The NANO VNA

Getting Started

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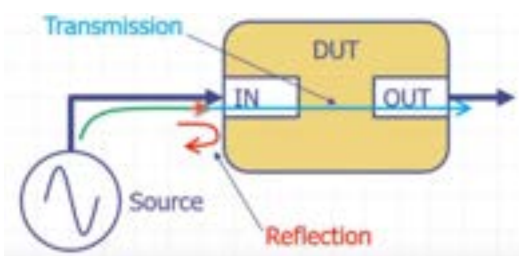
Topics

- What is a VNA?
- How does a NanoVNA work?
- Using the NanoVNA – menus
- SWR Measurements
- The Smith Chart
- Measuring discrete components
- Analyzing LCR circuits
- Analyzing filters
- Determining coax loss
- Determining coax length and faults
- Resources

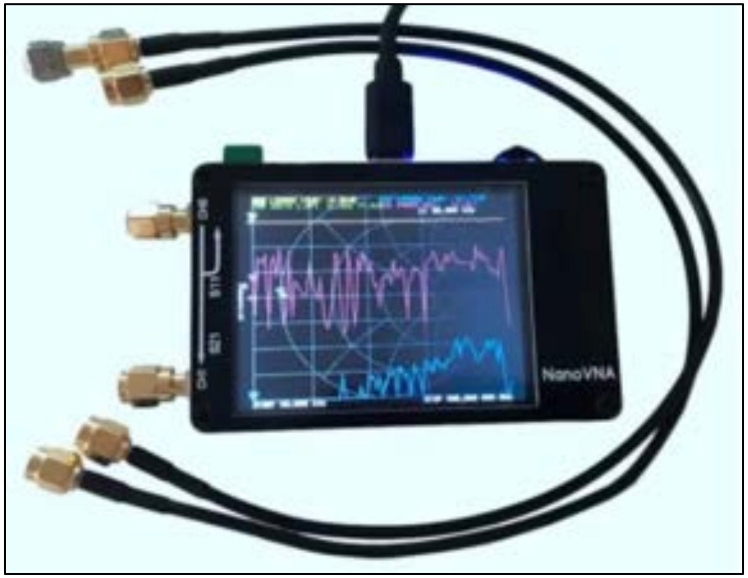
What is a VNA?

A Vector Network Analyzer allows for a complex analysis of a DUT (Device Under Test) by emitting a a range of known signals (amplitude and frequency) and measuring the reflection and/or transmission of these signals by measuring both *magnitude* and *phase* reflected from or passed through the DUT.



A DUT affects the signal that goes through it as well as the signal being applied to it.

Main Differences Between VNA and SWR Meter:



- The VNA can measure and display the phase as well as amplitude
- The VNA can sweep frequencies and show curves graphically
- The SWR meter supports much higher forward power

Most Common Uses for NanoVNA

Single Port

Reflection

- Antenna SWR
- Complex Impedance
- R, L, C values from components
- Feedline length
- Distance to a fault

Two Port

Transmission

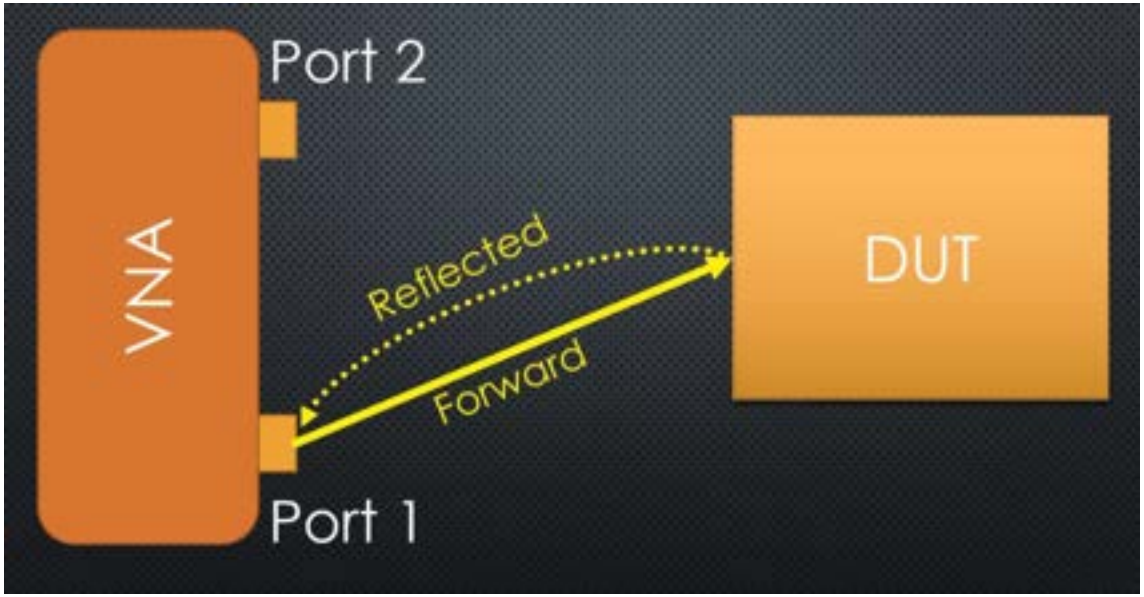
- Filter shape
- Loss in feedline
- Delay
- Amplifier gain
- Frequency response

Limitations of NanoVNA (H4):

- Only 101 trace points (external software can help)
- Output is a square wave with amplitude about 600mV$_{pp}$
- Not really intended for frequencies above 300 MHz (uses 3rd and 5th harmonics to achieve up to 1.5 GHz)
- CH1 receiver reference level not adjustable
- No directional coupler on CH1 (for S12 measurements)
- Resolution BW is not adjustable (external software can help)

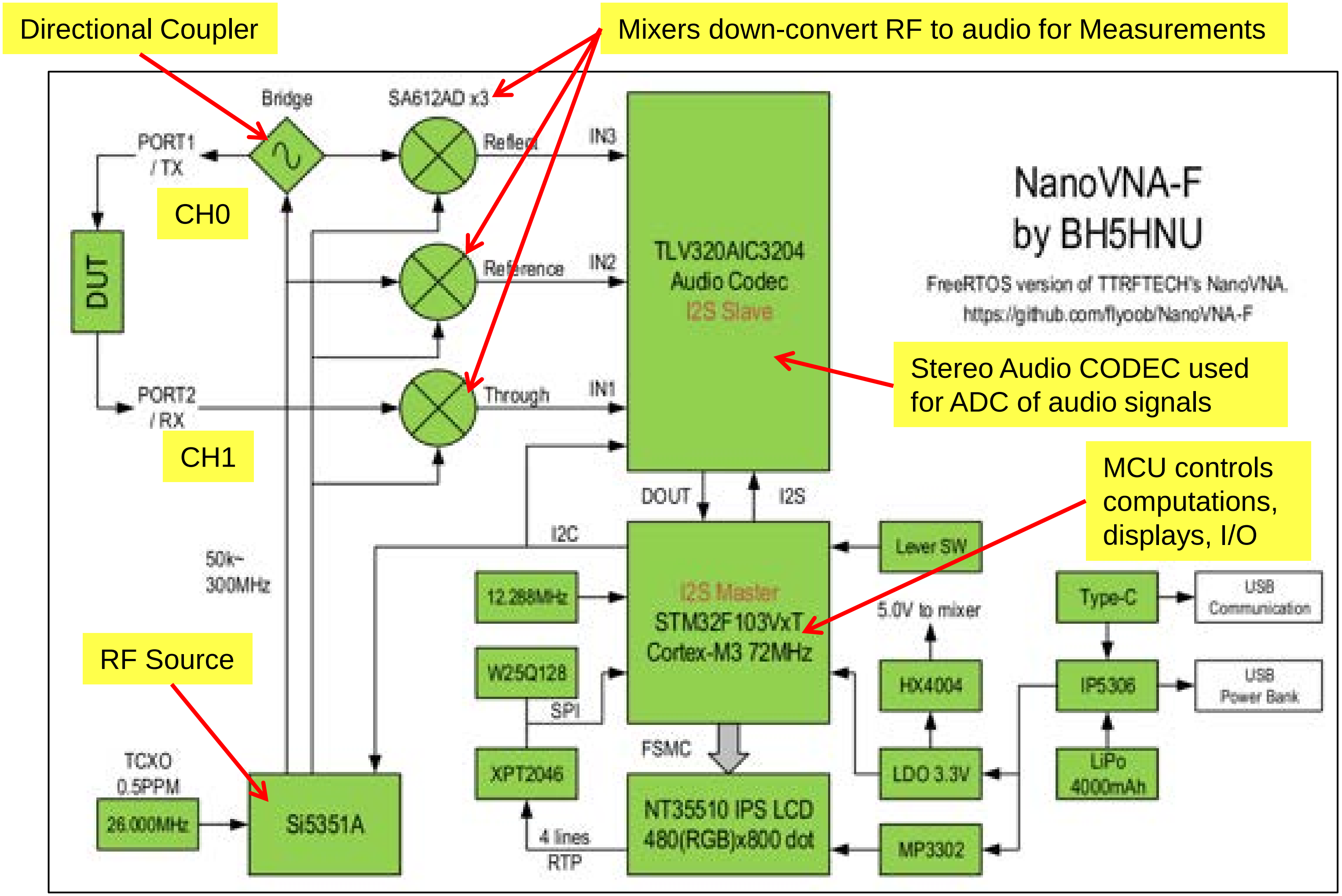
One Port and Two Port Devices

- Antennas or individual components are referred to as "one port devices". The VNA sends out a signal and measures amplitude and phase of the reflected signal on the same port (VNA Port 1 = Channel 0).

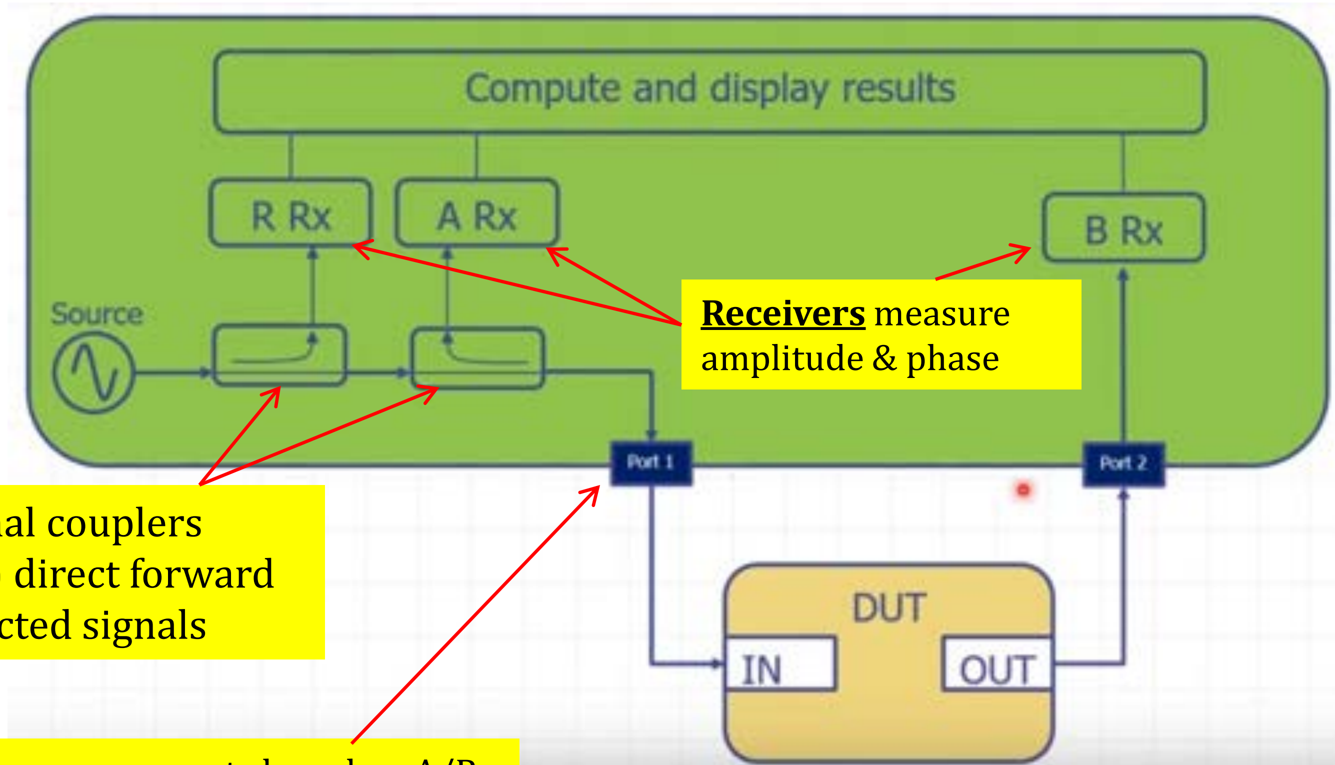


- Filters are examples of "two port" devices as the known signal leaves through Port 1 (Channel 0 and returns through Port 2 (Channel 1).

What's In the NanoVNA?



Simplified VNA



Receivers measure amplitude & phase

Directional couplers (bridges) direct forward and reflected signals

Reflection measurements based on A/R:

- VSWR
- Reflection Coefficient, S11
- Return Loss
- Input Impedance

Transmission measurements based on B/R:

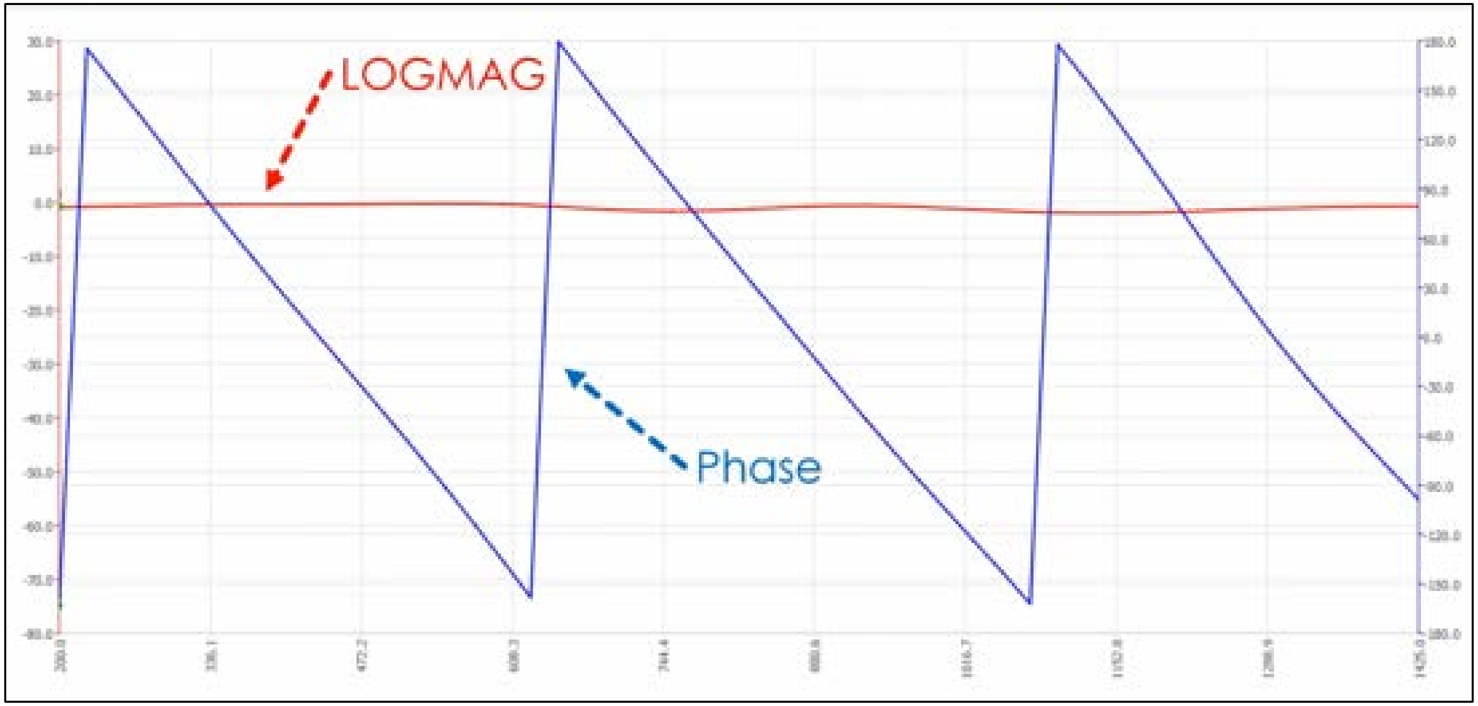
- Gain/Loss
- S21
- Transmission Coefficient
- Insertion Phase/Group Delay

R = Reference Signal

NanoVNA Terminology:
"Scattering Parameters" or "S-Parameters"

- **The reflected signal is called S11 because the signal is transmitted from and received (measured) on Port 1 (CH0)**
- **The signal measured by Port 2 (CH1) is S21 because it is transmitted from Port 1 and measured by Port 2 – the "forward transmission coefficient"**
- **Since there is no directional coupler (bridge) on Port 2, no S12 measurements can be made with the NanoVNA**

Single Port Test



- On NanoVNA, Amplitude is called "Logarithmic Magnitude" or "LOGMAG" in dB. For S11 measurements it is always < 1.0 and the positive value (magnitude) = "Return Loss"
- The higher the reflected power compared to the forward power, the worse the match (higher SWR and lower return loss)

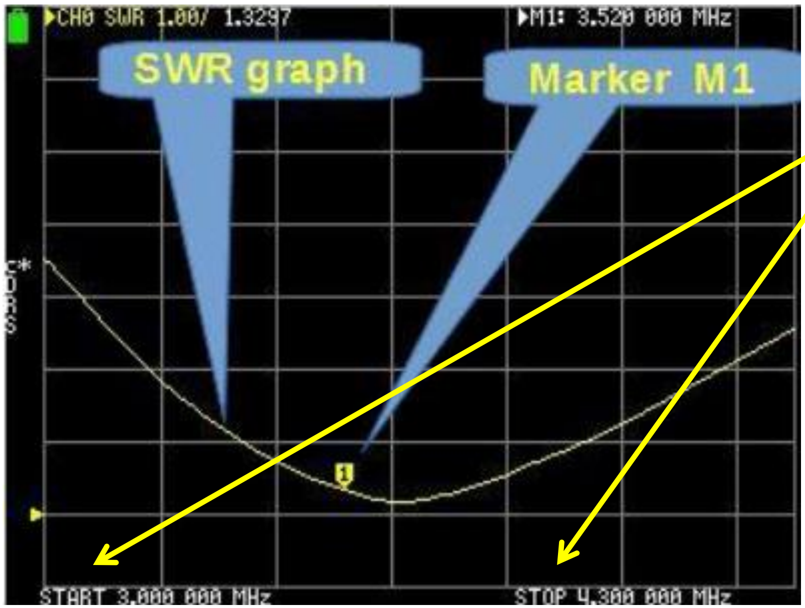
NanoVNA Displays

- **Most measurements show <u>Frequency on horizontal axis</u>**
  - **The <u>vertical axis is logarithmic </u>(LOG-Magnitude) for:**
    - **Reflection and Transmission Coefficients (S11 and S21)**
  - **The <u>vertical axis is linear </u>for:**
    - **VSWR is plotted as a ratio of X:1 (eg. 2.3:1)**
    - **Delay, Insertion Phase, Group Delay**
- **The <u>Smith Chart </u>is used to plot:**
  - **Complex Impedance**
- **TRANSFORM measurements have <u>Time on the horizontal axis</u>**
  - **Use linear scale to get sharper peak when measuring distance to fault or length of cable**

Displaying the Measurements

The NanoVNA draws the measurements on the screen as a graph (trace) and/or on a Smith Chart.

