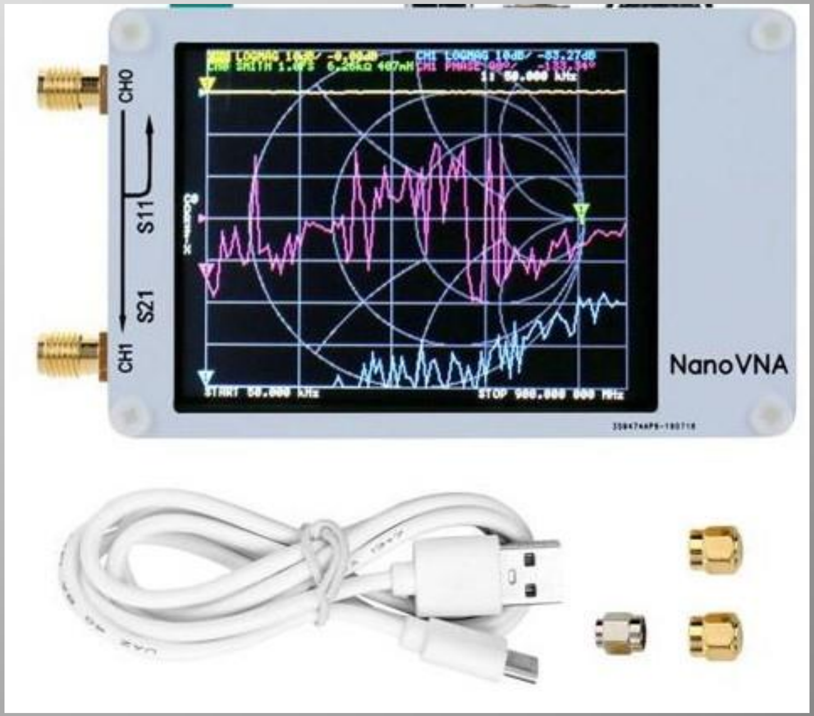
Vector Network Analyzers

Barry2   k3eui



What Devices do Network Analyzers Test?

Filters

RF Switches

Couplers

Cables

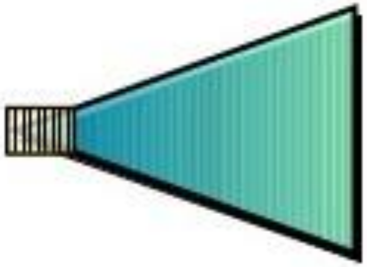
Amplifiers

Antennas

Isolators

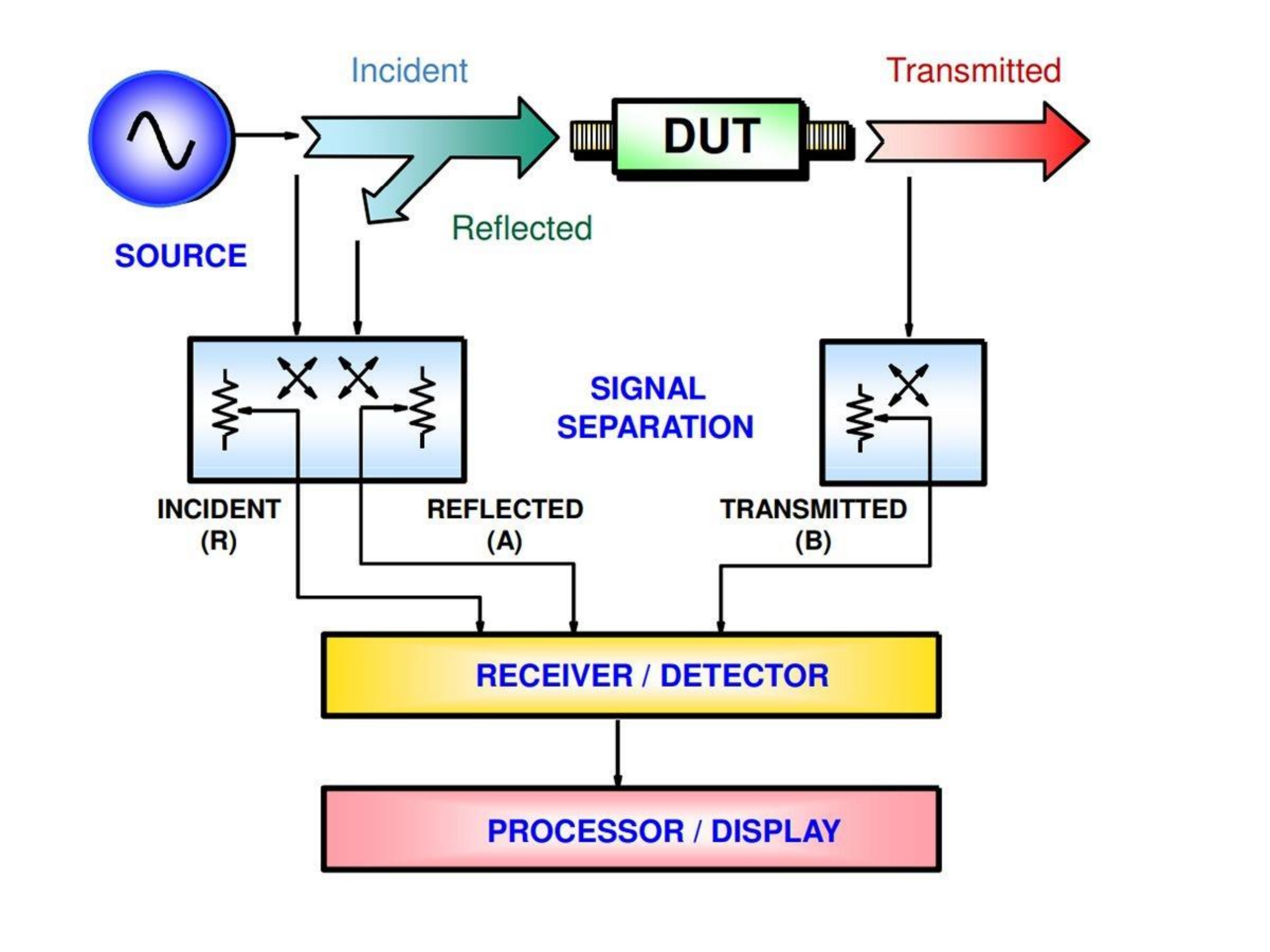
Mixers

...



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

Flow Chart: Vector Network Analyzer



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

Evolution of MFJ Antenna Analyzers

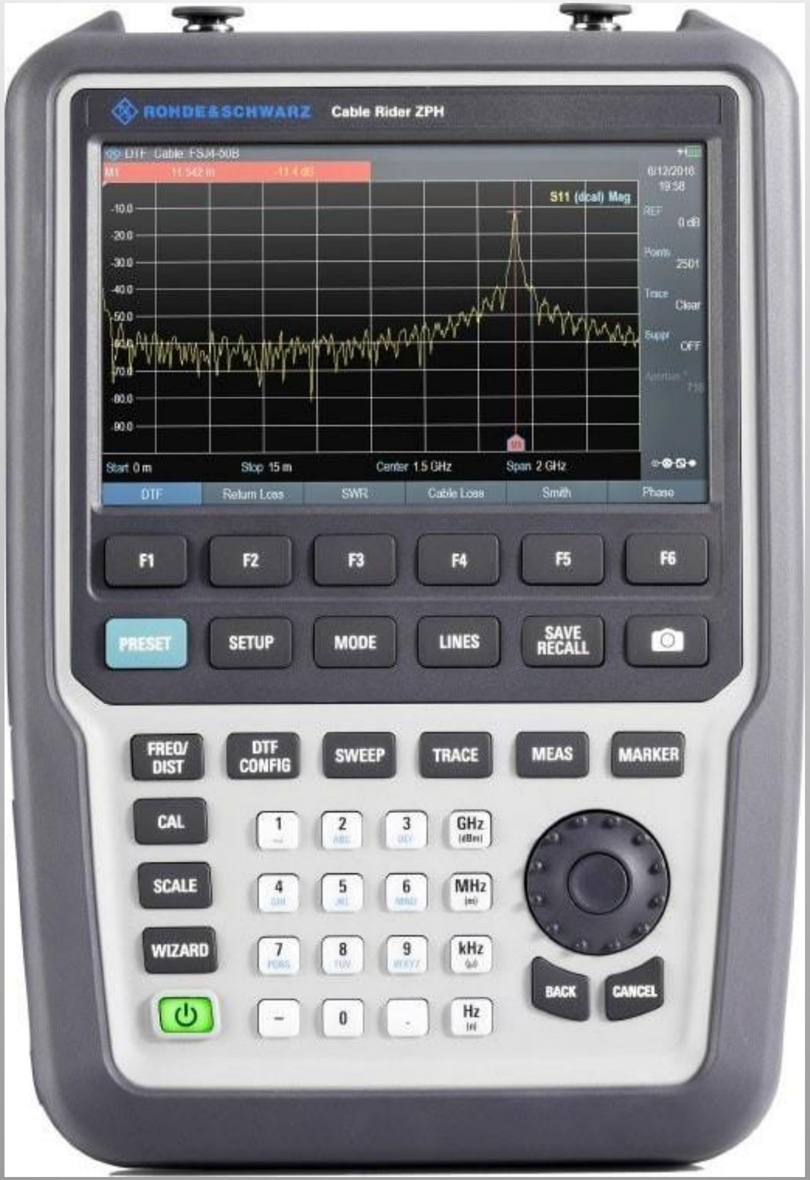
259D measures frequency, SWR, Resistance, Reactance, Impedance

