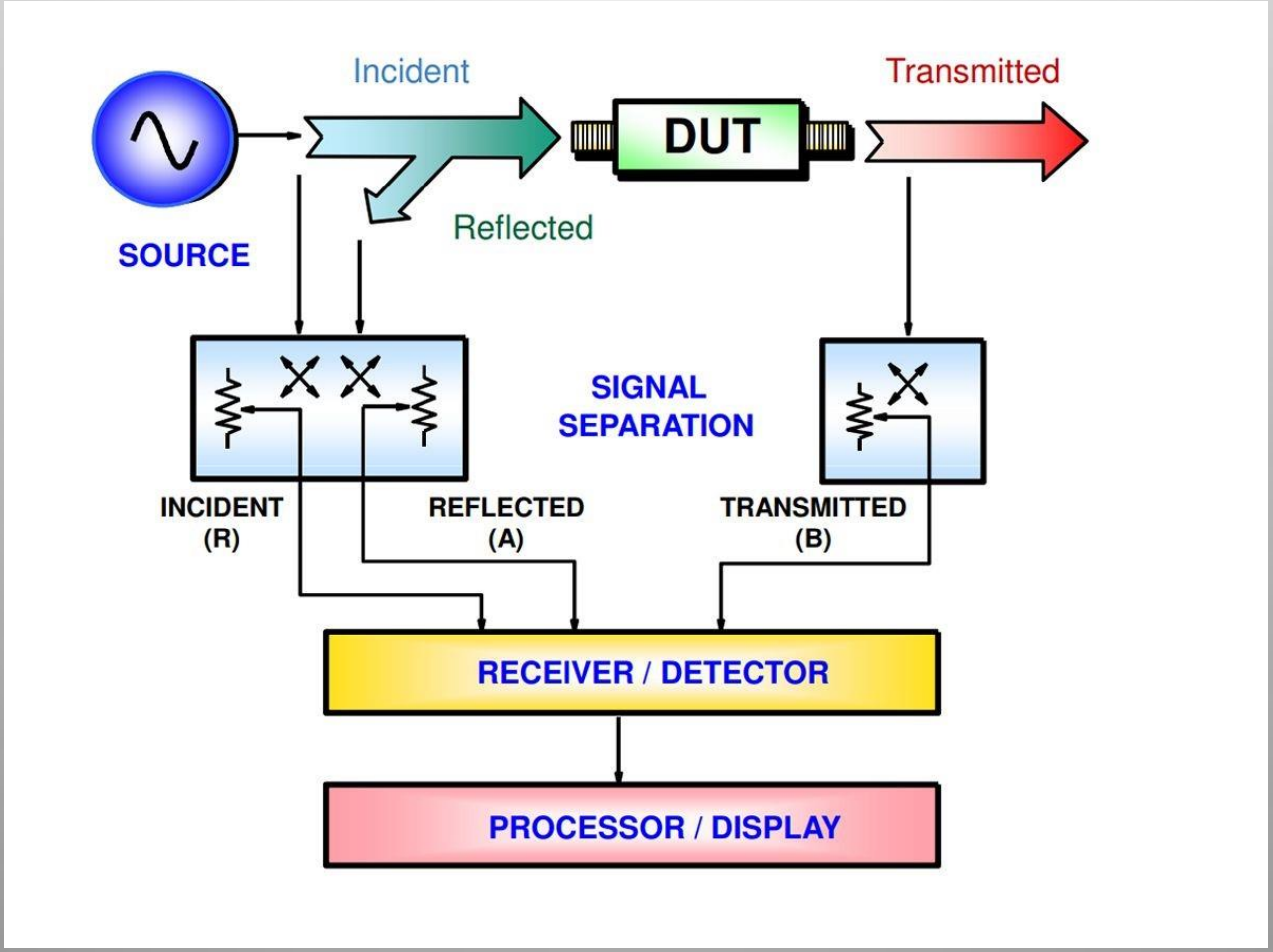
Antenna Analyzers
Vector Network Analyzers

Barry2 k3eui

Flow Chart: Vector Network Analyzer



What Devices do Network Analyzers Test?

Filters

RF Switches

Couplers

Cables

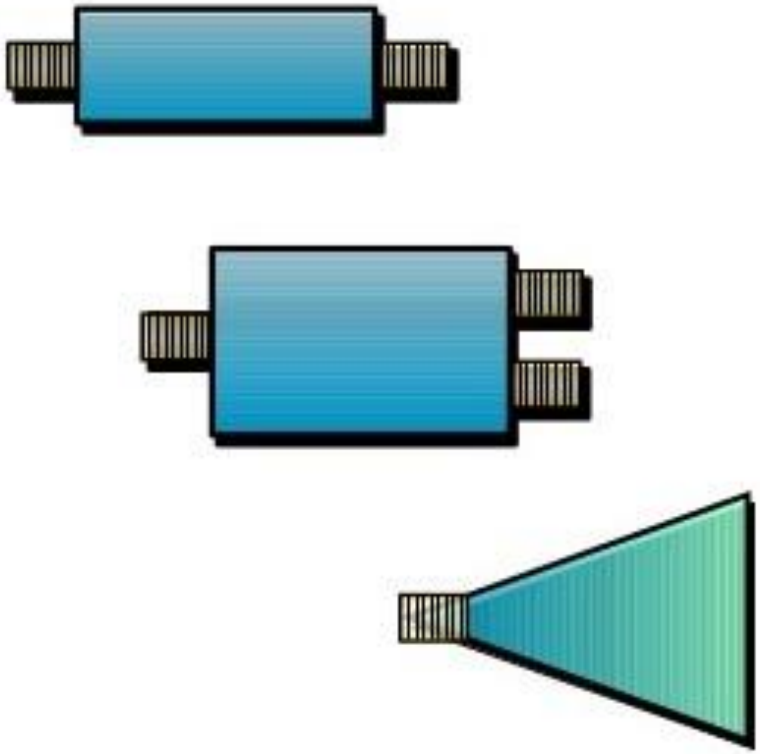
Amplifiers

Antennas

Isolators

Mixers

...



Most 2 (or more) port devices (and some 1 port devices)

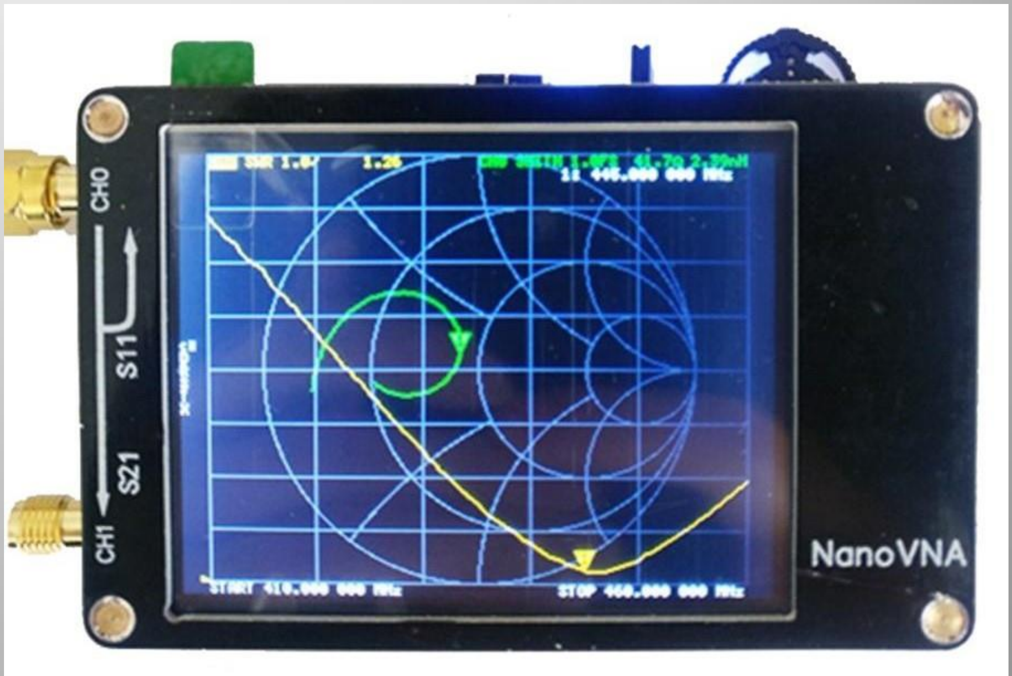
Measure antenna characteristics

resistance, reactance, impedance

resonance, SWR, Smith Chart

cable impedance and attenuation

Which device would you rather have in your ham shack?
They each cost about $50



Evolution of MFJ Antenna Analyzers

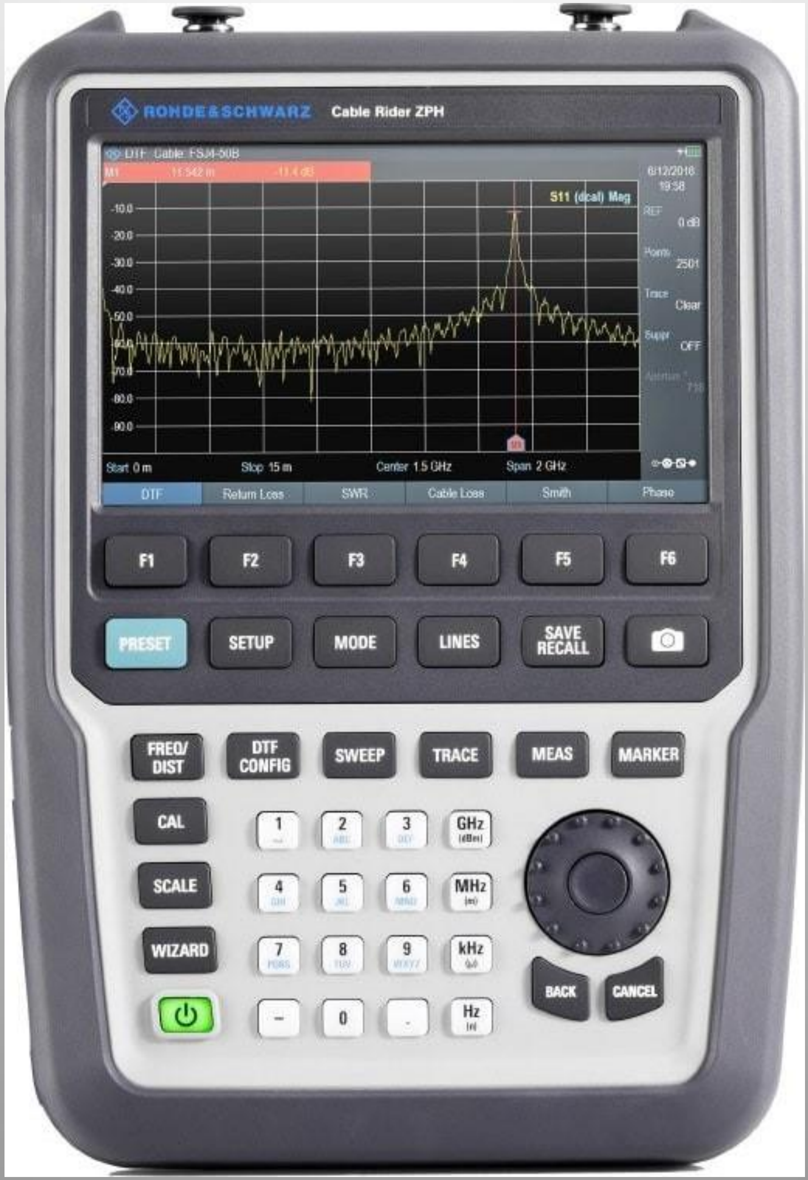
259D measures frequency, SWR, Resistance, Reactance, Impedance

223 can display graphs in multiple colors

Rig Expert has many models with various graphical displays
CCAR has one in W3EOC

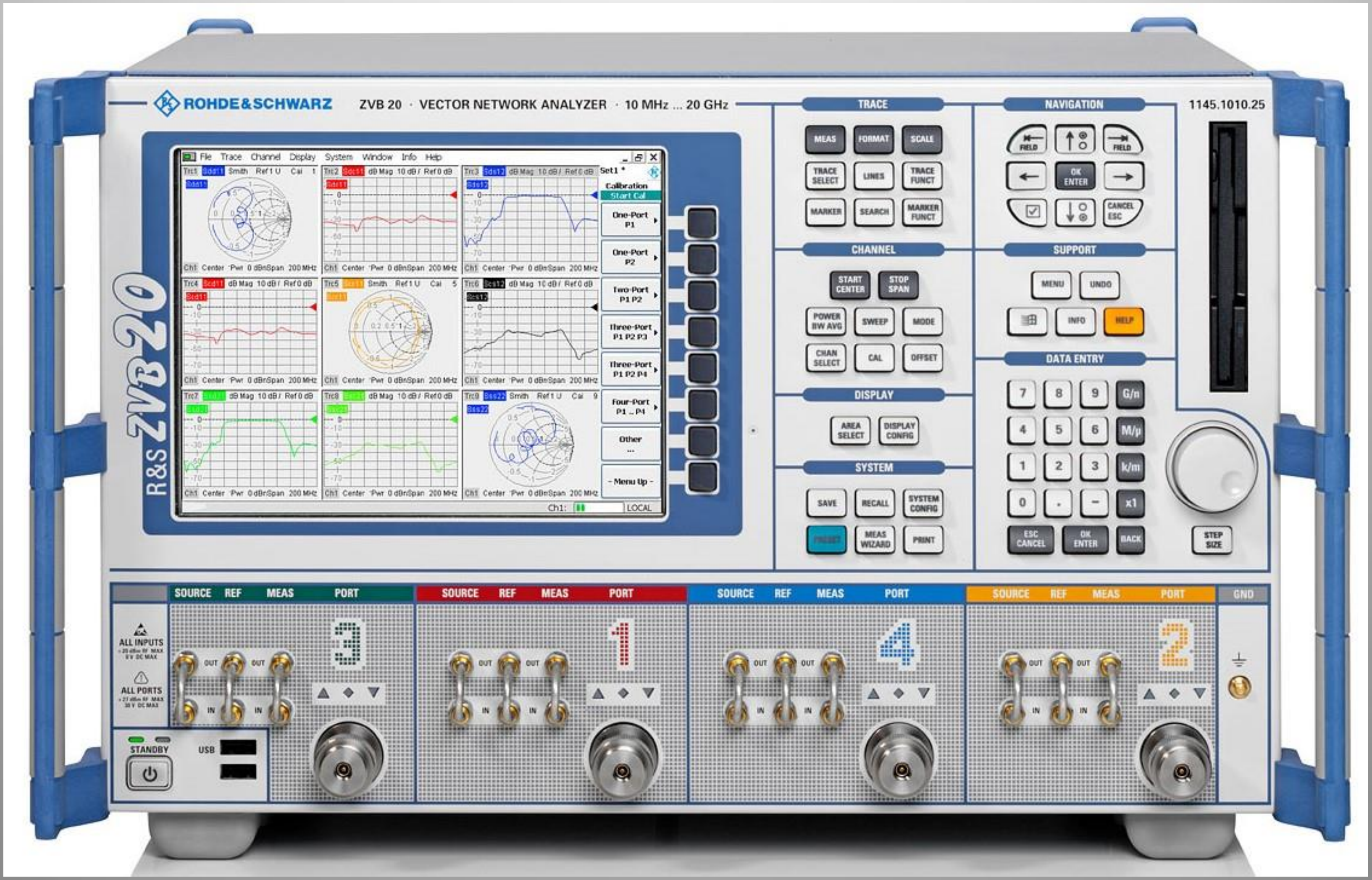
Comet makes a nice looking Antenna Analyzer
note the analog scales measure **SWR** and **Impedance**

Rohde & Schwarz: can you afford this portable one?



The “high-end” Vector Network Analyzers

Can you afford this beauty?



Enter the Nano VNA instrument: $50

Two “ports”: Ch 0 and Ch 1
4 traces in 4 colors

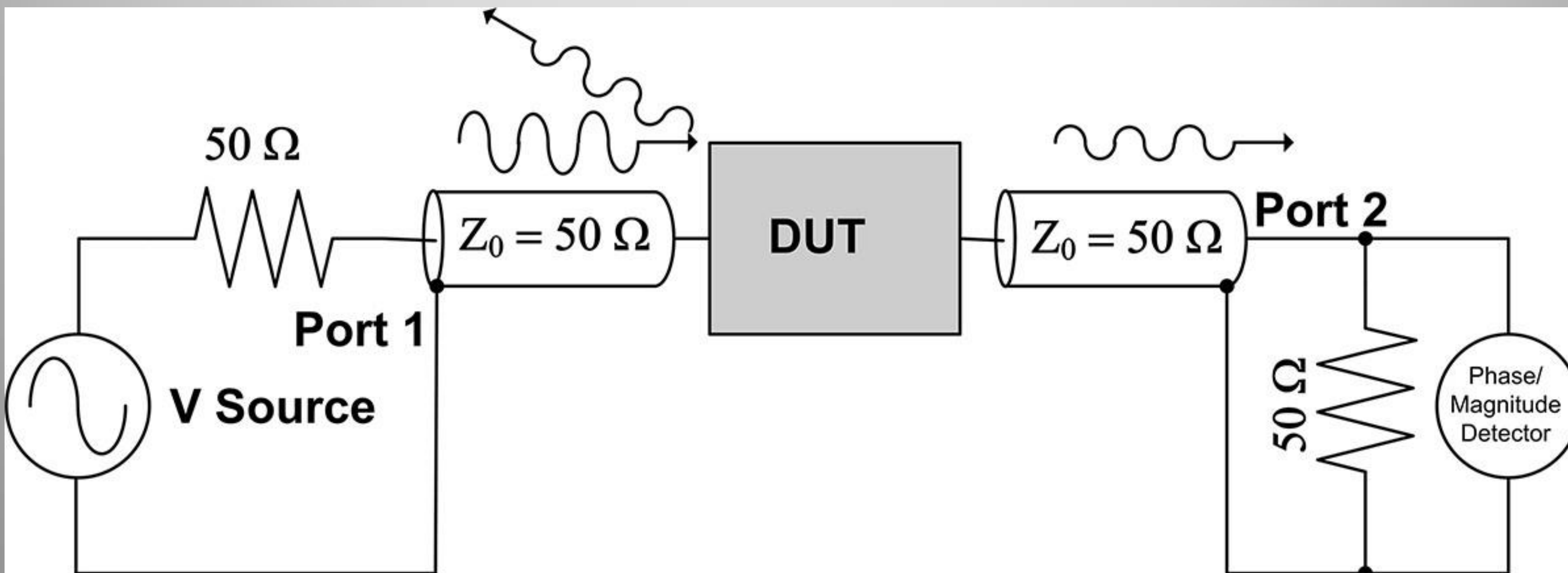
Measurement: limit of 100 data points

resistance, reactance, impedance, SWR, return loss, phase

Smith Chart plots

cable length and attenuation

FORWARD - REFLECTED - THROUGH signals
DUT = "device under test"
typical reference impedance = 50 ohms



Important Parameter Definitions

Reflection coefficient = V (reflected) / V (incident)

reflection coefficient = **ρ** (rho)

$$0 < \rho < 1$$

REFLECTION LOSS (dB) = - 20 log (**ρ**)

SWR = (1 + ρ) / (1 – ρ) = V(max) / V (min)

How these relate to each other

Reflection Parameters

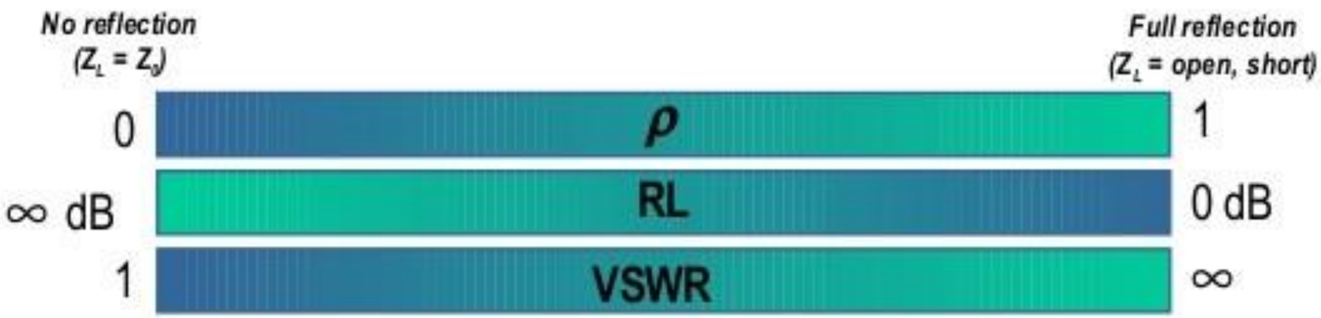
- **Return Loss, VSWR, Impedance, and Scalar Reflection Coefficient are calculated from measured Vector Reflection Coefficient** (Γ)

$$\text{Reflection Coefficient } (\Gamma) = \frac{V_{reflected}}{V_{incident}} = \rho\angle\Phi = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$\rho = |\Gamma|$$

$$\text{VSWR} = \frac{\text{Vmax}}{\text{Vmin}} = \frac{1+\rho}{1-\rho}$$

$$\text{Return Loss} = -20\log(\rho)$$



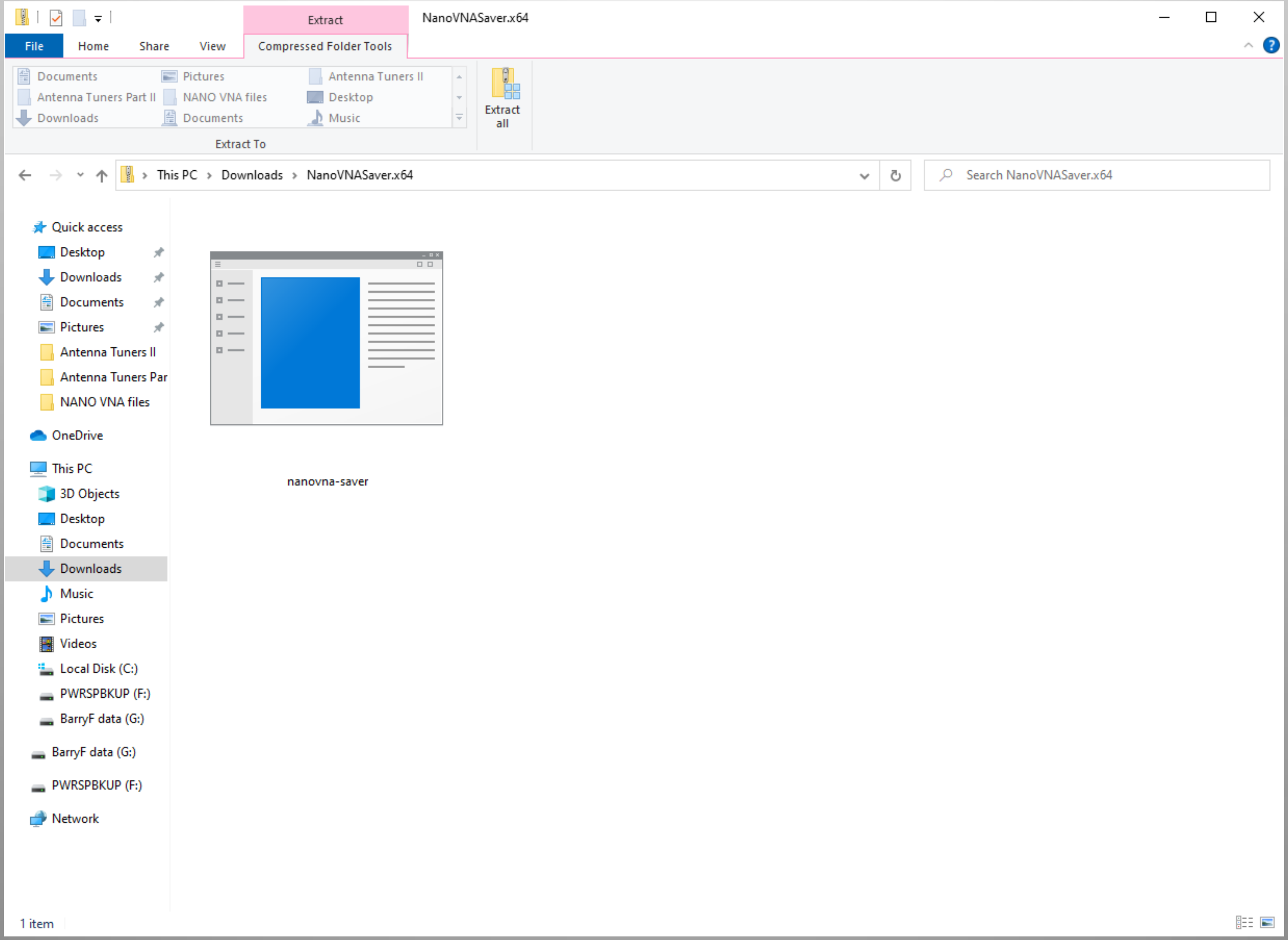
First Step: CALIBRATE over a frequency range (MHz)
Calibration standards included as SMA connectors
Short, Open, Load (50-ohm), and Through

Useful Cables: SMA to SO239 coax

USB connections to computer and battery charger

Nano VNA Saver software

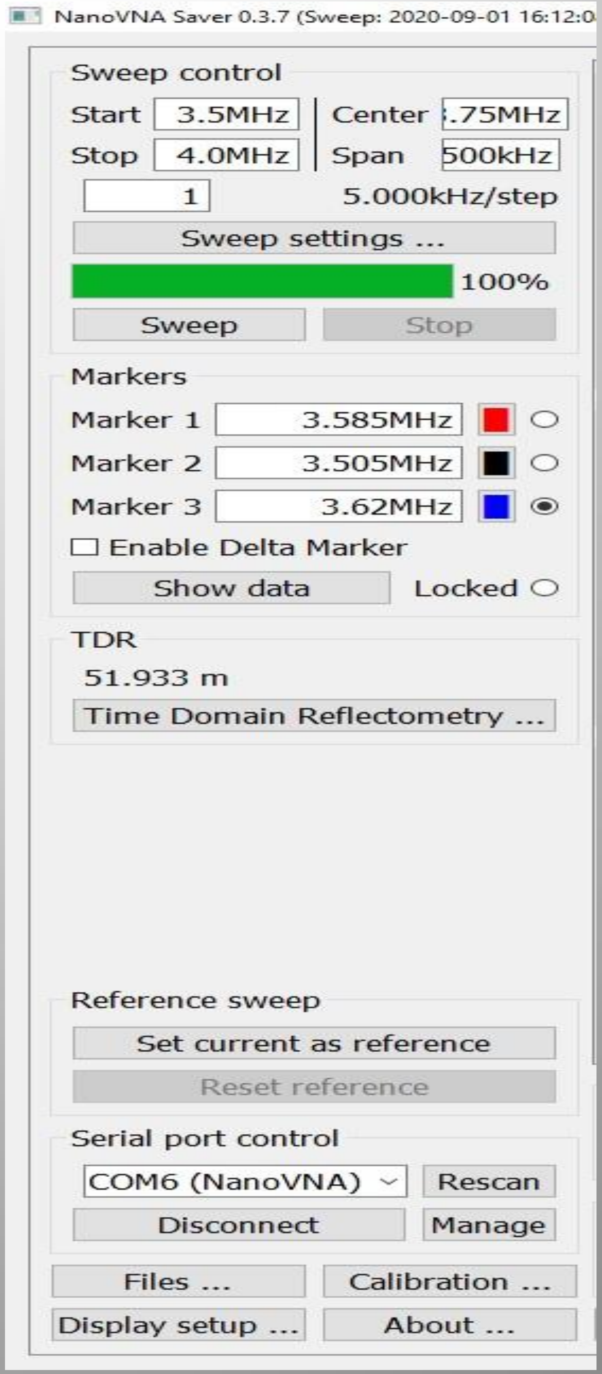
much easier to use by computer control



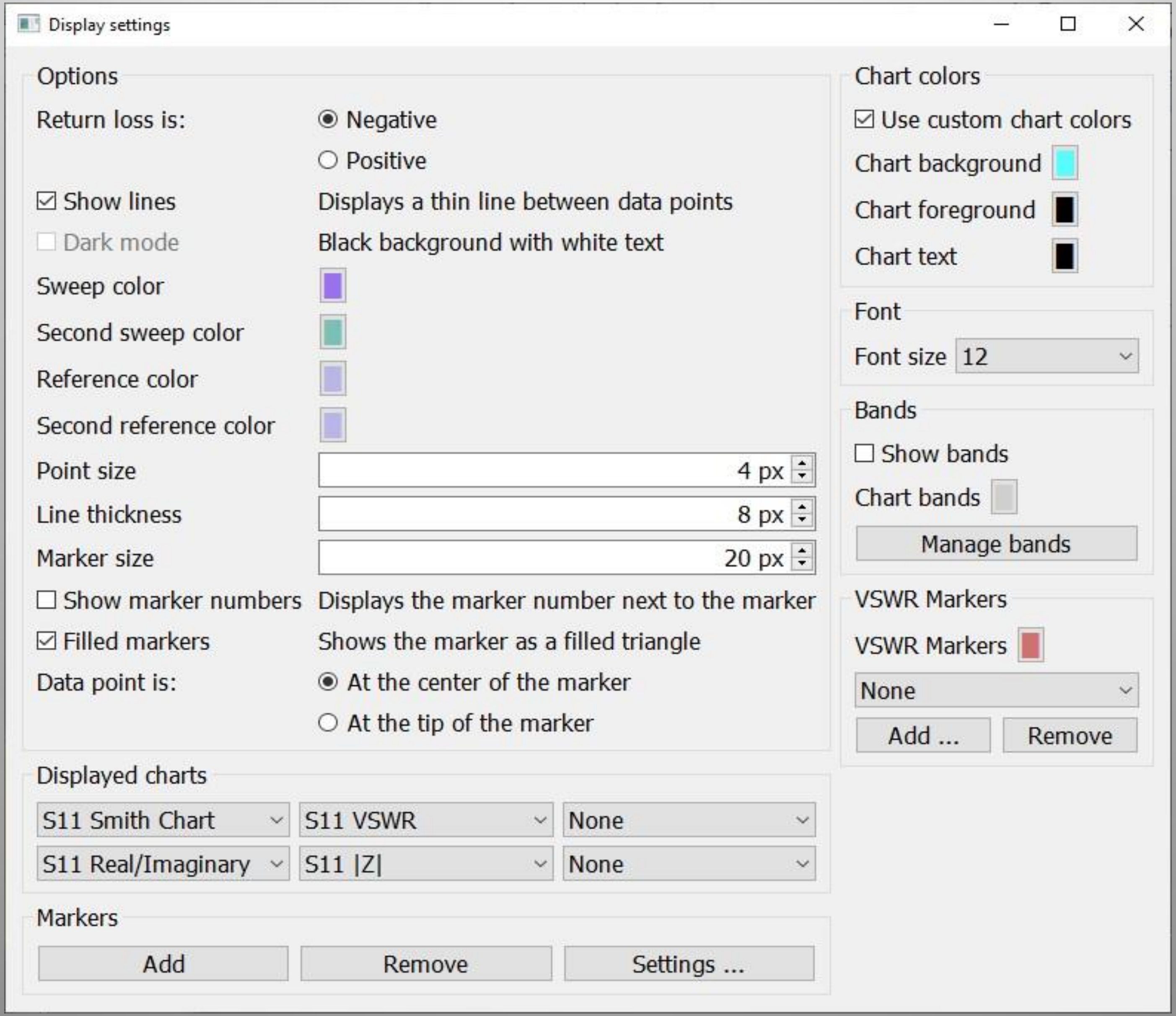
Computer Control
Settings

Com Port select
Frequency Range
Markers

Sweep resolution
SAVE and RETRIEVE files
Display setup of GRAPHS
Calibration



Choose Graphs to display (up to 6) Colors, etc.