Example 1: SWR versus Frequency



- The X and Y axes are not labeled
- We selected START and STOP freq
- The marker (M1) can be moved along the trace and display the numerical values at the top of the screen
- In this example, SWR = 1.3297 at Freq = 3.520 MHz

NanoVNA can display up to four traces or three traces plus a Smith Chart simultaneously.

NanoVNA and Frequency Steps

The NanoVNA does not generate a continuous range of frequencies. Instead, it uses 101 discrete frequency steps within the specified frequency range. This is why it is important to specify a relatively narrow frequency range so that the required precision can be obtained.

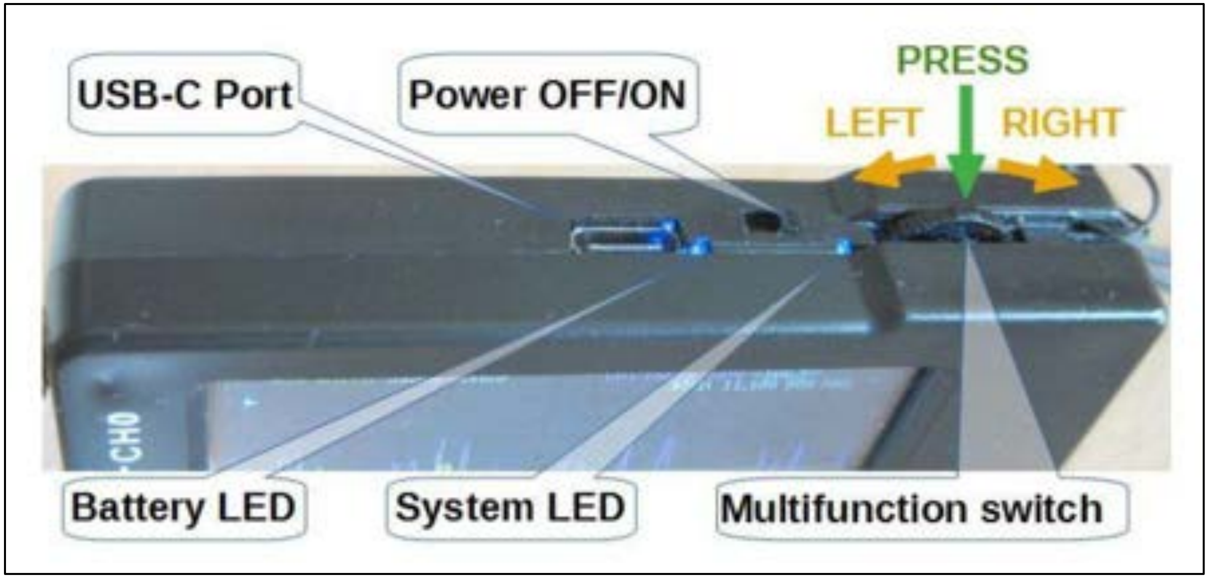
Example 1: Frequency range: START 3.0 MHz – STOP 30.0 MHz

(30-3)/101 = 267 kHz steps

Example 2: Frequency range: START 3.0 MHz – STOP 4.0 MHz

(4-3)/101 = 9.9 kHz steps

Getting Started with the NanoVNA



Main parts

Multifunction Switch:

- Press to open a menu or to execute selected menu command
- Slide right or left to select a command from the menu
- Slide right or left to move marker along a trace on screen

NOTE: Tapping on the screen with stylus/guitar pick also opens or closes a menu

Before Each Measurement

1. Determine which traces to display (up to four or three with Smith chart)
2. Select trace channel CH0 (REFL) or CH1 (THRU) for each trace separately
3. Decide on scale (units of measurement per each horizontal line, for each trace separately) - optional
4. Choose reference position for each trace separately - optional
5. Specify sweep frequency range (aka “stimulus frequency”)
6. Calibrate the NanoVNA

Return Loss and VSWR

1. Both terms refer to the reflection (or return) of a signal when transmitted into a load (typically, an antenna)
2. Return loss is the measure of how small the return (echo) is. We want a small return, so a large loss is good. Smaller return loss is bad and means less energy is going into the antenna
3. VSWR – Voltage Standing Wave Ratio : between transmitted and reflected voltage standing waves – the lower the better
4. Return loss is measured in dB whereas VSWR is a ratio

Return Loss & VSWR Table

Return Loss in dB	What It Means	VSWR Number
0 dB	100% reflection, no power into the antenna, all reflected back	Infinite
1 dB	80% reflection, 20% power into the antenna	17
2 dB	63% reflection, 37% power into the antenna	9
3 dB	50% reflection, 50% power into the antenna	6
5 dB	32% reflection, 68% power into the antenna	3.5
6 dB	25% reflection, 75% power into the antenna	3
8 dB	16% reflection, 84% power into the antenna	2.3
10 dB	10 dB (10% reflection, 90% power into the antenna)	2
15 dB	15 dB (3% reflection, 97% power into the antenna)	1.4
20 dB	20 dB (1% reflection, 99% power into the antenna)	1.2

Example 1: Measuring SWR – 80m Antenna

An antenna is a one port device so we will use PORT 1 only, transmit a signal over a range of frequencies and measure the reflected waves.

1. Determine which traces to display (up to four or three with Smith chart) – We will only use one trace, TRACE 0

- Open menu DISPLAY | TRACE and deselect all traces except TRACE 0 (On my H4, there is a check box that indicates selected.)
- Tap BACK to return to previous menu

Example 1: SWR Cont'd

2. Select trace channel - S11 (REFL):

Example 1: SWR Cont'd

3. Decide on FORMAT – We want SWR

- On H4: Select DISPLAY➔ Format ➔ SWR
- Note checkbox is now checked

Example 1: SWR Cont'd

4. Decide on scale (units of measurement per each horizontal line, for each trace separately):

- On H4, says "SCALE" on bottom left.
- Tap "1" then "ENT" on bottom right

Example 1: SWR Cont'd

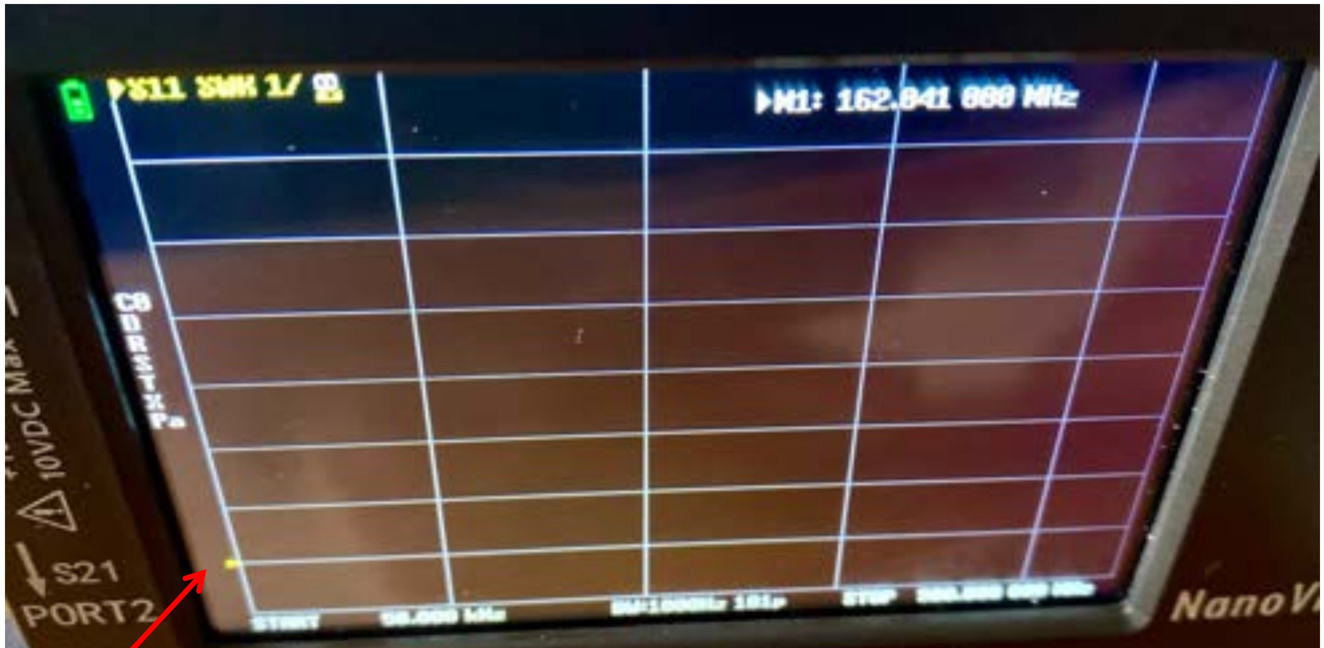
5. Decide on reference position: Second horizontal line from bottom

- Note: "REFPOS" in bottom left corner.

- Tap "1" then "ENT"
- This places the reference line on the second line from the bottom

Example 1: SWR Cont'd

5. Decide on reference position: Second horizontal line from bottom



The yellow triangle marks the reference line on the second line from the bottom

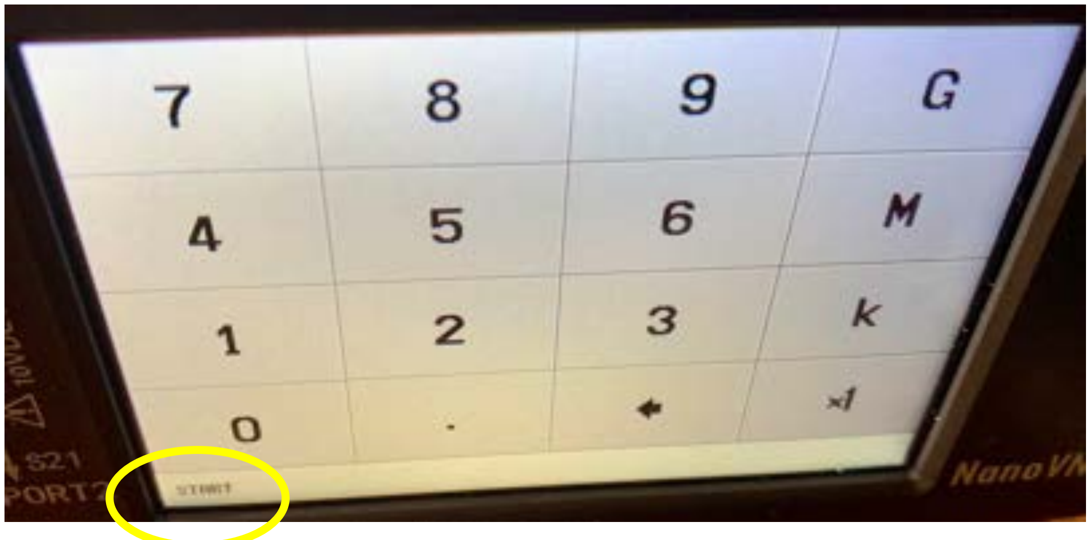
Example 1: SWR Cont’d

6. Set stimulus frequency selection: We want 3.0 to 4.3 MHz

- From Home, Select Stimulus➔ Start
- Tap “3M” for 3MHz
- Select Stimulus ➔ Stop
- Tap “4.3M” for 4.3MHz
- Select “DONE” and then save to a memory

Example 1: SWR Cont'd

6. Set stimulus frequency selection: We want 3.0 to 4.3 MHz

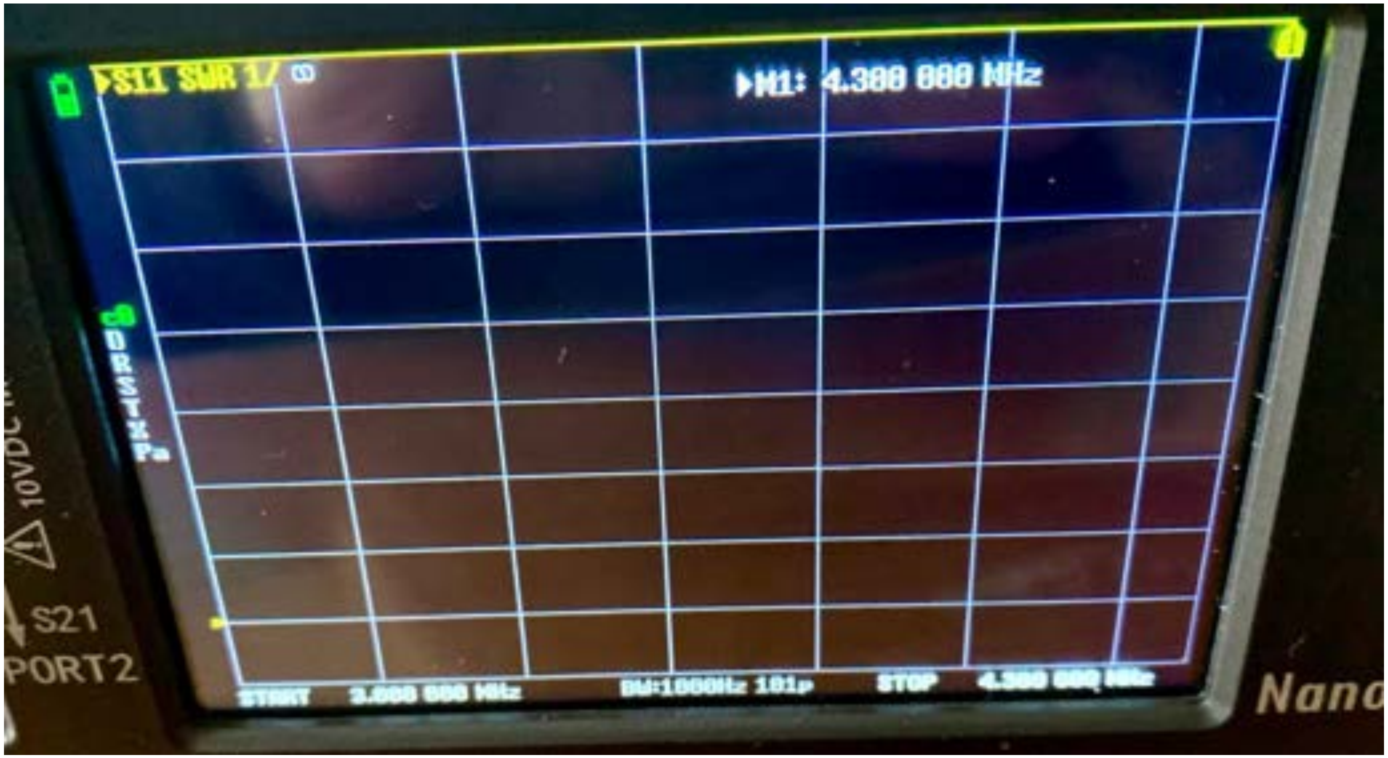


- From Home, Select Stimulus➔ Start
- Tap "3M" for 3MHz

- Select Stop
- Tap "4.3M" for 4.3MHz
- This sets the range of the scan to the 80m band and a bit beyond

Example 1: SWR Cont'd

Check on setup so far:



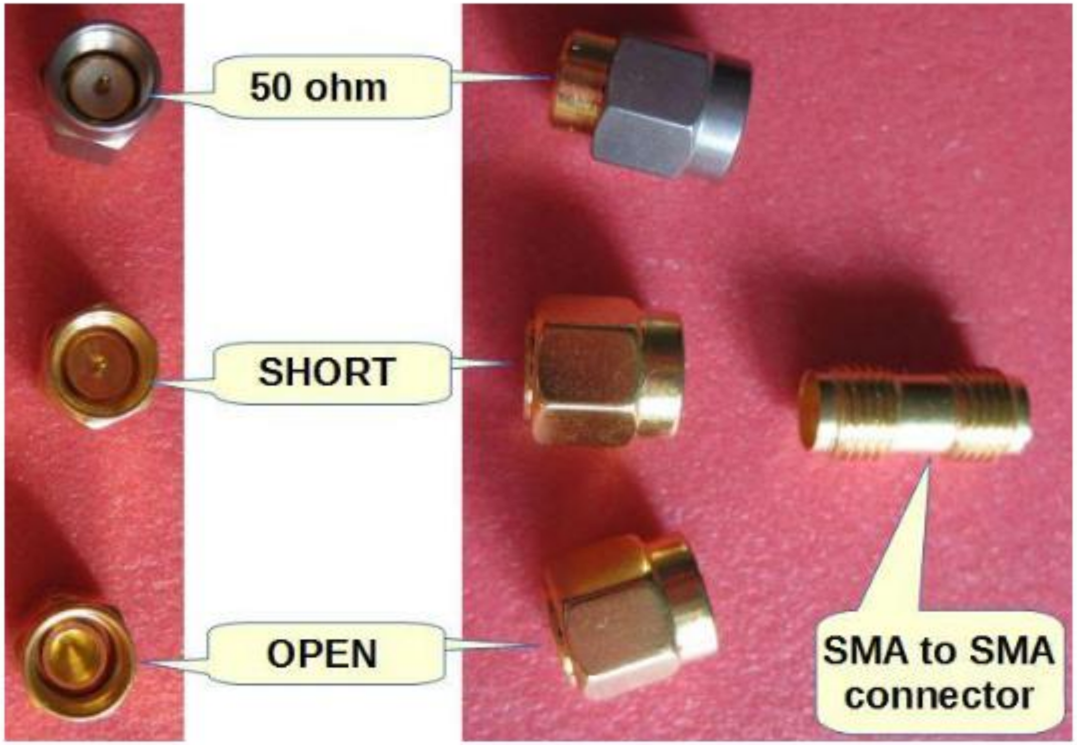
- We are displaying SWR for single port (S11)
- The Marker M1 is set at max frequency
- The reference line (SWR 1:1) is the second horizontal line (from the bottom)
- The stimulus range is from START = 3.0 MHz to STOP = 4.3 MHz
- Note on left side we see c0 in green. This means we need to calibrate.

Step 7 is Calibration – But Why?

- The factory calibration can't account for all situations as there are so many different types of measurements we can do.
- We need to manually calibrate the NanoVNA whenever we change cables and/or adapters and when we change frequency ranges.
  - Changing cables/adapters affects the path length of the signals ("reference plane")
  - Changing frequency range might not require recalibration if only interested in amplitude (not phase). This would only affect the interpolation of data points.
- Changing cables changes the delay (phase) from the DUT to the NanoVNA. We call the point where the cable attaches to the DUT the "measurement plane".

