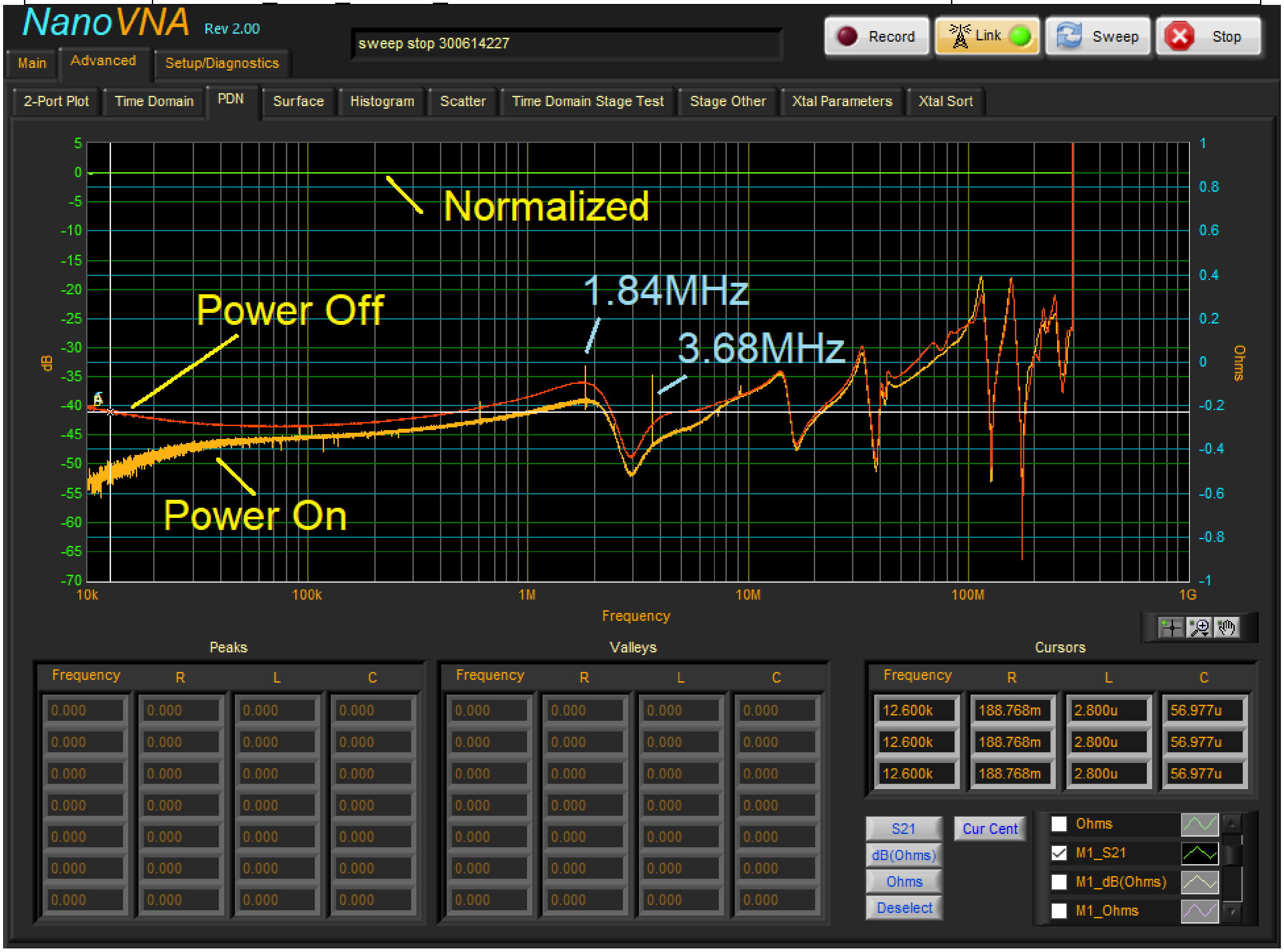


Shown with a 7805 linear regulator, 1.84MHz oscillator, meter and various caps. The DC blocks and transformer are installed.



Shown looking at the normalized data, and with the PDN in both the powered and unpowered states swept all the way up to 300MHz. This is about the limit of the original NanoVNAs hardware.

We can clearly see the various resonance frequencies for the different capacitors. We can also see the effects of our oscillator.