223 can display graphs in multiple colors and scan bands

Rig Expert has many models with various graphical displays

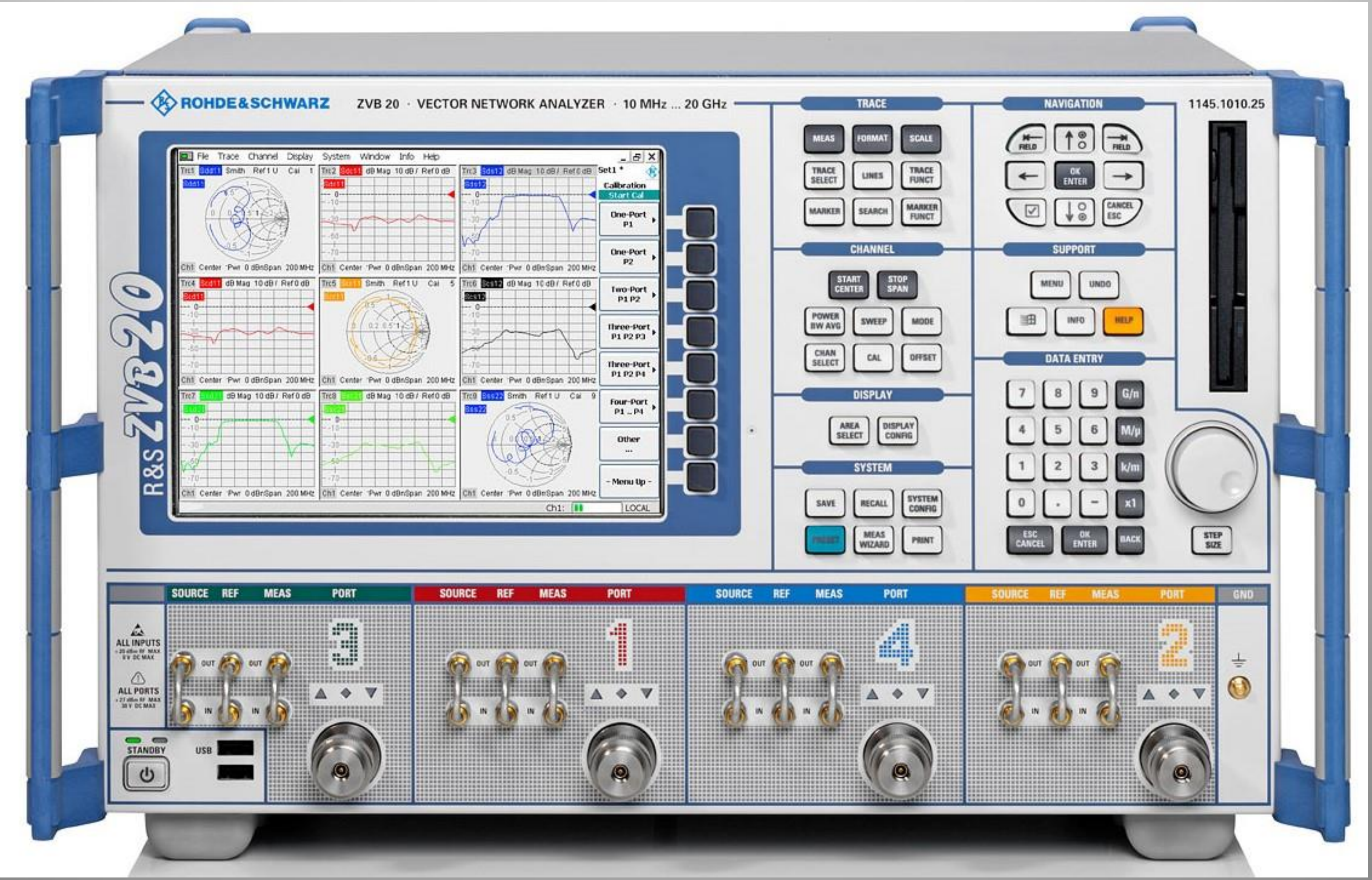
Comet makes a nice looking Antenna Analyzer
note the analog scales measure **SWR** and **Impedance**

Rohde & Schwarz: can you afford this portable one?