Back to Example 1: SWR Cont'd

7. Calibration: For Port 1, we want OSL only (**O**pen/**S**hort/**L**oad)



These terminators come with the NanoVNA

Example 1: SWR Cont'd

7.a Calibration: Connect the OPEN terminator to Port 1

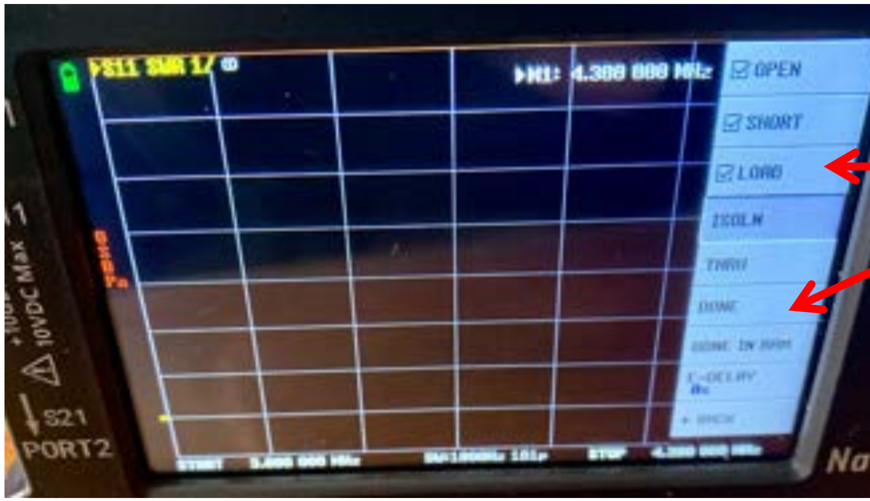
- Select DISPLAY ➔ CALIBRATE
- Tap OPEN

7.b Calibration: Connect the SHORT terminator to Port 1

- Tap SHORT

Example 1: SWR Cont'd

7.c Calibration: Connect the LOAD terminator to Port 1



- Select DISPLAY ➔ CALIBRATE
- Tap LOAD
- **Tap DONE**

7.d Save calibration to Empty 1 (for re-use)

SAVE

Example 1: SWR Cont'd

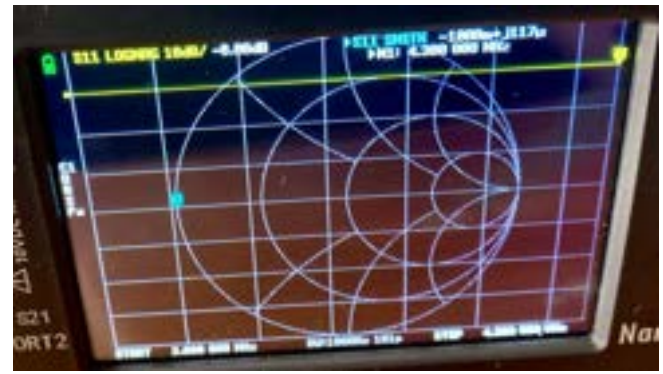
Verify the Calibration: Display Smith chart

DISPLAY ➔TRACE ➔ SMITH R + jX

Example 1: SWR Cont'd

Verify the Calibration: Display Smith chart

OPEN



SHORT

LOAD

If just turning unit on and calibration has been saved, from HOME screen select DISPLAY ➔ RECALL and select saved calibration.

The calibration can be tested by connecting PORT1 with the three end caps

Example 1: SWR Cont'd

Connect DUT – Typically by using the SMA to SO-239 Adapter

2:1 Line

Results are shown for my 80m shunt-fed tower antenna. 2:1 SWR bandwidth from 3.533 to 3.728 MHz

The position of the marker yields the values shown at the top.

The marker can be moved by sliding the multifunction switch or dragging it with the stylus.

Calibration Notes:

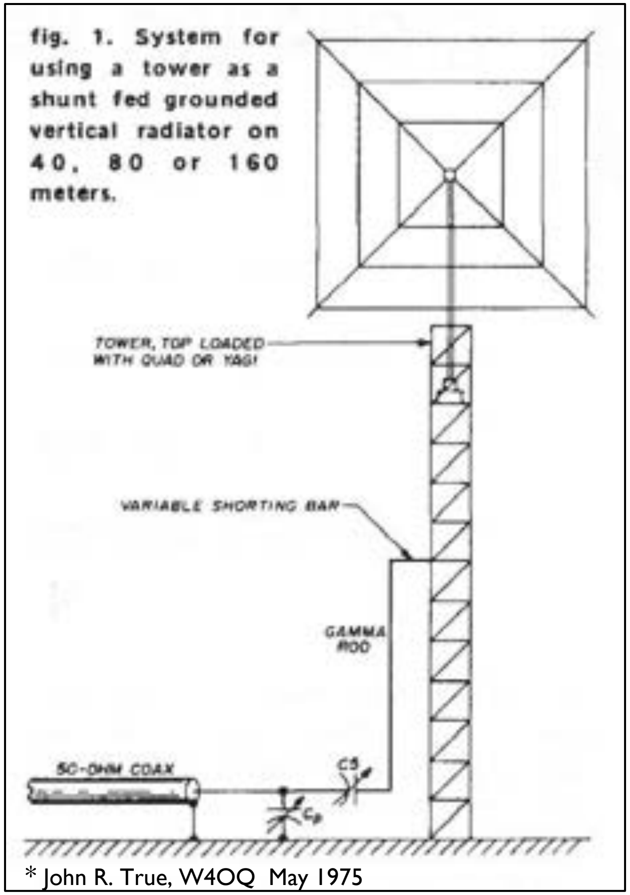
C: Calibrated for current frequency range
c: Calibration loaded but doesn't match frequency range
0, 1, 2, 3, 4, *: Calibration values storage location (*=none)

D: Directivity error correction applied (CH0)
R: Reflection Tracking error correction applied (CH0)
S: Source Match error correction applied (CH0)
Pa: Power level set to automatic (CH0)

T: Transmission Tracking error correction applied (CH1)
X: Crosstalk error correction applied (CH1)

If using an adapter, different coax, etc., you need to move the "measurement plane" by either recalibrating at the input/output of the DUT or by using the "Port Extension" feature called "Electrical Delay" until the phase rotation is removed on the Smith chart. This is only important when you need an accurate phase measurement.

Example 2: Antenna Tuning



Shunt-fed tower antenna for 160m

Shunt capacitor and motor

Shunt wire

Inside shack is an "H" switch that sends 12V to motor at base of tower that rotates air variable capacitor in order to tune for minimum SWR. How does this look on NanoVNA?

Example 2: Antenna Tuning

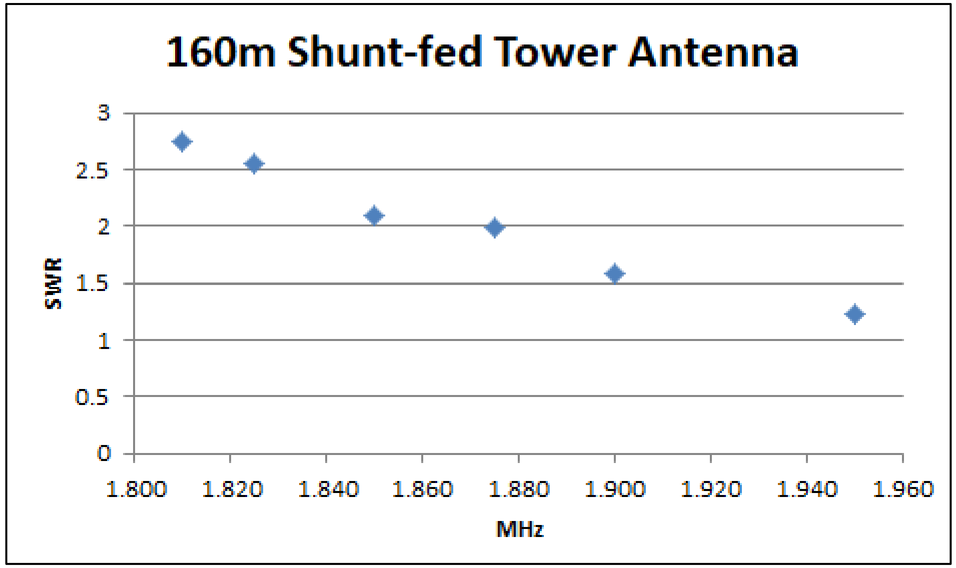
1. Determine which traces to display (up to four or three with Smith chart) – This time we will use SWR and Smith Chart
2. Trace 0 will be SWR and Trace 1 will be Smith Chart (R + jX)
3. Scale Units – Default
4. Scale = 1 for both traces (default)
5. Reference Position = default
6. Stimulus: Specify START = 1.800 MHz and STOP = 1.900 MHz
7. Calibrate and Save (Memory 2 = C2)
8. Attach SMA to SO-239 Cable to NanoVNA and connect to antenna

Example 2: Antenna Tuning

Notes:

- Calibration now shows C2
- Can see yellow trace (SWR) minimum = 2.035 at 1.853 MHz
- Can see cyan trace (Smith) still has inductive reactance (positive j)
- Ideal situation is to have both markers in center (50 ohms purely resistive)
- Can watch measurements change as motor is turned to tune antenna

Example 2: Antenna Tuning

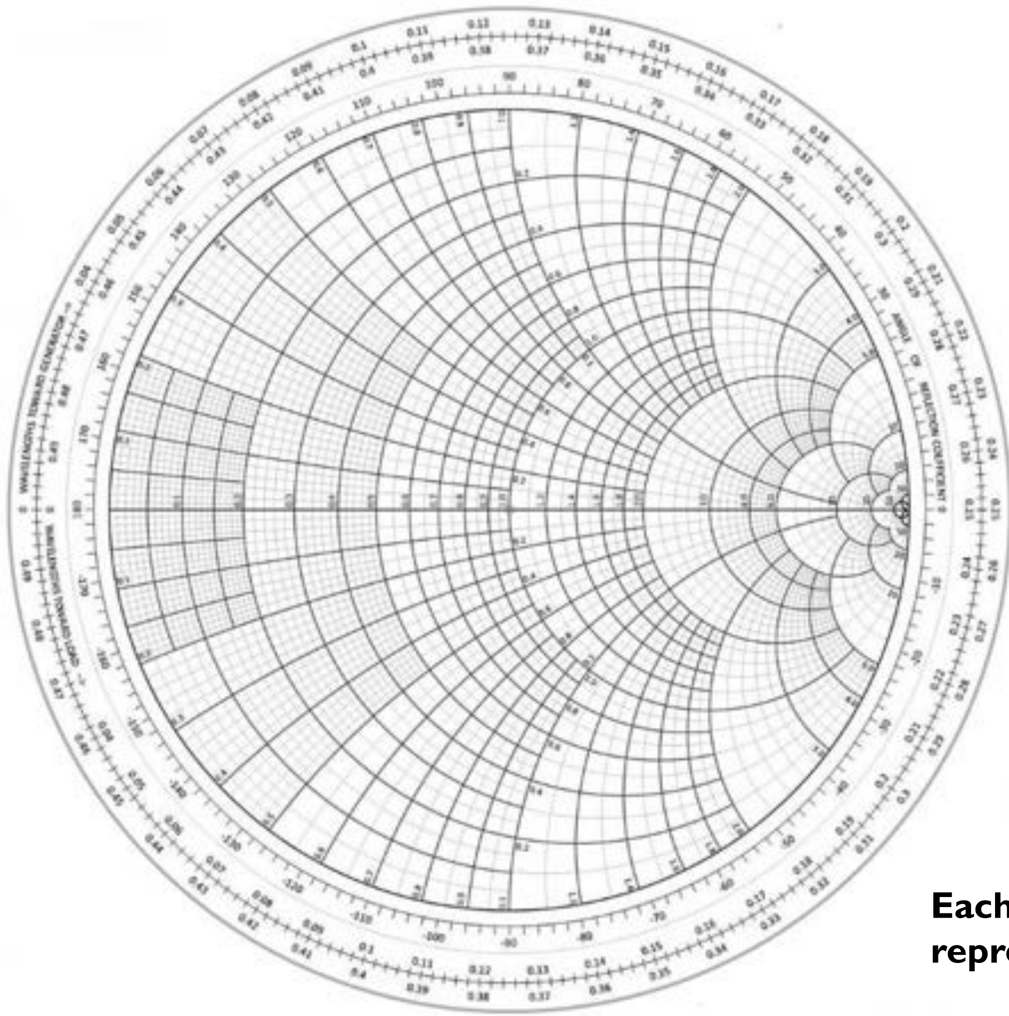


Notes:

- The tower is only 40' high and a bit too short to tune the 160m band
- These measurements were made with an MFJ-259 three years ago. They agree with the NanoVNA
- The tower tunes well on 80m (separate shunt wire and match) – as seen in the previous example

How Does NanoVNA Display Impedance?

OH NO! The Dreaded Smith Chart!



Phil Smith, Inventor
1905-1987 – Bell Labs

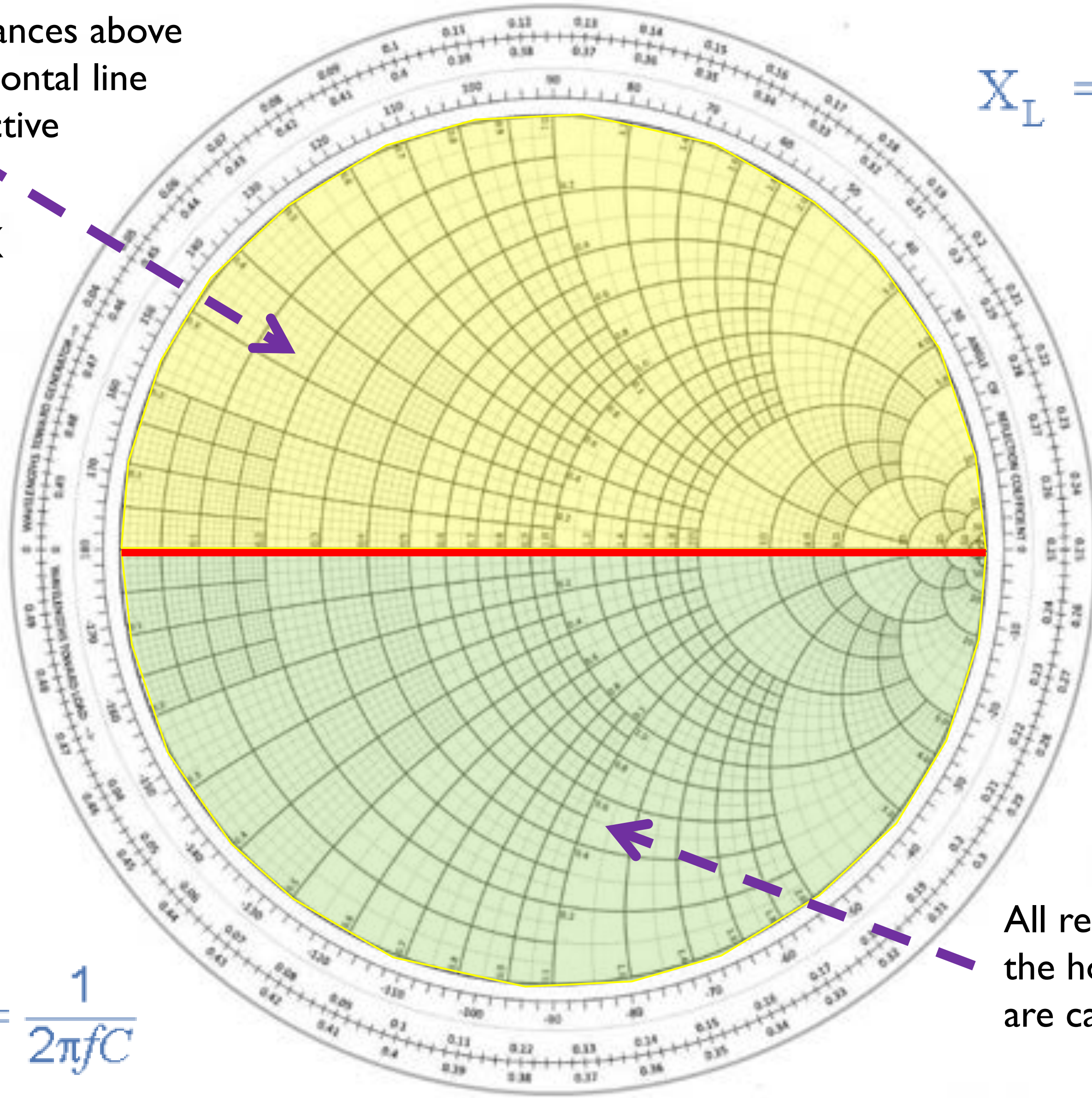
Each point on the Smith Chart represents an impedance