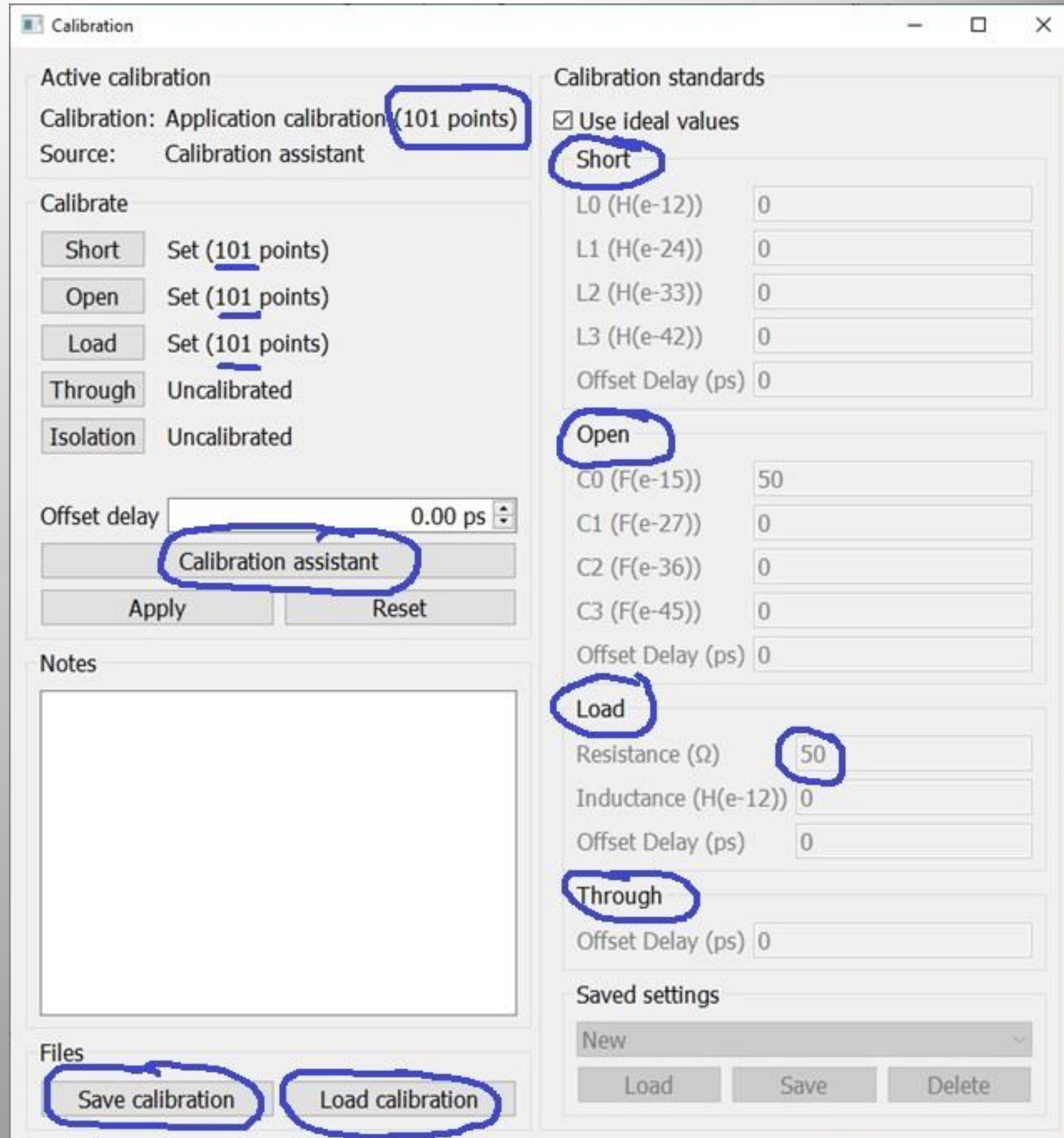


Do a calibration first
Calibration “assistant”

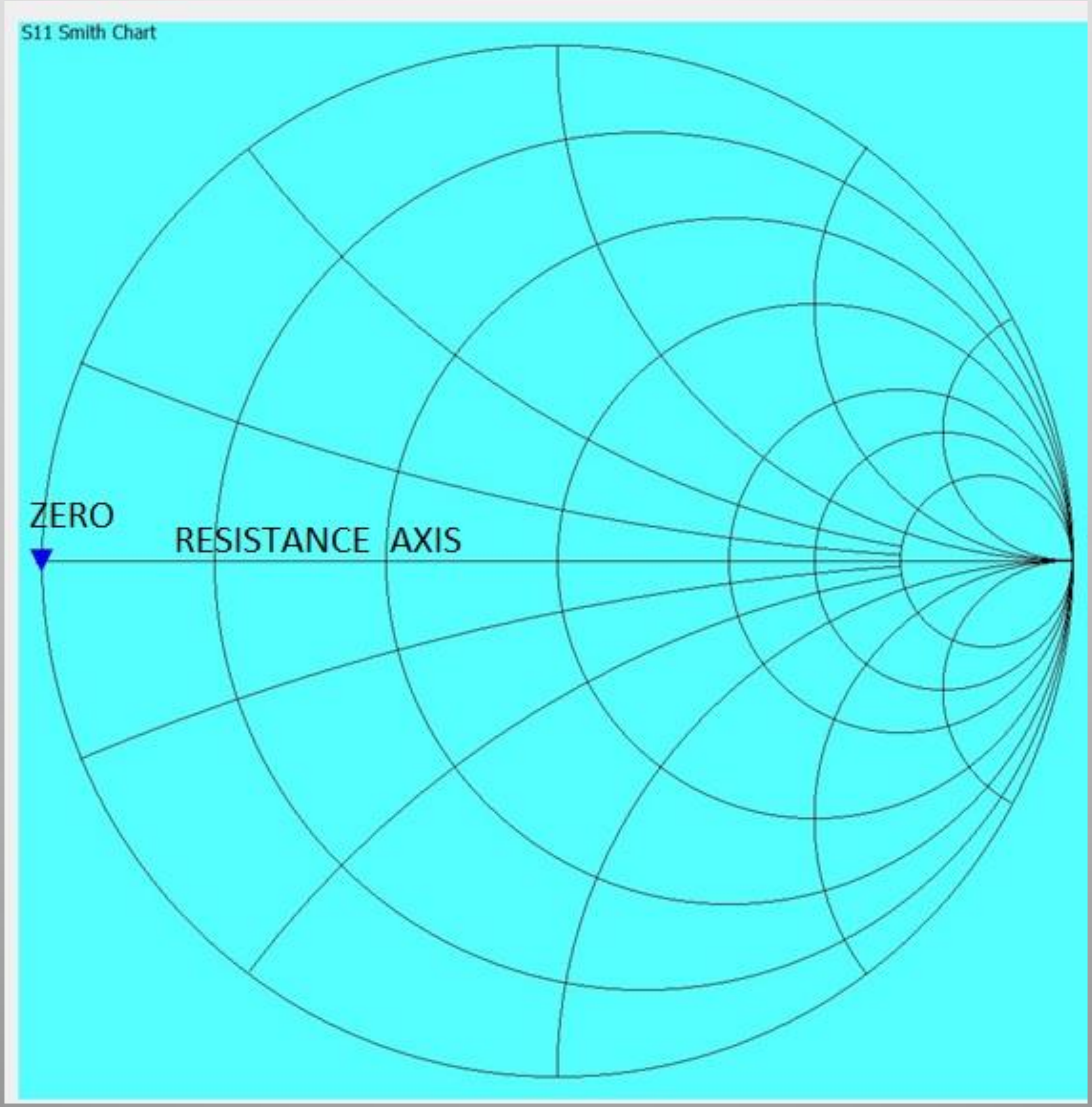
take min of 101 readings
SHORT
OPEN
LOAD
THROUGH two ports
ISOLATION two ports

SAVE CAL files

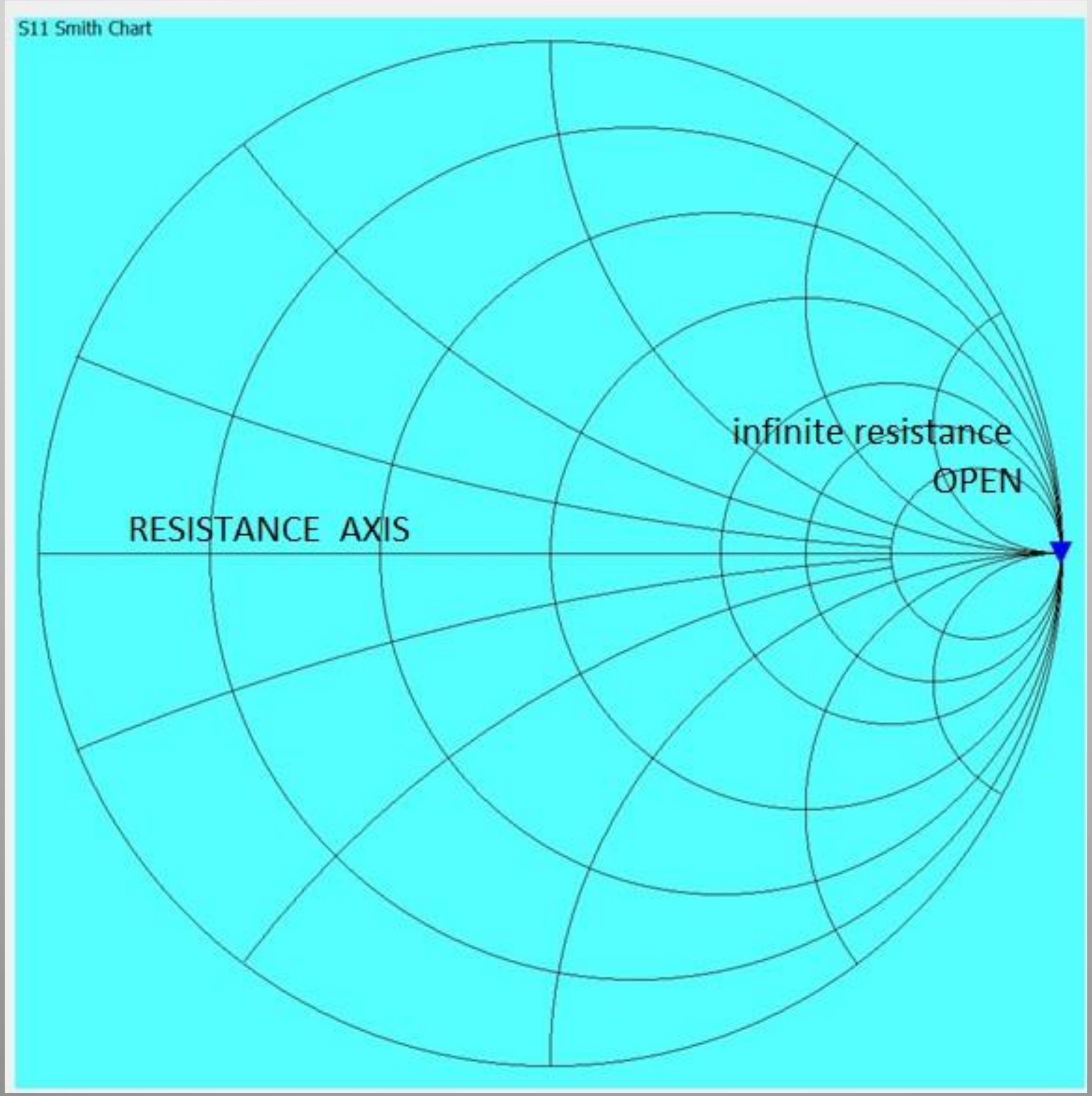
You can use up to 5000 data points to plot



Calibration: **SHORT** circuit (ZERO R) on far left of the Smith Chart RESISTANCE axis

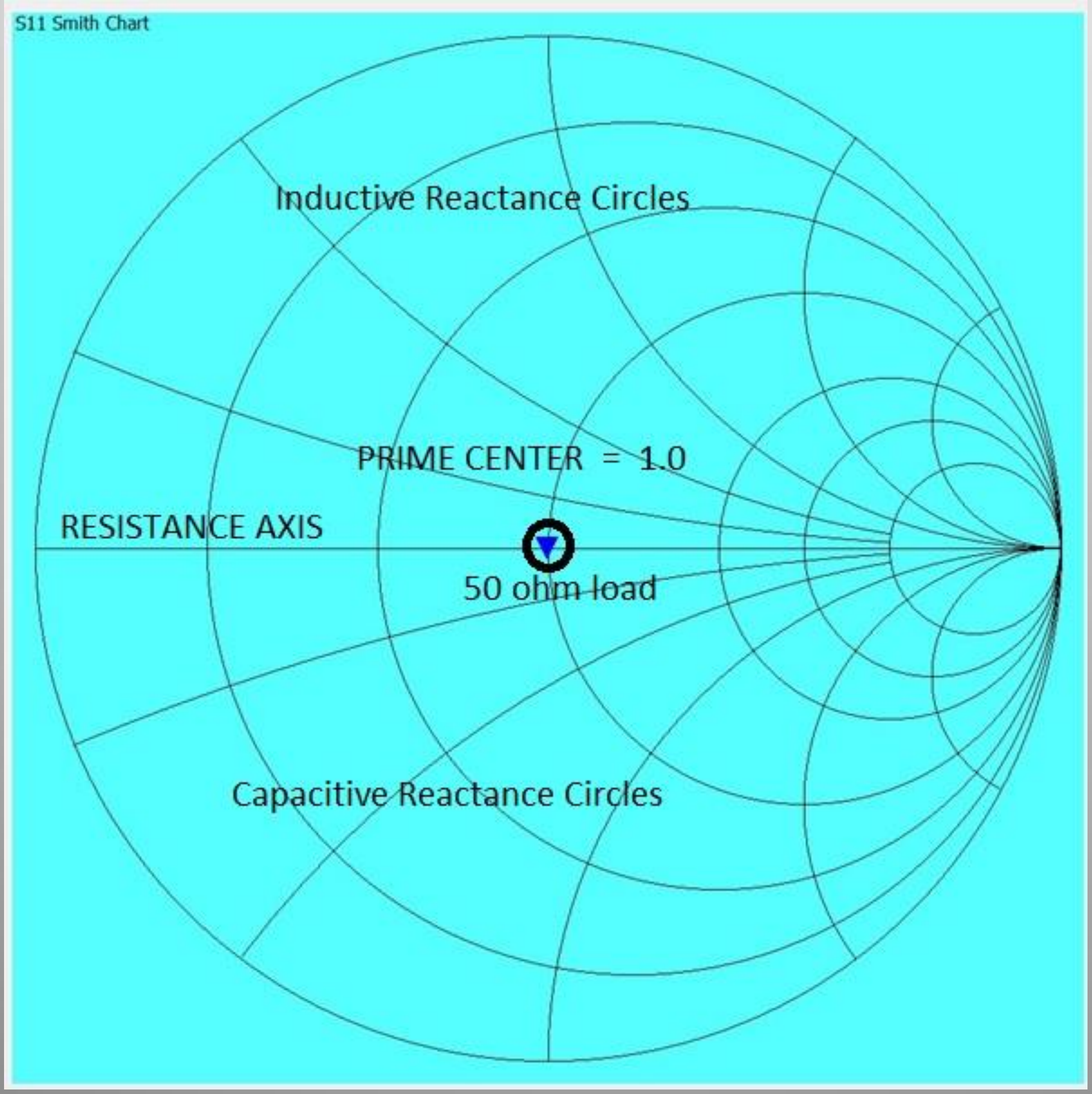


Calibration: **OPEN** circuit (infinite R) on far right of the RESISTANCE axis



Calibration: **<u>50-ohm</u> LOAD (prime center)**

middle of the RESISTANCE scale: normalized to **1.0**

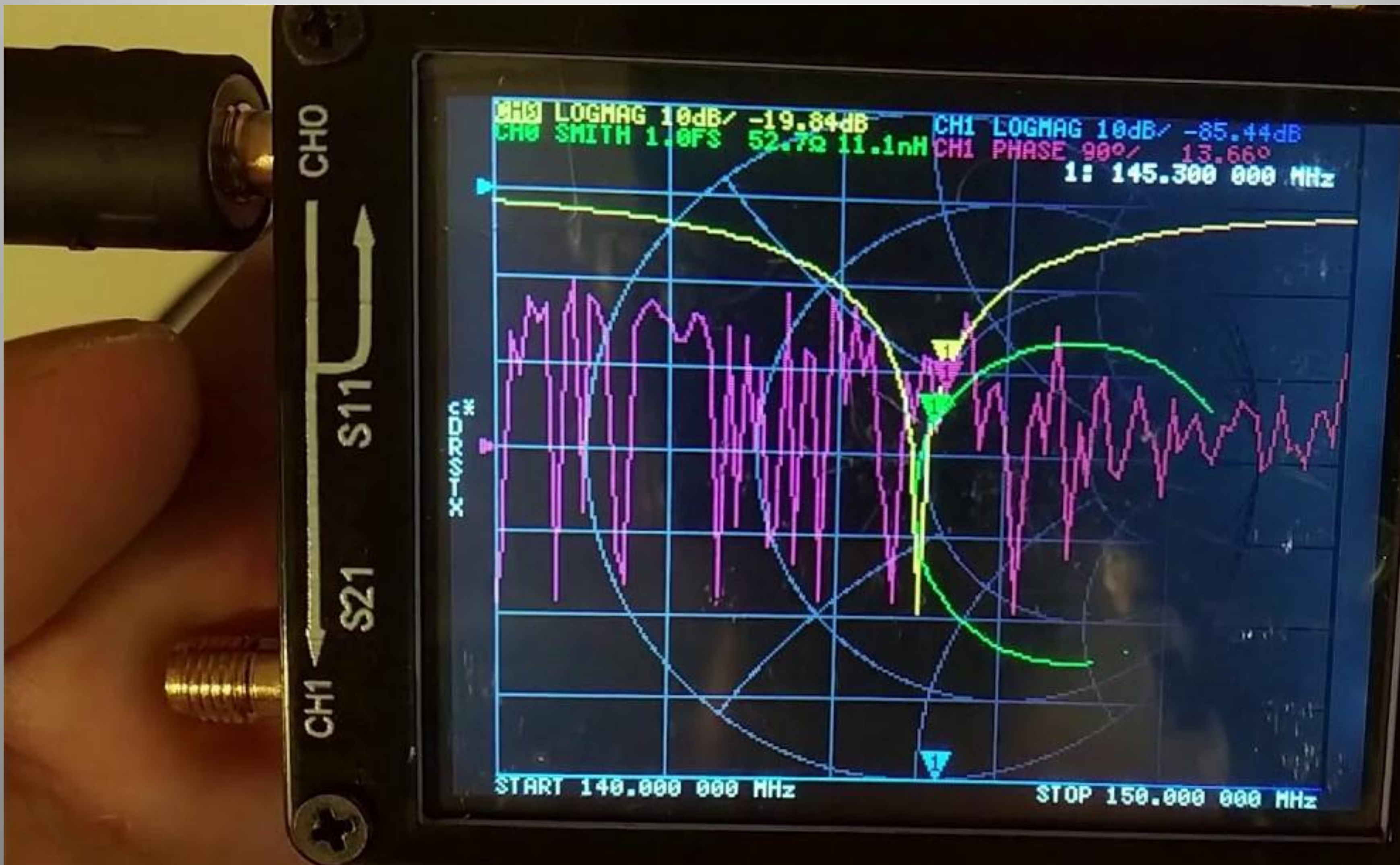


We WILL return to Smith Charts later

You can also CALIBRATE the device on its own (small) screen: limit of 101 data points

Signal goes out and returns via same CH0 port (Ch1 empty)

You have FOUR colors and FOUR graphs (if you want)