The "high-end" Vector Network Analyzers

Can you afford this beauty? 10 MHz to 20 GHz
Four ports and 9 graphs in color

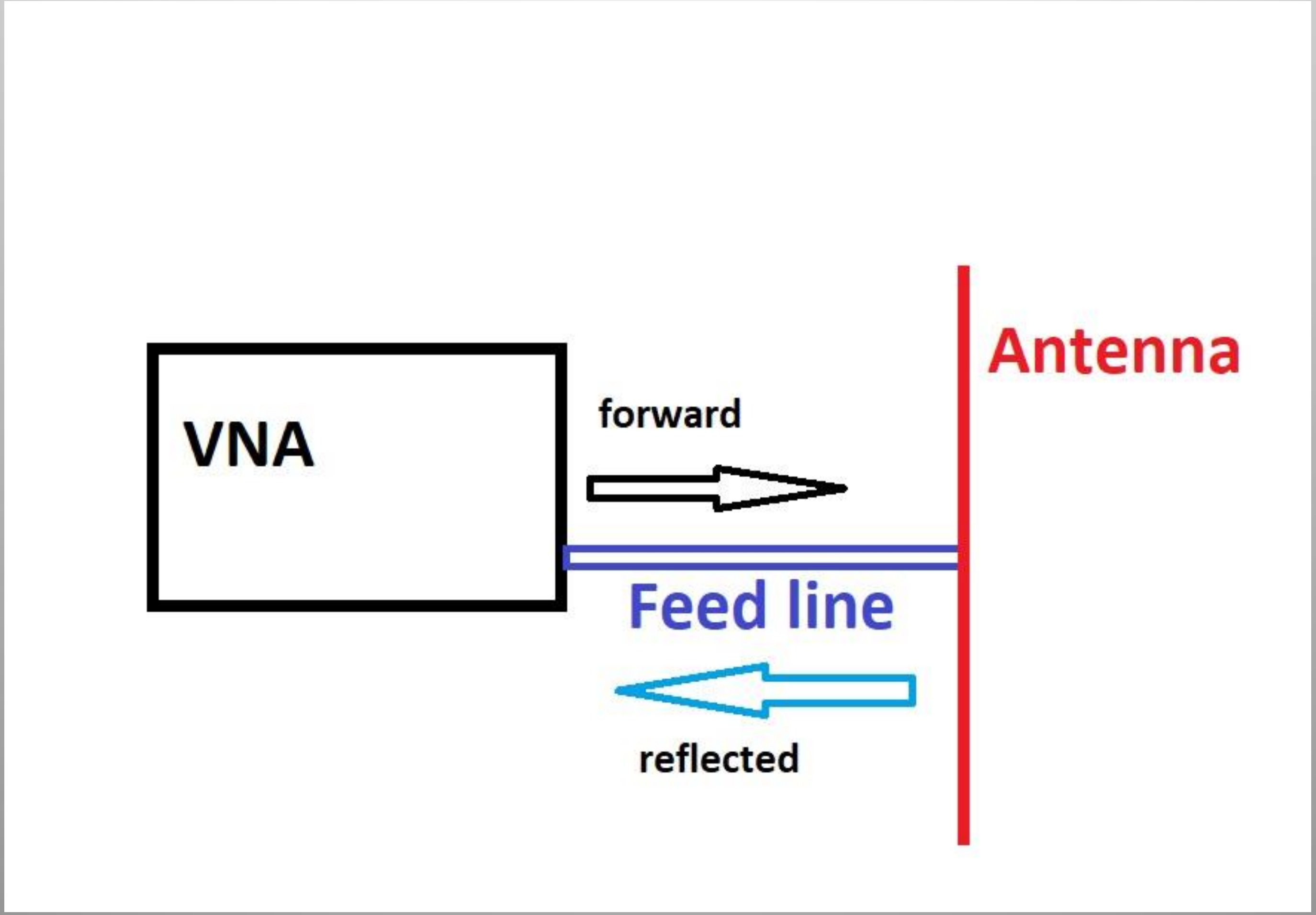


Enter the **Nano VNA** instrument USB connectivity

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

Measurement limit of 101 data points internal battery for field work

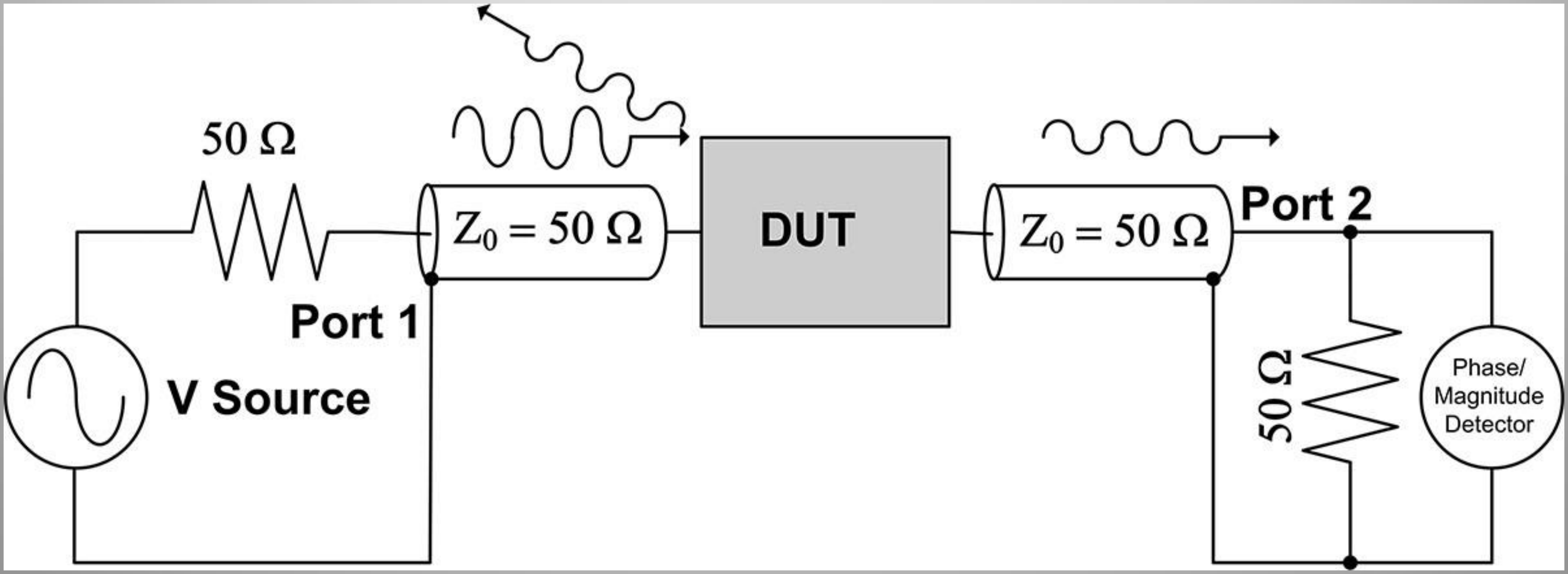
The VNA measures the V(forward) and the V(reflected) signals at various frequencies as a vector (magnitude and phase)



FORWARD - REFLECTED - THROUGH signals

DUT = "device under test"

typical reference impedance = 50 ohms



Important Parameter Definitions

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

Γ (gamma) = a complex number

|gamma| = **ρ** (rho)

0 < ρ < 1

RETURN LOSS (dB) = - 20 log (ρ)

usually written as a positive number since log (**ρ**) is <0

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

Reflection Parameters

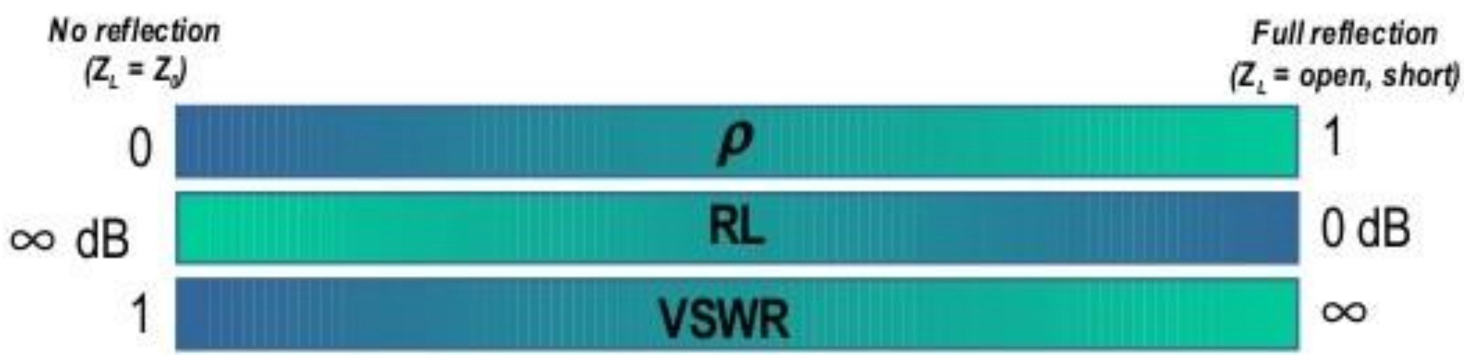
- **Return Loss, VSWR, Impedance, and Scalar Reflection Coefficient are calculated from measured Vector Reflection Coefficient** (Γ)

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

$$\rho = |\Gamma|$$

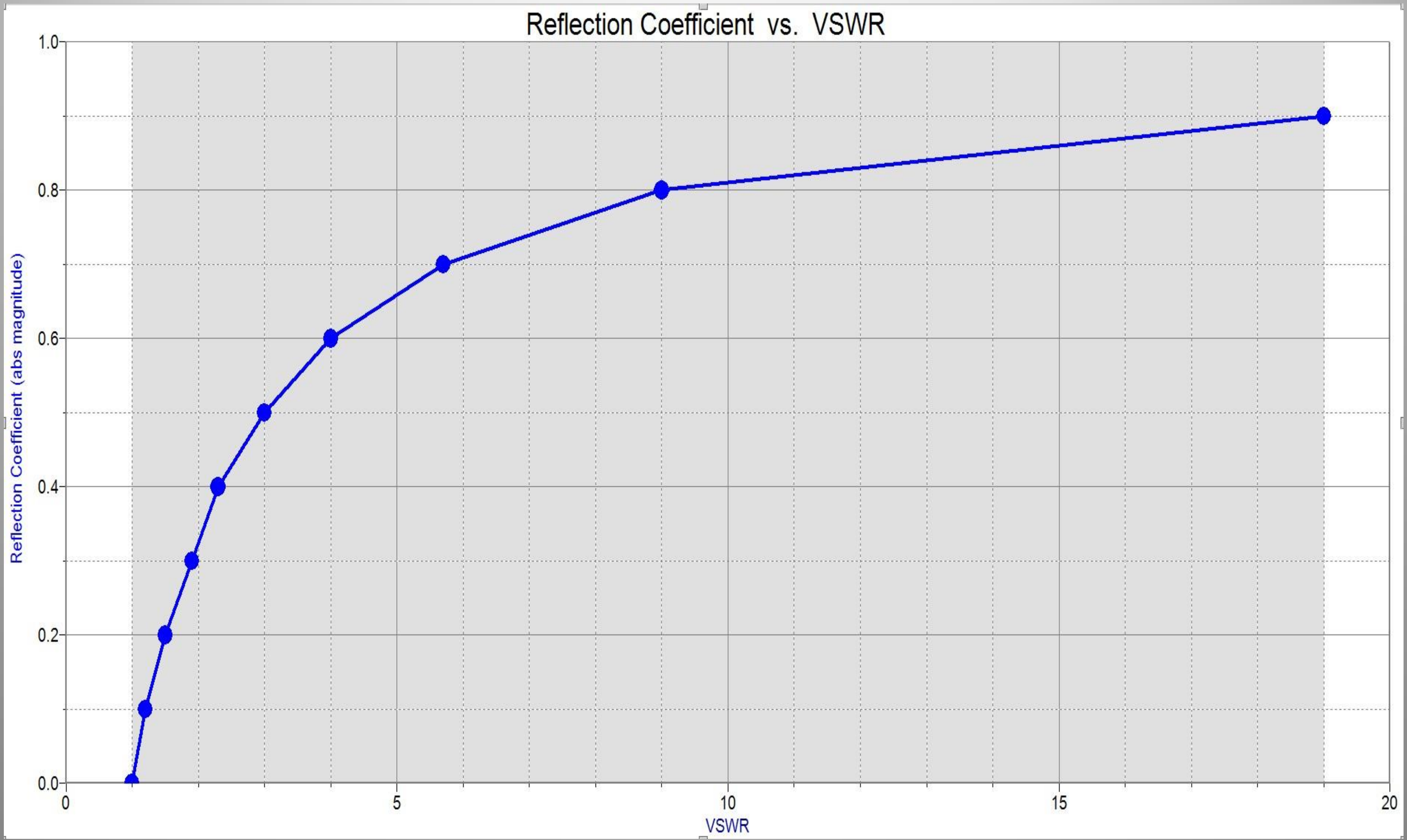
$$\text{VSWR} = \frac{\text{Vmax}}{\text{Vmin}} = \frac{1+\rho}{1-\rho}$$