Smith Chart Key Impedances

All reactances above the horizontal line are inductive

R + jX

$$X_L = 2\pi f L$$

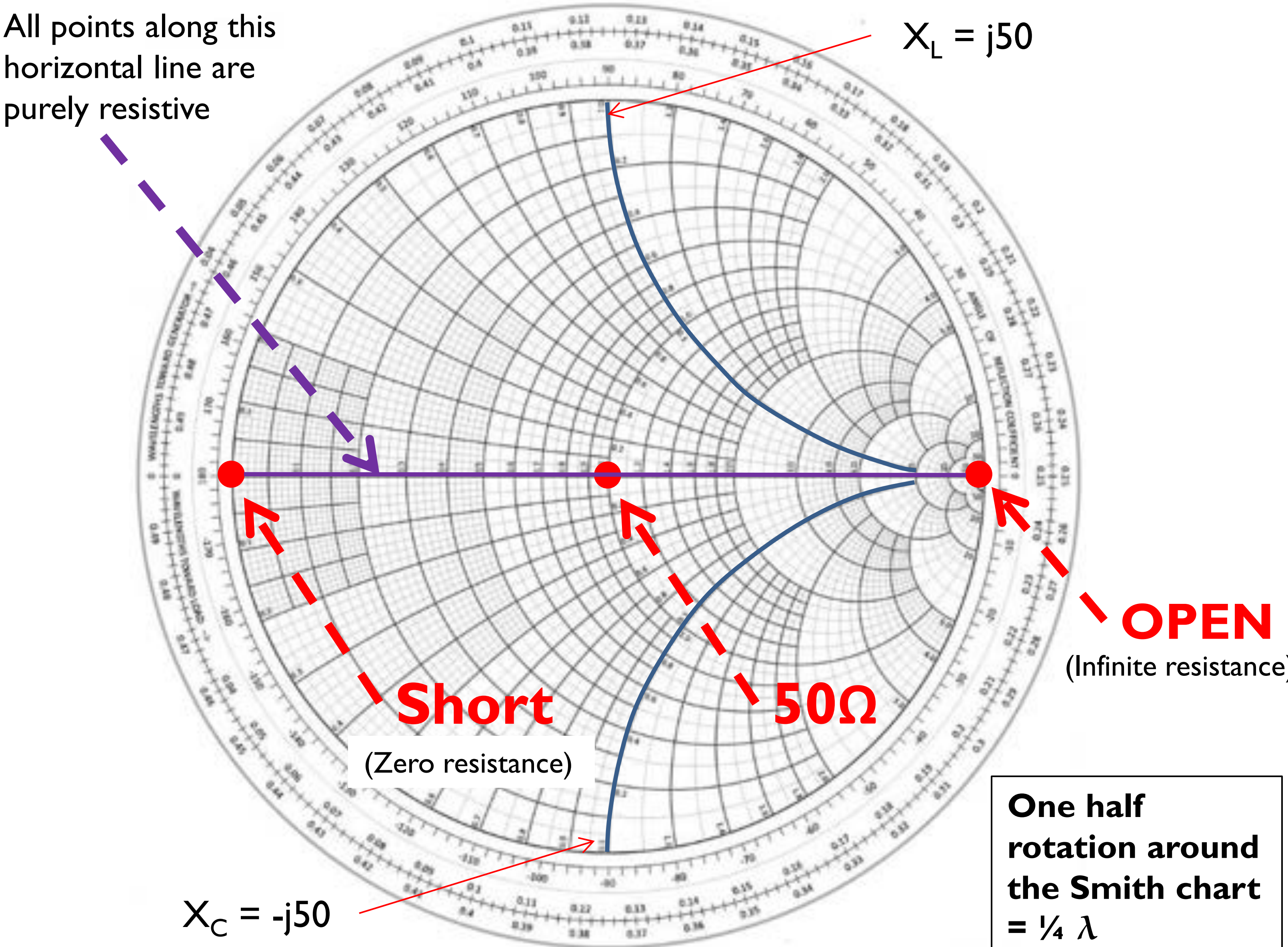


R - jX

All reactances below the horizontal line are capacitive

$$Xc = \frac{1}{2\pi f C}$$

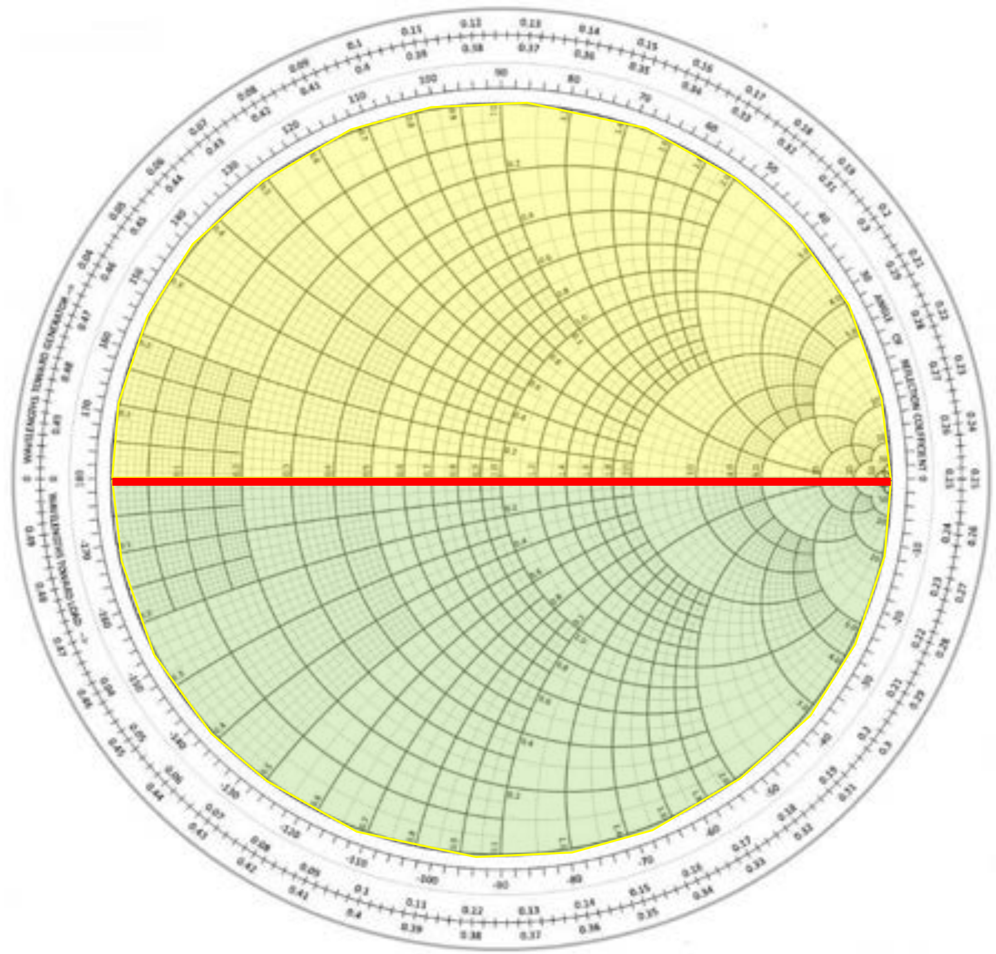
Smith Chart Key Impedances



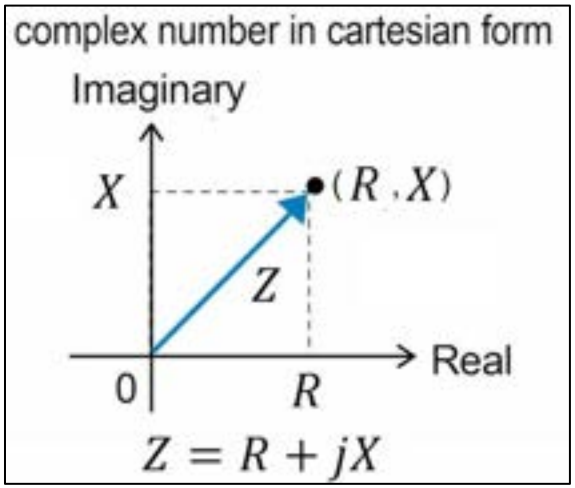
One half rotation around the Smith chart = ¼ λ

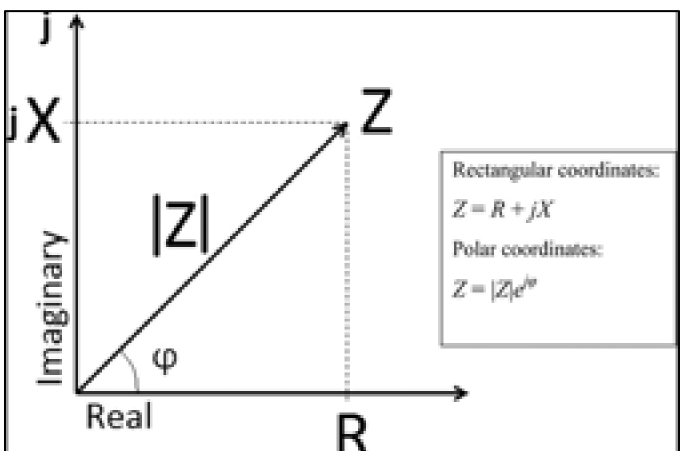
Why Would I use a Smith Chart?

I can use VSWR or Return Loss to see if I have a good match for an antenna. But if my match is poor, I can use the Smith Chart to determine how to compensate and achieve a better match (changing inductance or capacitance).



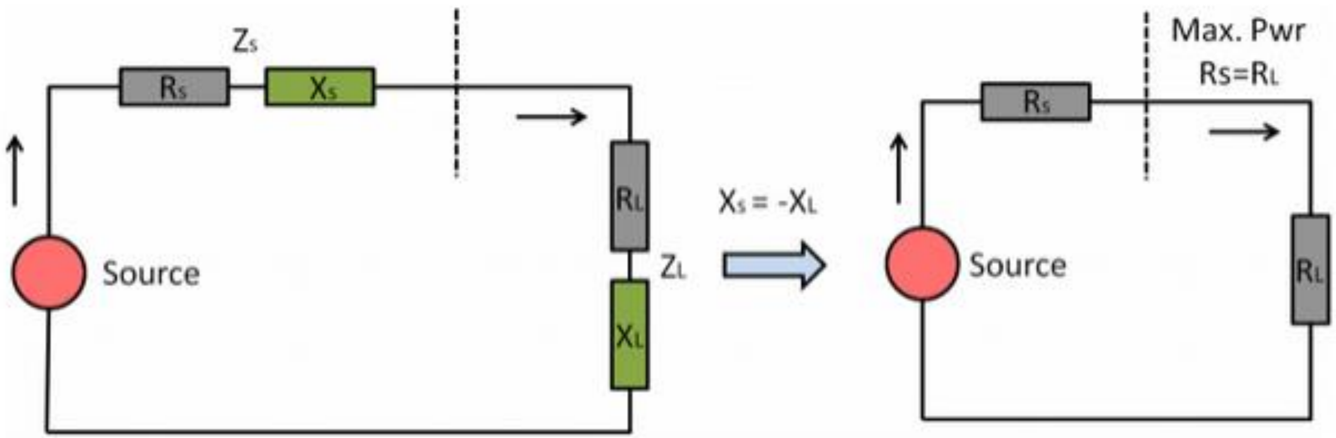
Before Deriving the Smith Chart…
A little math review





- In both Cartesian and Polar form, the x-axis is the "Real" part = resistance, and the y-axis is the "Imaginary" = reactance
- When there is no dependency on frequency, the imaginary part disappears – leaving us with pure resistance
- The "j" part of impedance represents a phase shift of 90°
- The NanoVNA uses both formats to show impedance

The best power transfer from source to load:



Source is characterized by $Z_S = R_S + jX_S$
Load is characterized by $Z_L = R_L + jX_L$

For the best power transfer, the source impedance must equal the complex conjugate of the load impedance:
$R_S + jX_S = R_L - jX_L$ so $R_S = R_L$ and $X_S = -X_L$

<u>In other words:</u> We can maximize power transfer if we can get the reactances (imaginary part) to cancel and leave nothing but pure resistance. This means they must be equal and opposite.

Deriving the Smith Chart

Let's start by writing the equation for the reflection coefficient of a load impedance, given a source impedance:

$$\Gamma = \frac{Z_{source} - Z_{load}}{Z_{source} + Z_{load}}$$

Source	Load	Refl Coeff
Ω	Ω	Ω
50	50	0.00
50	25	0.33
50	10	0.67
50	75	-0.20
50	100	-0.33
50	200	-0.60
50	500	-0.82
500	50	0.82

- If source and load impedances are equal, there is zero reflection
- The greater the difference between Z_{source} and Z_{Load}, the greater the reflection coefficient ➔ Maximum = 1

Deriving the Smith Chart, Cont'd

Let's now divide each term by Z_{load} to normalize the equation:

$$\Gamma = \frac{Z_{source} - Z_{load}}{Z_{source} + Z_{load}}$$

$$\Gamma = \frac{\frac{Z_{source}}{Z_{load}} - \frac{Z_{load}}{Z_{load}}}{\frac{Z_{source}}{Z_{load}} + \frac{Z_{load}}{Z_{load}}}$$

$$\Gamma = \frac{Z_O - 1}{Z_O + 1}$$

Where $Z_0 = Z_{source}/Z_{load}$

Deriving the Smith Chart, Cont'd

$$\Gamma = \frac{Z_O - 1}{Z_O + 1}$$

But what is Z_0? Impedance is a complex number with a real and imaginary part. We use the form R + jX in polar form. We can also use rectangular coordinates in the form A + jB:

$$A + jB = \frac{R + jX - 1}{R + jX + 1}$$

Let's now solve for the real and imaginary parts by multiplying by the complex conjugate but first separating the real and imaginary parts by using brackets:

$$A + jB = \frac{(R-1) + jX}{(R+1) + jX} \cdot \frac{(R+1) - jX}{(R+1) - jX}$$

$$A + jB = \frac{R^2 - 1 + X^2 + 2jX}{(R+1)^2 + X^2}$$

Deriving the Smith Chart, Cont'd

$$A + jB = \frac{R^2 - 1 + X^2 + 2jX}{(R+1)^2 + X^2}$$

Let's now separate out the real and imaginary components:

$$A = \frac{R^2 - 1 + X^2}{(R+1)^2 + X^2} \text{ (Equation 1)}$$

$$B = \frac{2X}{(R+1)^2 + X^2} \text{ (Equation 2)}$$

Solving Equation 1 for X^2:

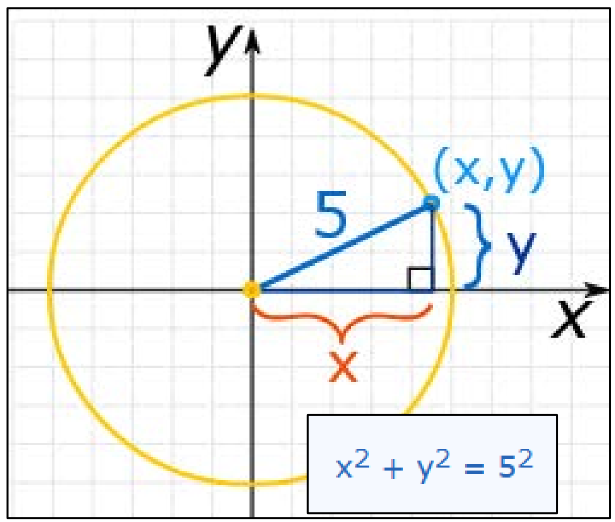
$$X^2 = \frac{A(R+1)^2 - R^2 + 1}{1 - A} \text{ (Equation 3)}$$

Deriving the Smith Chart, Cont'd

Substituting Equation 3 into Equation 2:

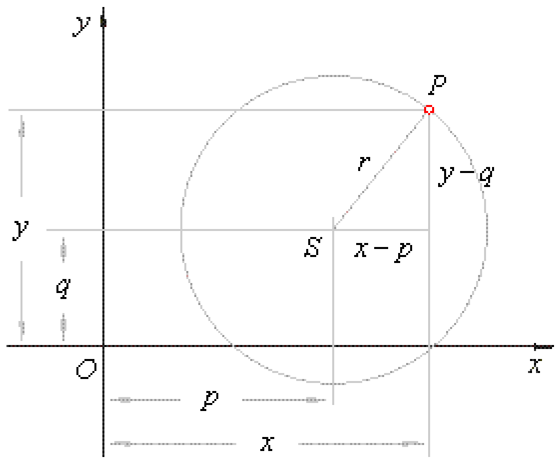
$$(A - \frac{R}{R+1})^2 + B^2 = (\frac{1}{R+1})^2 \text{ (Equation 4)}$$

Do you remember the equation of a circle? $X^2 + Y^2 = R^2$



Deriving the Smith Chart, Cont'd

And the more general formula for a translated circle?



$$\boxed{(x-p)^2+(y-q)^2=r^2}$$

$$(A-\frac{R}{R+1})^2+B^2=(\frac{1}{R+1})^2 \text{ (Equation 4)}$$

So Equation 4 represents a circle of radius: 1/(R+1) and a center of: (R/(R+1), 0). It represents a constant value of **RESISTANCE**

Deriving the Smith Chart, Cont'd

$$(A-\frac{R}{R+1})^2+B^2=(\frac{1}{R+1})^2 \text{ (Equation 4)}$$

circle of radius: 1/(R+1)
center of: (R/(R+1), 0)

By varying the value of R, you can draw each circle in the Smith Chart

If we now go back to Equation 2 and solve for R, we will get:

$$R=\frac{\sqrt{-BX(BX-2)}-B}{B}$$

Which, if substituted in Equation 1 you get Equation 5:

$$(A-1)^2+(B-\frac{1}{X})^2=(\frac{1}{X})^2 \text{ (Equation 5)}$$

This is also a circle, with radius: 1/X with centers (1, 1/X) and represents a constant value of **REACTANCE.** In this case, there are two set of circles.

Implications of Equations 4 and 5:

$$(A - \frac{R}{R+1})^2 + B^2 = (\frac{1}{R+1})^2 \text{ (Equation 4)}$$

circle of radius: 1/(R+1) center of: (R/(R+1), 0)

$$(A-1)^2 + (B - \frac{1}{X})^2 = (\frac{1}{X})^2 \text{ (Equation 5)}$$

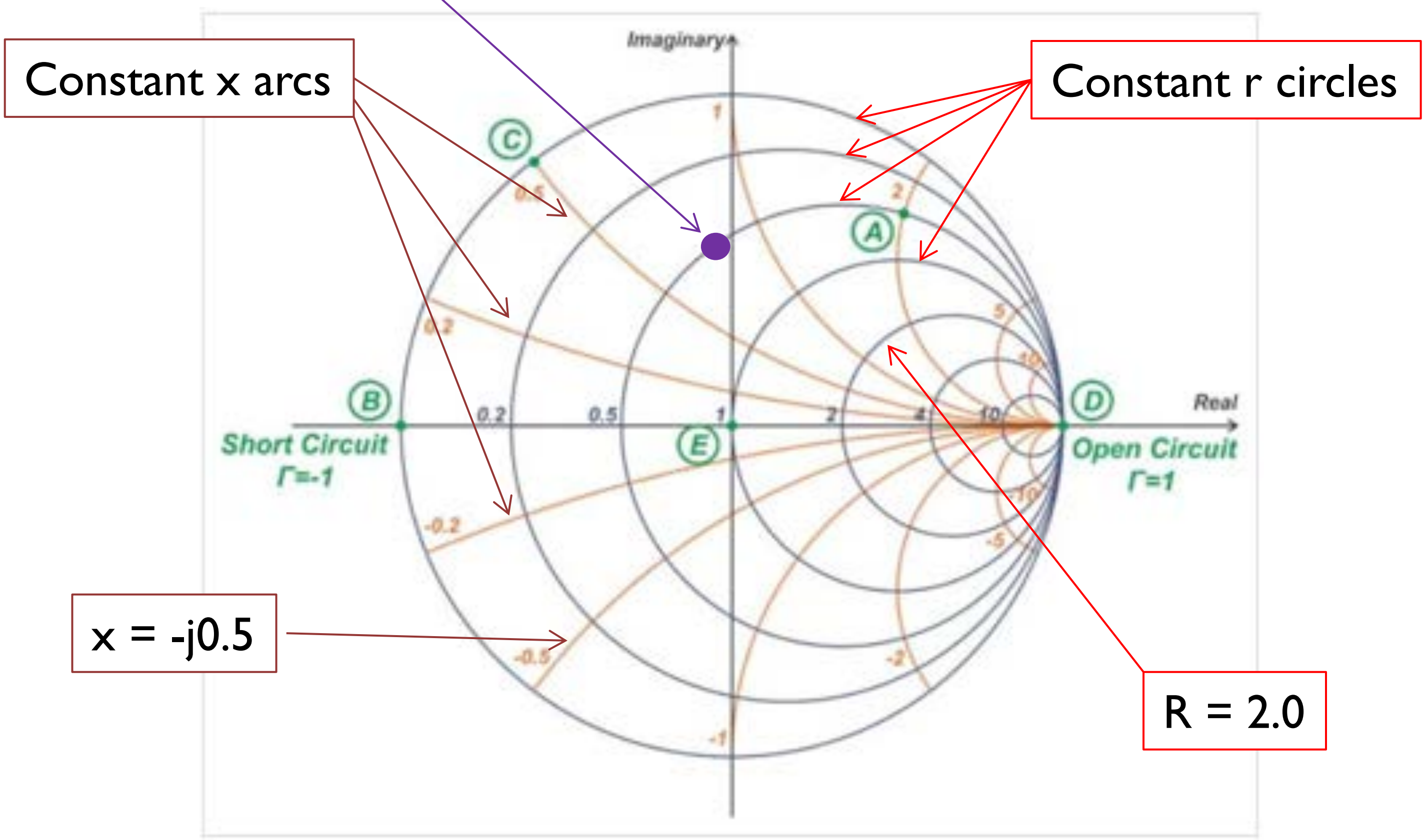
circle, with radius: 1/X with centers (1, 1/X)