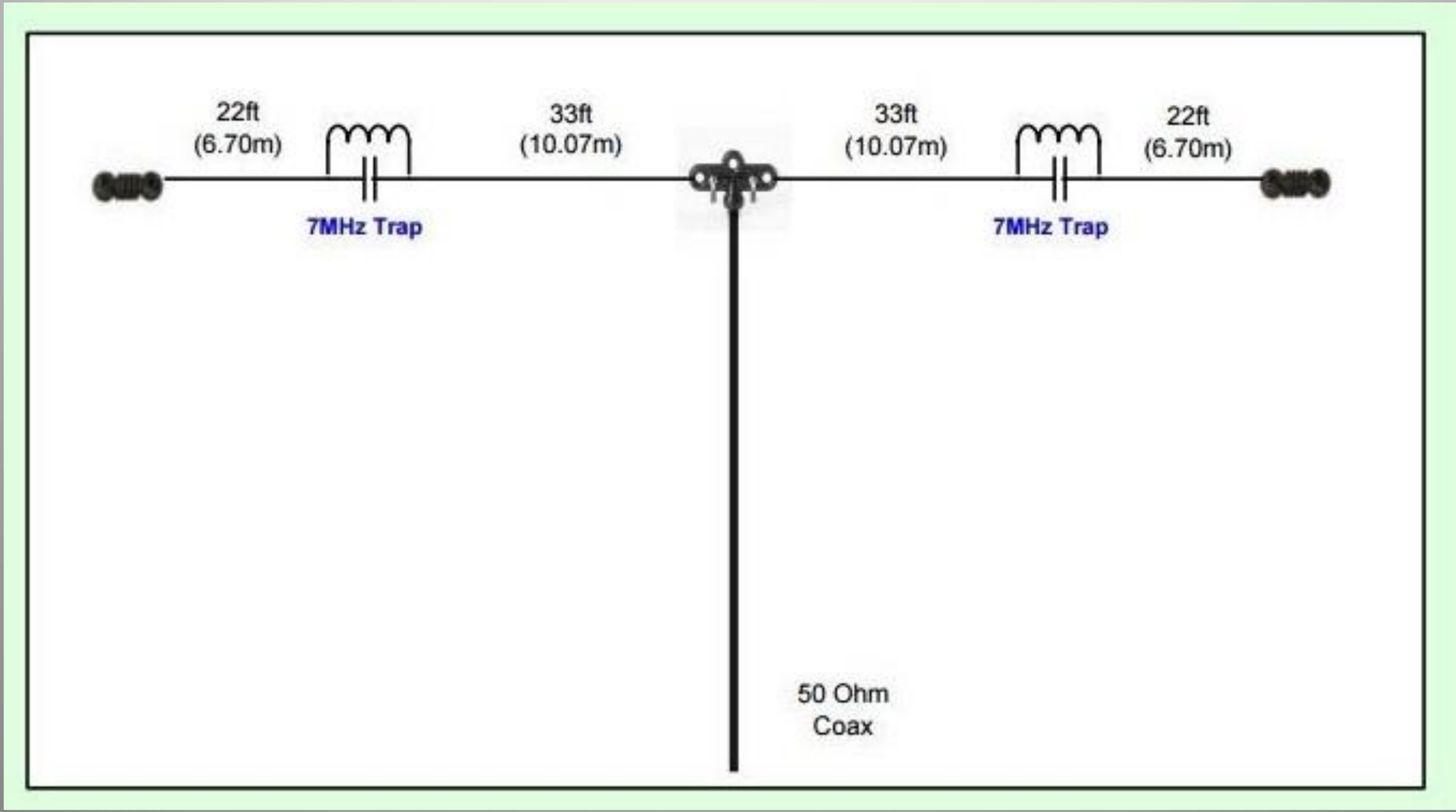


Let’s check out some of the antennas at K3EUI QTH

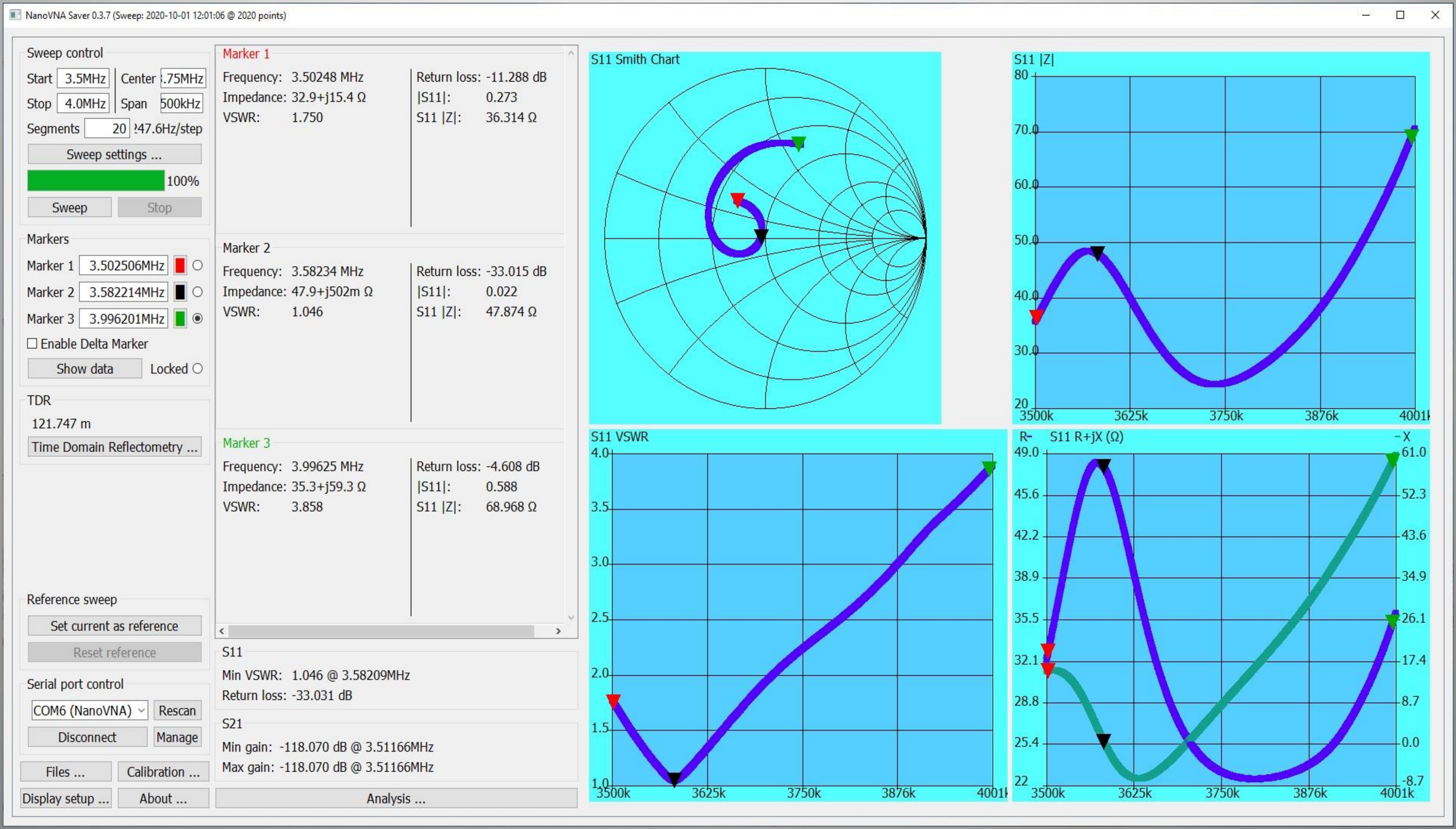
80 and 40 meter TRAP DIPOLE

Trap is high-impedance LC tuned to 7 MHz

Overall length about 110 feet

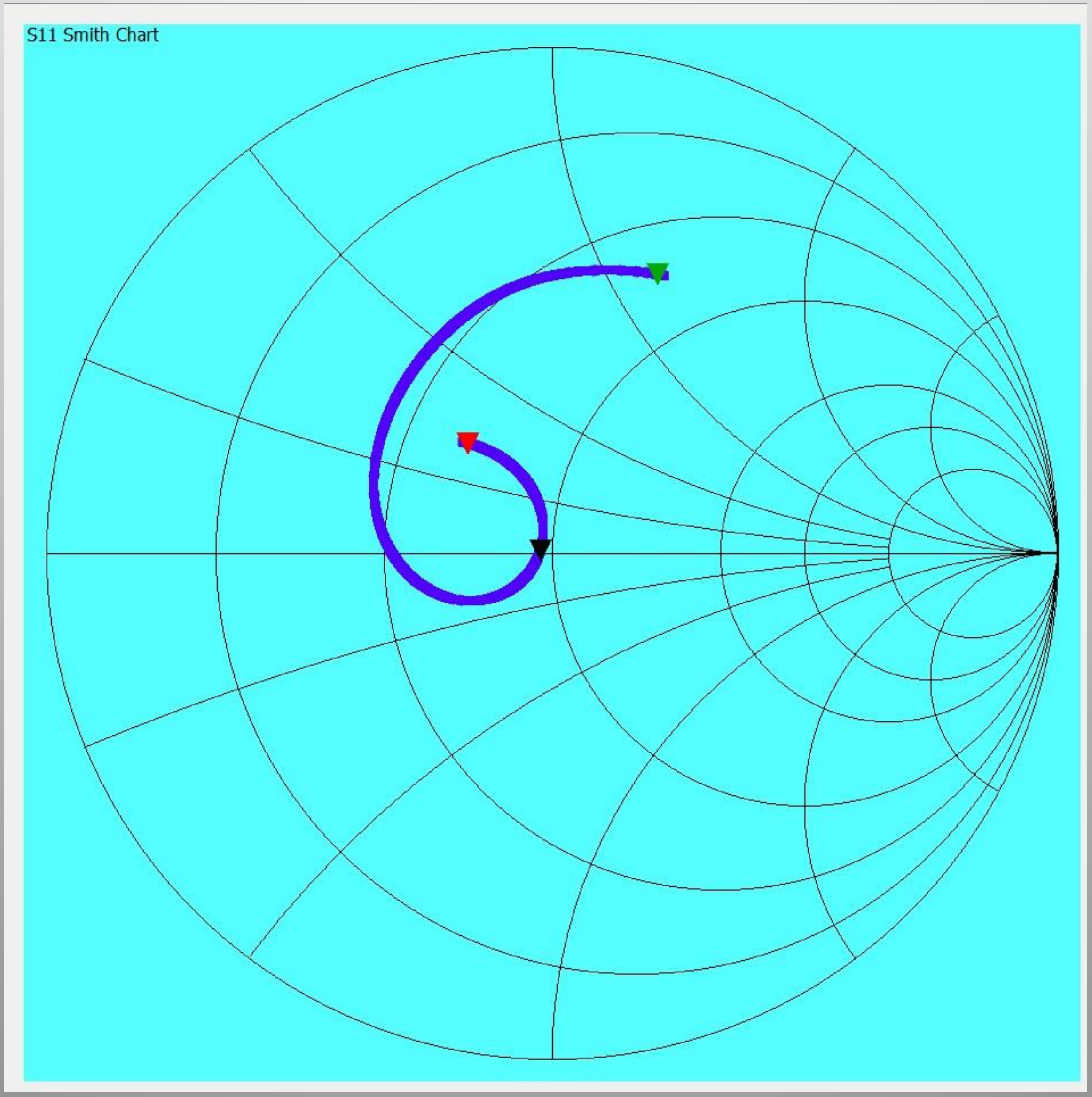


80/40 meter trap dipole: 80m traces
25 feet above ground
Tuned to the "low" end of 80m band



80/40 meter Trap Dipole: **Smith Chart**

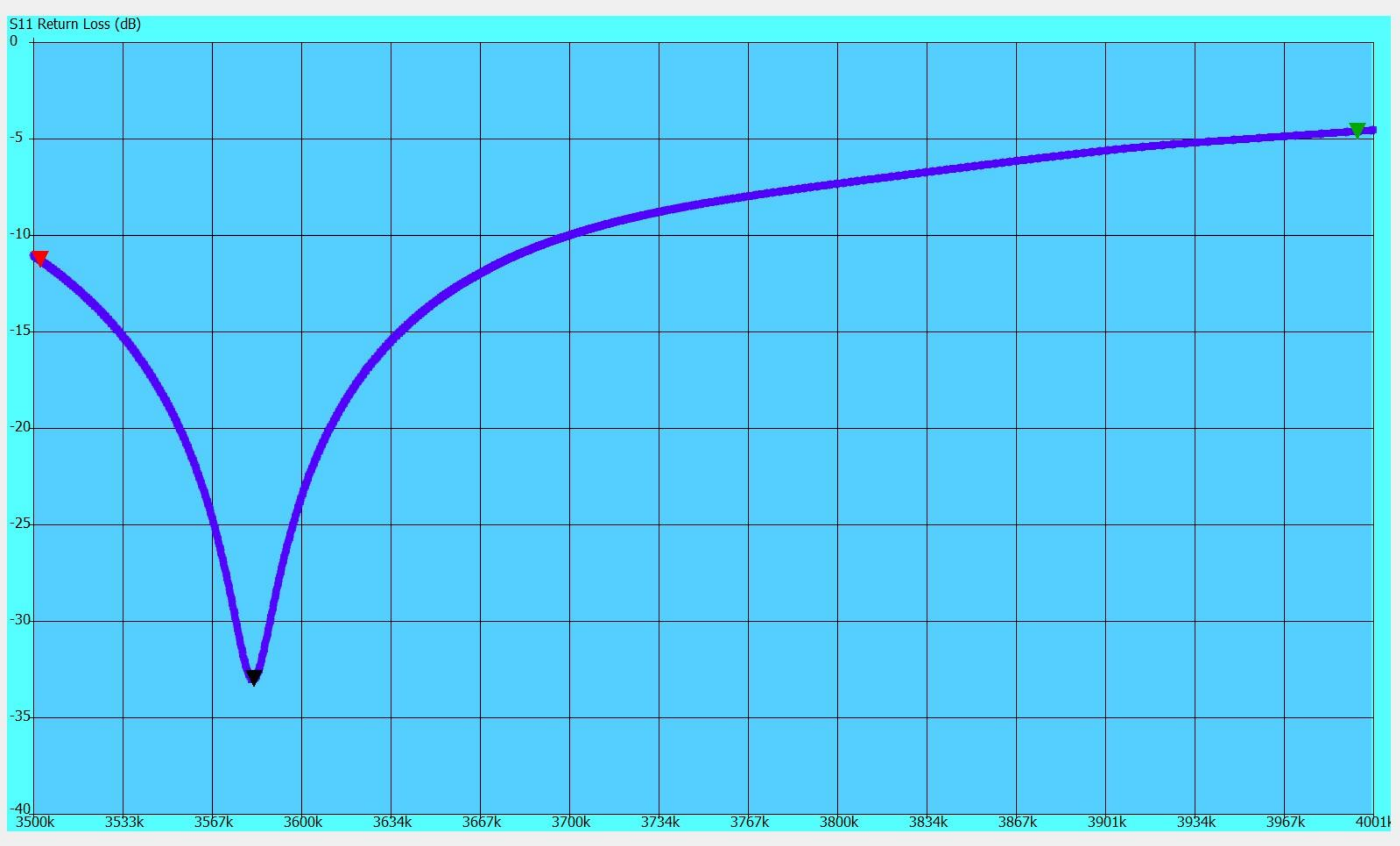
Markers: RED 3500 kHz , BLACK 3600 kHz, GREEN 4000 kHz



80/40m trap dipole: **RETURN LOSS** (dB)

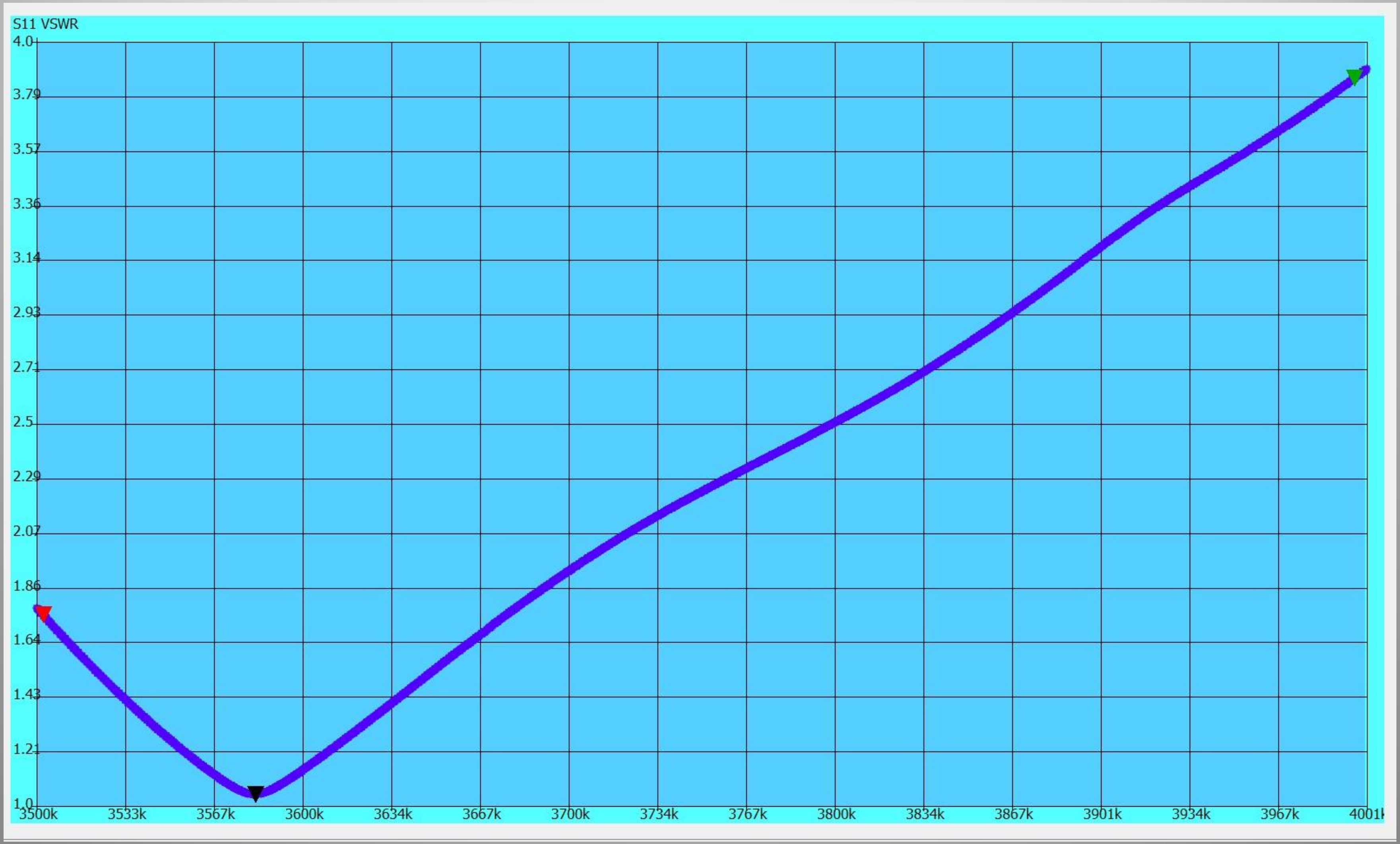
RL = -20 log (Voltage reflected / Voltage incident)

If SWR = 1:1 then RL is infinite



SWR 80/40m trap dipole 3.5 to 4.0 MHz

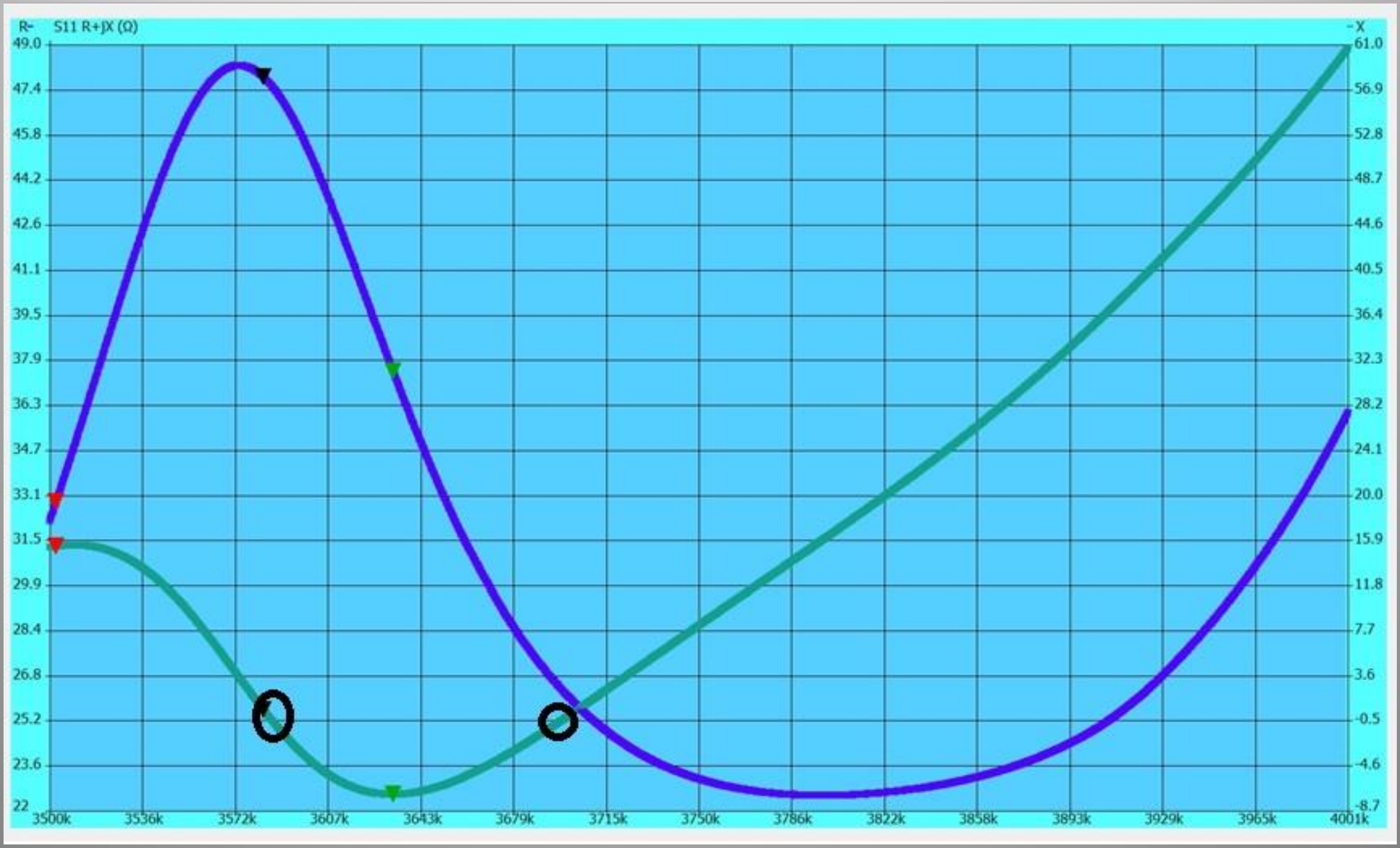
Markers: Red 3500 kHz, Black 3580 kHz, Green 3990 kHz



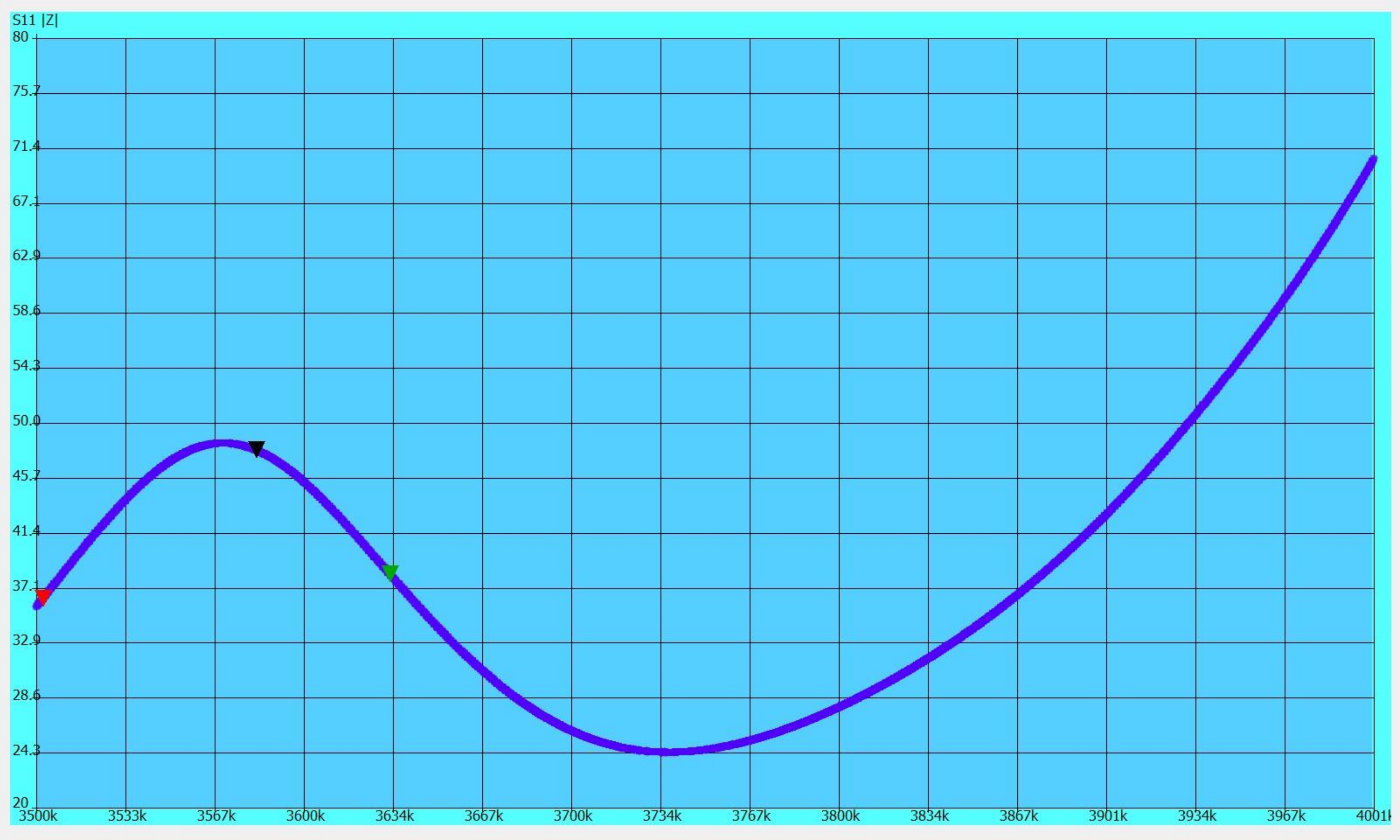
80/40 meter Trap Dipole

Resistance R (left scale) BLUE and **Reactance X** (right scale)

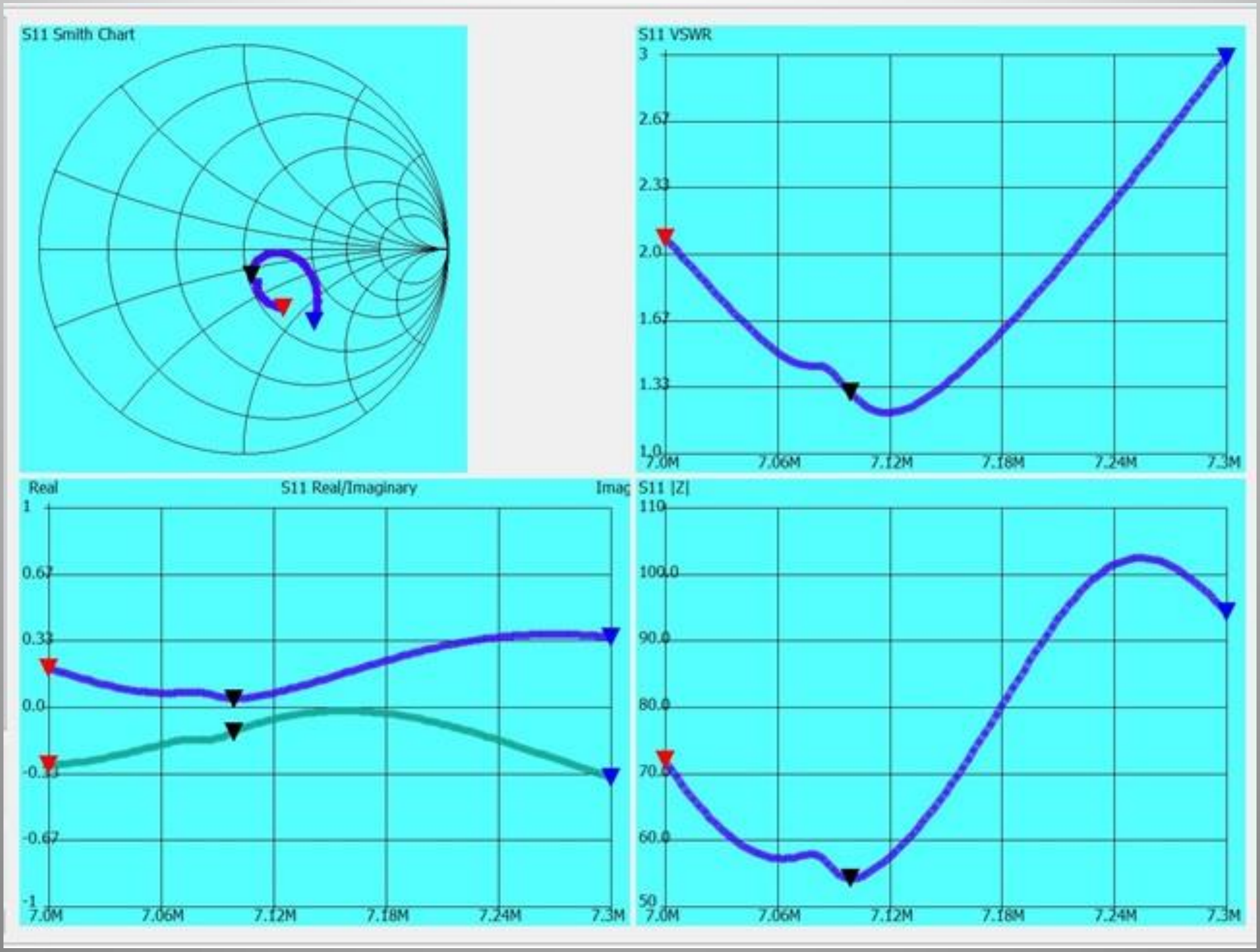
Note <u>TWO</u> locations where X = 0 (resonance)



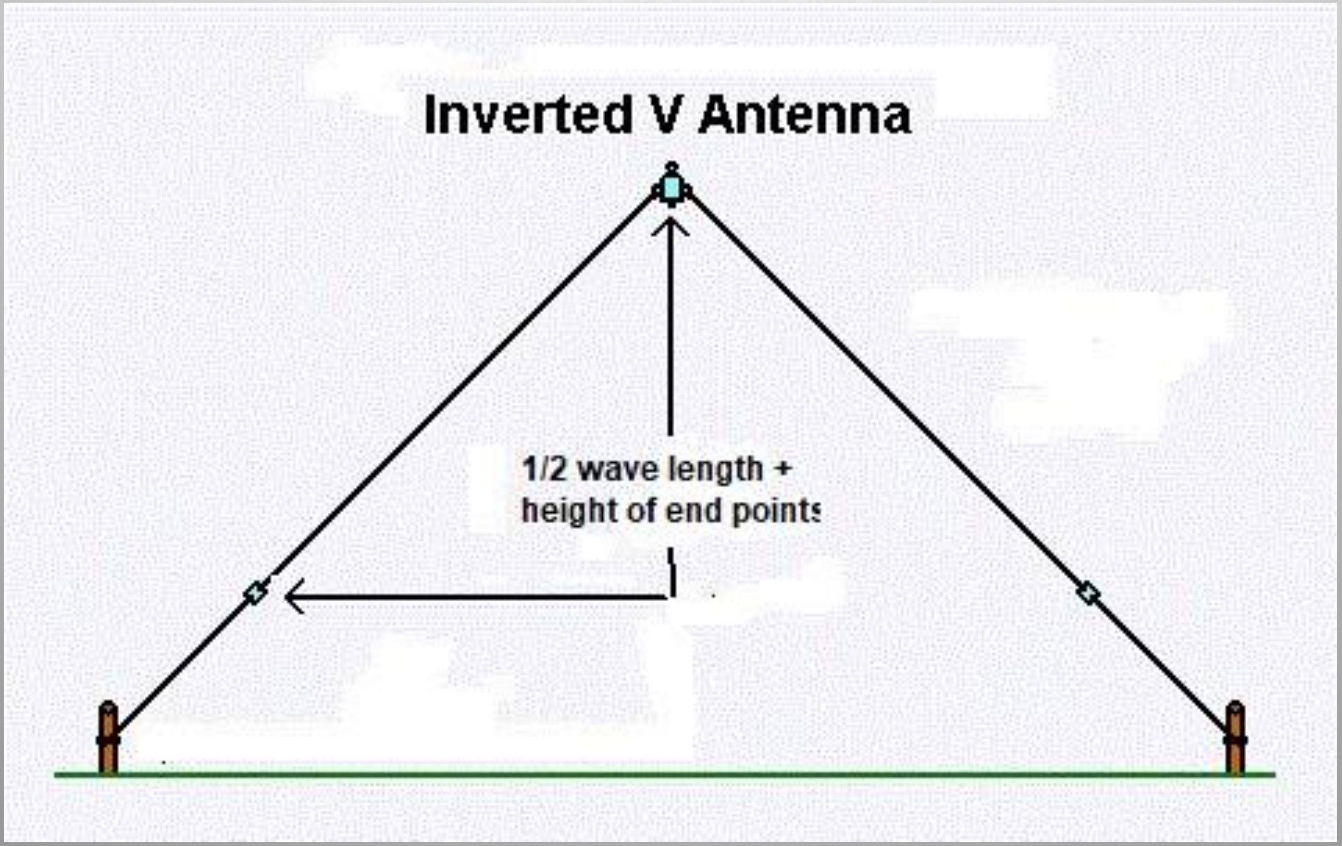
Trap Dipole 80/40 meter: **Impedance** (Z)
Ideal = 50 ohms to match 50 ohm coax