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

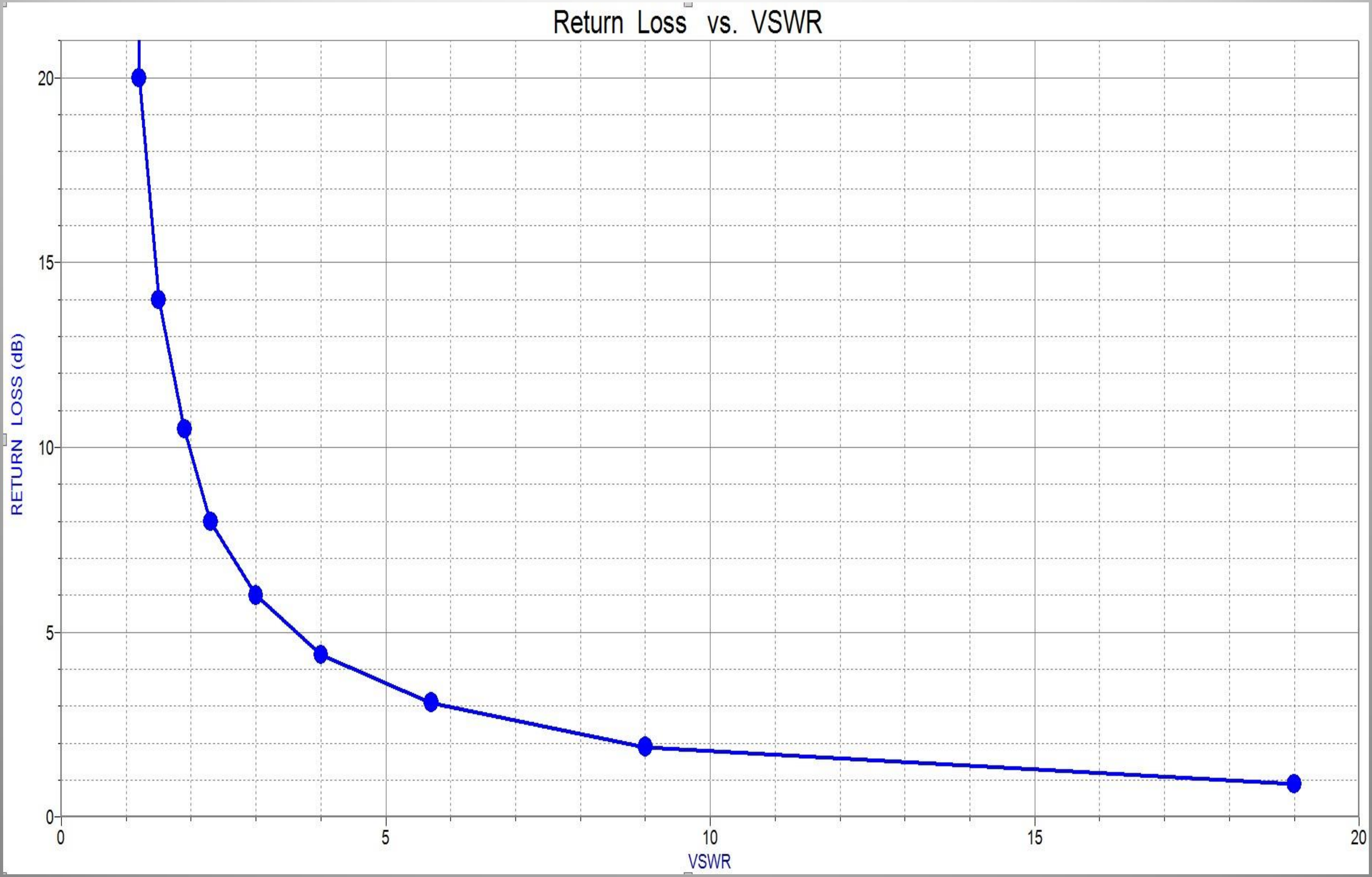


VNA Measurements	Calculated	Calculated
REFLECTION COEFFICIENT	RETURN LOSS (dB)	SWR
0	infinite	1.0
0.1	20.0	1.2
0.2	14.0	1.5
0.3	10.5	2.0
0.4	8.0	2.3
0.5	6.0	3.0
0.6	4.4	4.0
0.7	3.1	5.7
0.8	1.9	9.0
0.9	0.9	19.0
1	0.0	infinite
ρ = V(reflected) / V(forward)	RL = -20 log (ρ)	SWR = (1+ρ) / (1-ρ)

Reflection Coefficient vs. VSWR



RETURN LOSS (dB) vs. VSWR



Smith Chart
A graphical representation of
RESISTANCE and **REACTANCE**

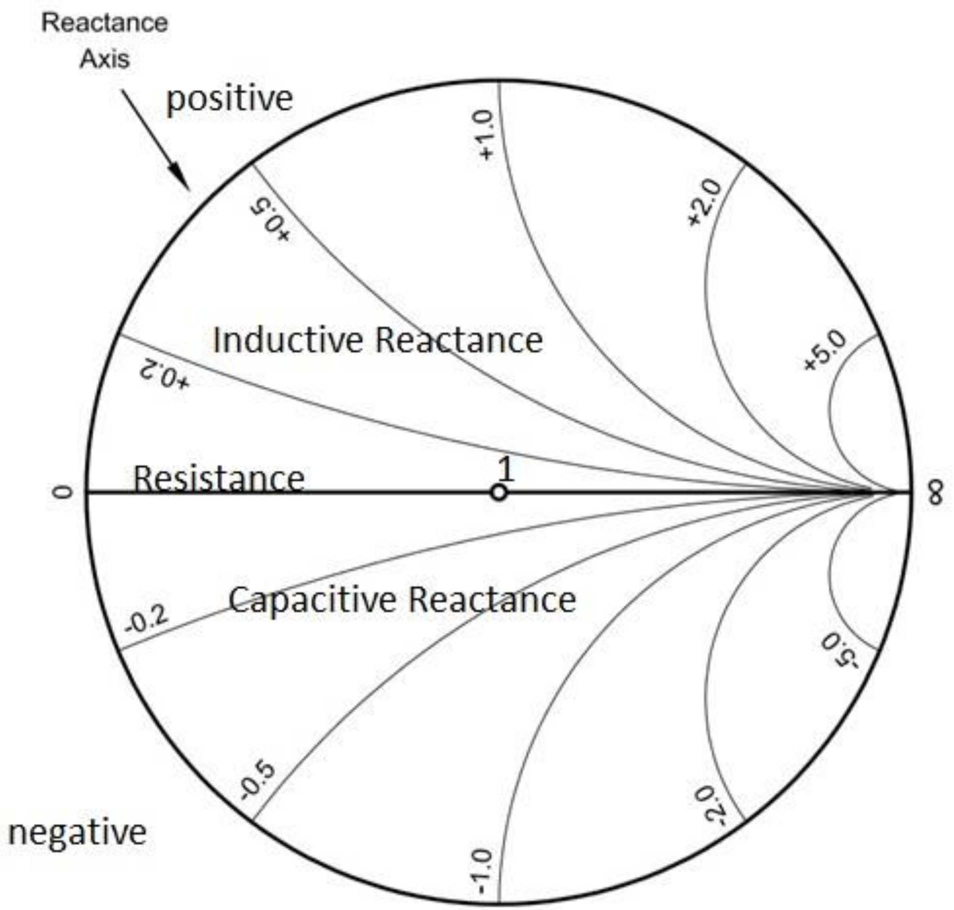
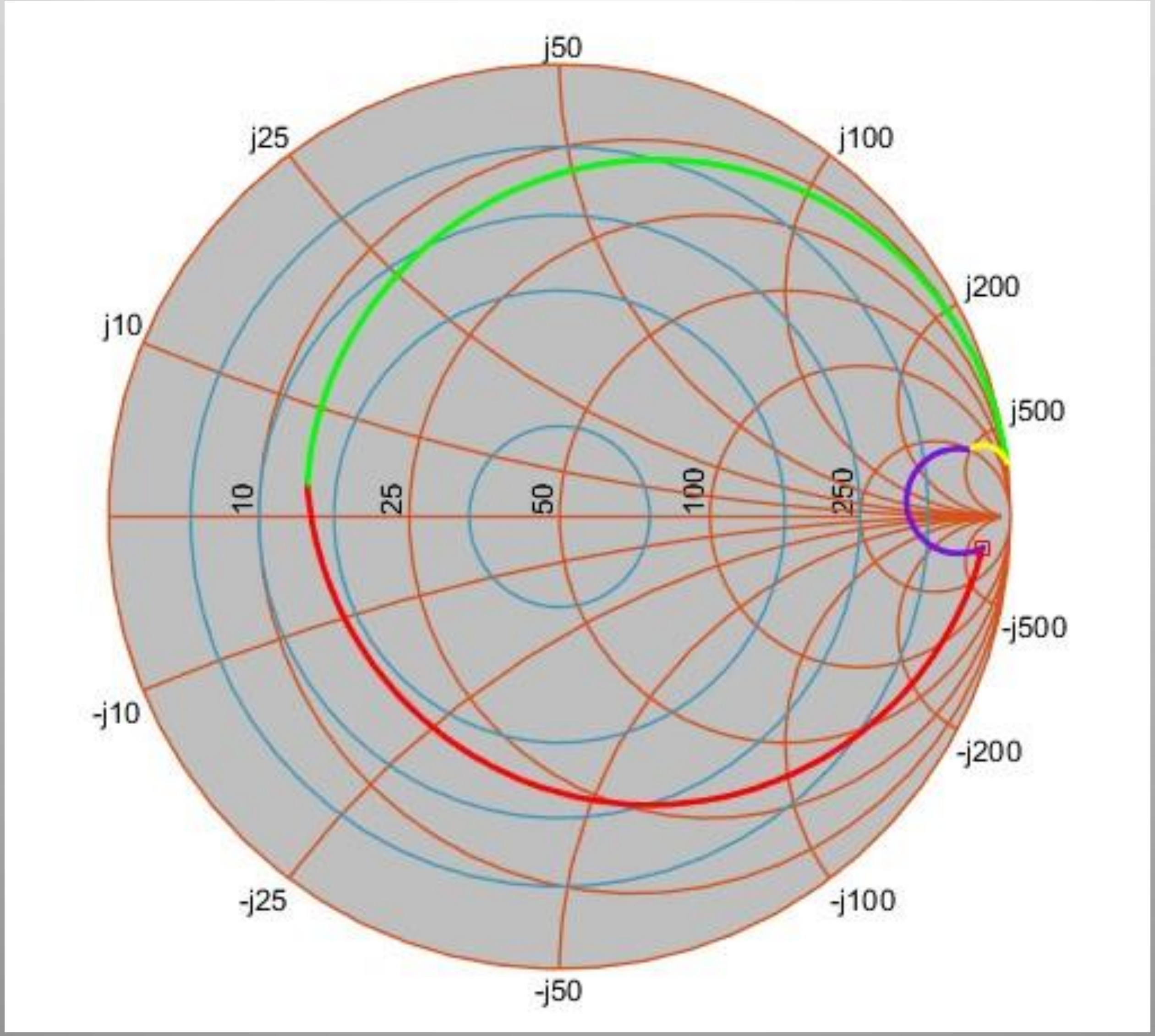
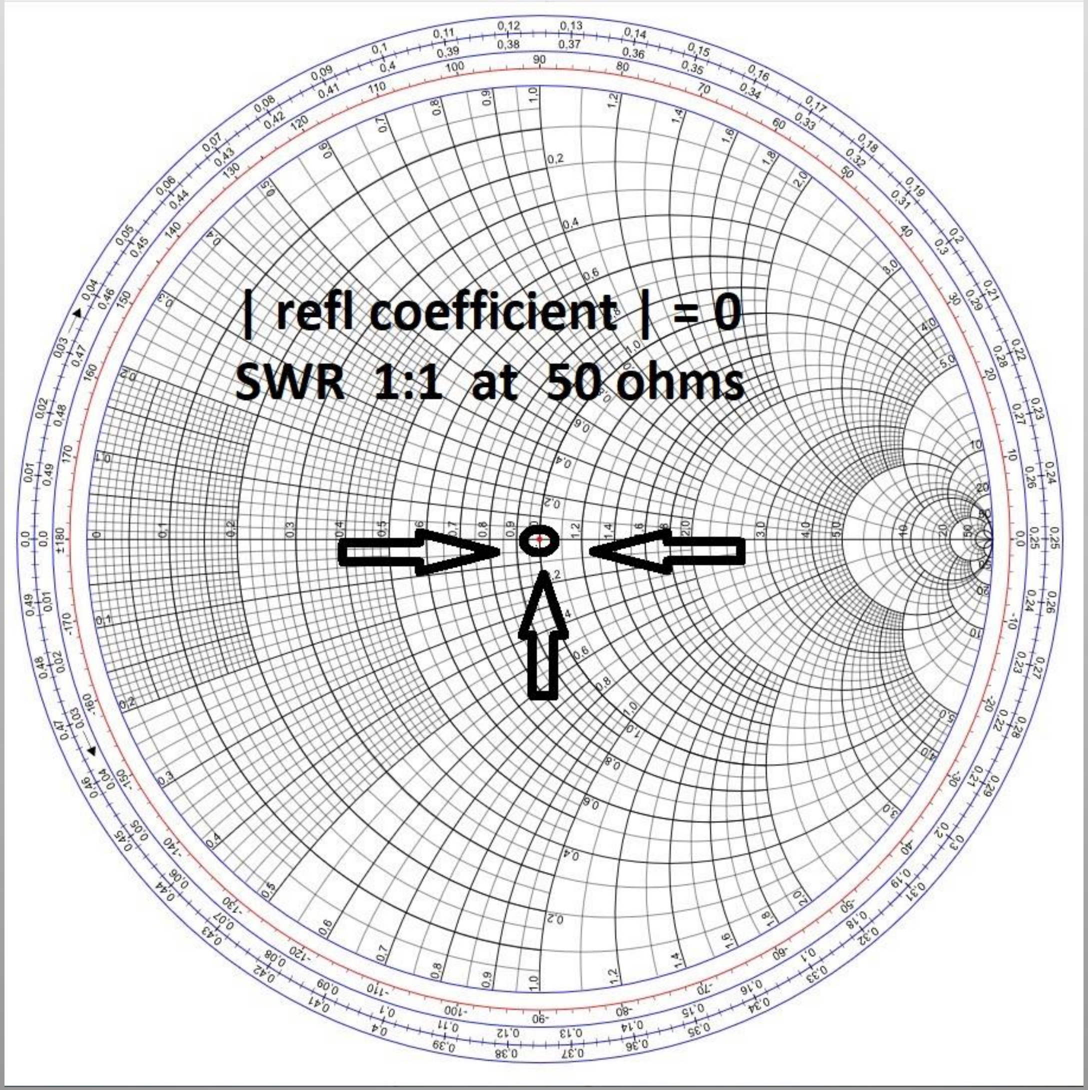