- If R and X are infinite, both circles have $A^2 + B^2 = 0$, so A,B = (1,0)
- If R = 0, the $A^2 + B^2 = 1^2$ so A,B = (-1,0)
- Approaching X=0 results in infinite radius which is represented by line crossing center of chart ("the real axis")
- Reactances above the real axis are inductive and those below are capacitive
- Every point on the chart represents a series combination of resistance and reactance (R + jX)

Implications of Equations 4 and 5:

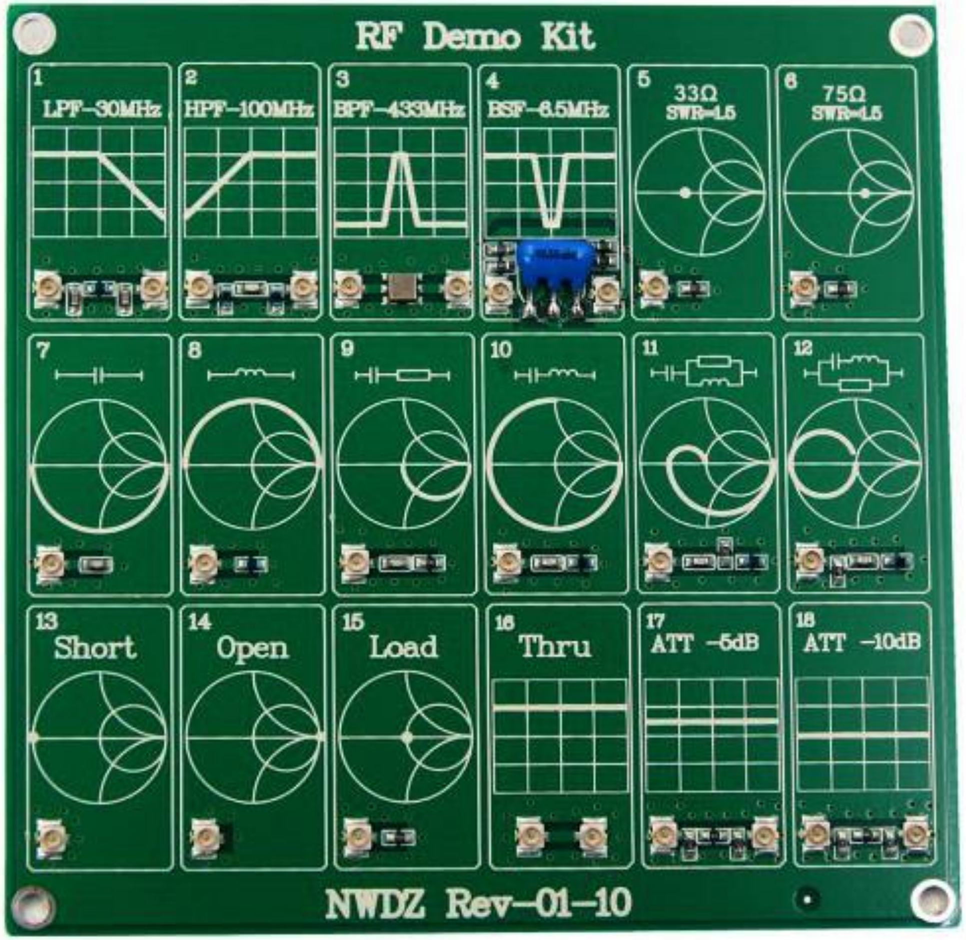
The Smith Chart is Normalized:

Example: if $Z = 25 + j40$ and $Z_o = 50\Omega$, then we divide by 50 and plot $z = 0.5 + j0.8$



Part 2: Digging Deeper

More on the Smith Chart!



Making sense of the Smith Chart

Calibrating RF Demo Kit

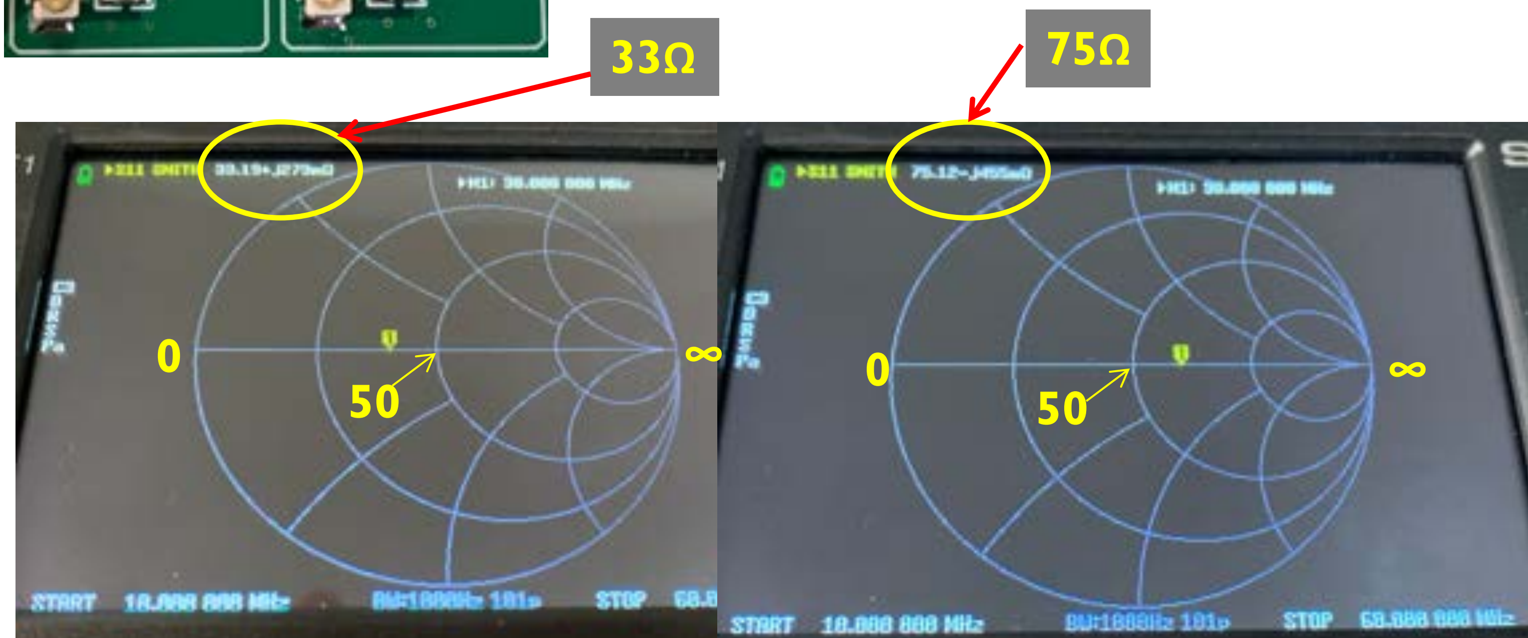
We need to calibrate for two reasons:

- With the extended cables we have changed the plane of the measurement
- Different frequency ranges require re-calibration

Note: When doing the isolation calibration we need to have 50Ω loads on both CH0 and CH1. We can use 15 Load for one and either 17 or 18 for the other as they are also 50 Ω loads.

Measuring Pure Resistances

- These are one port measurements with zero reactance – resistors to ground
- The values lie on x-axis (X=0)

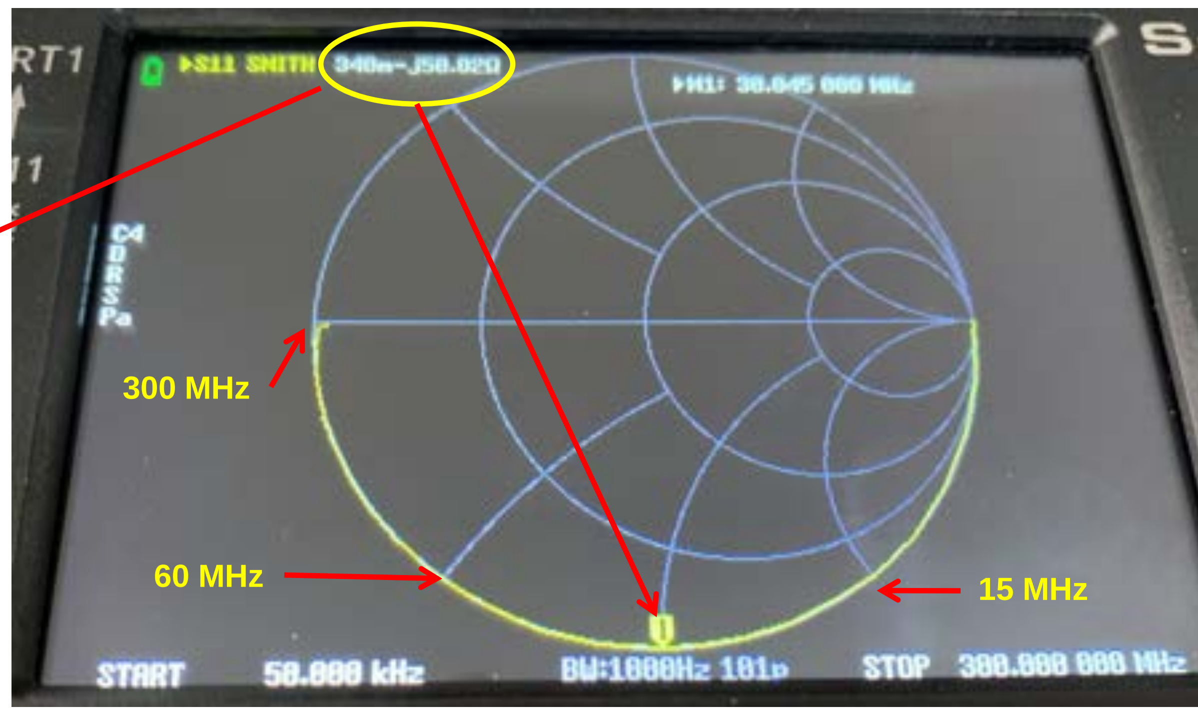


Frequency range = 10MHz to 60MHz

Measuring Capacitors

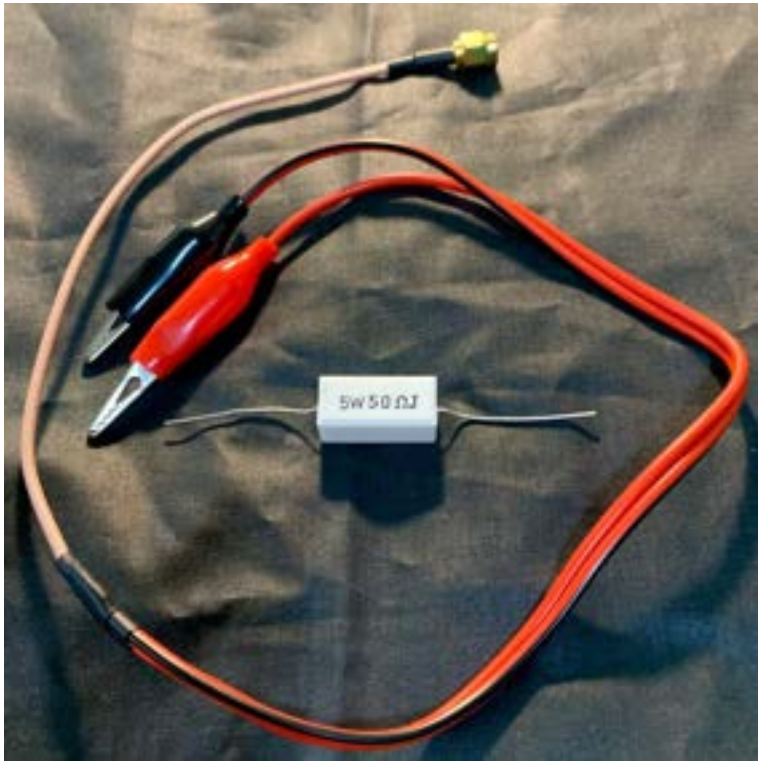
- Stimulus: 50 kHz to 300 MHz
- All reactances below horizontal axis
- Can read capacitance value for particular frequency by moving M1
- Zero X_L over entire frequency range
- Highest frequency on left – the more it looks like short

340mΩ-j50
= almost zero R
and all C



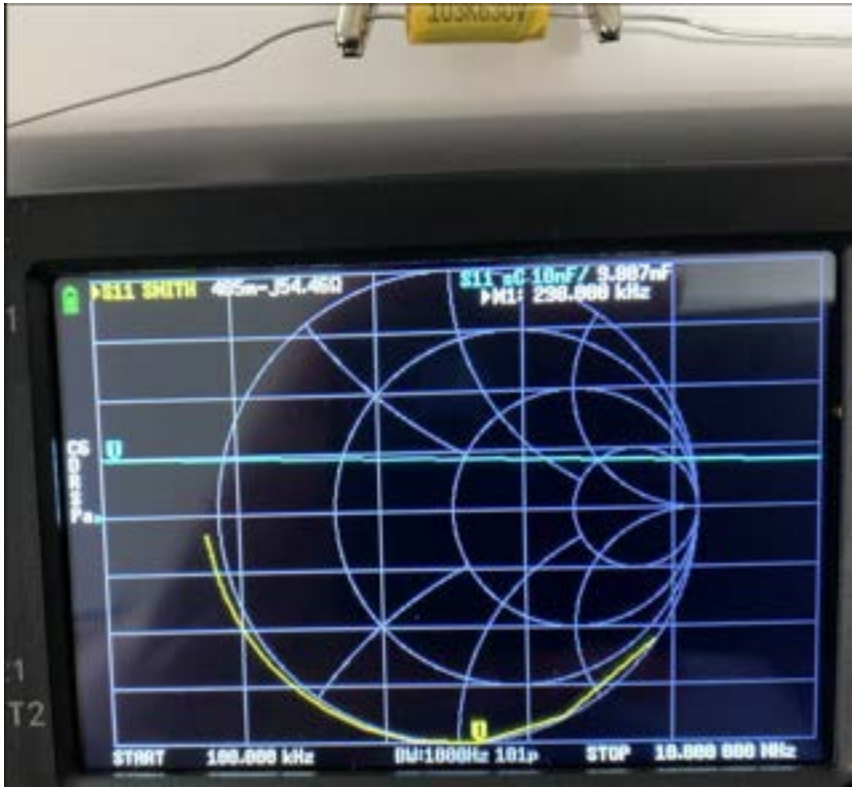
Measuring Capacitors

What about measuring random capacitors in the junk box?



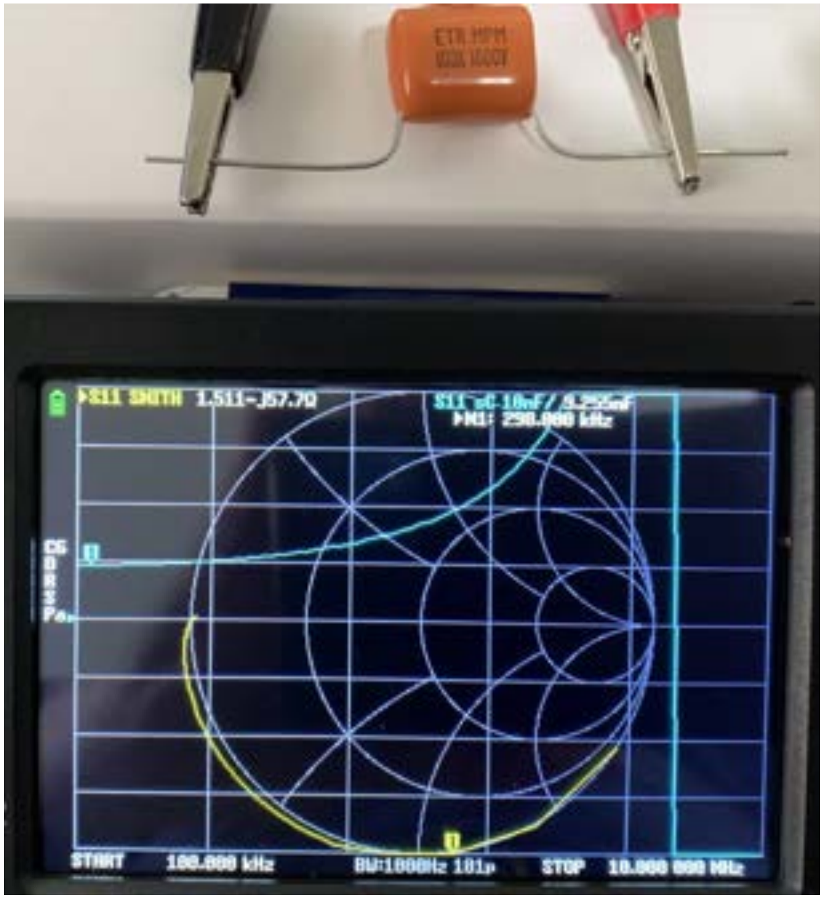
- Need some alligator leads with SMA adapter
- Need a 50Ω resistance for calibration
- All components contain R, L and C
- Important to use correct frequency range
- Can read capacitance value for particular frequency by moving M1 to –j50 intercept on Smith chart
- For Trace 1:
  DISPLAY➔FORMAT➔MORE➔MORE ➔SERIES C (OR PARALLEL C)

Measuring Random Capacitors



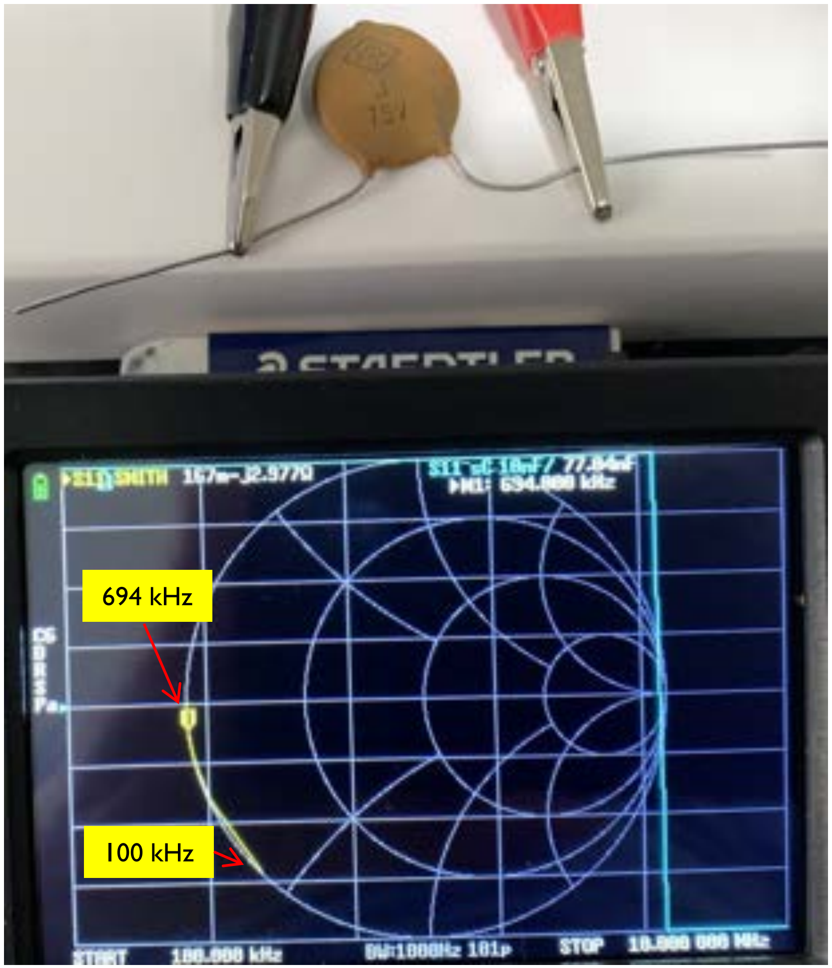
- Capacitor is “Polypropylene” type
- Capacitor spec’d value = 103K = 10 000 or 10,000pF = 10nF (k= +/- 10% tolerance)
- S11 = sC = 9.887nF (close to 10nF)
- Frequency range 100 kHz to 10 MHz
- Note value near R=0 and X_C close to 50Ω but moving M1 anywhere in the arc would still show about 10 nF

Measuring Random Capacitors

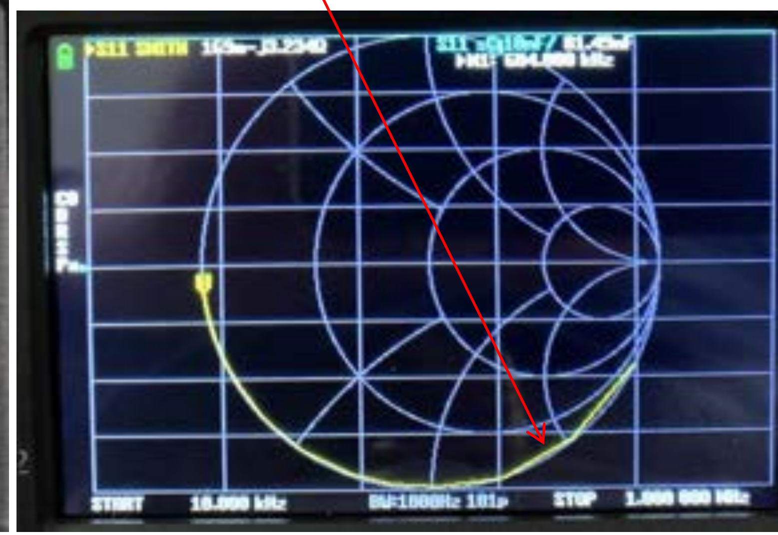


- Capacitor is “Polyester” type
- Capacitor reads 103K = 1 0 000 or 10,000pF = 10nF (k= +/- 10% tolerance)
- S11 = sC = 9.255nF (close to 10nF)
- Frequency range 100 kHz to 10 MHz
- Very similar to previous capacitor

Measuring Random Capacitors



- Capacitor is “Ceramic” type
- Capacitor spec’d value 0.1 = 0.1 μF = 100nF
- S11 = sC = 77.64nF (not so good)
- Frequency range 100 kHz to 10 MHz
- Doesn’t appear to act like a capacitor at frequencies above 694 kHz
- Change stimulus 10 kHz to 1 MHz



Ceramic capacitors of this size work at low frequencies. In general, the smaller the physical size of the capacitor, the higher the frequency range.