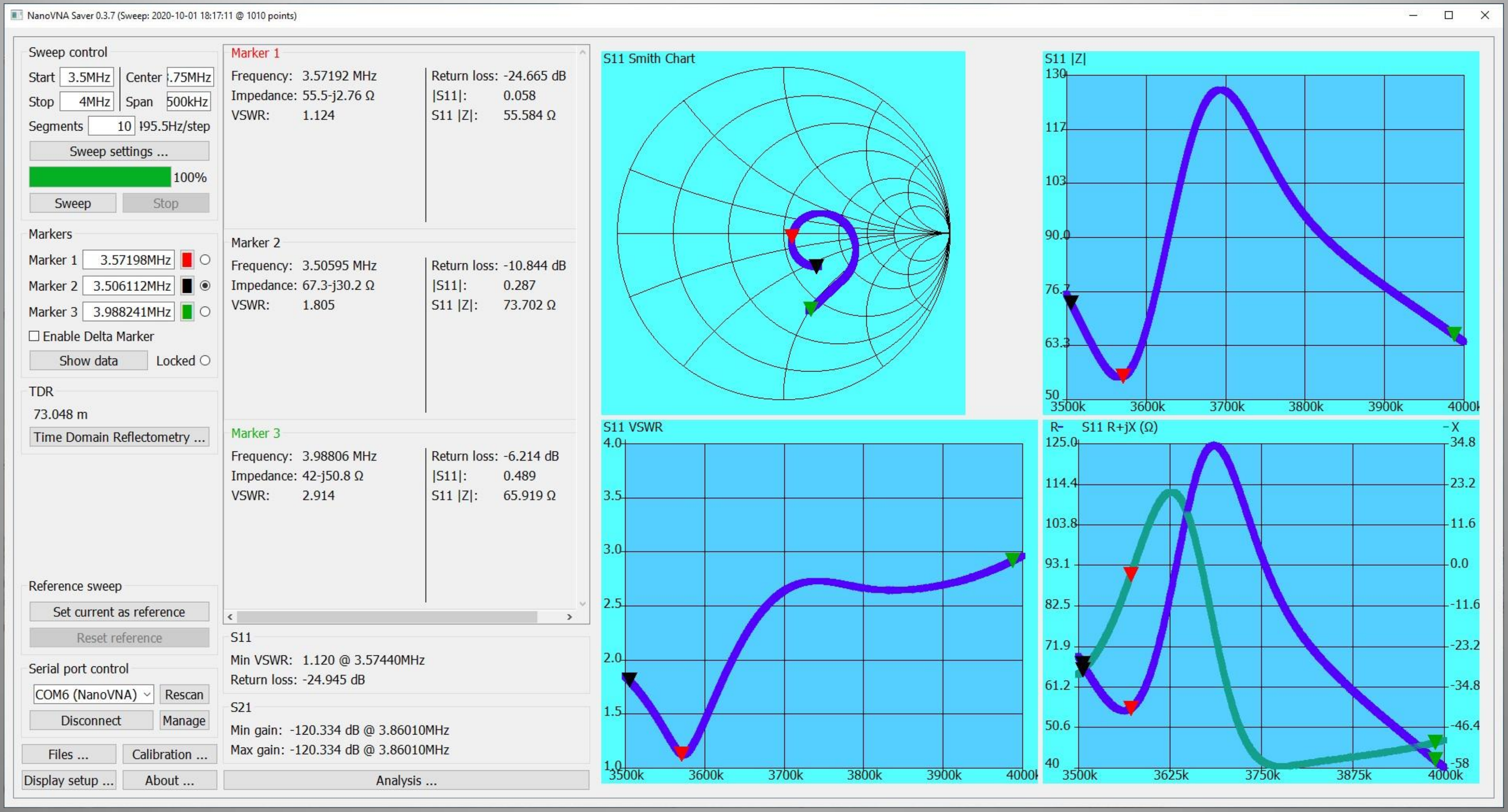
80/40m trap dipole on 40 meters: 7.0 - 7.3 MHz



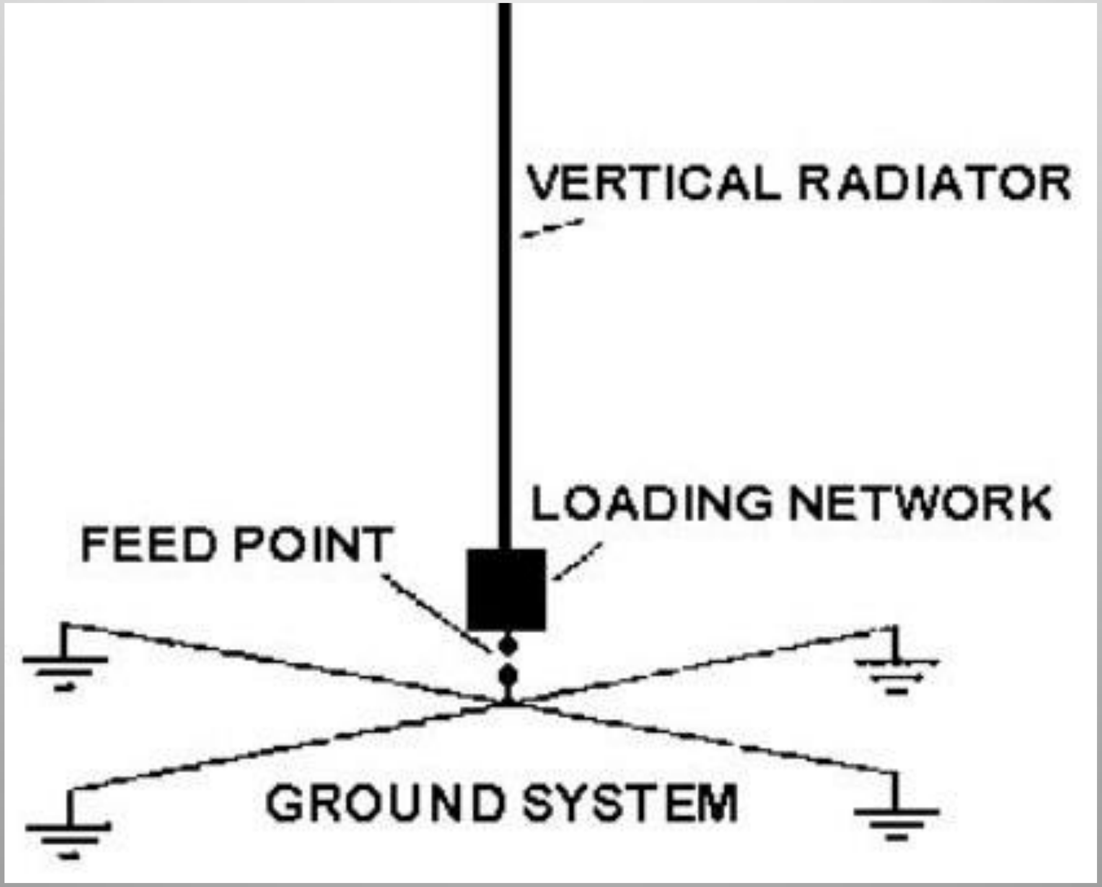
80 meter Inverted V
fed with 100 ft RG213 and W2DU balun



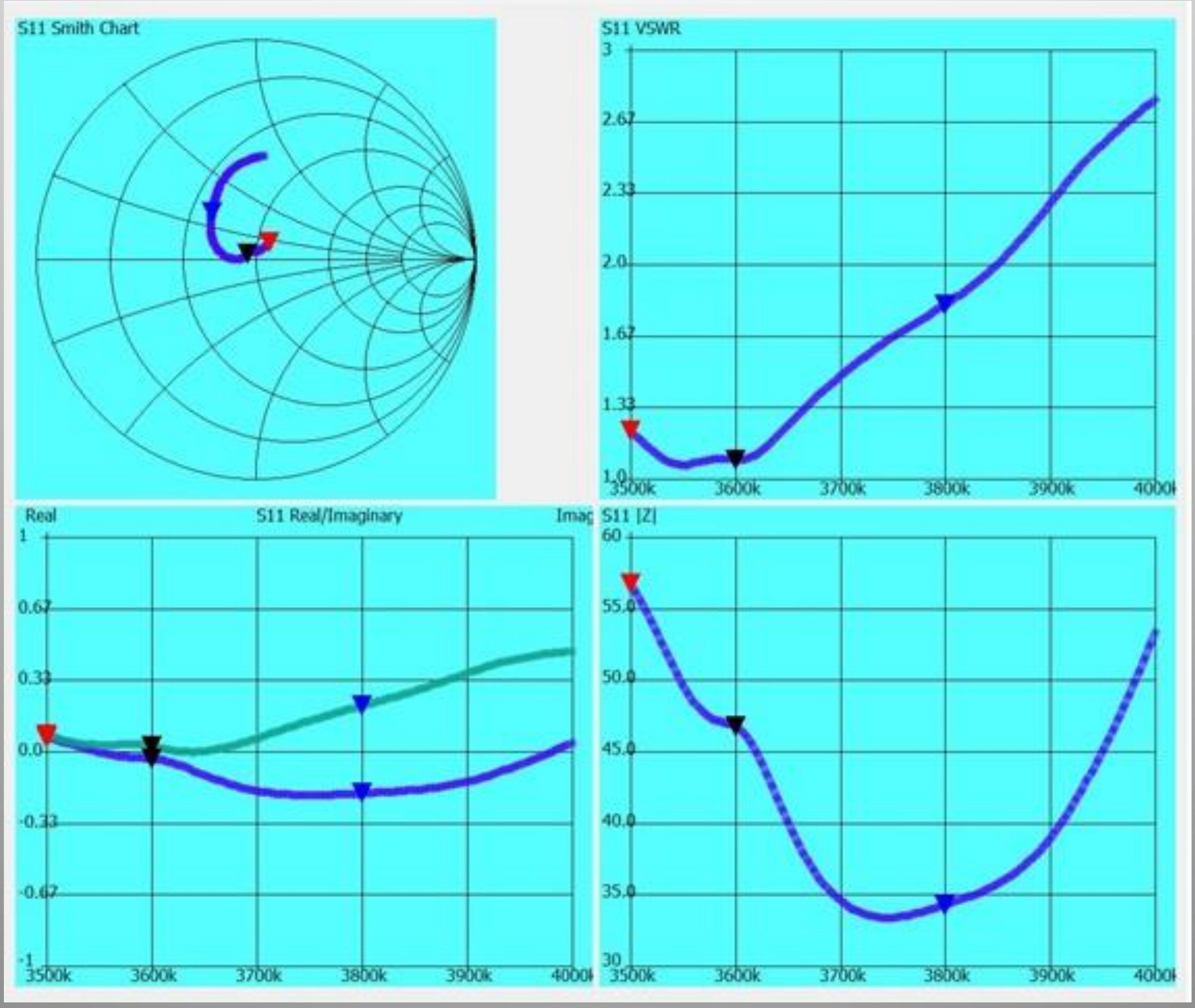
80m Inverted V on porch
cut for low end of band around 3580 kHz



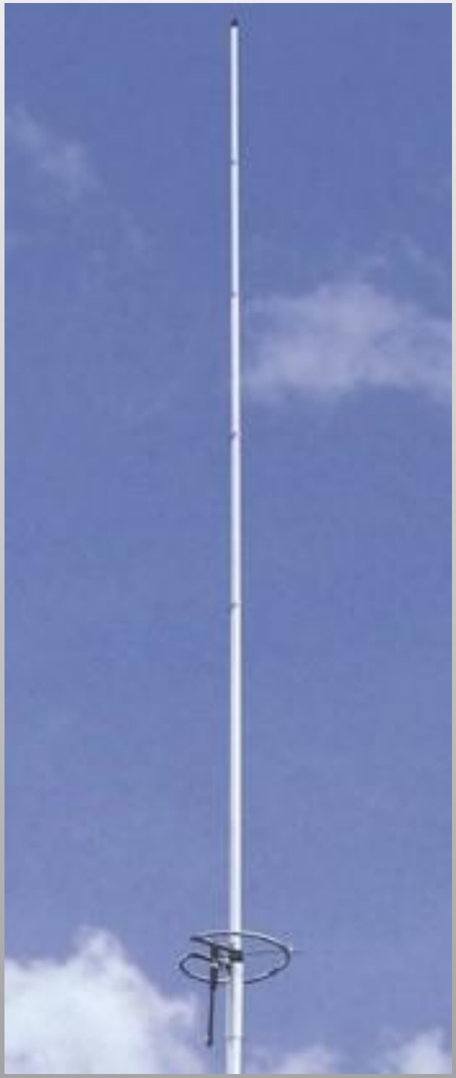
80m Vertical: 40 ft tall with "loading coil" at base and two 65 ft radials 10 ft above ground



80 meter Vertical made from 40 ft of 2-inch surplus aluminum tubing tuned as ¼ wave (with loading coil) with two 65 ft radials



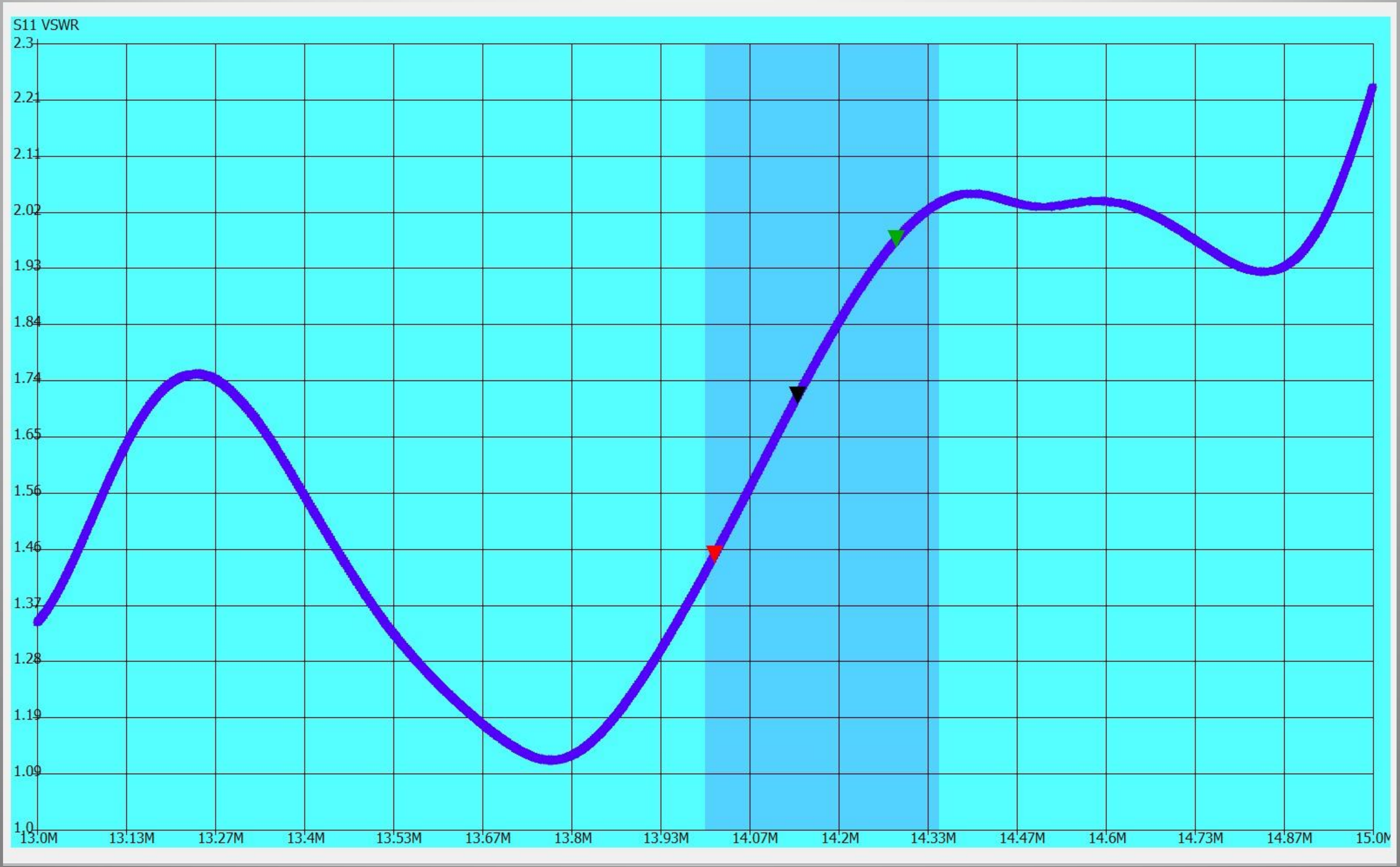
20 m Vertical with 17 ft radials



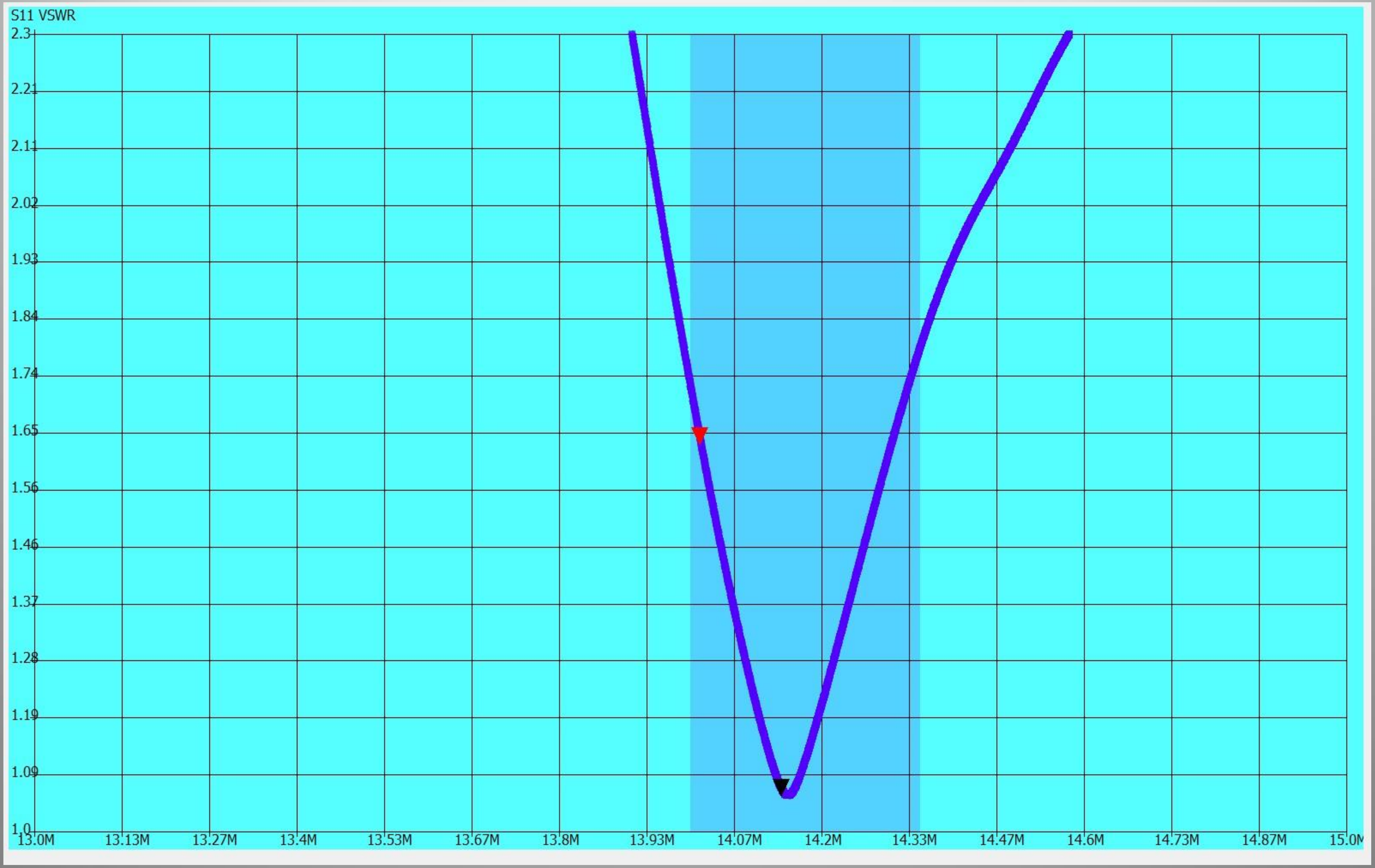
20 meter **home brew** vertical: 17 ft high with two 17 ft radials

this is obviously **mis-tuned** to 13.8 MHz

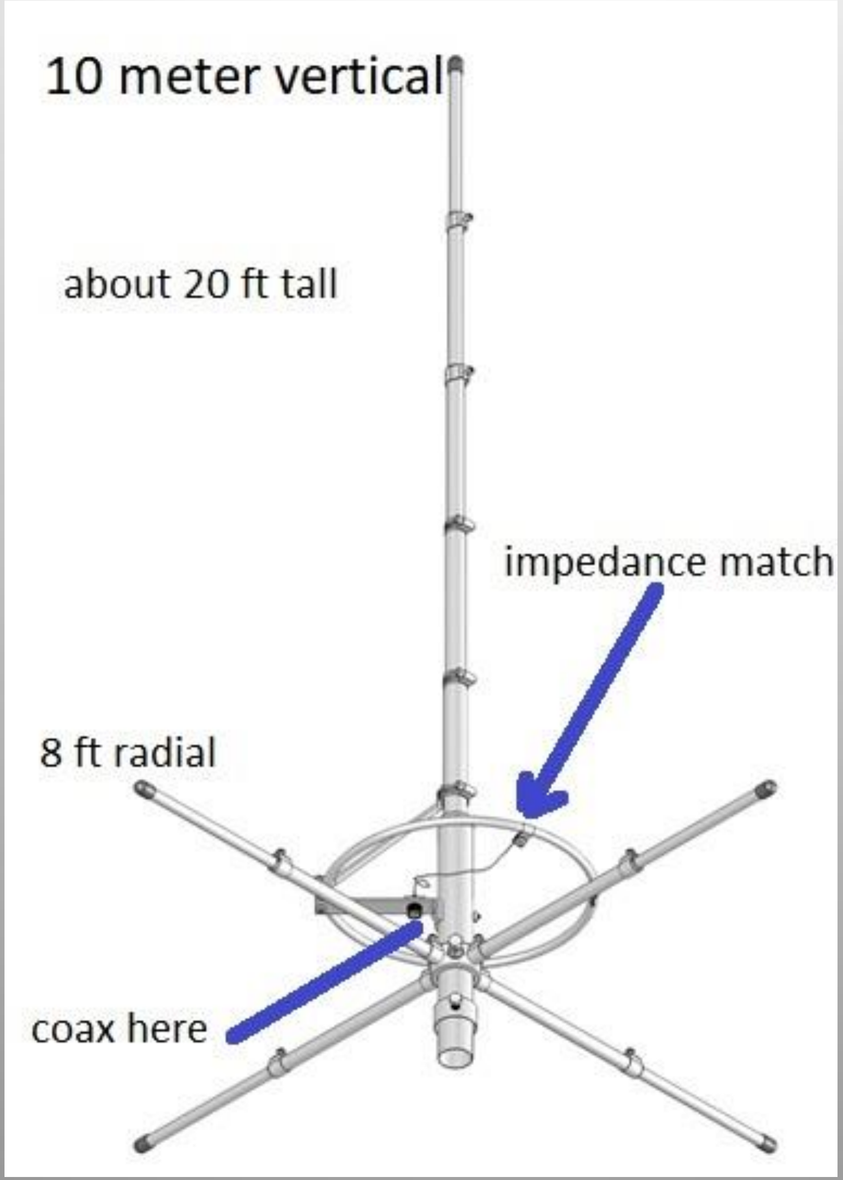
Conclusion: shorten the vertical and the radials to about 16.5 feet



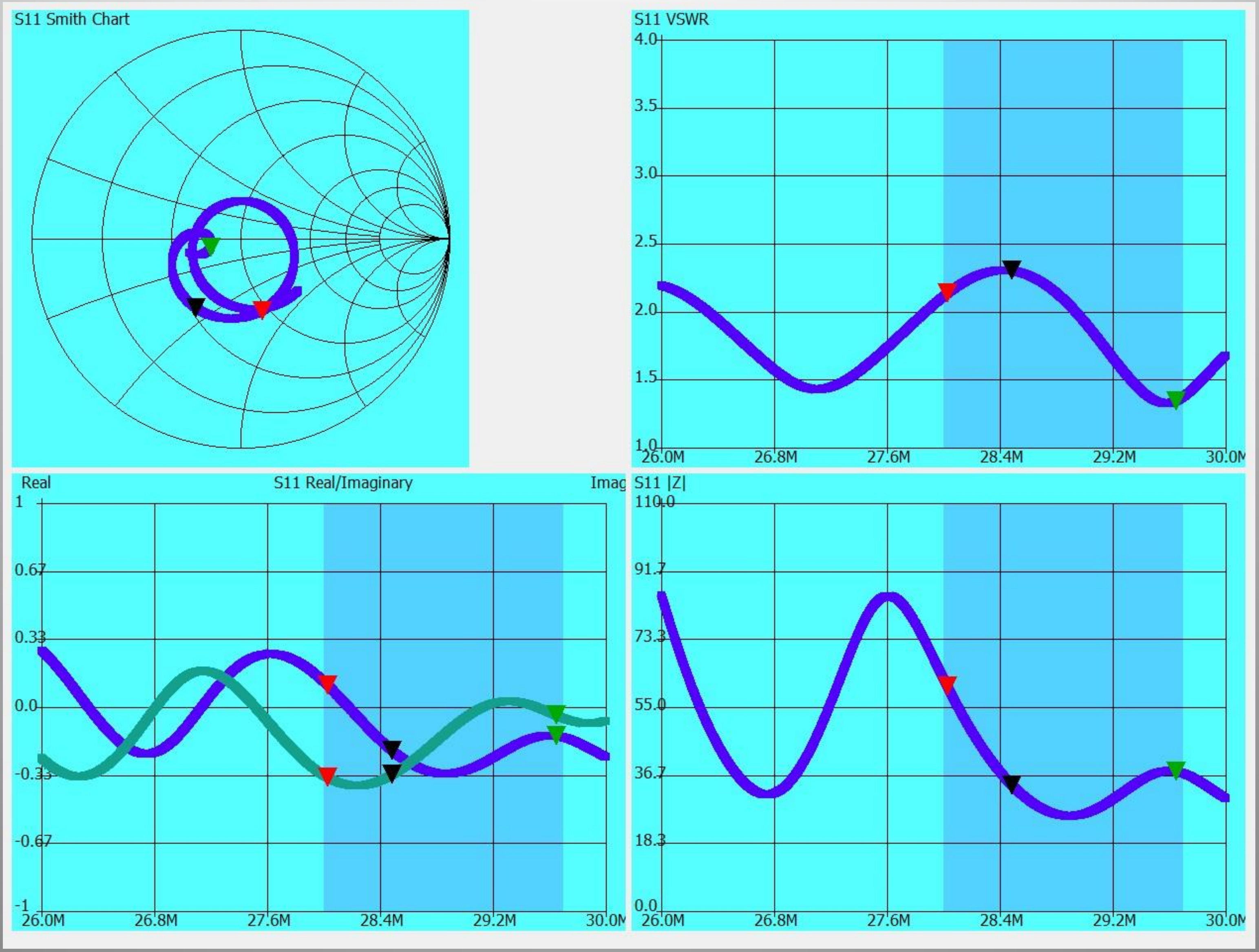
OR, just hook up my antenna tuner in the shack and lower the SWR on 20m