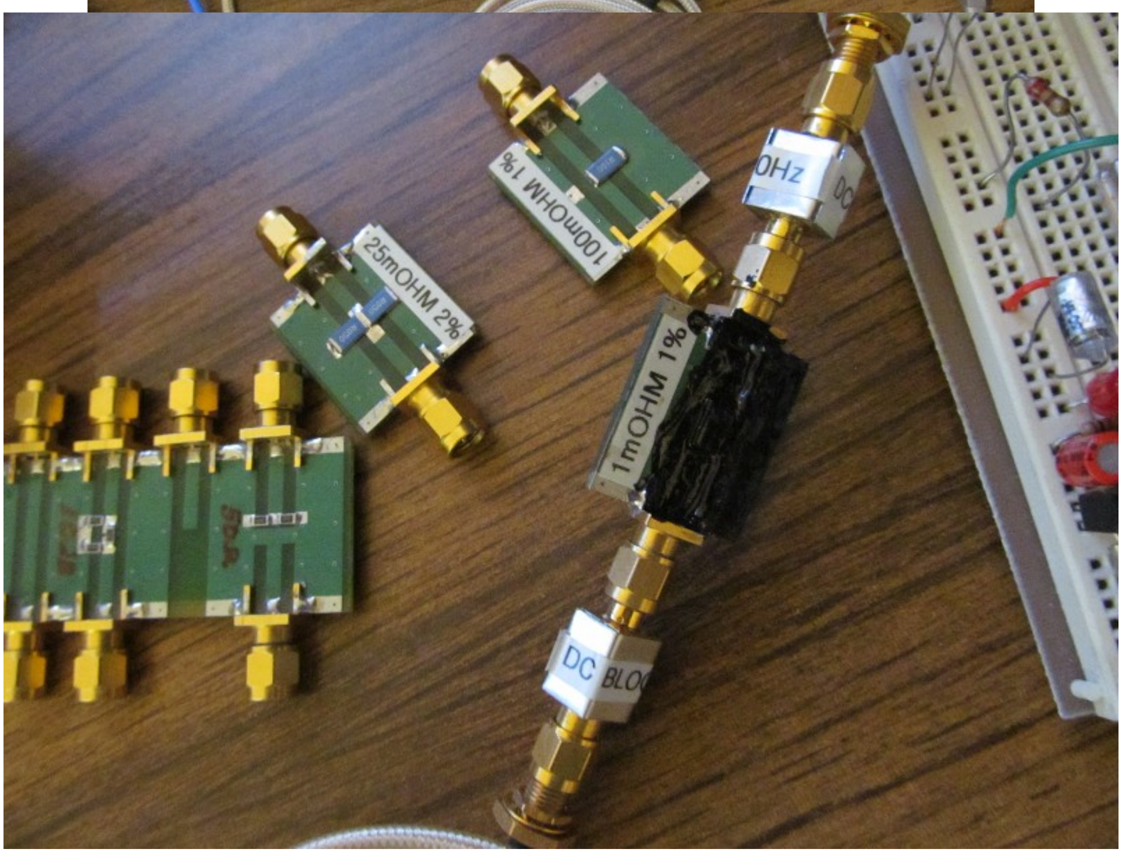


24.9 So, Just How Low Can the Original NanoVNA Measure??

Now that we have a complete measurement system with some standards, just how well can the $50 VNA make these measurements? Is it only good for measuring 50 ohms? Could we use it to design the PDN for our next VirtexInfaStrata FPGA drawing 10 million Amps at 1mV? Well, it is $50. But we now have some test resistors that we can use to get some idea.