Measuring Random Capacitors

The manual for this meter states:

"For small values the frequency of operation (test frequency) is about 750 KHz decreasing to about 60 KHz at .1 mFd's or 10 mHy's and about 20 KHz at 1 mFd or 100 mHy's."

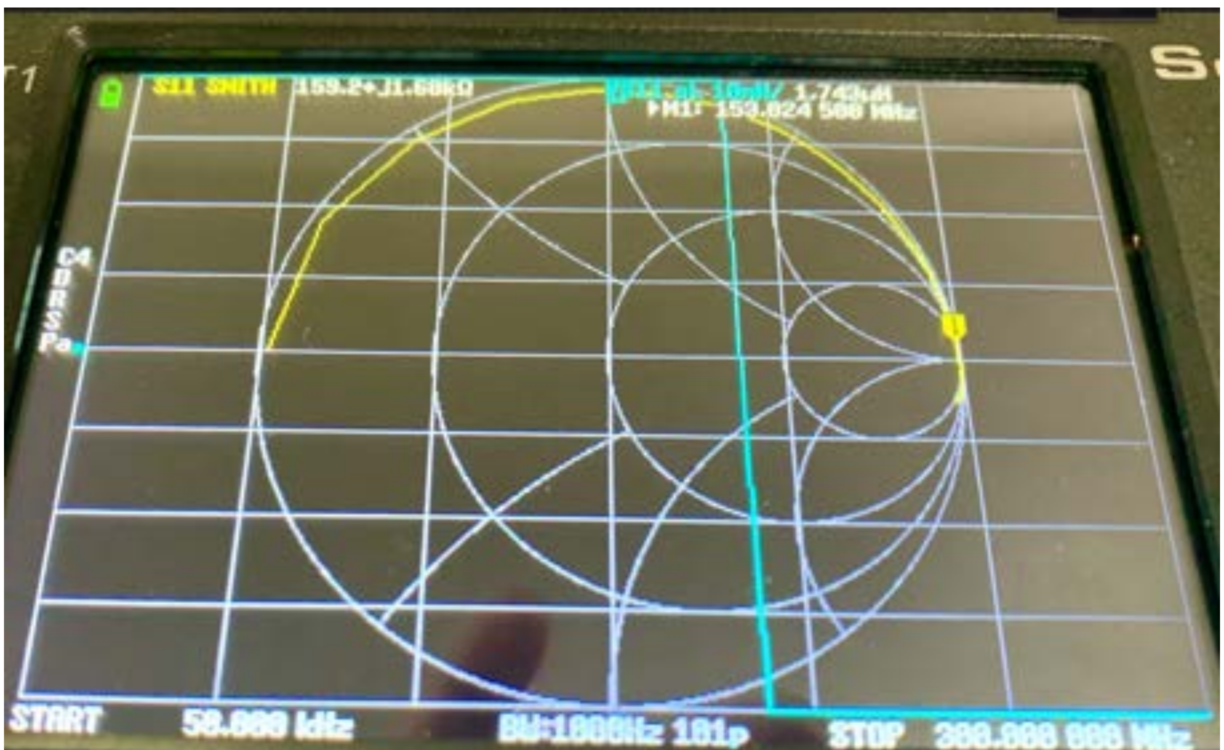
Lesson learned: No such thing as a "pure capacitor". Must specify the frequency range of operation. There are many types and sizes of capacitors.

Measuring Inductors

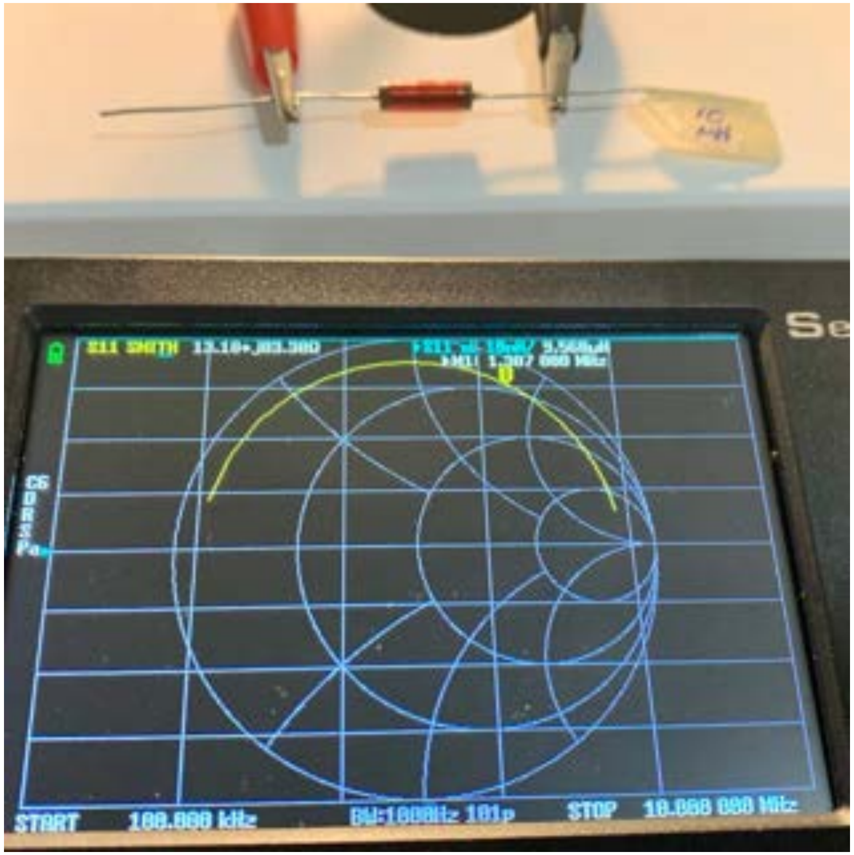
- Stimulus: 50 kHz to 300 MHz
- All reactances above horizontal axis
- Can read L value for particular frequency by moving M1
- Almost Zero X_C over entire frequency range

Measuring Inductors

- Stimulus: 50 kHz to 300 MHz
- Added Trace 1: Serial Inductance
- Measured 1.743 µH below 150 MHz
- Curve appears below “ideal” circle due to R
- Stops acting like inductor above 153 MHz



Measuring Random Inductors

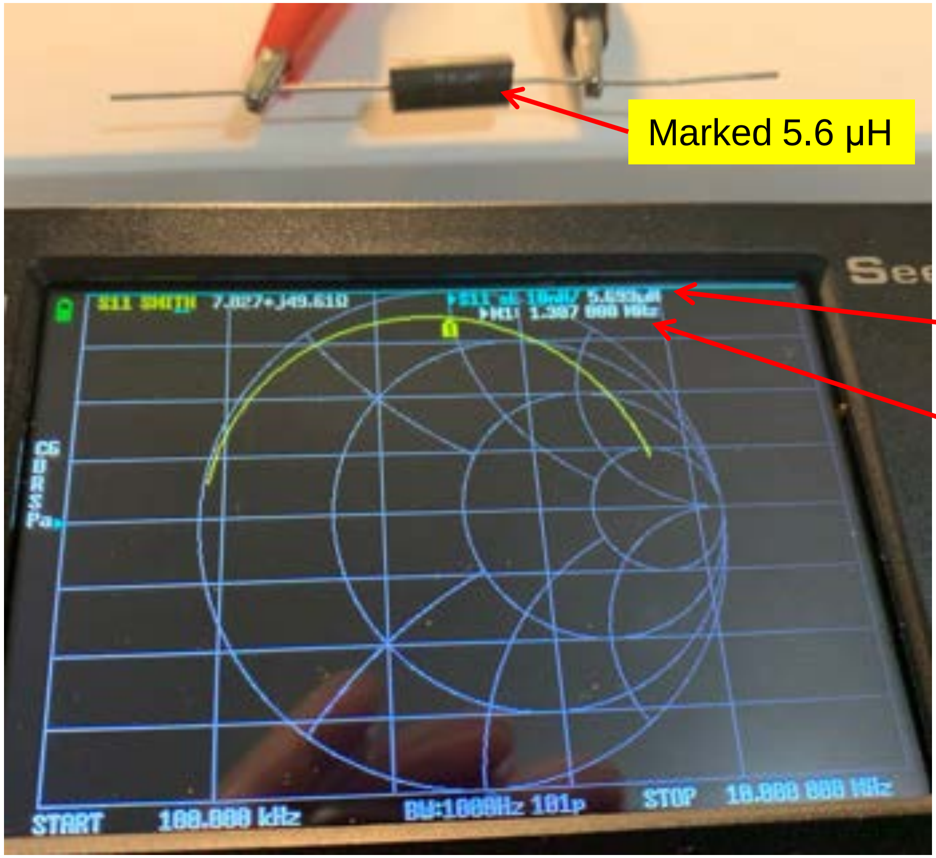


- Stimulus: 100 kHz to 10 MHz
- Added Trace 1: Serial Inductance (cyan)
- Measured 9.56 µH across entire range of frequencies
- Highest frequency on right (opposite of capacitors) – the more it looks like infinite R

Q. Why is this inductor not following outermost circle?

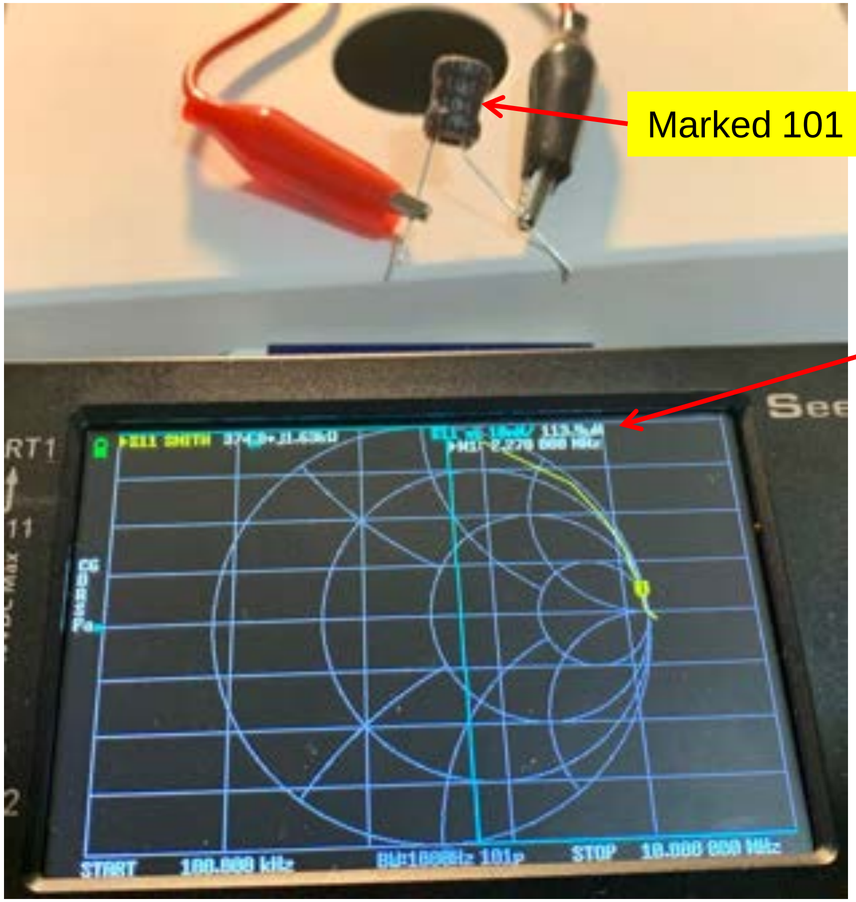
R. A small amount of C exists between turns of the coil and the R is significant (loss)

Measuring Random Inductors



- Encased inductor
- Stimulus: 100 kHz to 10 MHz
- Added Trace 1: Serial Inductance (cyan)
- Measured 5.69 µH across entire range of frequencies
- From Smith chart, requires frequency of 1.387 MHz to present X_L =j50 – Marker M1

Measuring Random Inductors



- Encased inductor
- Stimulus: 100 kHz to 10 MHz
- Added Trace 1: Serial Inductance (cyan)
- Measured 113.9 μH near maximum frequency (2.2 MHz)
- Below 1 MHz, L is much closer to 100 μH
- Need to change vertical scale to see entire range of L (top line is 90 μH)

Measuring Random Inductors

- High current inductor
- Stimulus: 100 kHz to 10 MHz
- Added Trace 1: Serial Inductance (cyan)
- Measured 97.9 µH near maximum frequency (2.2 MHz)
- Below 1 MHz, L is much closer to 100 µH
- Need to change vertical scale to see entire range of L (top line is 90 µH)
- Appears to act as a capacitor above 2.2 MHz ?

Series C and R

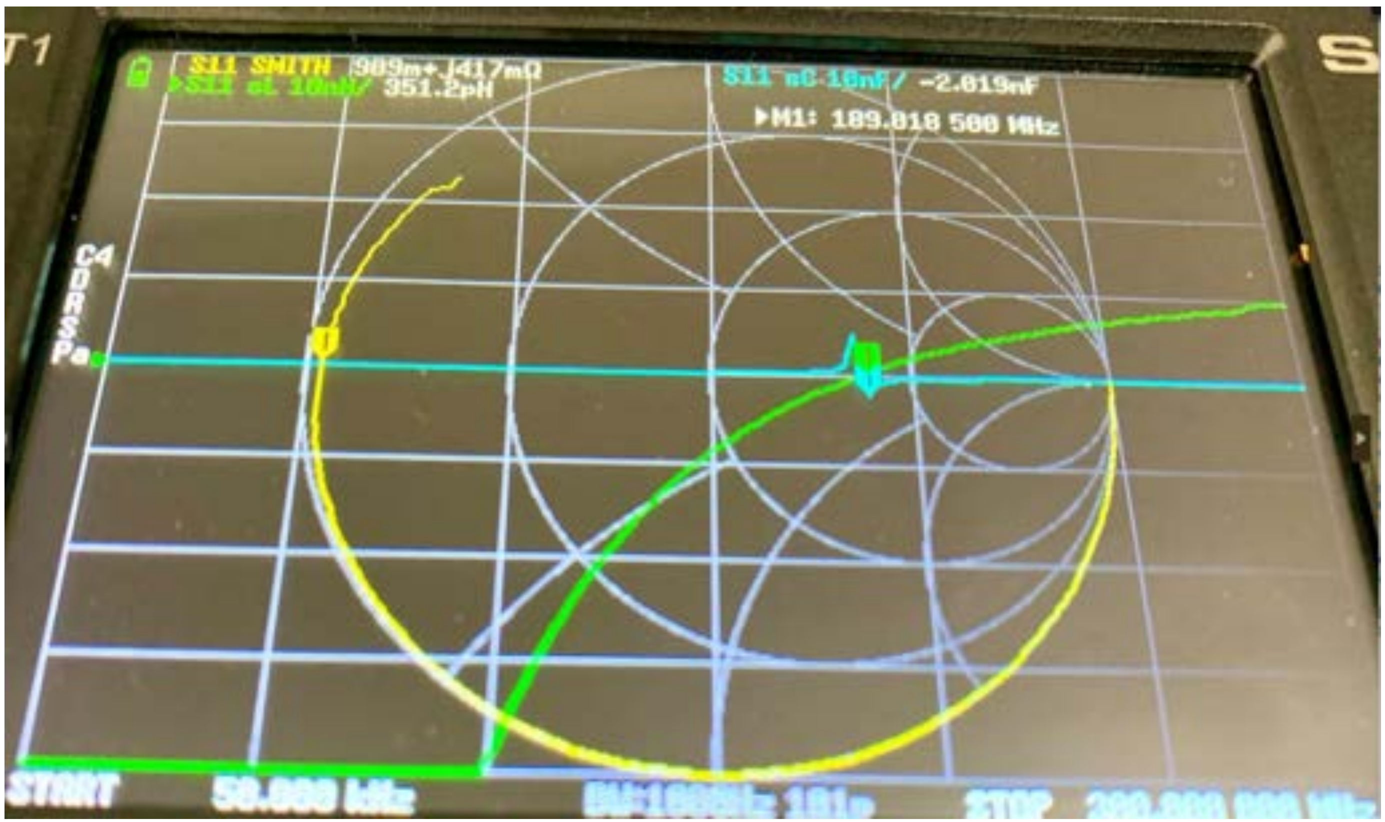
- Stimulus: 50 kHz to 300 MHz
- Curve below X-axis shows reactance is capacitive
- Circular arc indicates pure R
- M1 at 159 MHz shows R=50Ω
- M1 at 30 MHz shows R=50Ω
- Can I tell the value of C?
    - Set TRACE 1 to Series C
    - C = 106 pF