Fig 2—Reactance circles (segments) of the Smith Chart coordinate system.

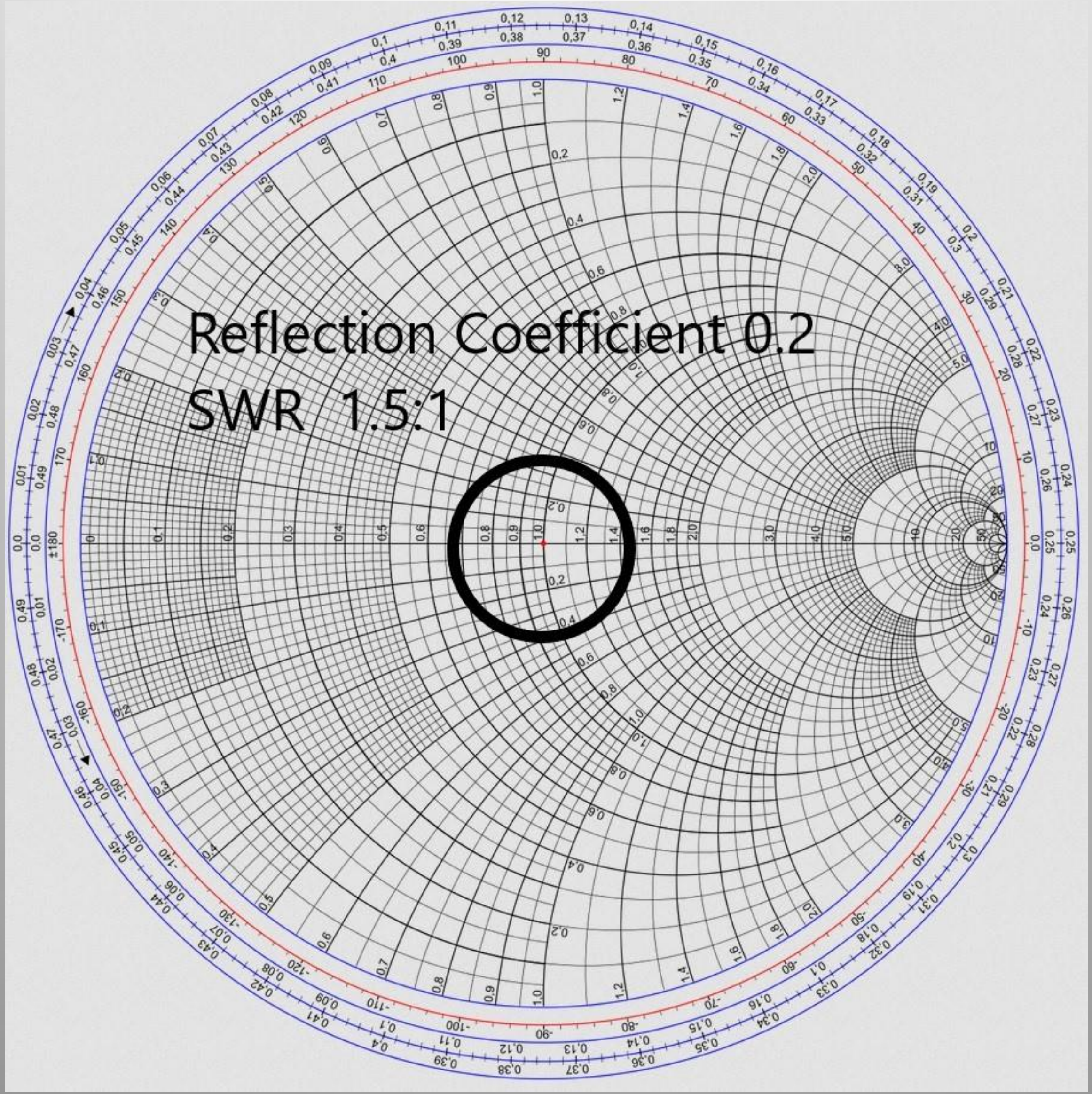
We can make the Bull's Eye 50 ohms



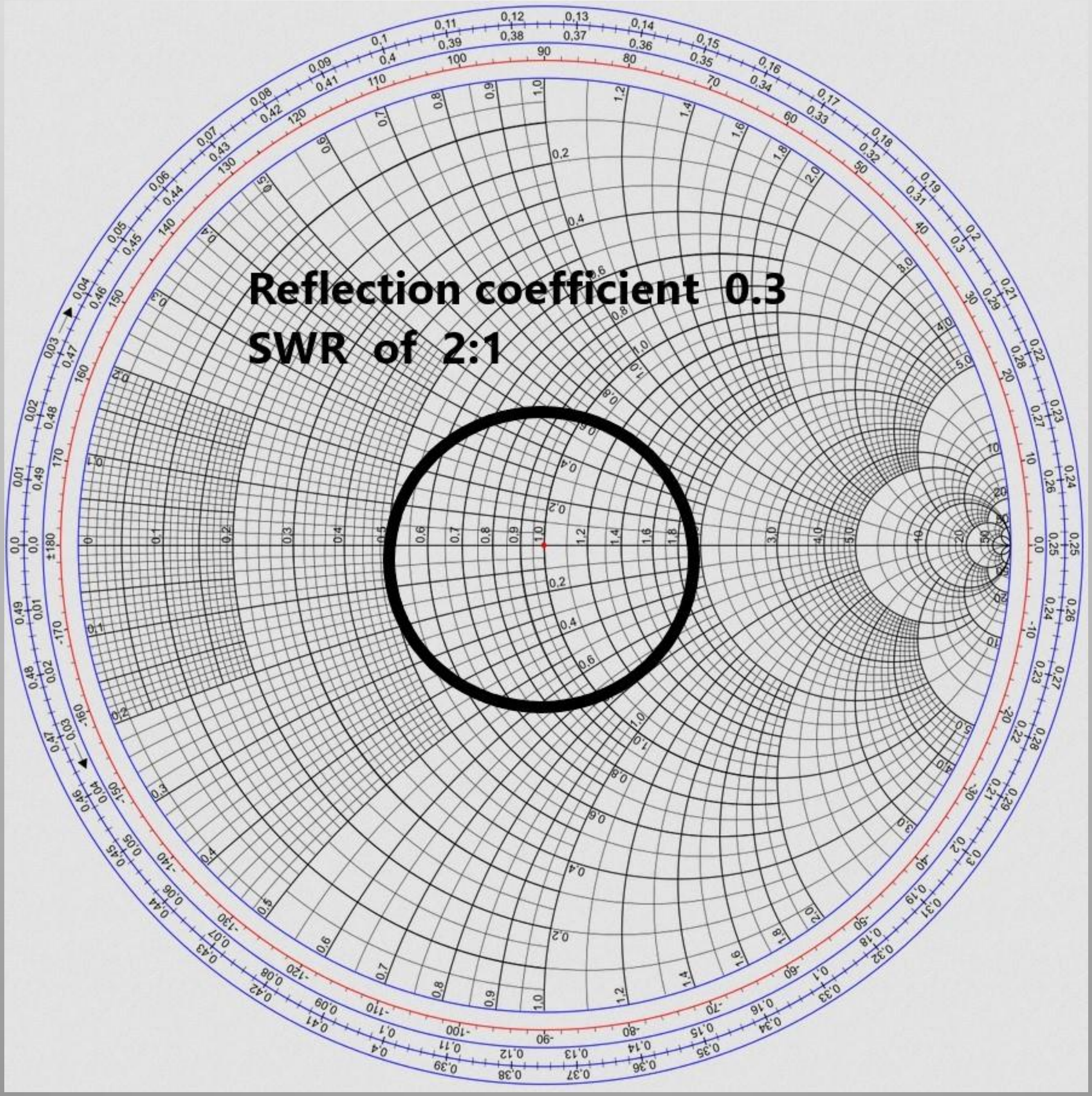
Smith Chart (think DART BOARD)
reflection coefficient ρ and SWR