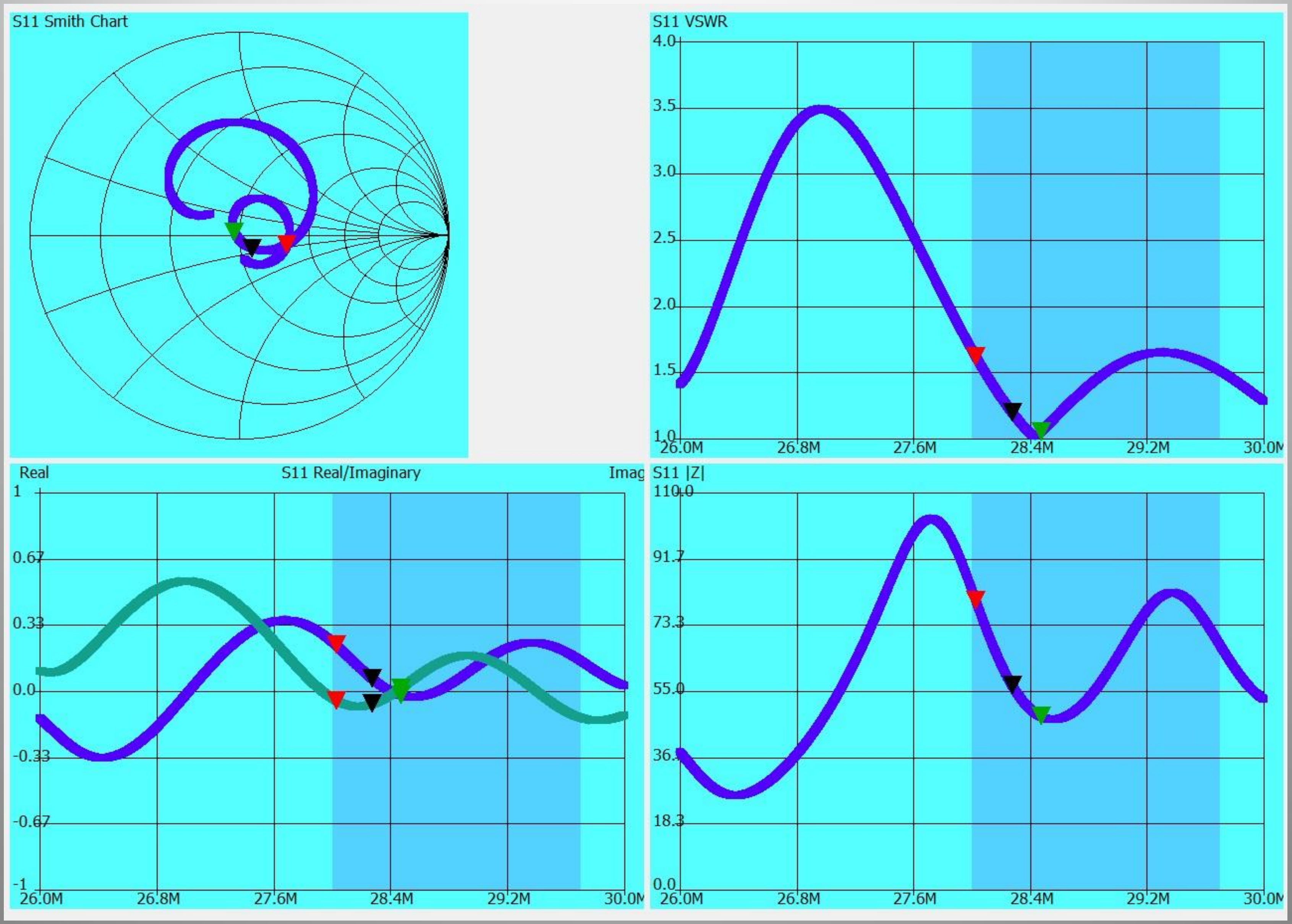
Jetstream 10m vertical: 5/8 wave



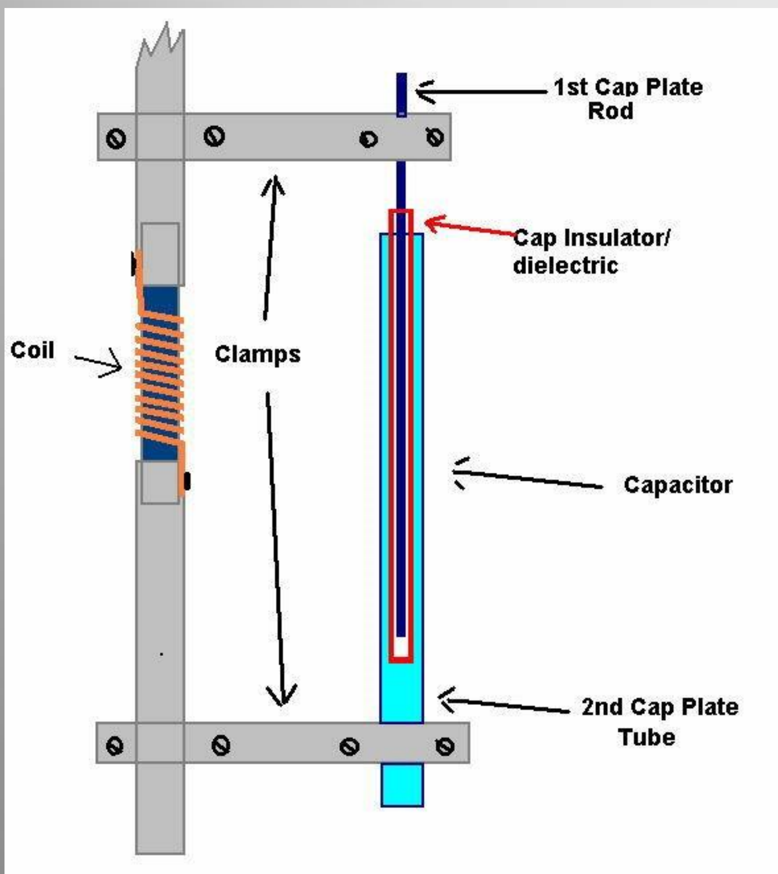
10 meter vertical: 5/8 wave (about 20 ft tall)
badly mistuned below the 10m band to 26.8 MHz



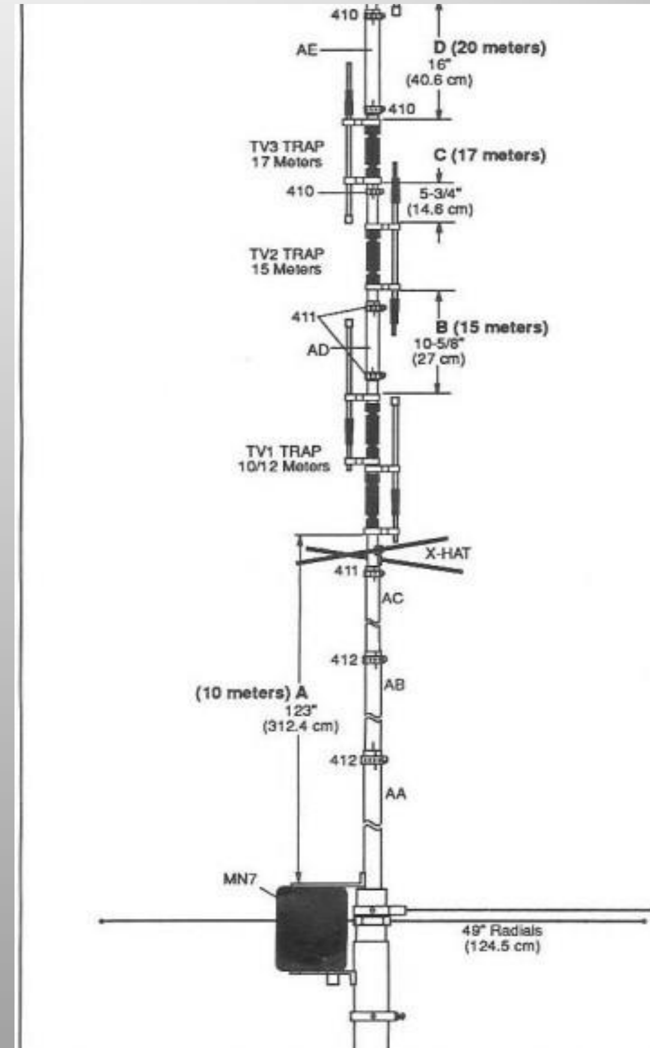
Same 10m antenna post antenna tuner



Cushcraft **R5** Vertical (5 bands) with "traps" for 10/12/15/17 m bands (Traps act as parallel tuned High-Z circuits to isolate each band)

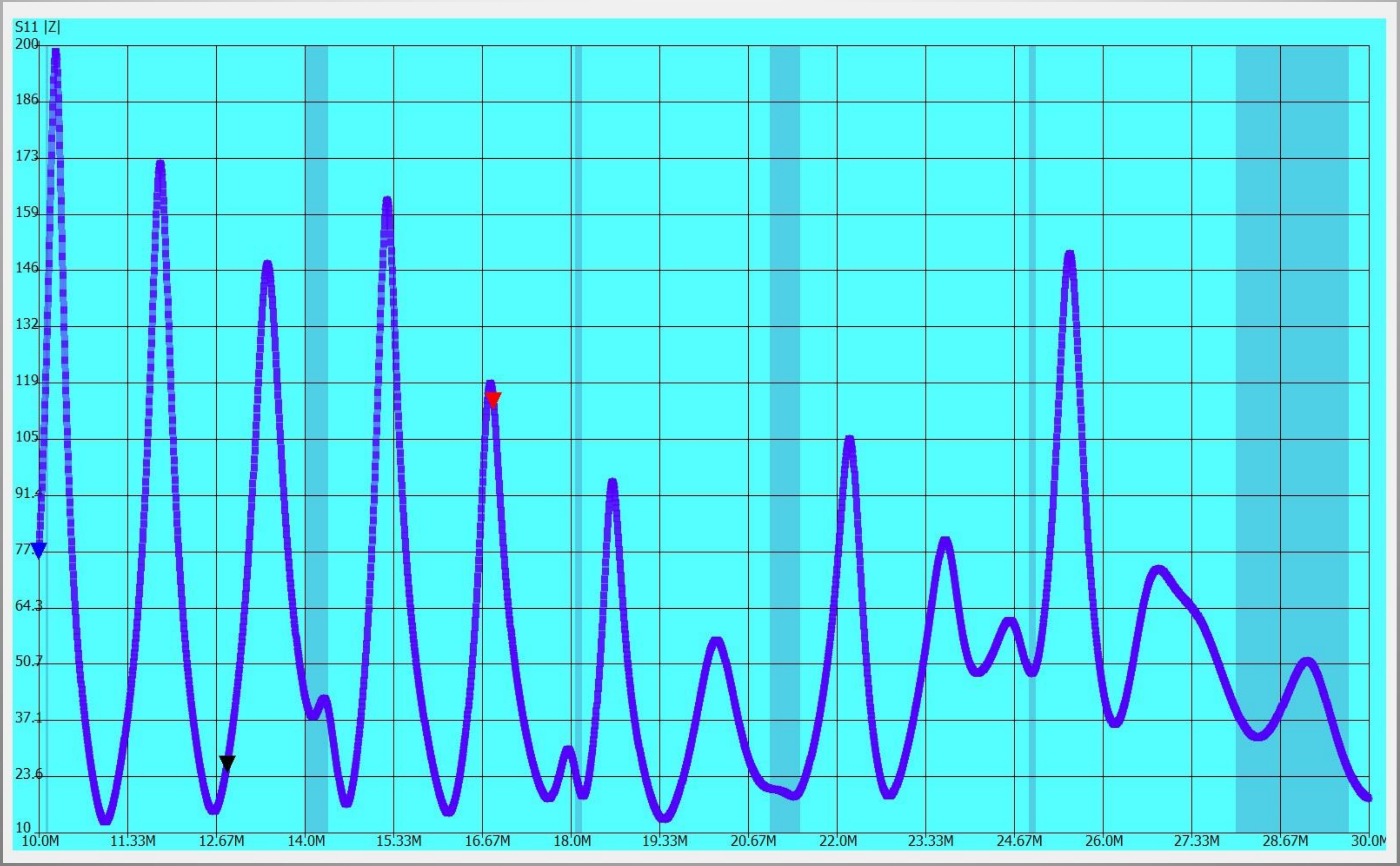


Typical R5 / R7 Trap



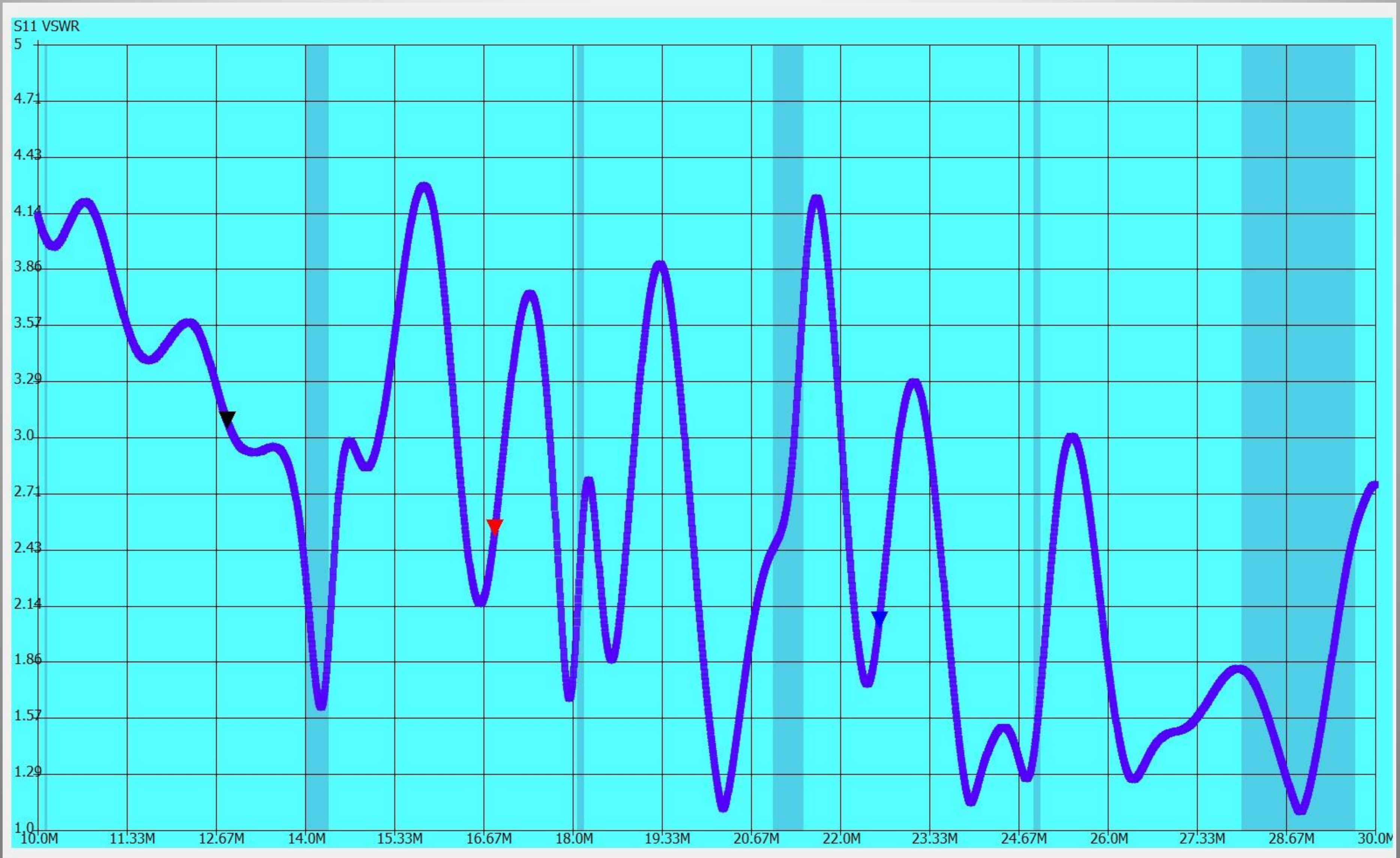
Cushcraft R5 Vertical

Impedance (10/12/15/17/20 meters)



Cushcraft R5 **SWR** 20,17,15,12,10 meters

15 meter trap poorly adjusted **SWR = 2.5 : 1** at 21 MHz

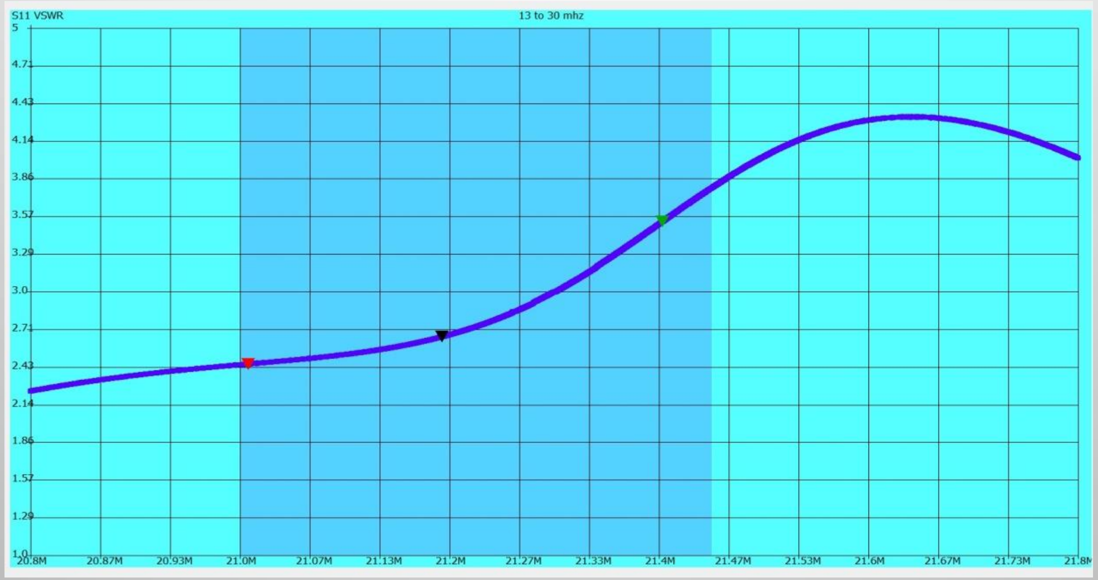


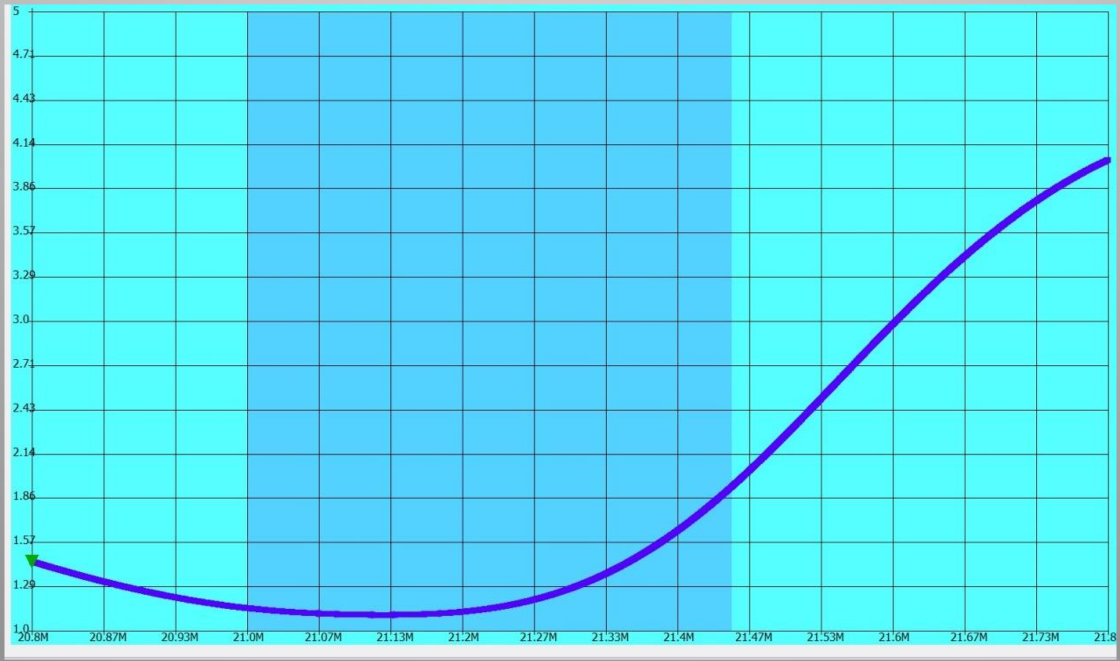
Houston: we have a problem

What can we do to improve 15m SWR
On this Cushcraft R5 multi-band vertical?

Enter: our Antenna Tuner (in the shack)

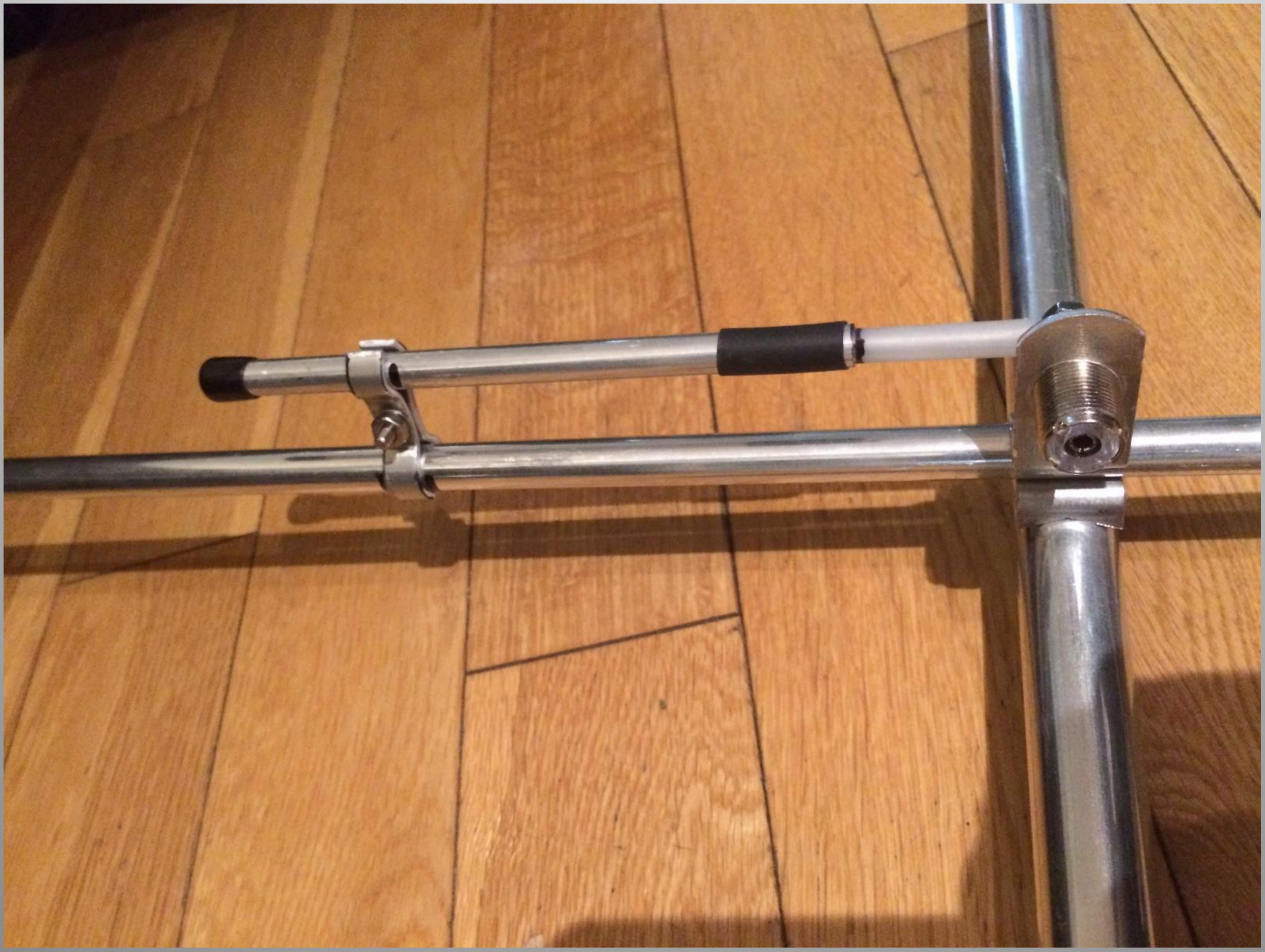
Cushcraft R5 SWR on 15 meters: before and after Antenna TUNER