Series C and L

- Stimulus: 50 kHz to 300 MHz
- Curve below X-axis shows X_C present and portion above X-axis shows X_L present
- M1 at 60 MHz shows C = 51 pF and L = 137 nH
- Cyan = TRACE1 = series capacitance
- Green = TRACE2 = series inductance
- Note: All markers tied together at same frequency

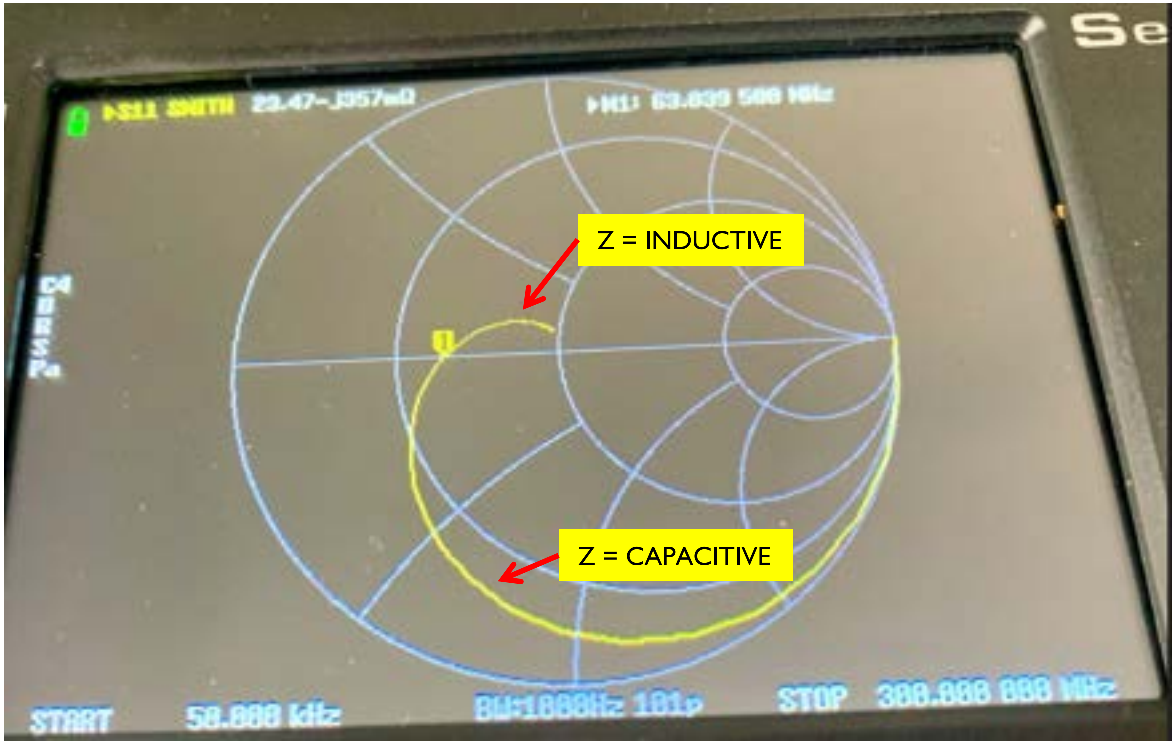
Series C and L – Cont’d

- Stimulus: 50 kHz to 300 MHz
- Setting M1 on horizontal axis, $X_C = X_L$. This happens at 189 MHz
- Note M1 on the sC and sL traces intersect
- The reactance is cancelled so the impedance is purely resistive
- THIS IS RESONANCE



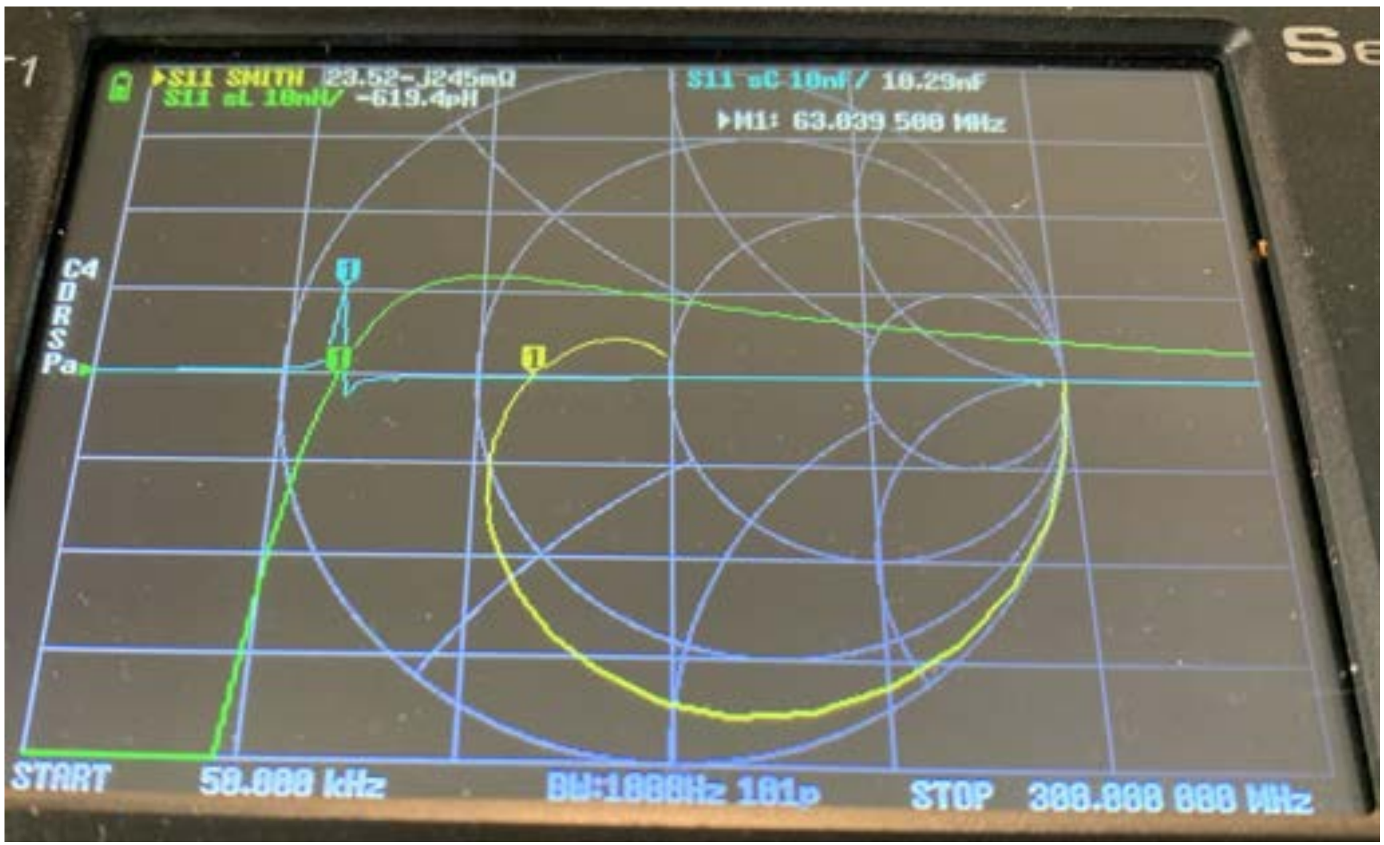
Series C with Parallel L and R

- Stimulus: 50 kHz to 300 MHz
- Setting M1 on horizontal axis, $X_C = X_L$. This happens at 63 MHz where R = 23Ω. Is there a second resonance at higher frequency?
- If frequency = ∞, then C➔ short and L ➔ open, the circuit looks like pure R
- If frequency = 0, then C ➔ open and circuit looks like an open
- For f < 63 MHz, C dominates and for f > 63 MHz, L dominates
- To change the resonant frequency, we could change either L or C



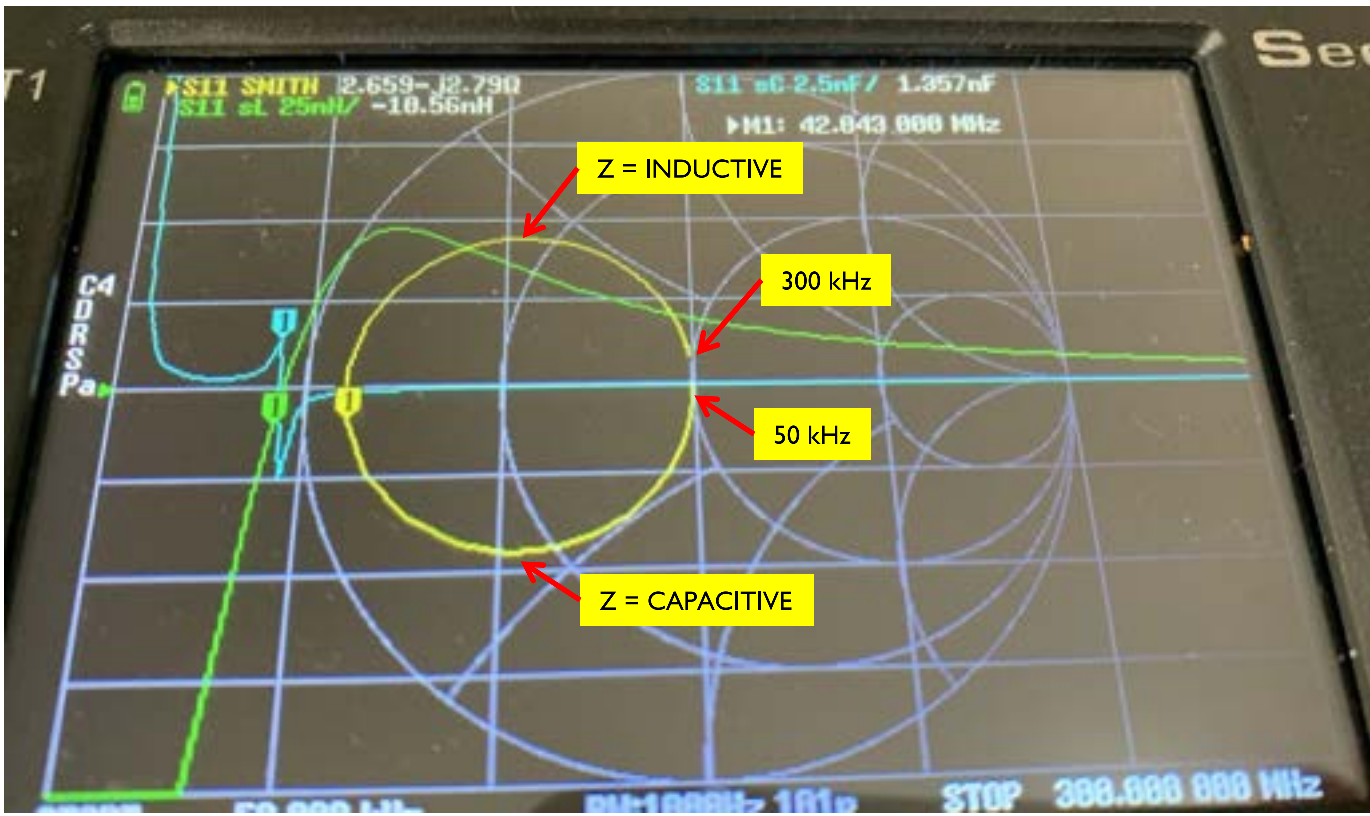
Series C with Parallel L and R Cont'd

- Same Circuit 11
- Added TRACE1 (cyan): sC, TRACE2 (green): sL (Series L & C)
- When yellow M1 is on horizontal axis (resonance) note X_C and X_L intersecting (resonance)
- Using the values for L and C, 1/(2π)SQRT(LC) = 63.074 MHz

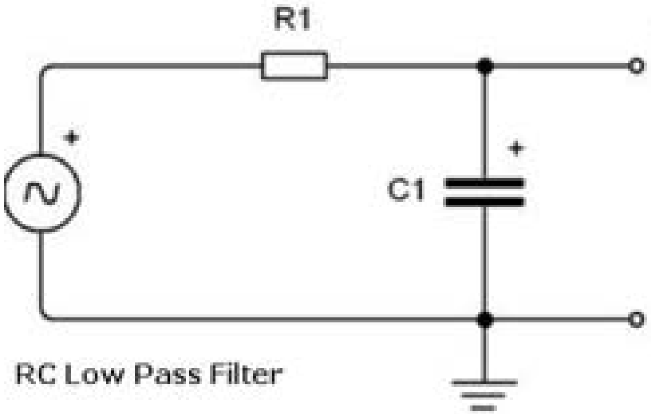


Series L and C with Parallel R

- Smith chart yellow curve:
- If frequency ➔ ∞, then C➔ short and L ➔ open, the circuit looks like pure R
- If frequency = 0, then C ➔ open and L ➔ short and circuit looks like pure R
- R appears to be 50 Ω
- $F_0 \cong 42$ MHz
- R at $F_0 \cong 2\ \Omega$, the resistance of the inductor and R in parallel



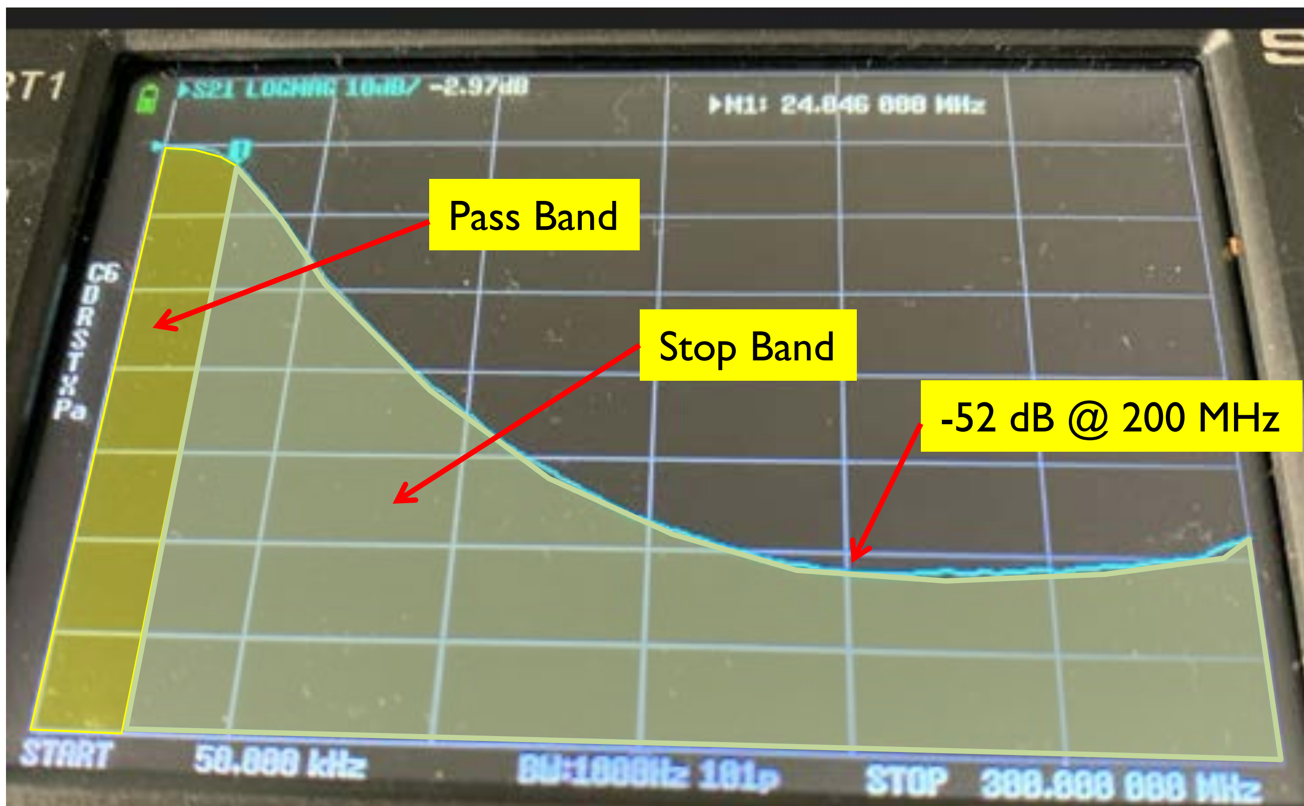
Low Pass Filter – 30 MHz



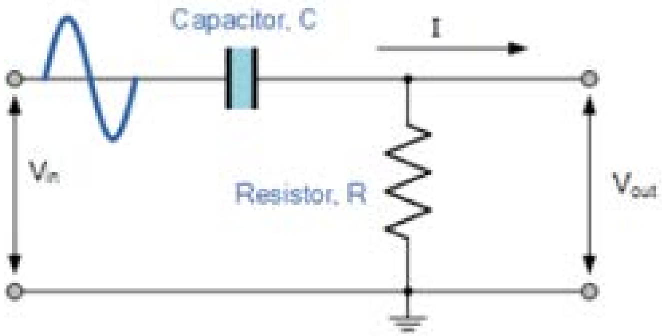
- Simplest circuit is R and C as above
- The higher the frequency the more C acts to shunt current to ground and the circuit acts like a voltage divider
- R is often replaced by L (typically a toroid)
- Main purpose of LPF is to attenuate harmonics and higher frequency spurious signals
- Cutoff point is the frequency (f_c) that attenuates the input signal by 3dB ("3dB down point"), which reduces the output power to ½ the input power ("half power point")

Low Pass Filter – 30 MHz, Cont'd

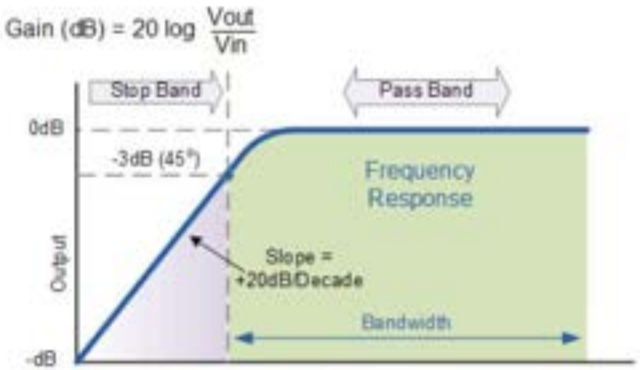
- First thing to note is that this is a S21 measurement as we are measuring the output relative to the input
- S21 measurements require calibration of SOL plus Thru and Isolation: Use "Thru" for 50Ω load and either 17/18 (ATT) for Isolation as these are also 50Ω
- Need to turn on Trace1 (cyan) set to LOGMAG 10dB
- Discover f_c is at about 24 MHz, not 30 MHz