Bull's Eye is a "perfect" match with zero reflected power



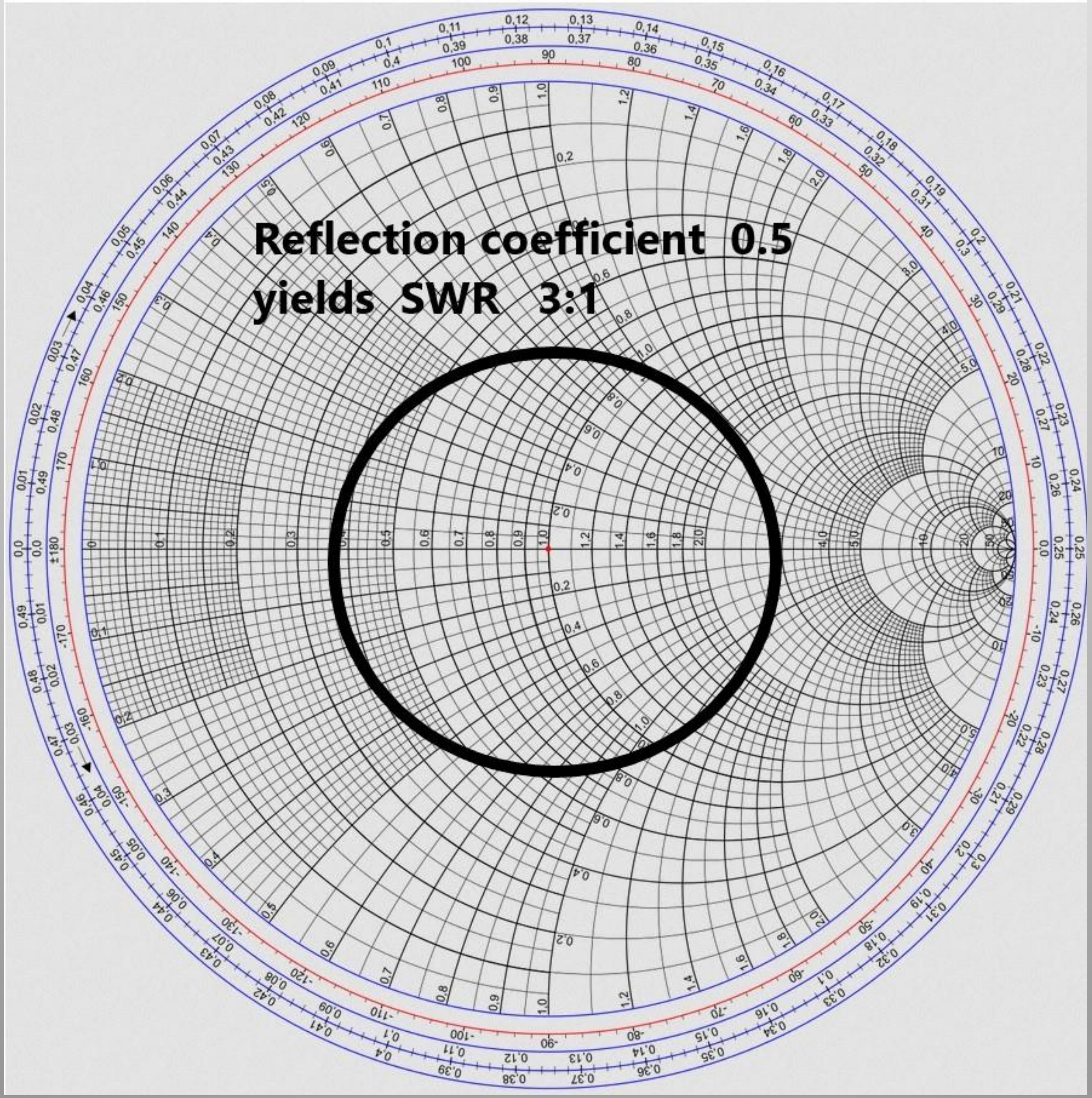
20% of incident voltage is reflected: SWR 1.5 : 1



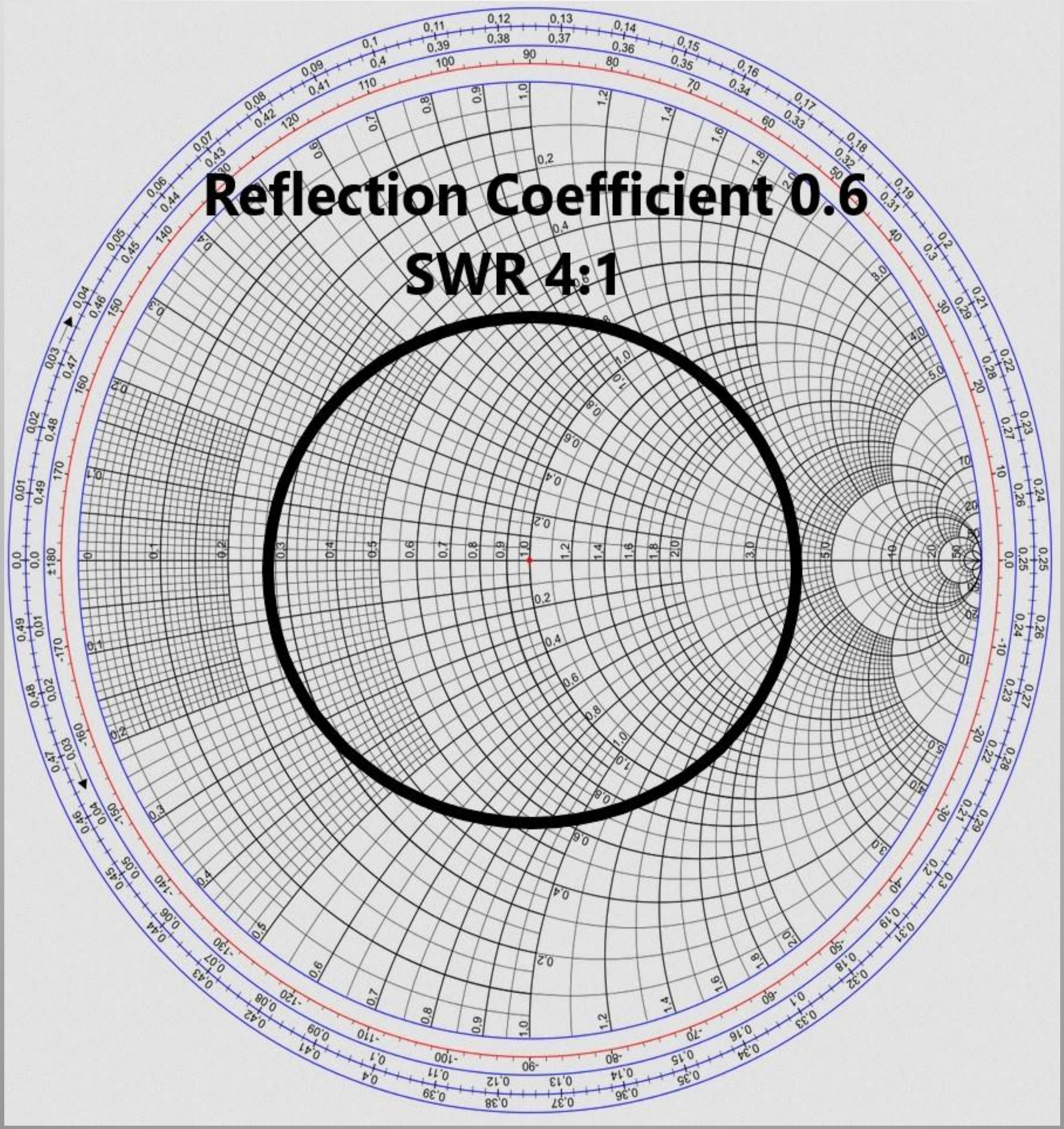
33% of incident voltage is reflected SWR 2:1