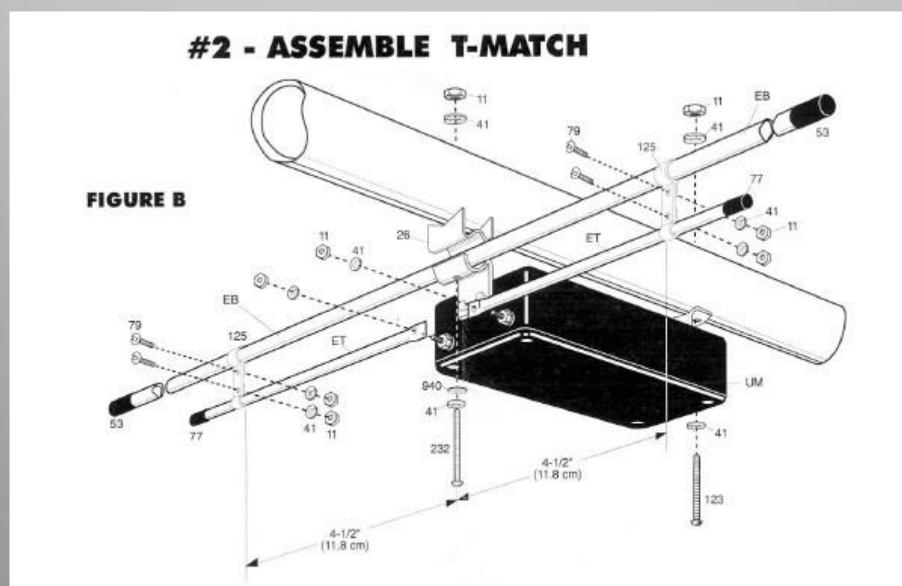


Cushcraft 10 element 2m beam

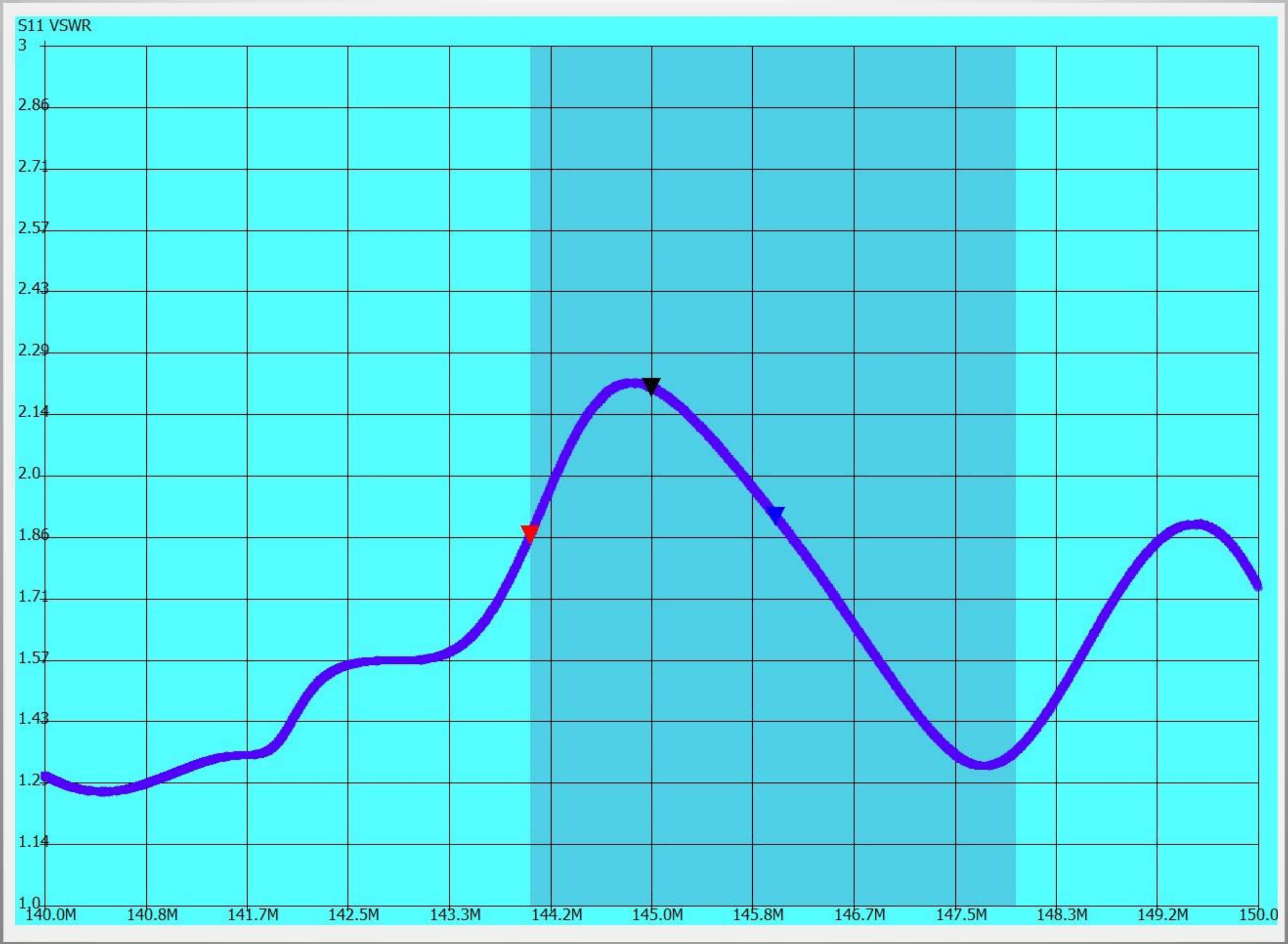
The "**Gamma Match**" is an UN-BALANCED circuit used to match the low impedance of beam to 50 ohms for coax



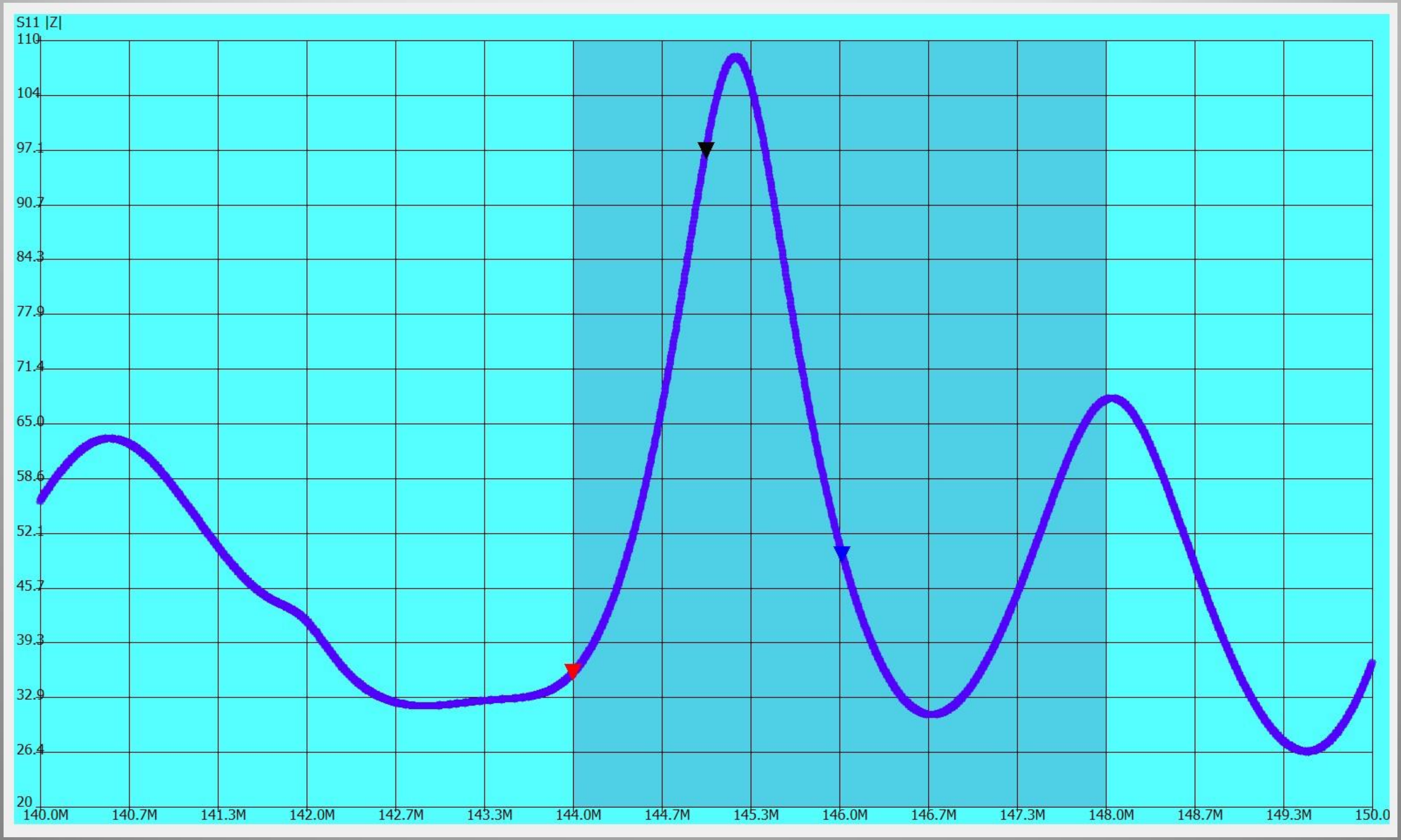
Cushcraft “**Ultra-Match**” is just two Gamma matches but provides a <u>BALANCED</u> approach relative to ground



SWR Cushcraft 10 element 2m BEAM

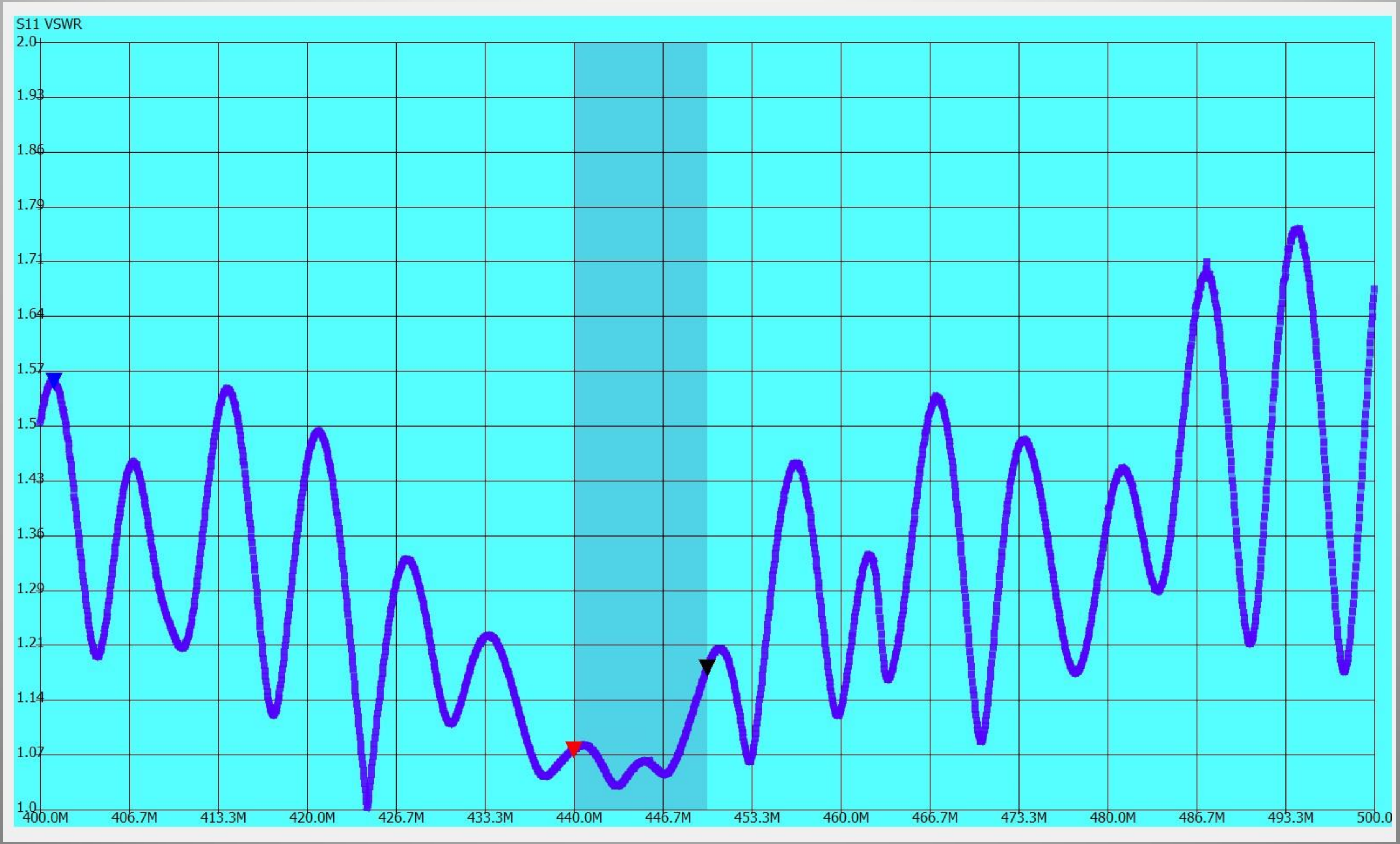


Impedance Cushcraft 2m BEAM

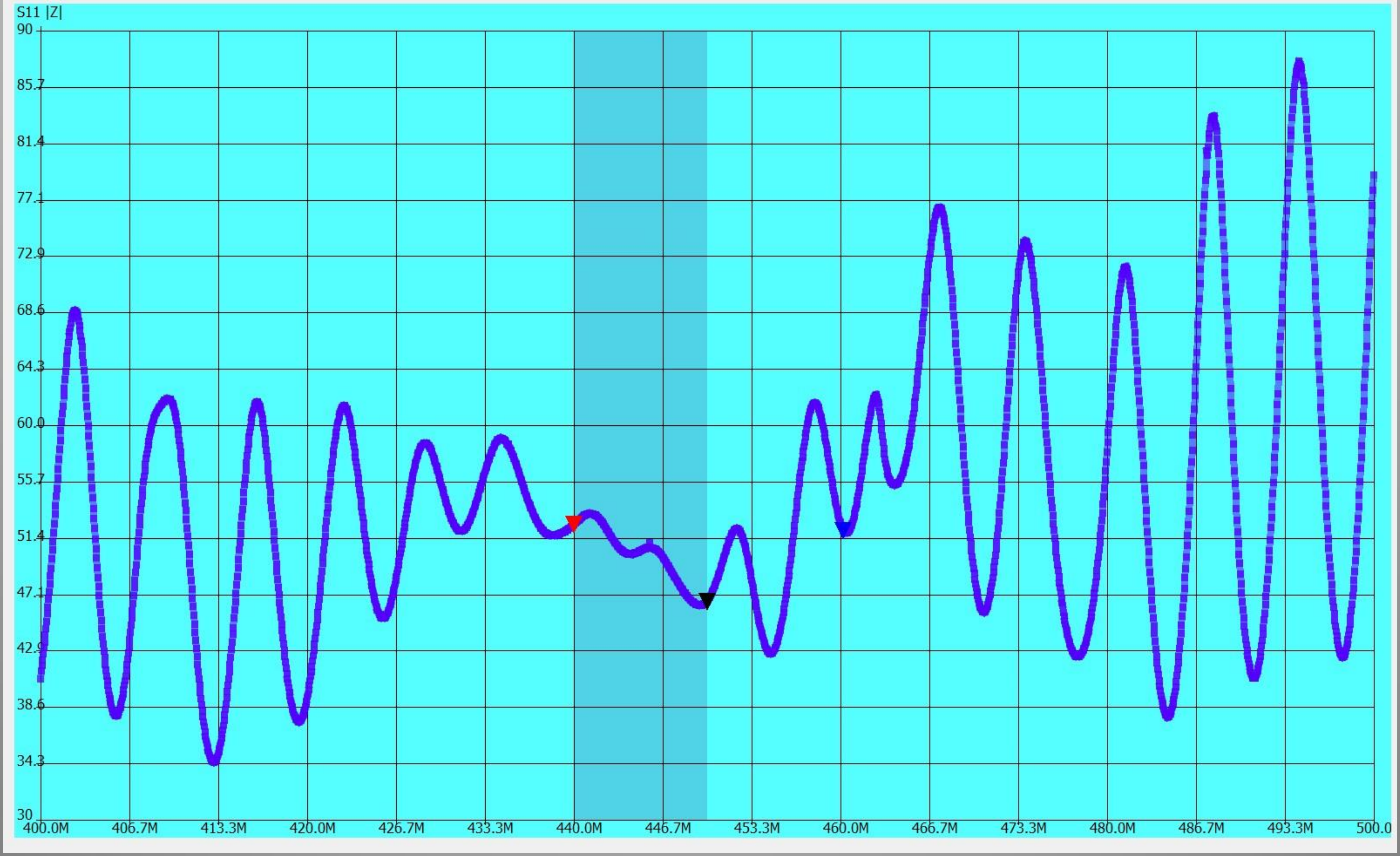


Cushcraft 11 element 70cm BEAM
now SWR is getting to be critical - why?

SWR Cushcraft 11 element 70 cm BEAM

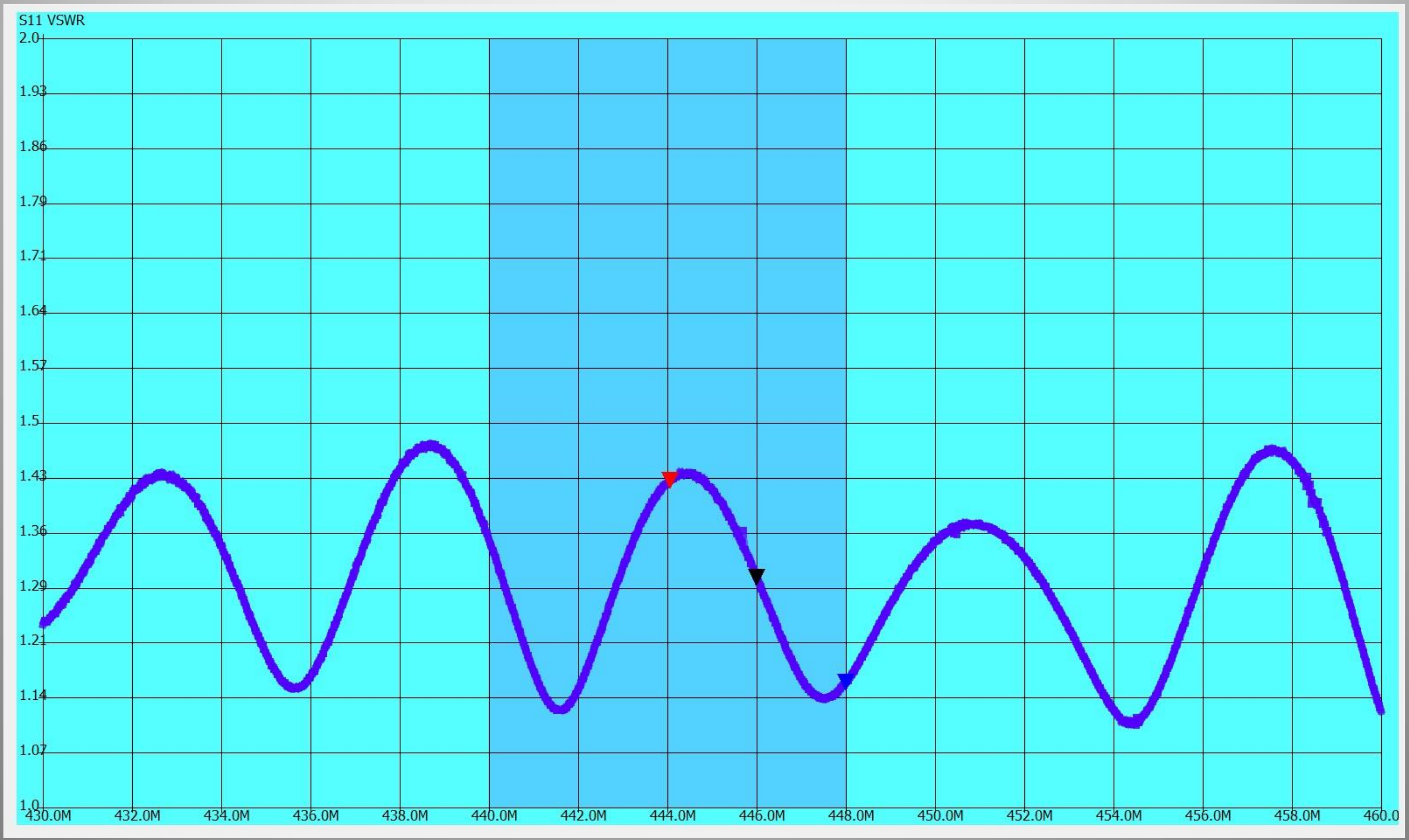


Impedance Cushcraft 70cm BEAM



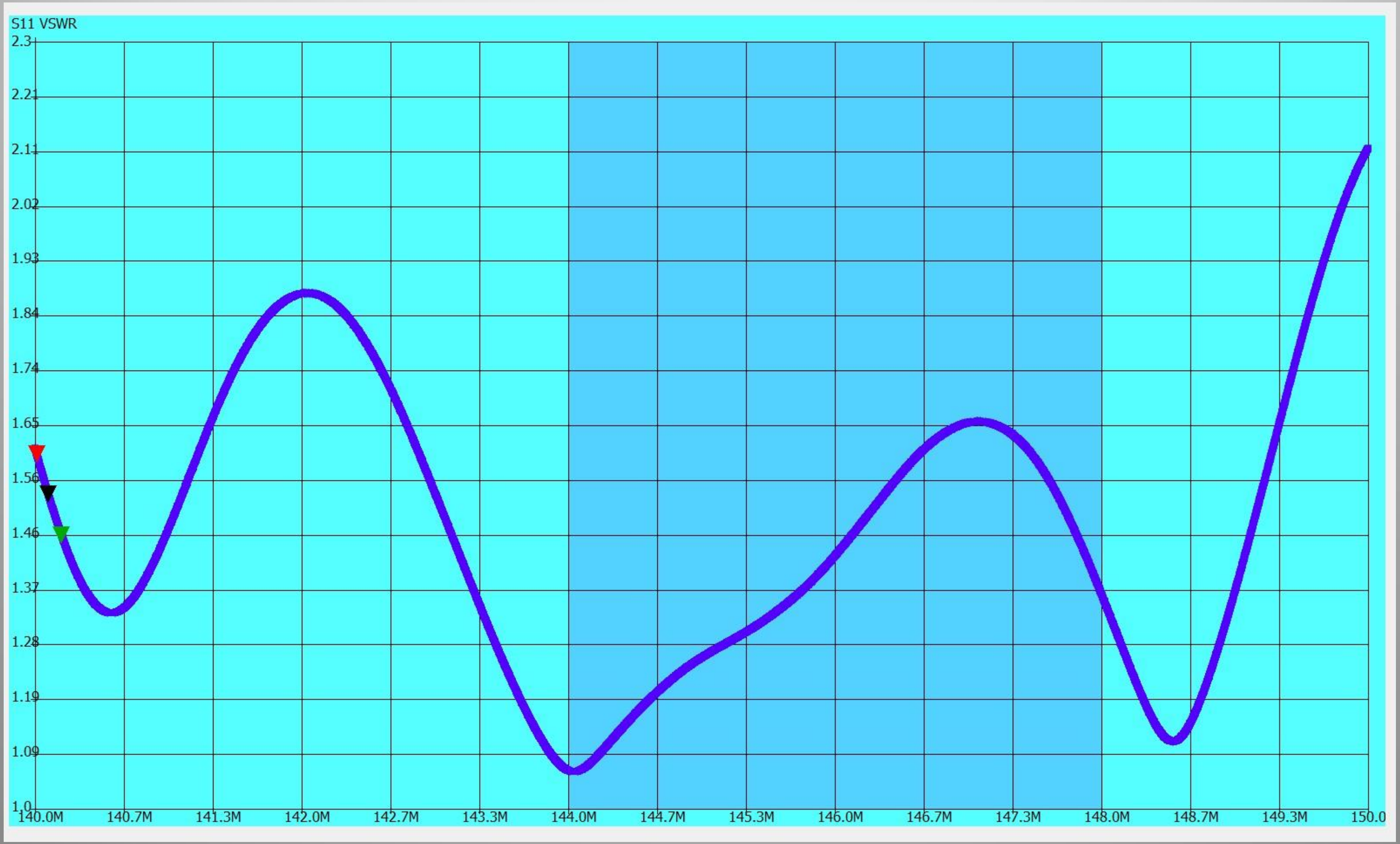
Diamond 70cm Vertical

Diamond 70cm Vertical
SWR below 1.5:1 across entire 70cm band



Hustler G6 2 meter vertical "gain" antenna

Hustler G6 2m vertical
What could I "adjust" to improve this a bit?



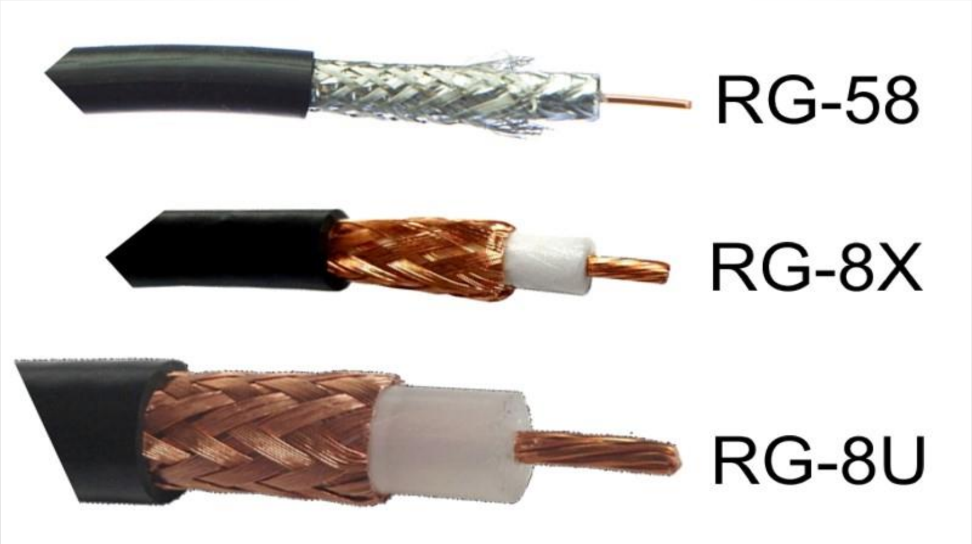
Other uses for a Nano VNA

Measure Cable Length
Measure Cable characteristic impedance (Z)
Measure Cable loss (attenuation) in dB/100 ft

Measure the Q (sharpness) of an antenna trap
Measure the inductance L of a coil
Measure the capacitance C of a capacitor
Measure the impedance Z of a RLC circuit
Measure PHASE ANGLES

Useful Adapter: SMA to SO239

but is the impedance still **<u>50 ohm </u>**in the SO239 socket?