High Pass Filter – 30 MHz

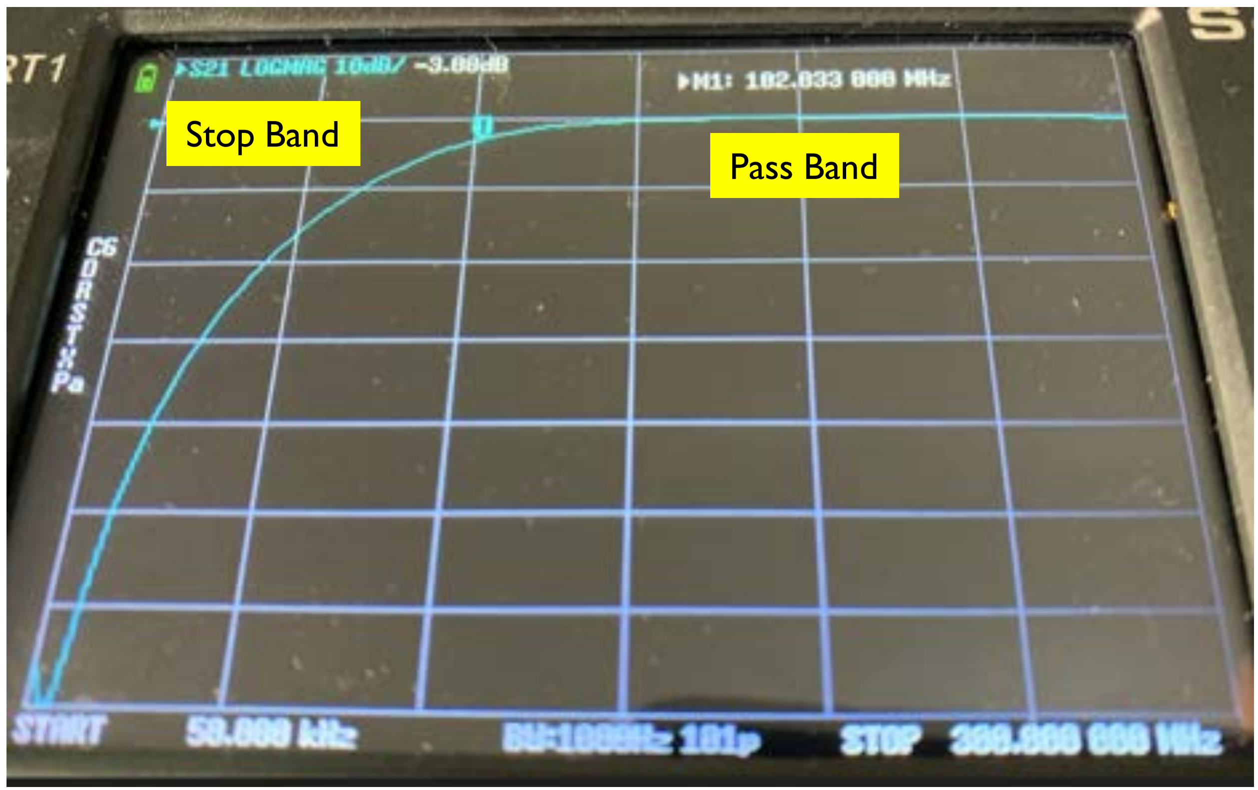


- Simplest circuit is R and C as above
- The higher the frequency the more C acts as a short circuit but the lower the frequency, the more C blocks the current (open at DC)
- Cutoff point is the frequency that attenuates the input signal by 3dB ("3dB down point"), which reduces the output power to ½ the input power ("half power point")



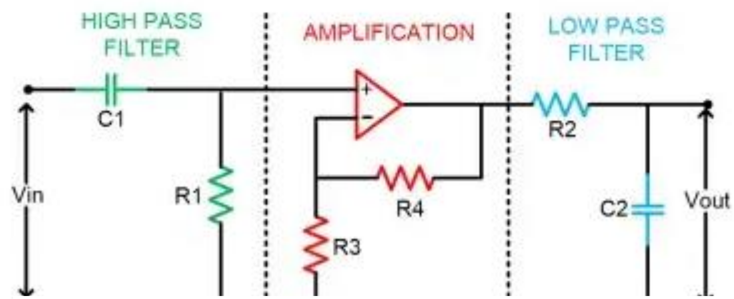
High Pass Filter – 30 MHz

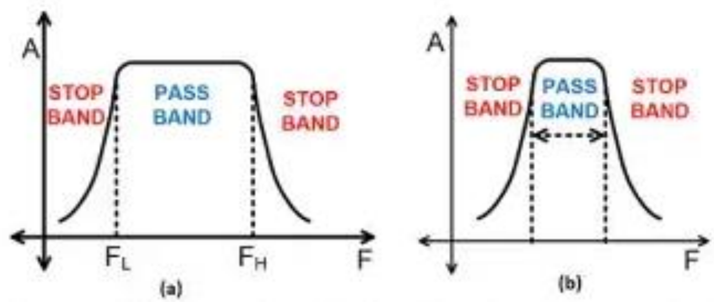
- Kept frequency range the same, so no need to recalibrate
- Turn on Trace1 (cyan) set to LOGMAG 10dB
- f_c is at about 100 MHz, as labeled



Band Pass Filter – 433 MHz

- We can select a narrow band of frequencies by adding a LPF to a HPF in series
- We add an amplifier after the first stage to compensate for attenuation (loss)





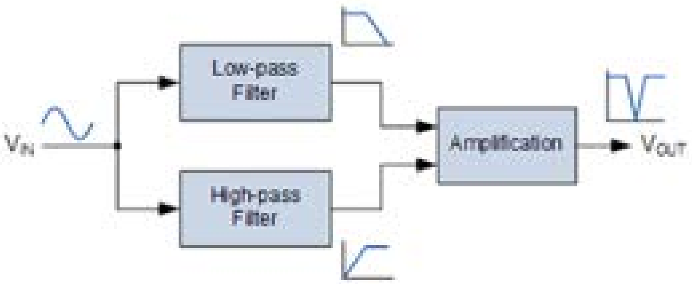
Frequency Responce of a) Wide Band Pass Filter b) Narrow Band Pass Filter

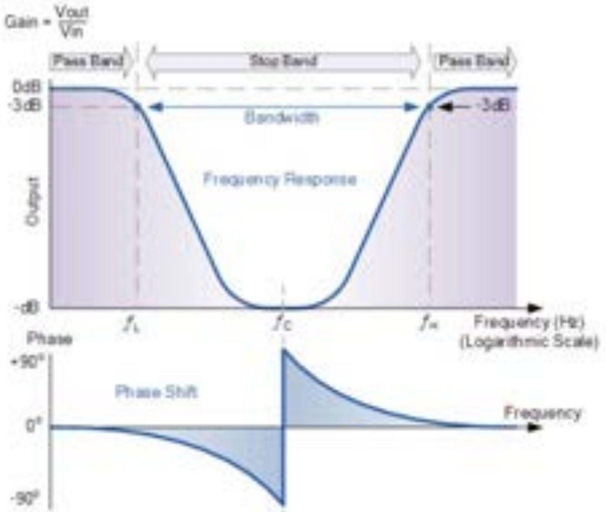
Band Pass Filter – 433 MHz

- Used “CENTER” and “SPAN” instead of START AND STOP in STIMULUS” in order to set frequencies. This allowed us to center on 433 MHz and investigate +/- 100 MHz either side
- Pass frequencies 431 to 437 MHz (-3dB) = “6 MHz wide”
- Note 2dB of loss in passband region (M1)
- -50dB points: <413 MHz and > 454 MHz

Band Stop Filter – 6.5 MHz

- More commonly called "Notch" filter
- Blocks/rejects frequencies between its two cut-off frequency points and passes all other frequencies either side of this range
- Consists of LPF and HPF in parallel, followed by amplification





Band Stop Filter – 6.5 MHz

- Used CENTER of 6.5 MHz and SPAN of 6 MHz
- Used MARKER function to select "MINIMUM"
- Max reject at 6.5 MHz, as labeled, max = -52dB
- Pass -18dB to -20dB (due to NanoVNA, not filter?)
- -3dB points: 6 MHz and 7 MHz (assume symmetry)

Looking at Coax Loss

Questions?

- Is this old piece of coax still good?
- Is it really better to use LMR400 over RG-213 in **HF** applications?

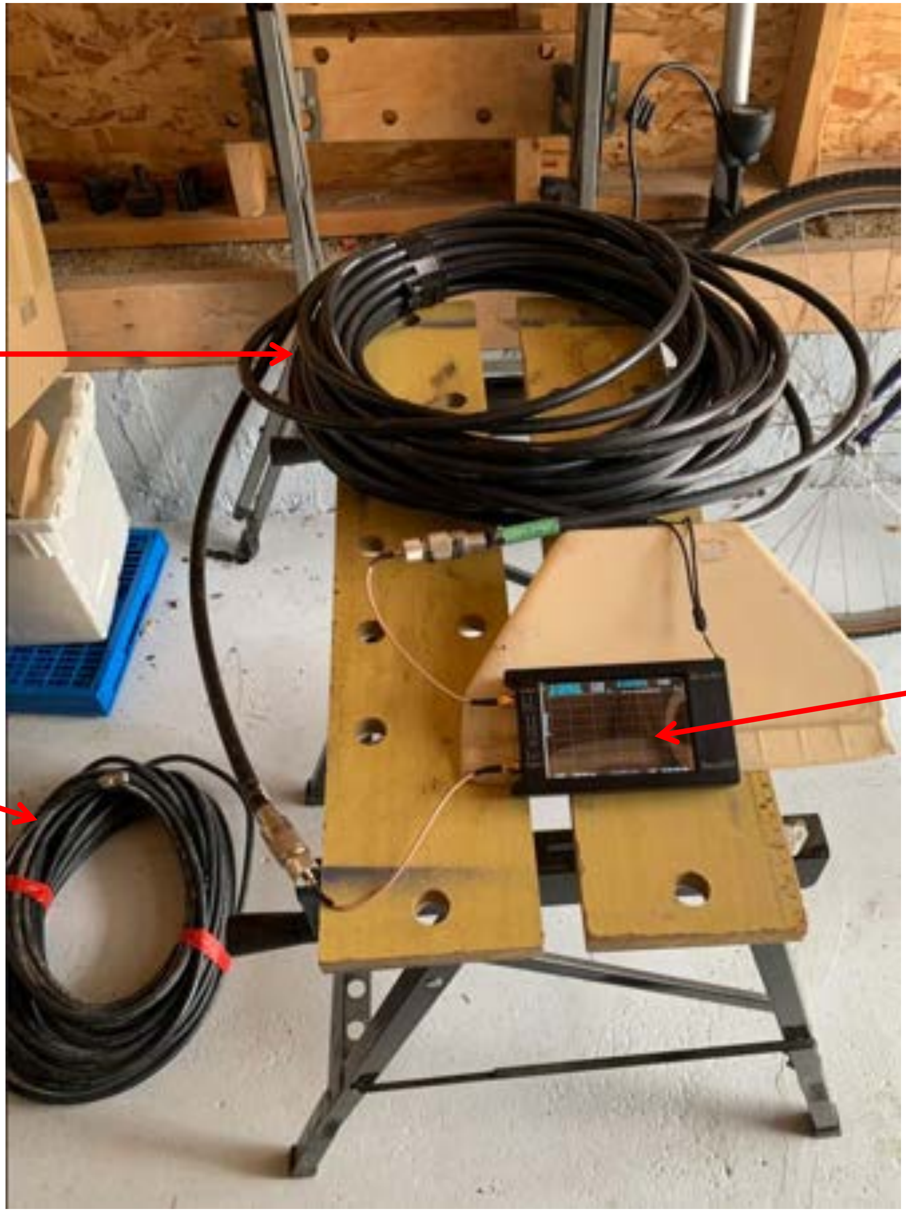
Let’s look at how the NanoVNA can help us analyze coaxial cable…

Looking at Coax Loss

Steps:

1. Select cables with proper connectors
    1. Both pieces of coax I would like to test have PL-259 UHF connectors
    2. Select female UHF connectors to SMA for the NanoVNA
    3. Select alligator clip for SHORT and double PL-259 as THRU
2. Calibrate NanoVNA
    1. Set START & STOP frequencies (1MHz to 30MHz)
    2. OPEN – Keep leads away from each other
    3. SHORT – Use an alligator clip on the UHF connector on Port 1
    4. LOAD – Use 50Ω dummy load on Port 1
    5. THRU – Use male to male UHF connector
       
    6. ISO – Use dummy load on Port 1 and 50Ω resistor (or second dummy load) on Port 2
    7. Save calibration for future use
3. Set markers for desired frequencies
4. Display Trace 1 only for LOGMAX
5. Test coax

Looking at Coax Loss



75’ RG-213/U

NanoVNA with SMA to UHF leads

65’ LMR400

Looking at Coax Loss

	M1	M2	M3	M4	M5	Coax Length (ft)
Freq (MHz)	1.87	3.61	7.09	14.05	28.55	
RG213 Loss (dB)	-0.22	-0.24	-0.39	-0.56	-0.82	76.1
LMR400 Loss (dB)	-0.18	-0.23	-0.32	-0.41	-0.57	75.9
RG213 db/ft	-0.0029	-0.0032	-0.0051	-0.0074	-0.0108	76.1
LMR400 dB/ft	-0.0024	-0.0030	-0.0042	-0.0054	-0.0075	75.9

Conclusion:

Essentially no difference in loss until above HF frequencies

Coax Length & Faults

This involves a reflection measurement (S11) that measures time (ns)

Steps:

1. DISPLAY → Turn off everything but Trace 0 (**no need to calibrate**)
2. FORMAT → S11 (REFL) → MORE → LINEAR (gives sharpest response)
3. Back → Back → TRANSFORM → LOW PASS IMPULSE
4. Back → TRANSFORM → TRANSFORM ON
5. Select VELOCITY FACTOR (Note: This is already in %)
6. Back → Back → STIMULUS:
    1. Low pass transform extrapolates to DC so START frequency must be as low as possible (set to 50 kHz)
    2. STOP Frequency determines max length of coax to be measured (Note: The higher the Fstop the shorter the distance range but greater the resolution. If unsure, use lower frequency (e.g., use 50 MHz instead of 64 MHz)

Fstop MHz	Max Distance (m)	VF RG213
193	10	0.66
97	20	0.66
64	30	0.66
48	40	0.66
39	50	0.66

Fstop MHz	Max Distance (m)	VF LMR400
246	10	0.84
123	20	0.84
82	30	0.84
62	40	0.84
49	50	0.84

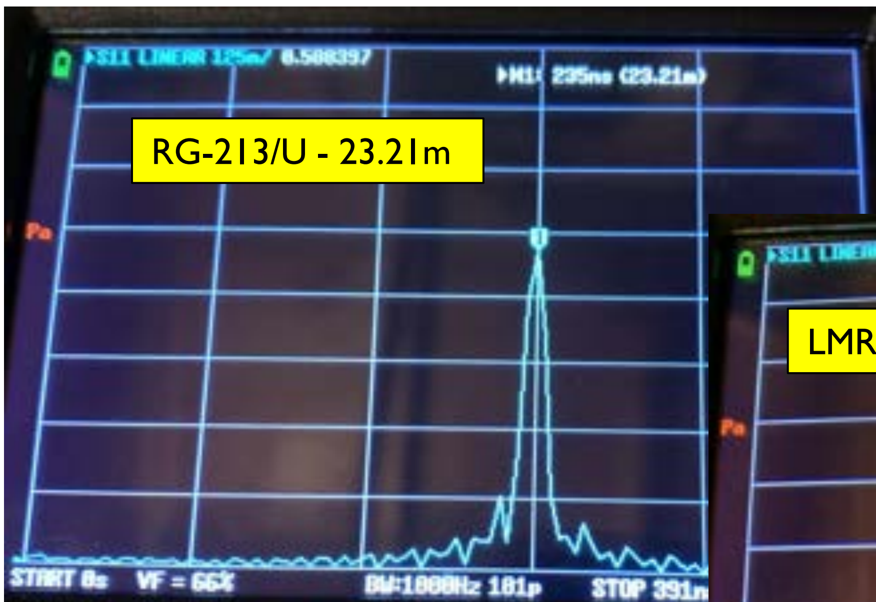
STOP Freq (MHz) = 2930 X (Velocity Factor)/Max Dist. (m)

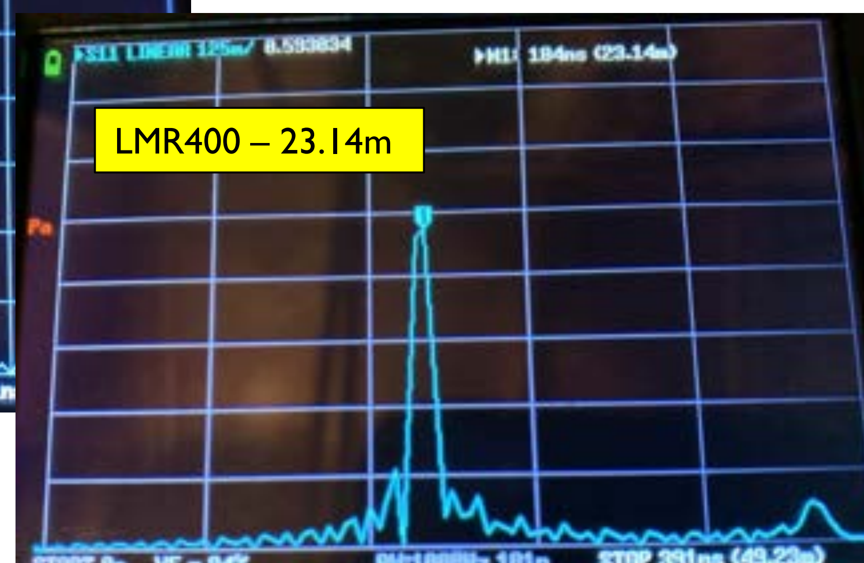
Coax Length & Faults

Steps Cont'd:

7. Hook up coax to be measured
8. Select Marker ➔ Search ➔ Maximum – will find peak value

Note: If the coax is defective, there could be one or more peaks before the main peak.

Resources:

- NanoVNA Website: Includes basic “How to Use”, PC apps, User Group information, recommended projects, etc. www.nanovna.com
- Gamblin, Trevor, Mathematical Construction and Properties of the Smith Chart, July 23, 2015, https://www.allaboutcircuits.com/technical-articles/mathematical-construction-and-properties-of-the-smith-chart/
- IMSAI Guy, NANOVNA RF Demo Board, https://www.youtube.com/watch?v=SneOI7l5Kw4
- Spiess, Andreas, How to properly use a NanoVNA V2 Vector Network Analyzer & Smith Chart (Tutorial), Nov 1, 2020, https://www.bing.com/videos/riverview/relatedvideo?q=NanoVNA%20circuits%20projects&mid=414971FF07EC6743BC10414971FF07EC6743BC10&ajaxhist=0
- Svaco, Martin, 9A2JK, Absolute Beginner’s Guide to the NanoVNA, Nov 6, 2020, http://www.nemarc.org/Absolute_Beginner_Guide_NanoVNA.pdf
- Wolke, Alan, W2AEW, Basics of Smith Charts, https://www.qsl.net/w2aew/youtube/Basics_of_Smith_Charts_W2AEW_2018.pdf
- Wolke, Alan, W2AEW, How to measure coax loss using a NanoVNA, https://www.youtube.com/watch?v=OSw9Epu4nu0
- Wolke, Alan, W2AEW, Introduction to VNAs & the NanoVNA, https://www.youtube.com/watch?v=4nnRAgQep0E
- Wolke, Alan, W2AEW, Use NanoVNA to measure coax length – BONUS Transmission Lines and Smith Charts, SWR and more, https://www.youtube.com/watch?v=9thbTC8-JtA