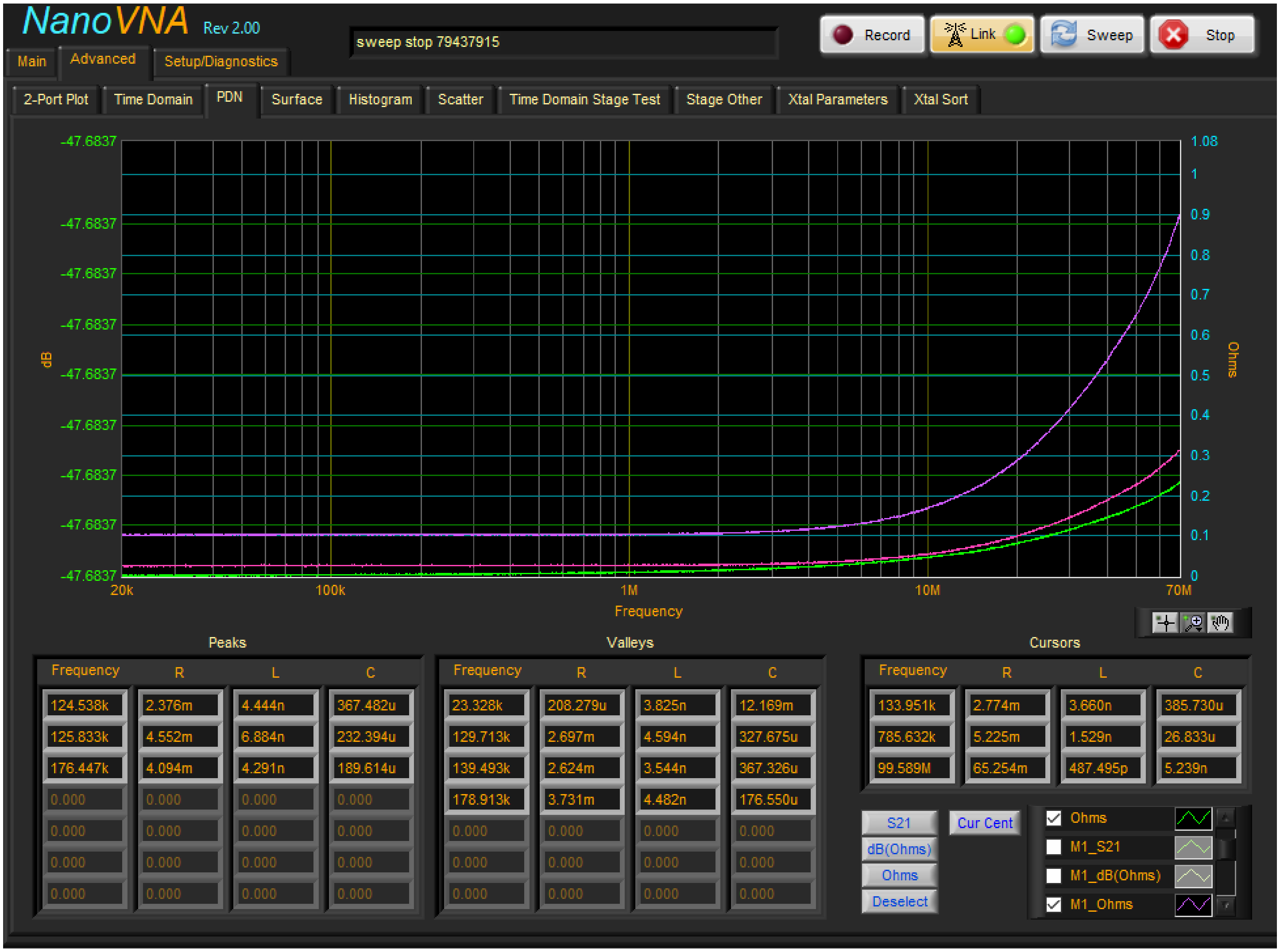
Shown using the completed setup to sweep the 100mOhm, 25mOhm and 1mOhm resistors from 20kHz to 70MHz.