Attenuation (dB per 100 feet)

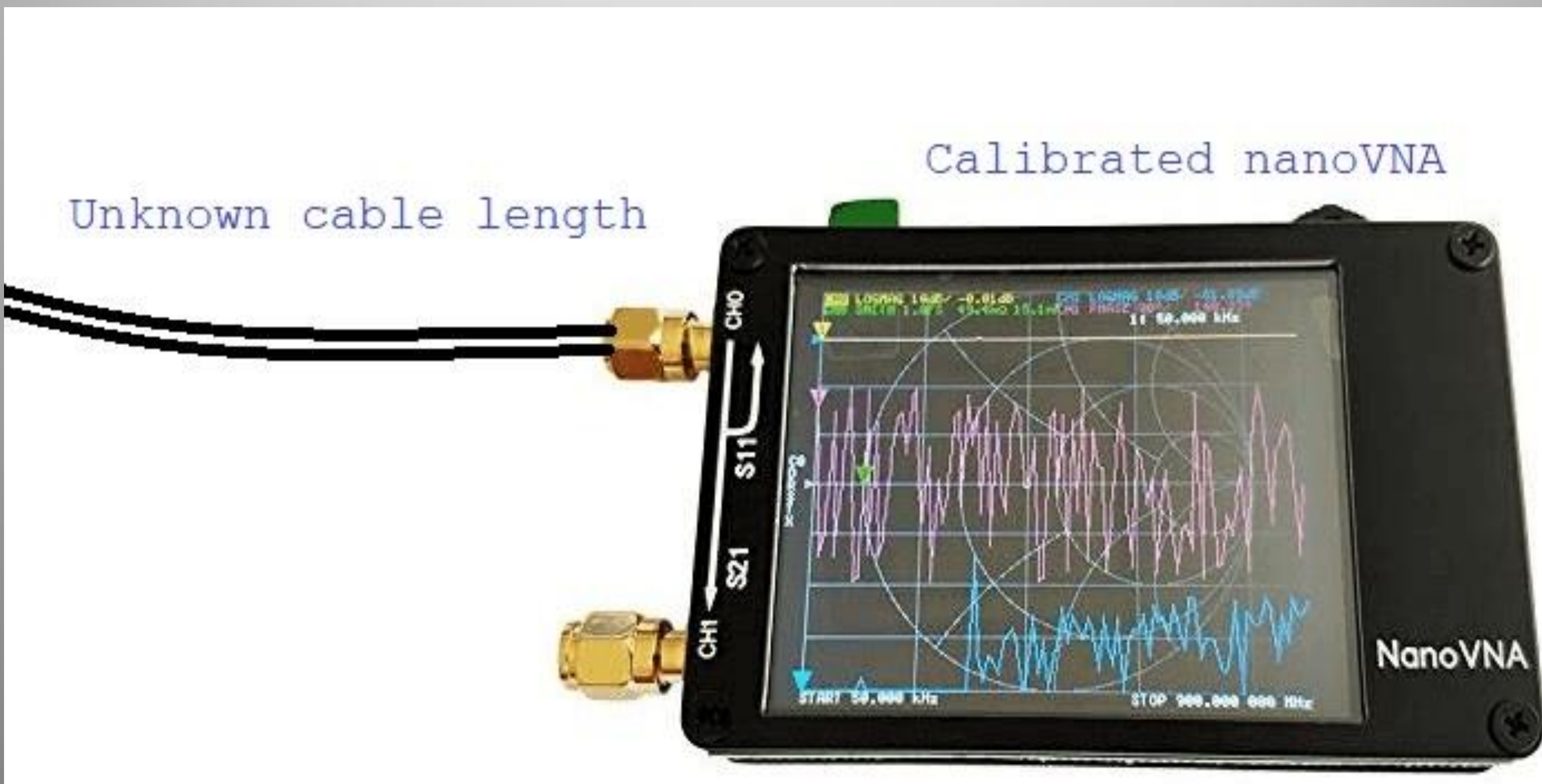
Coax Cable Signal Loss (Attenuation) in dB per 100ft*								
Loss*	RG-174	RG-58	RG-8X	RG-213	RG-6	RG-11	RF-9914	RF-9913
1MHz	1.9dB	0.4dB	0.5dB	0.2dB	0.2dB	0.2dB	0.3dB	0.2dB
10MHz	3.3dB	1.4dB	1.0dB	0.6dB	0.6dB	0.4dB	0.5dB	0.4dB
50MHz	6.6dB	3.3dB	2.5dB	1.6dB	1.4dB	1.0dB	1.1dB	0.9dB
100MHz	8.9dB	4.9dB	3.6dB	2.2dB	2.0dB	1.6dB	1.5dB	1.4dB
200MHz	11.9dB	7.3dB	5.4dB	3.3dB	2.8dB	2.3dB	2.0dB	1.8dB
400MHz	17.3 B	11.2dB	7.9dB	4.8dB	4.3dB	3.5dB	2.9dB	2.6dB

Use CH0 for both signal out and reflection in

“**Time Domain Reflectometry**” ==> distance = velocity x time

Velocity of RF in cable = velocity factor x speed of light

Measure the **loss** of the return signal (dB) = **cable attenuation**



HOW TO: Measure Length of unknown coax cable

Connect a cable that converts SMA to SO239 (coax female)

Calibrate the Nano VNA first, then SAVE CALIB file

Connect an unknown length of RG8X coax to Ch0 via a PL259 plug

Short out the “far” end of the 50 ohm RG8X coax

Set the FREQ sweep from 1 MHz to 100 MHz

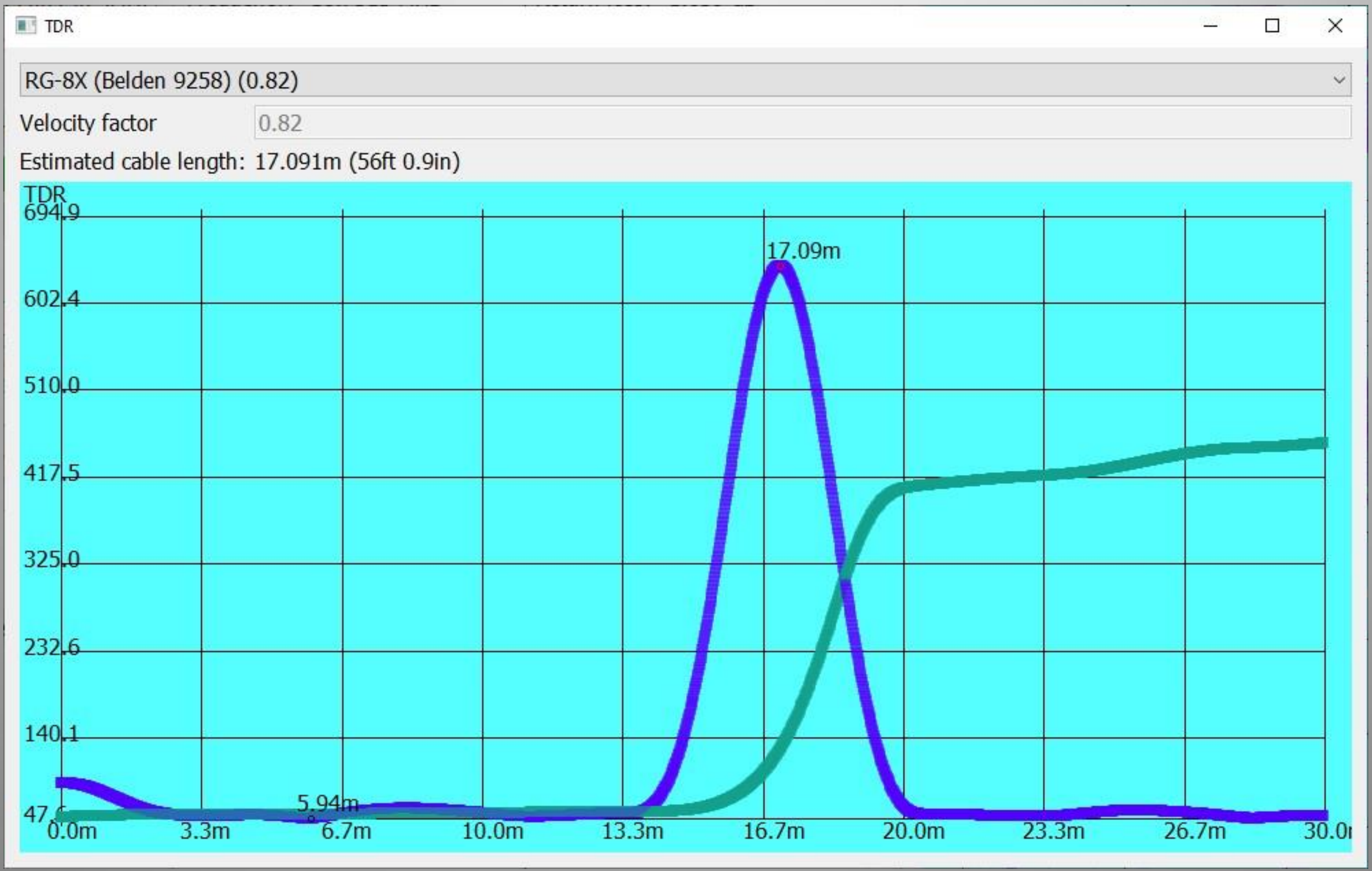
Set the TDR display function to ON

What “should happen”

When the RF gets to the shorted end of the coax, impedance = 0

100% of the RF should reflect back to Ch0 (SWR is infinite)

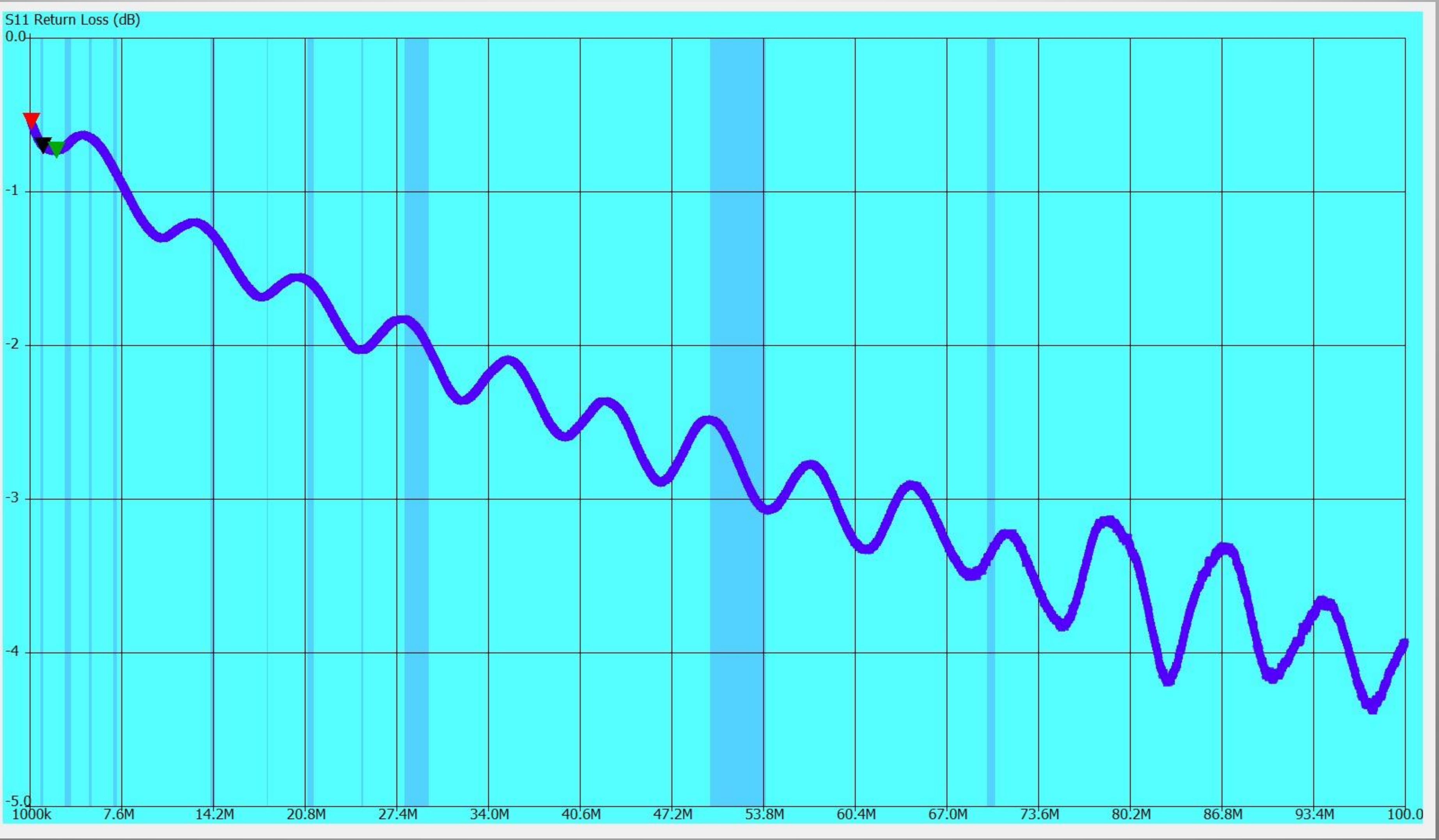
TDR display: Belden RG8X cable (VF = 0.82) An impedance "bump" appears 17.1 meters: WHY?

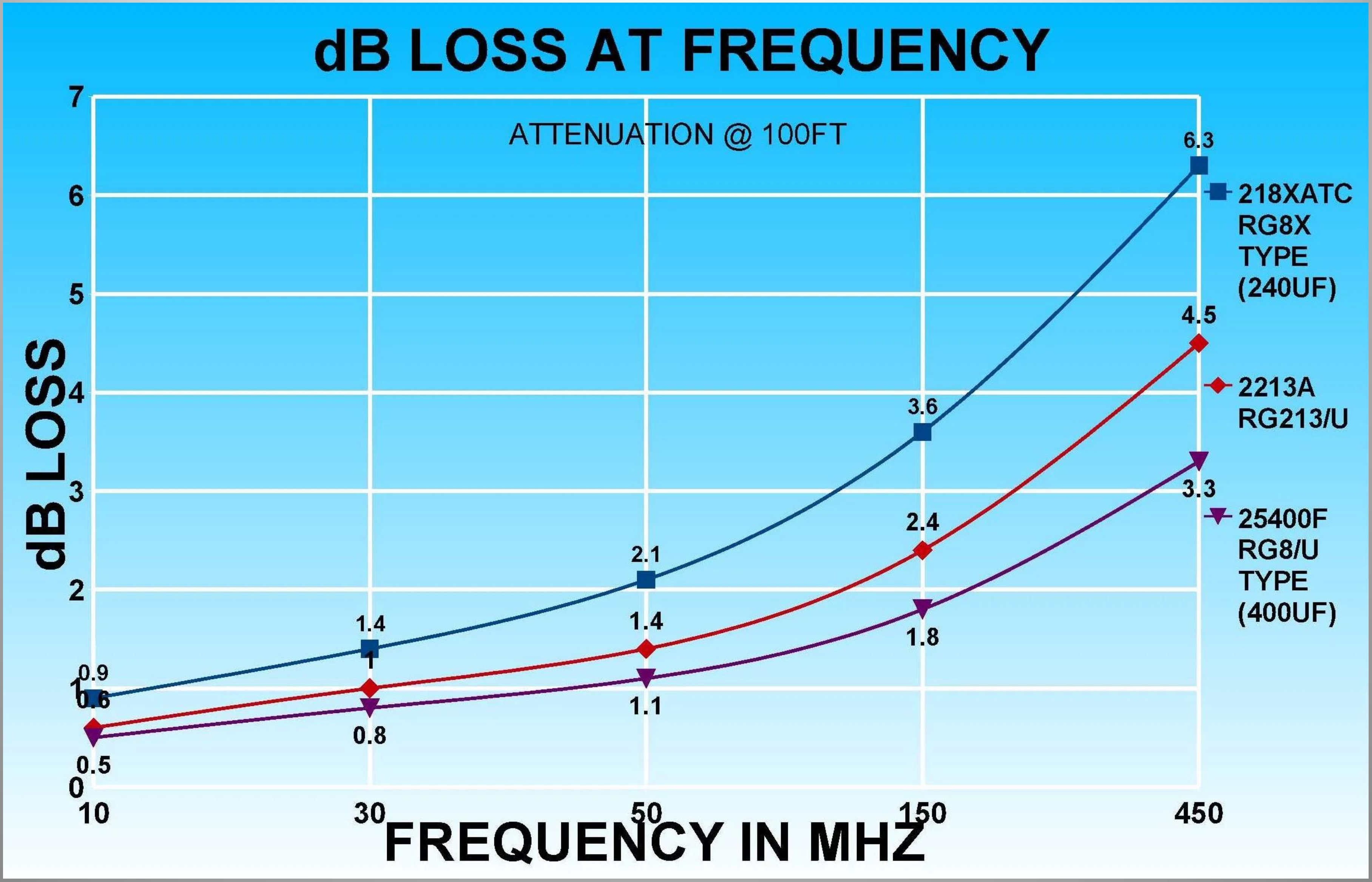


Attenuation (dB) of 50 ft **RG8X** vs. **Frequency** (1-100 MHz)

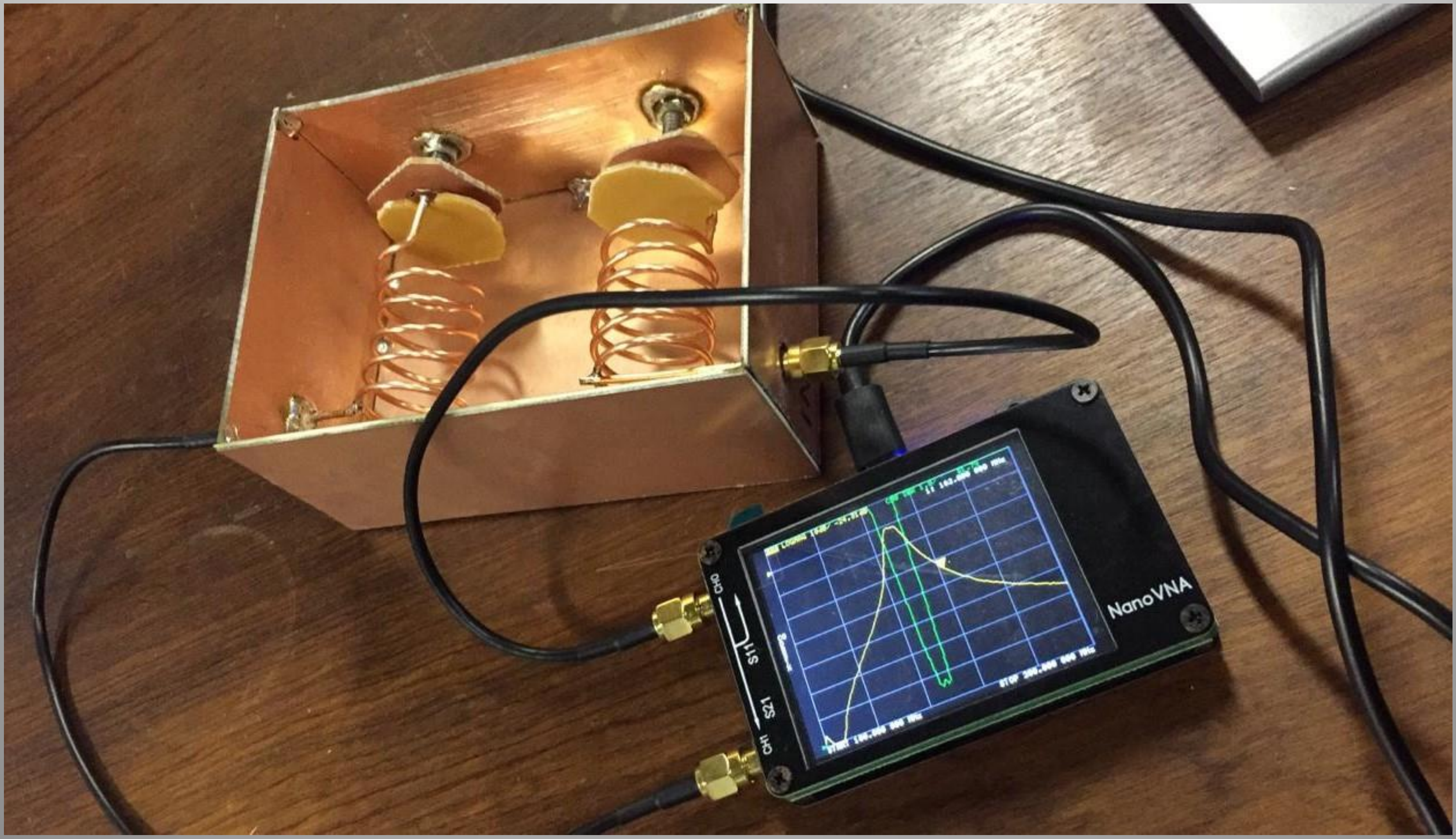
At what frequency is the “heat” loss = 50% of the power?

Why does the attenuation increase with frequency?




dB LOSS AT FREQUENCY
ATTENUATION @ 100FT
dB LOSS
FREQUENCY IN MHZ
0
1
2
3
4
5
6
7
10
30
50
150
450
0.9
1.4
2.1
3.6
6.3
0.6
1
1.4
2.4
4.5
0.5
0.8
1.1
1.8
3.3
218XATC RG8X TYPE (240UF)
2213A RG213/U
25400F RG8/U TYPE (400UF)

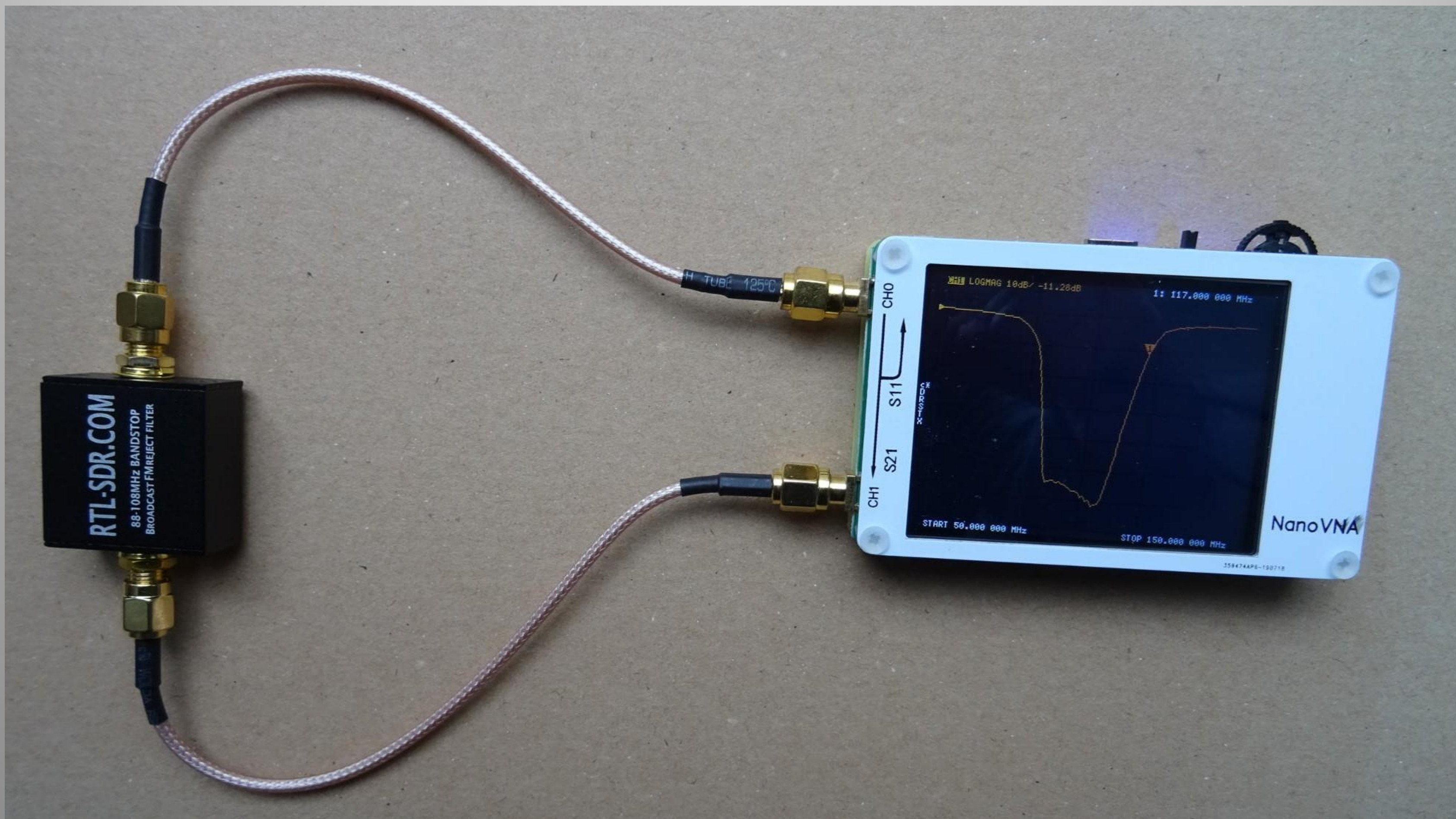
Measure the frequency response of a LC filter by measuring the “THRU” response: Ch0 to Ch1



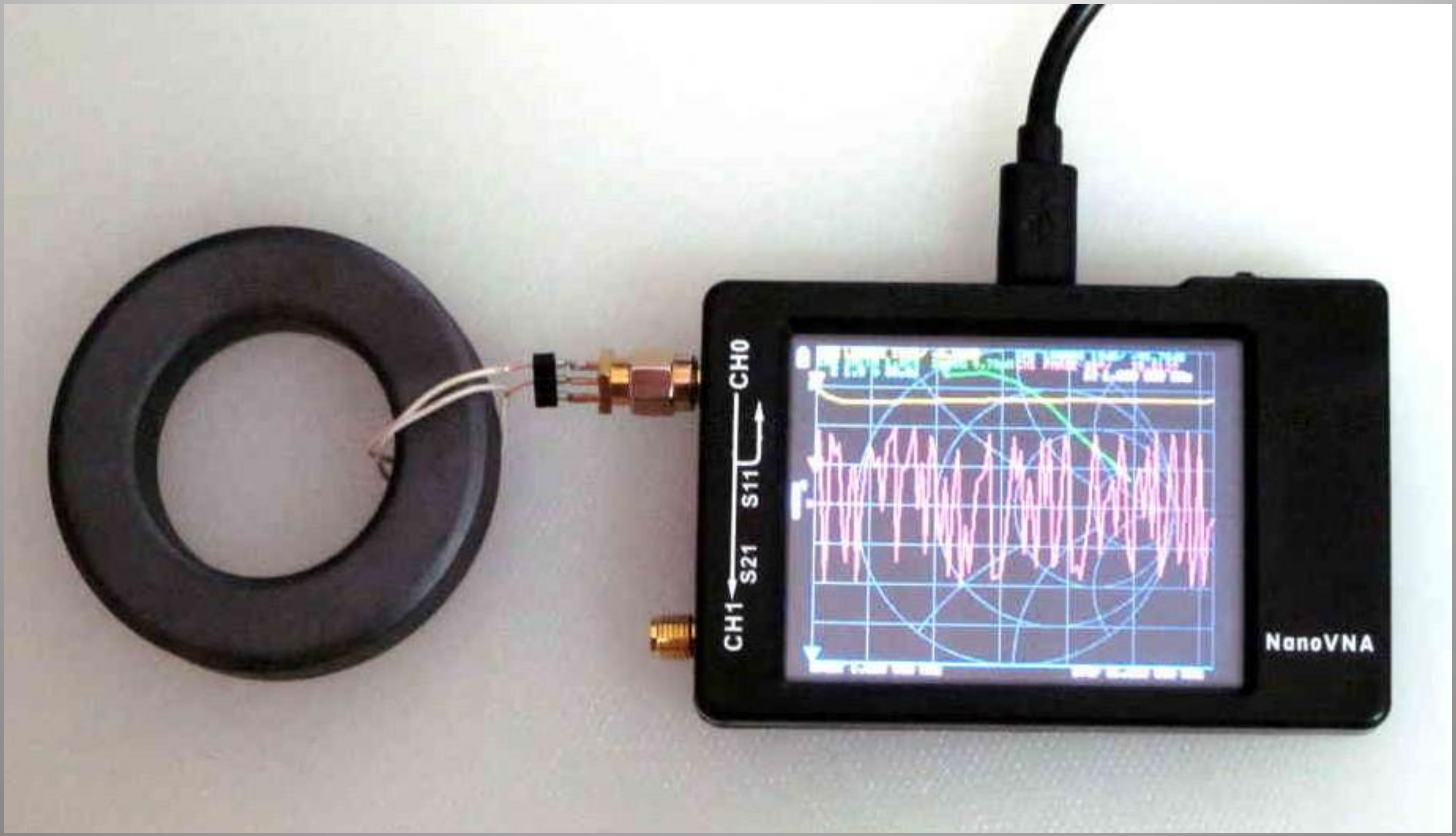
Help to adjust a manual ANTENNA TUNER
Where on the Smith Chart do you “want” the cursor?