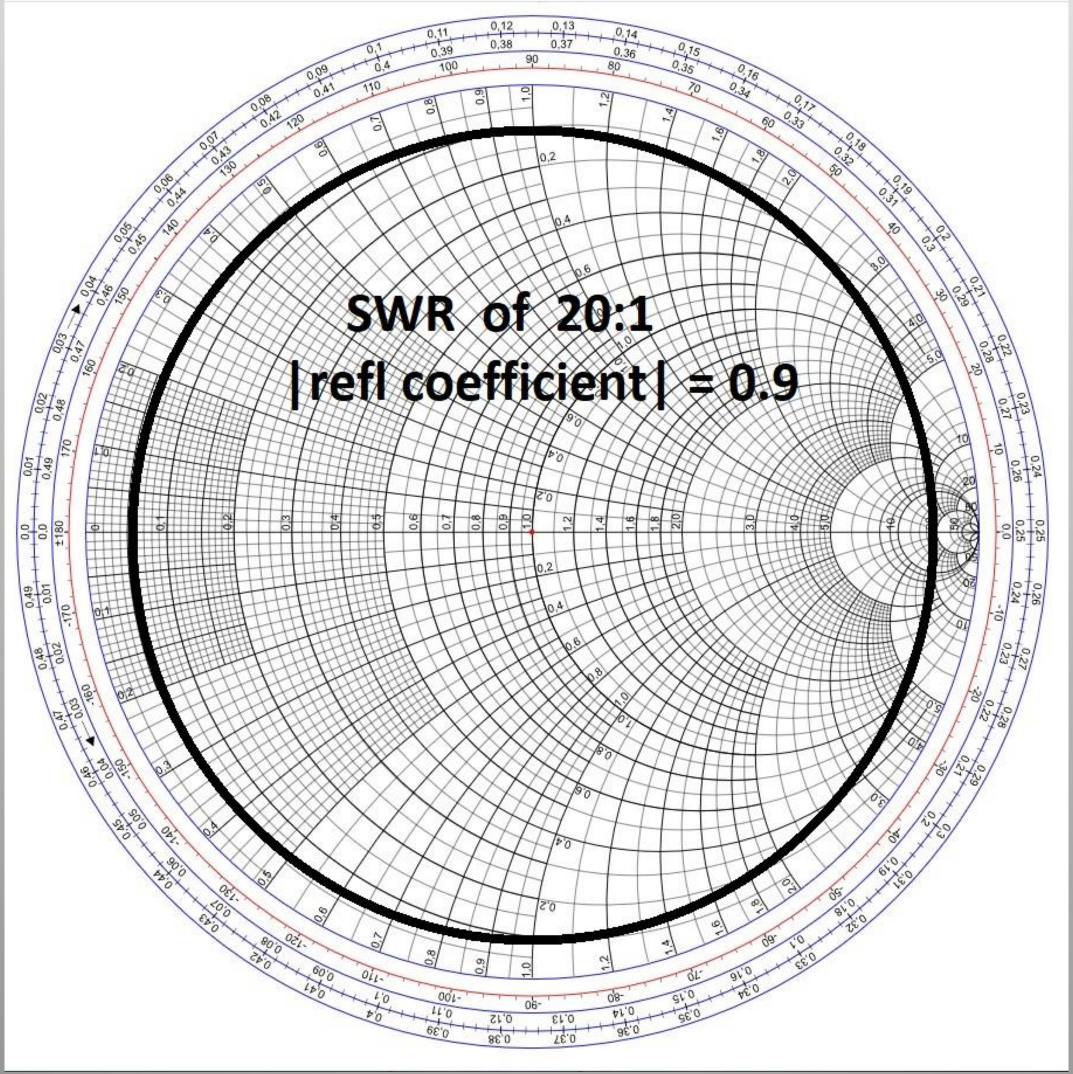
50% of incident voltage is reflected ==> SWR 3:1
All values or R+jX on perimeter show equal ρ and SWR



SWR of 4:1 with 60% reflected



90% reflected ==> SWR 20:1

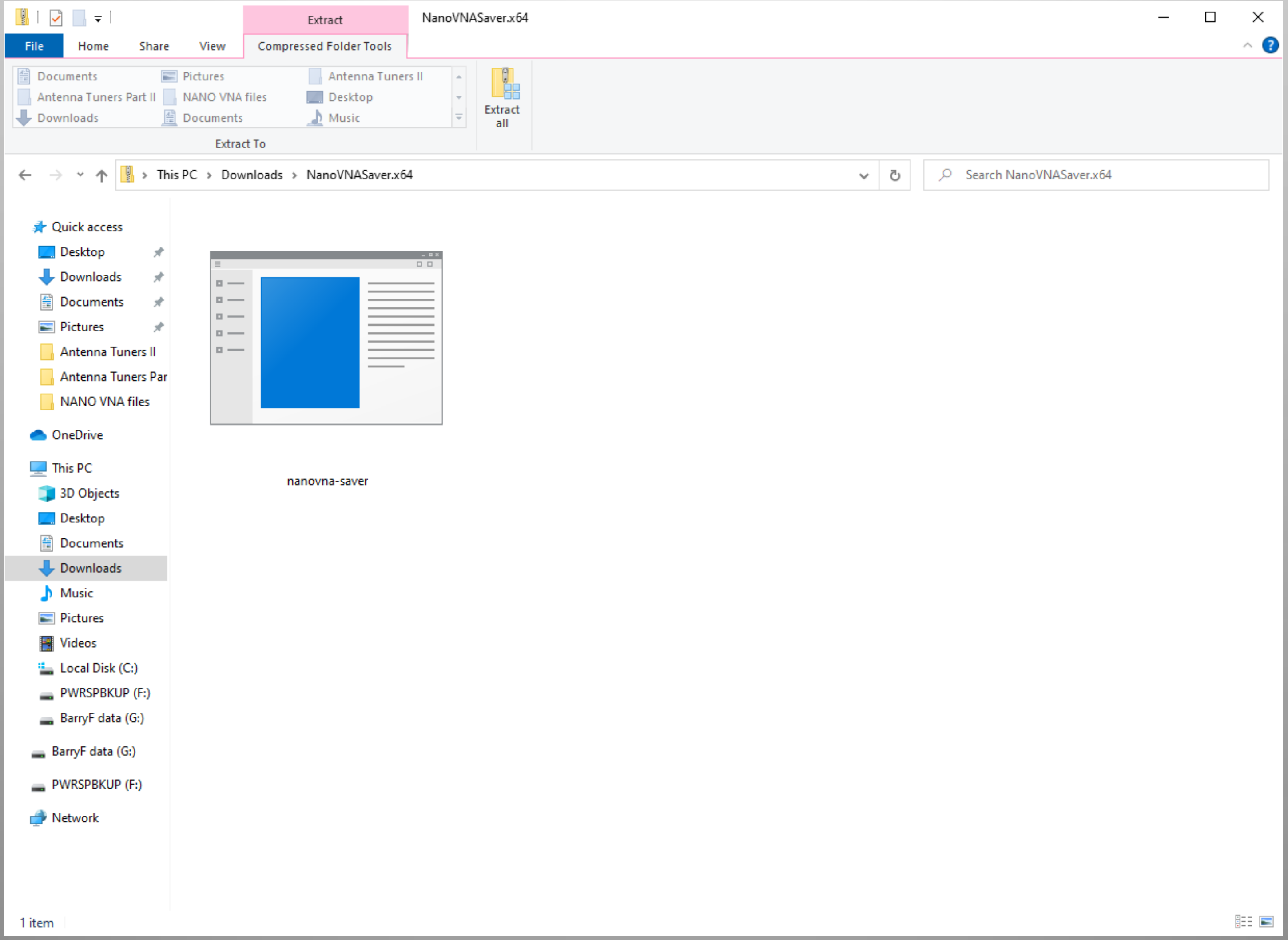


USB connections to computer and battery charger

Useful Cables: SMA to SO239 coax (for use with standard size coax)