COMMON MODE TRANSFORMER
-3dB @ 2.4GHZ
NANOCRYSTALLINE/Mn-Zn
50 OHMS
25mOHM 2%
100mOHM 1%
1mOHM 1%



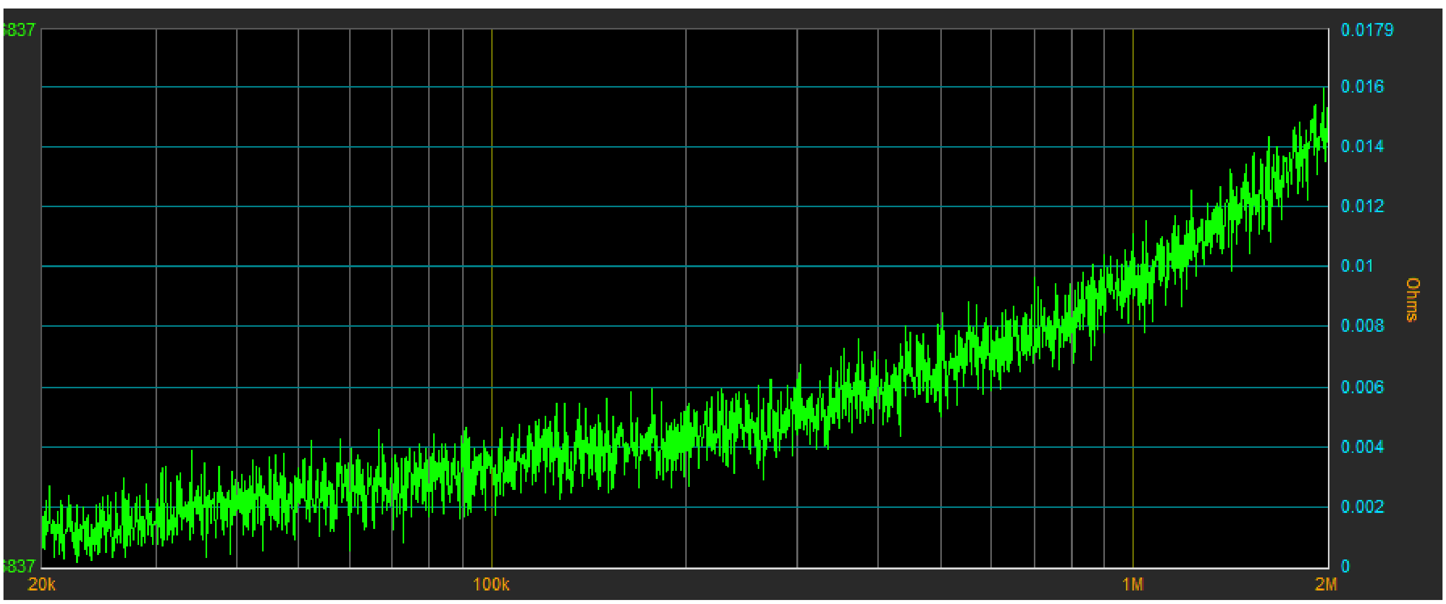
25mOHM 2%
100mOHM 1%
1mOHM 1%

Notice that all our test resistors start to become fairly inductive above 10MHz.



Let us have a look at the data below 2MHz. The 100mOhm resistor looks pretty good. So does the 25mOhm part. However, the scaling makes it difficult to see what it is going on with the 1mOhm part.

As we can see, the resistor/board becomes inductive above even 30kHz. The signal is dominated by noise.



If we compare these with our 100uOhm resistor, we can see even at the low frequencies the NanoVNA is not able to discern any difference. The 100uOhm device is however more stable over a wider range.

NanoVNA Rev 2.00
Main
Advanced
Setup/Diagnostics
sweep stop 794439
Record
Link
Sweep
Stop
2-Port Plot
Time Domain
PDN
Surface
Histogram
Scatter
Time Domain Stage Test
Stage Other
Xtal Parameters
Xtal Sort
-30.8
-31
-31.2
-31.4
-31.6
-31.8
-32
-32.2
-32.4
-32.6
-32.8
-33
dB
0.03
0.028
0.026
0.024
0.022
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Ohms
10k
100k
1M
10M
Frequency
Peaks
Frequency R L C
47.820k 550.122u 3.843n 2.882m
71.073k 945.493u 2.857n 1.755m
70.417k 453.447u 3.463n 1.475m
122.155k 976.542u 1.348n 1.260m
123.968k 625.995u 2.096n 786.523u
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
Valleys
Frequency R L C
37.101k 982.788u 5.009n 3.674m
48.747k 996.222u 4.143n 2.573m
63.201k 458.399u 2.851n 2.225m
73.205k 1.220m 2.811n 1.681m
169.763k 783.565u 773.470p 1.136m
0.000 0.000 0.000 0.000
0.000 0.000 0.000 0.000
Cursors
Frequency R L C
105.838k 407.383u 1.042n 2.171m
601.266k 168.690u 162.461p 431.278u
298.199k 1.561m 886.518p 321.322u
S21
dB(Ohms)
Ohms
Deselect
Cur Cent
S21
dB(Ohms)
Ohms
M1_S21

Appendix A – Factory Settings and Parameters

		FACTORY SETTINGS	
SETTING	RANGE	DEFAULTS	USER
Fcenter(MHz)		10	
Fspan(MHz)		2	
Fmin(MHz)		1	
Fmax(MHz)		300	
CW(MHz)		10	
Samp/Dec		10	
Port Ext (ns)		0	
Points		201	
Sweep Mode		Linear	
Rnorm		50 ohms	
Gain		Enabled	
Phase		Disabled	
Units		Meters	

Appendix B – Warranty

Because the software is available for use free of charge, there is no warranty for it, to the extent permitted by applicable law. Except when otherwise stated in writing the copyright holders and/or other parties provide the software as is *without warranty of any kind*, either expressed or implied, including, but not limited to, the implied warranties of merchantability and fitness for a particular purpose and the accuracy of the information contained within it. The entire risk as to the quality and performance of the software and associated parts are with you. Should the software and/or associated devices fail to work on your system, you assume the cost of all necessary servicing, repair or correction.

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