Advanced: measure trap Q but use TWO Channels

A FM broadcast band-stop "filter"



Measuring Toroid impedance



Ready for a closer look at

Smith Charts

Smith Chart for feed lines

Where a feed line connects to your radio (or antenna tuner) the impedance has a unique value: **Z = R +/- j X**

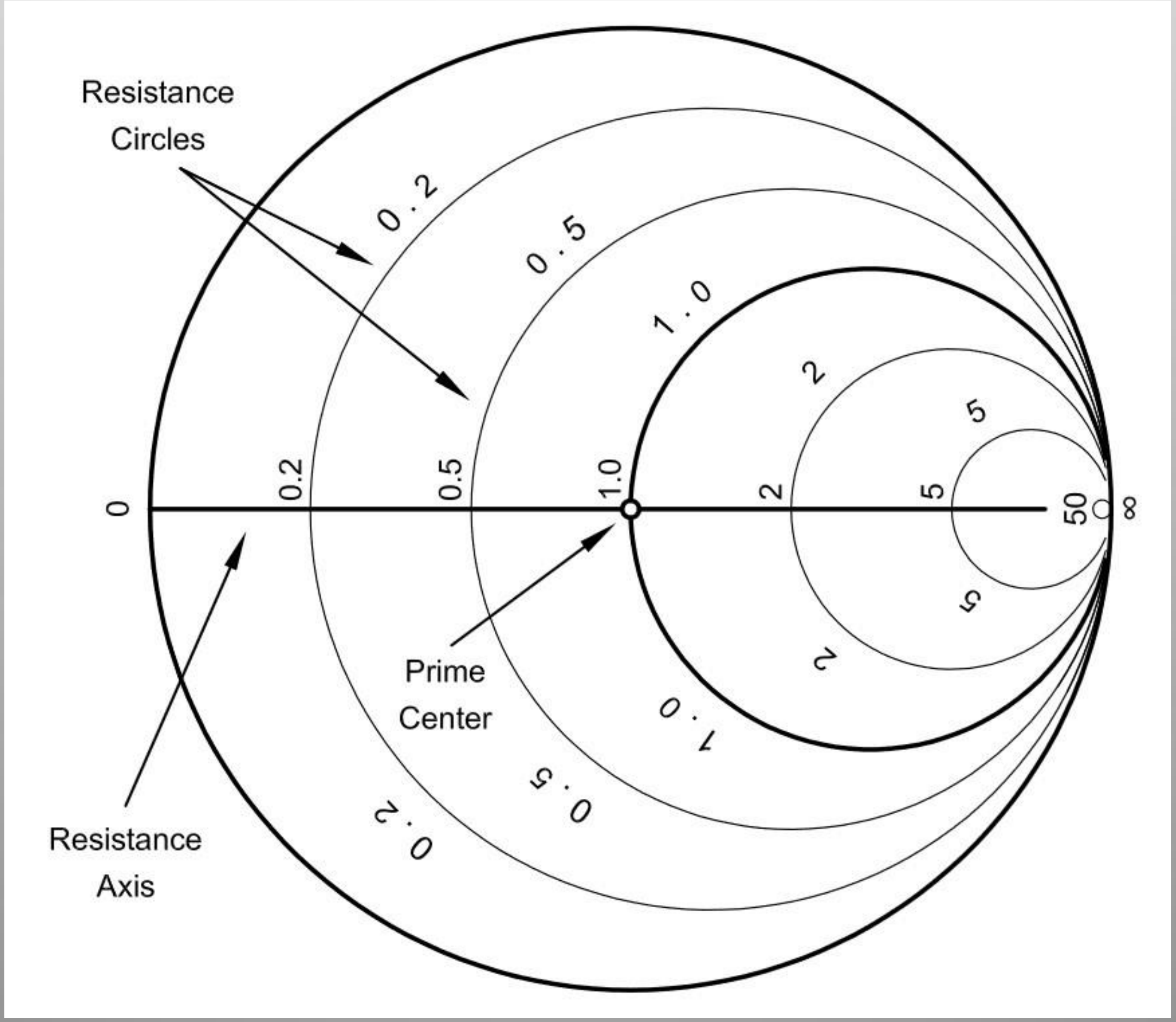
BUT….. your radio wants to "see" a 50-ohm resistance with zero reactance (50 ohm coax)

So….. Let's look at the

Smith Chart

to guide our thinking

ENTER the **“Smith Chart” - the “magic part” of tuners**
Resistance is plotted on **horizontal** axis from 0 to infinity
Often the PRIME **center** is set to 1.0 (for scale)



Plotting **REACTANCE**: circles tangent to RESISTANCE axis

Inductors produce POSITIVE reactance

Capacitors produce NEGATIVE reactance

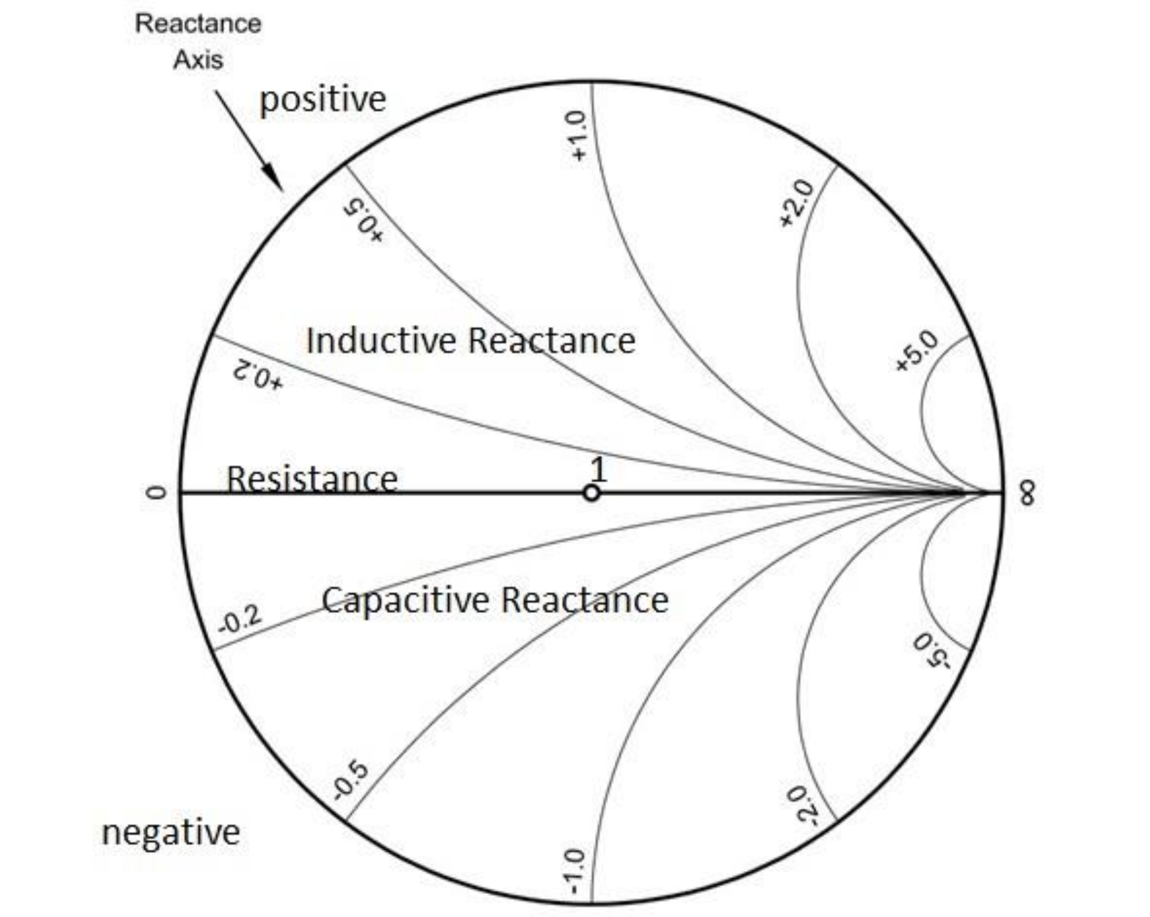


Fig 2—Reactance circles (segments) of the Smith Chart coordinate system.

Every impedance (R + jX) value has a **unique location** on this graph

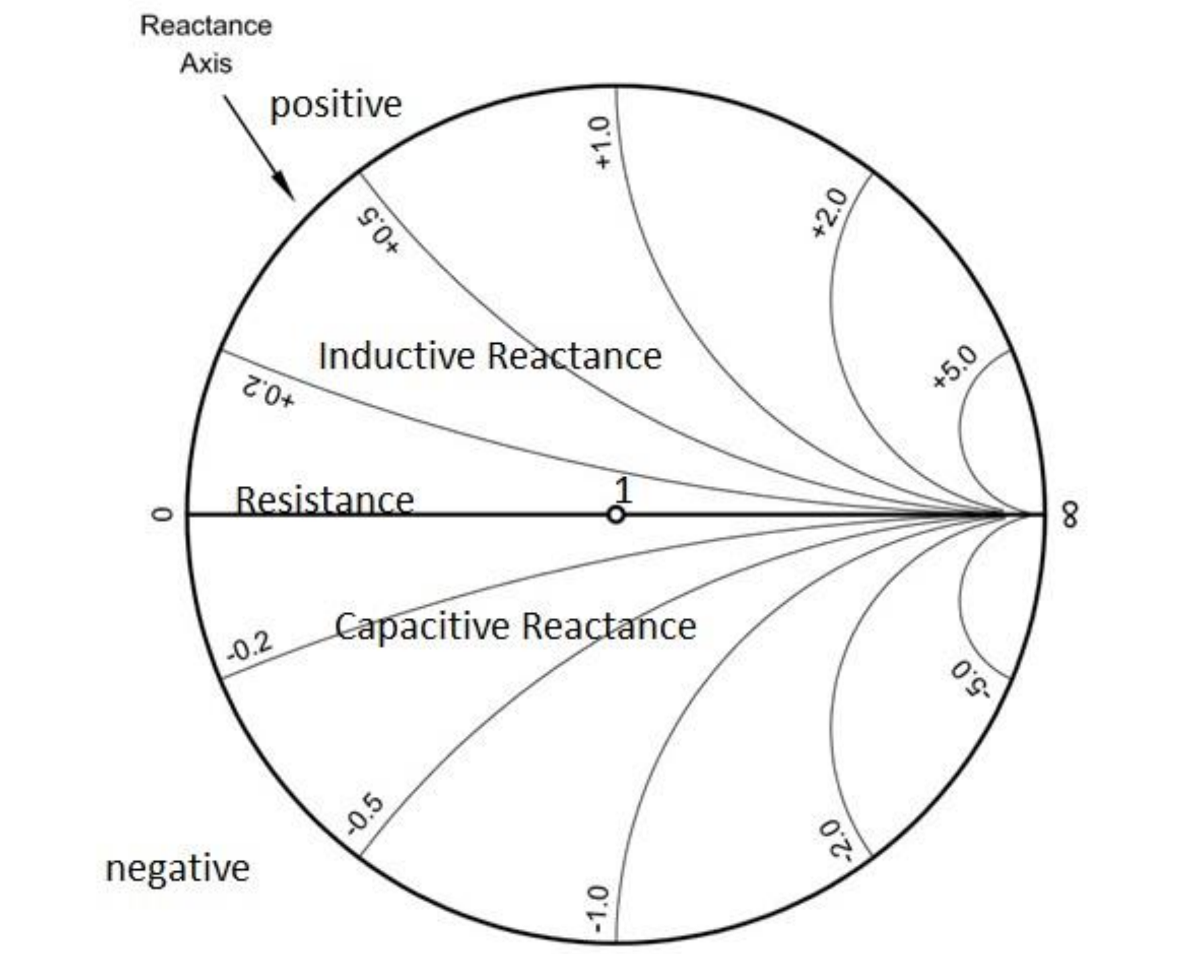


Fig 2—Reactance circles (segments) of the Smith Chart coordinate system.

All impedances INSIDE this red circle have SWR = 2:1 (or less)
SWR 2:1 impedances have a **variety** of R and X values

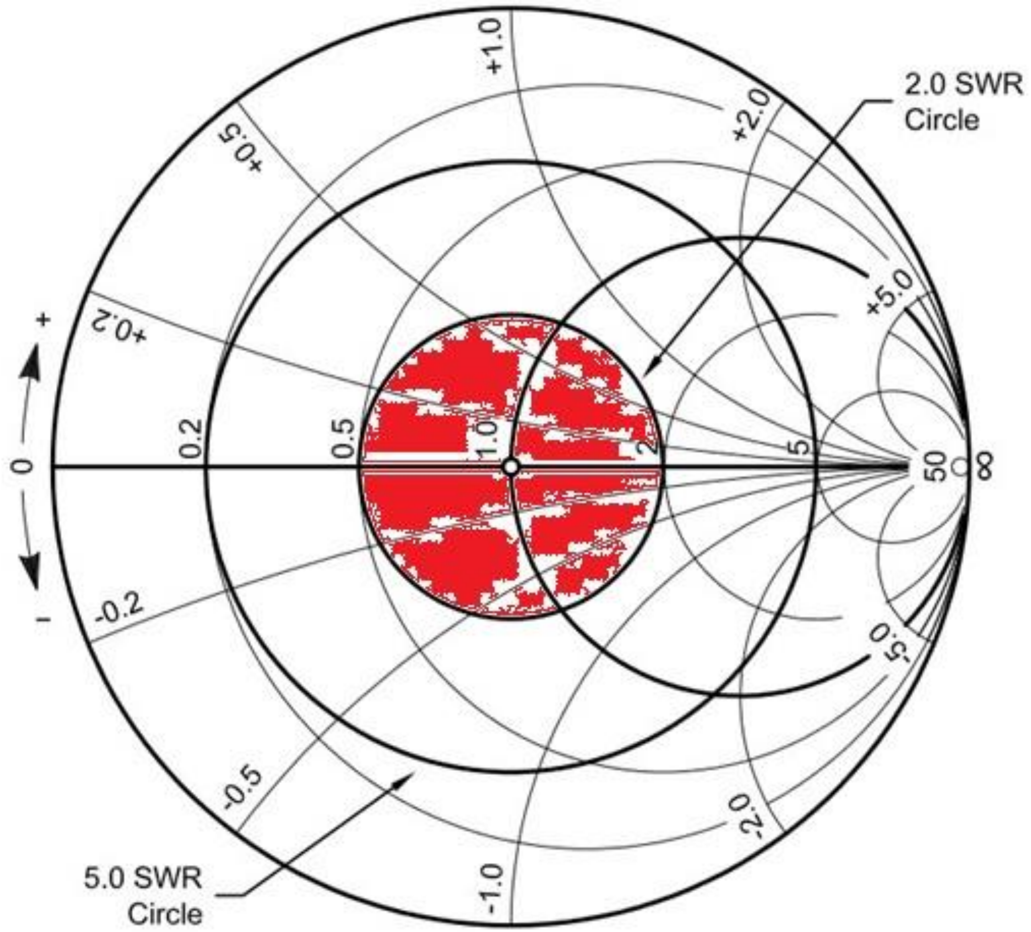
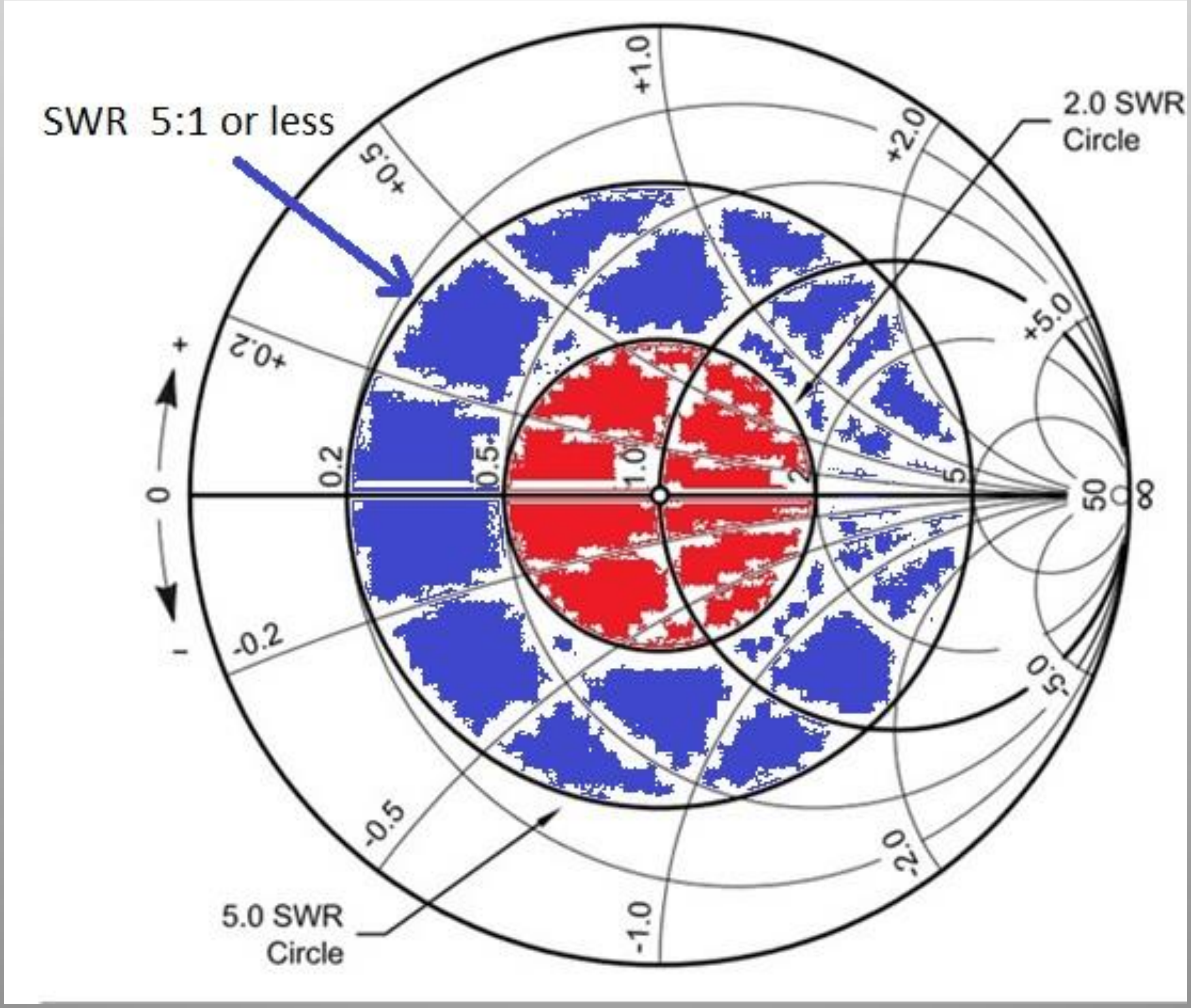


Fig 4—Smith Chart with SWR circles added.

Constant SWR circles

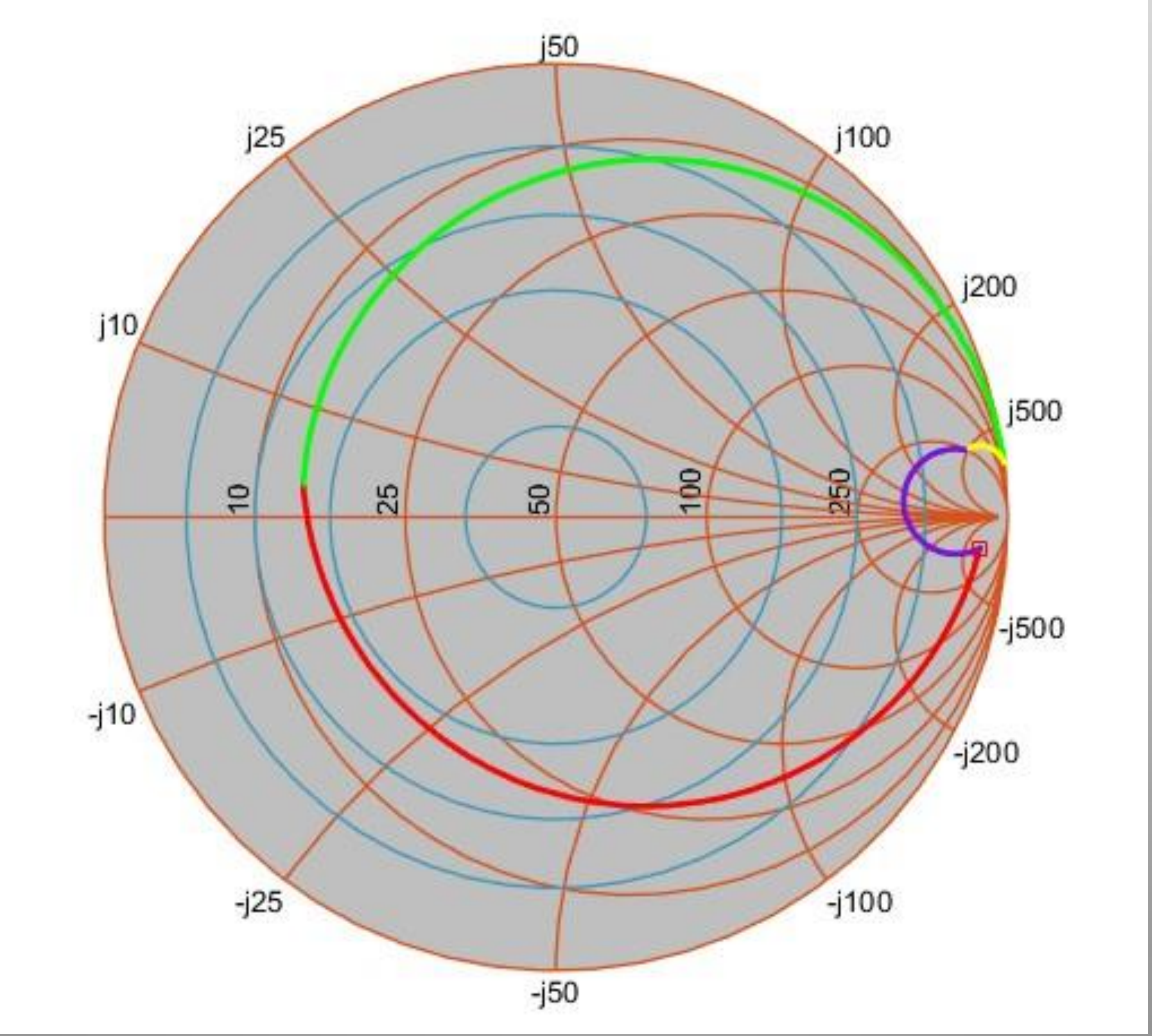
5:1 or less is inside BLUE circle 2:1 or less inside RED circle

(remember 1:1 is the single point at center)

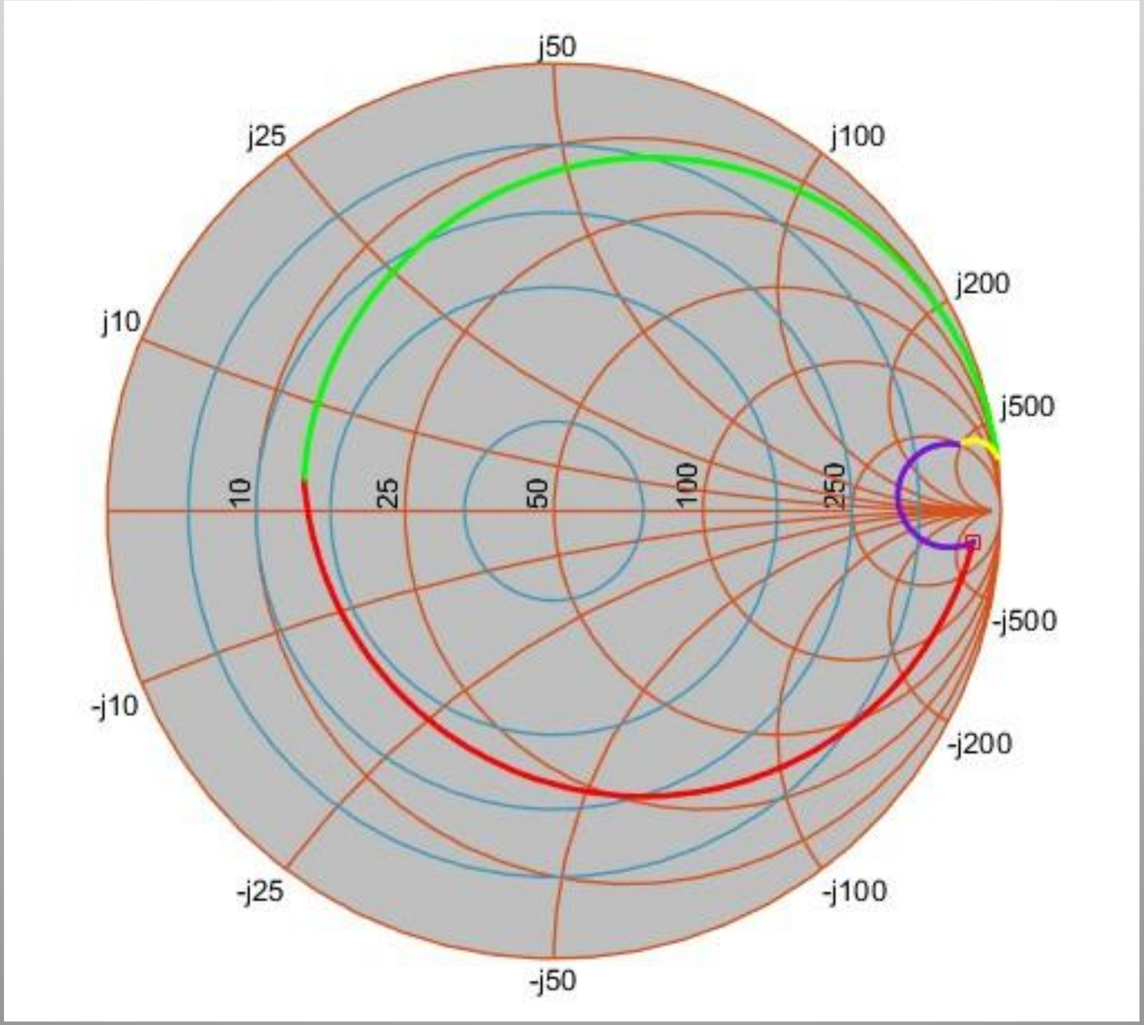


Smith Chart: conjugate match location

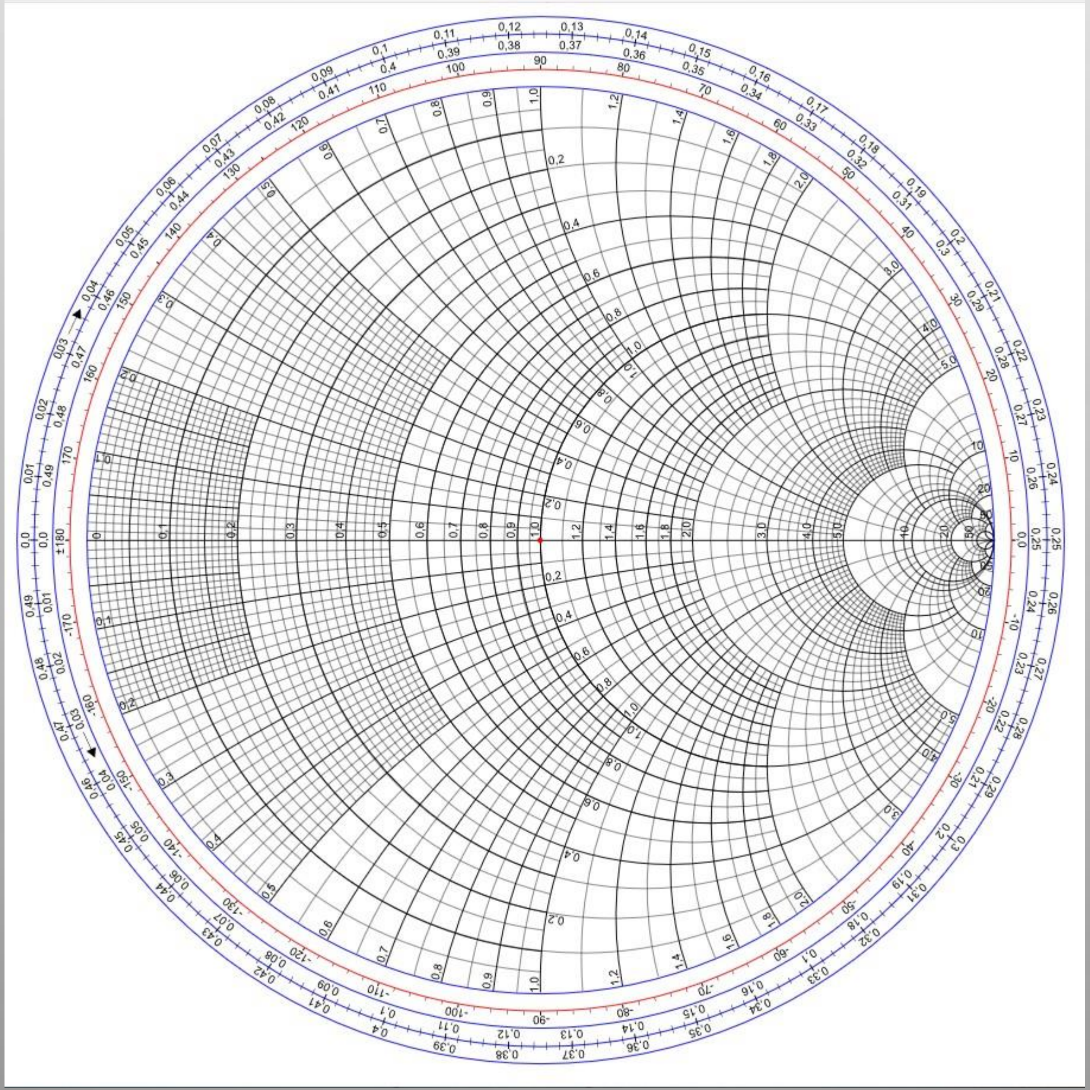
prime center now **normalized** to <u>**50 ohms**</u> for convenience



For every antenna impedance (**R + jX**)
there is a unique **“conjugate match”** location (**R – jX**)
that will **CANCEL the X** and end up with **50 ohms R**



A Great Teaching Tool !



This is via K5HAL Cullen