Nano VNA Saver software

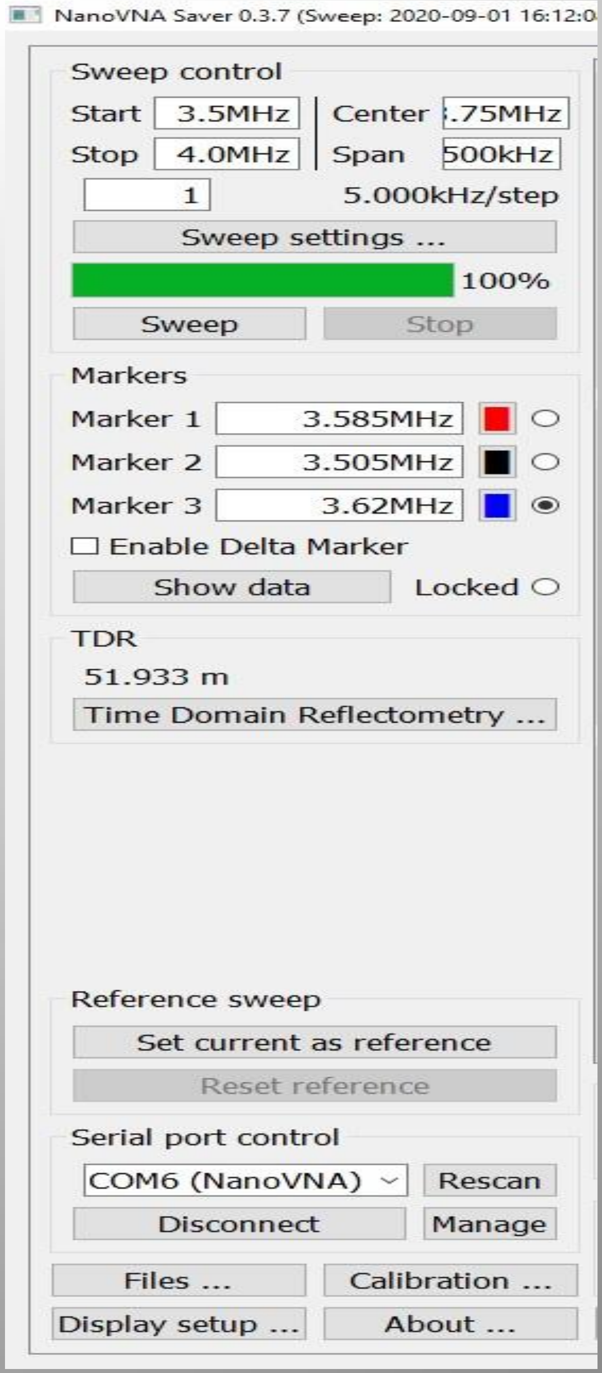
much easier to use by computer control



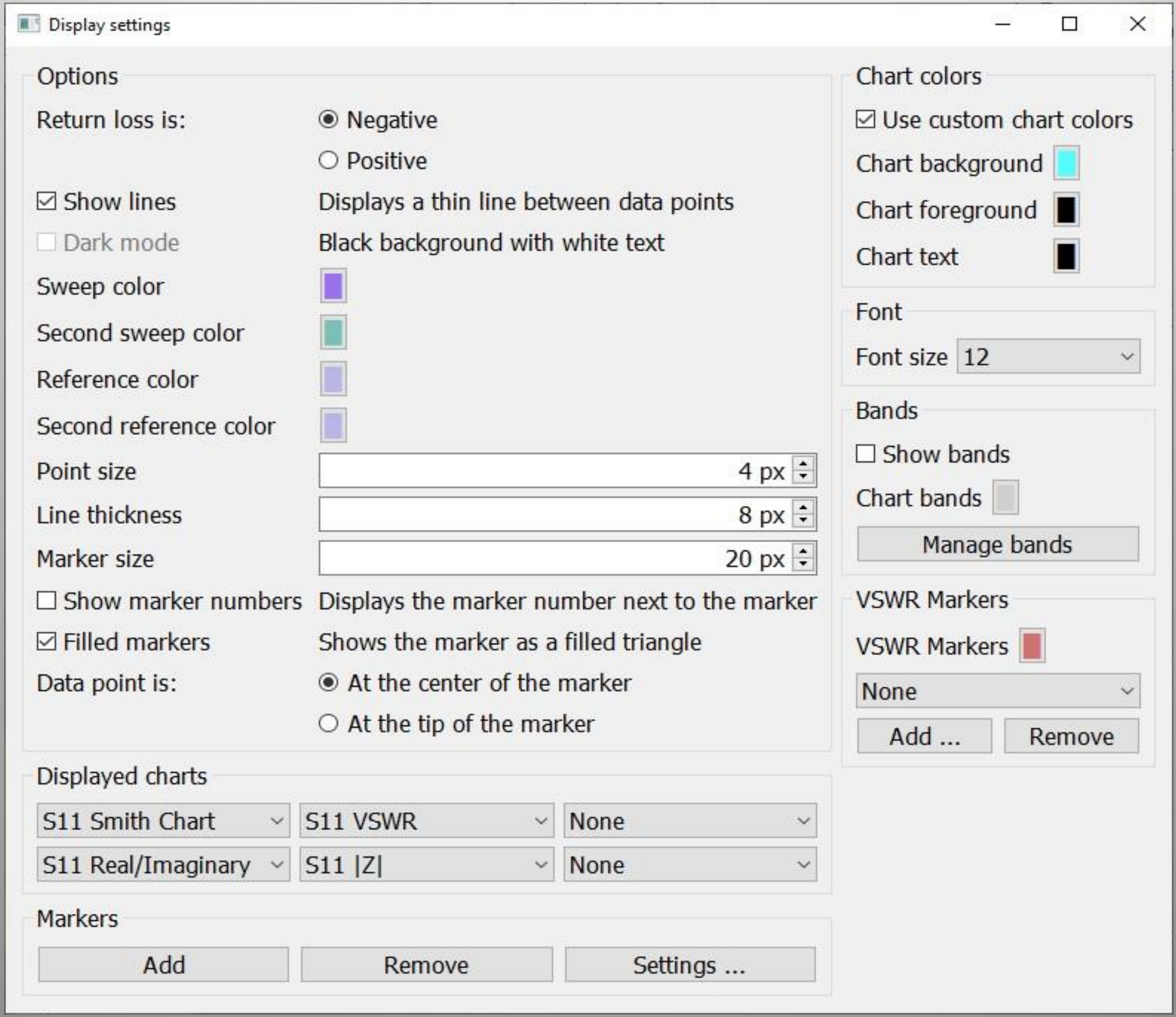
Computer Control
Settings

Com Port select
Frequency Range
Markers

Sweep resolution ENHANCED
Additional CAL points
SAVE and RETRIEVE files
Display setup of GRAPHS



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

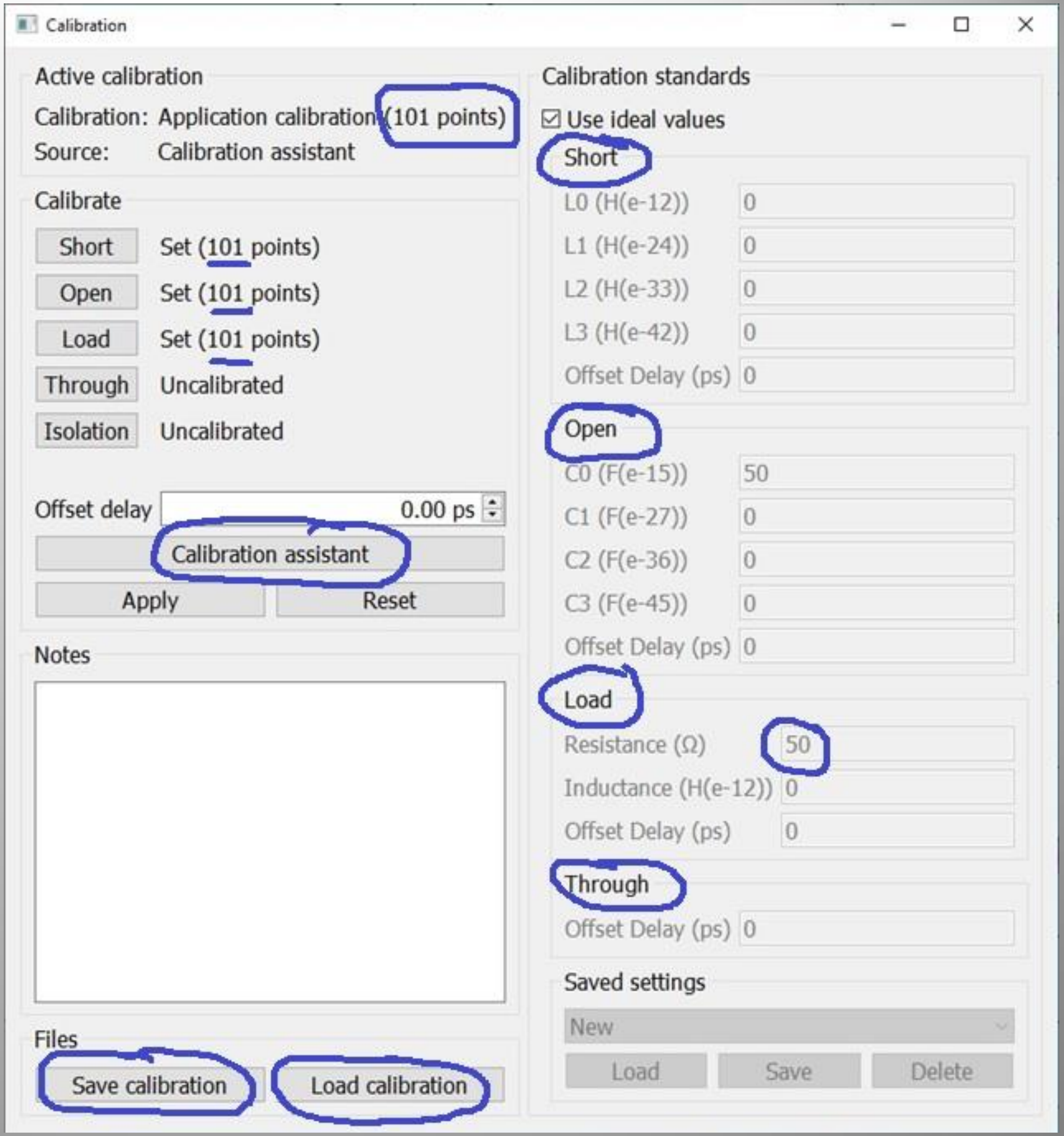


Do a calibration first
Calibration “assistant”

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

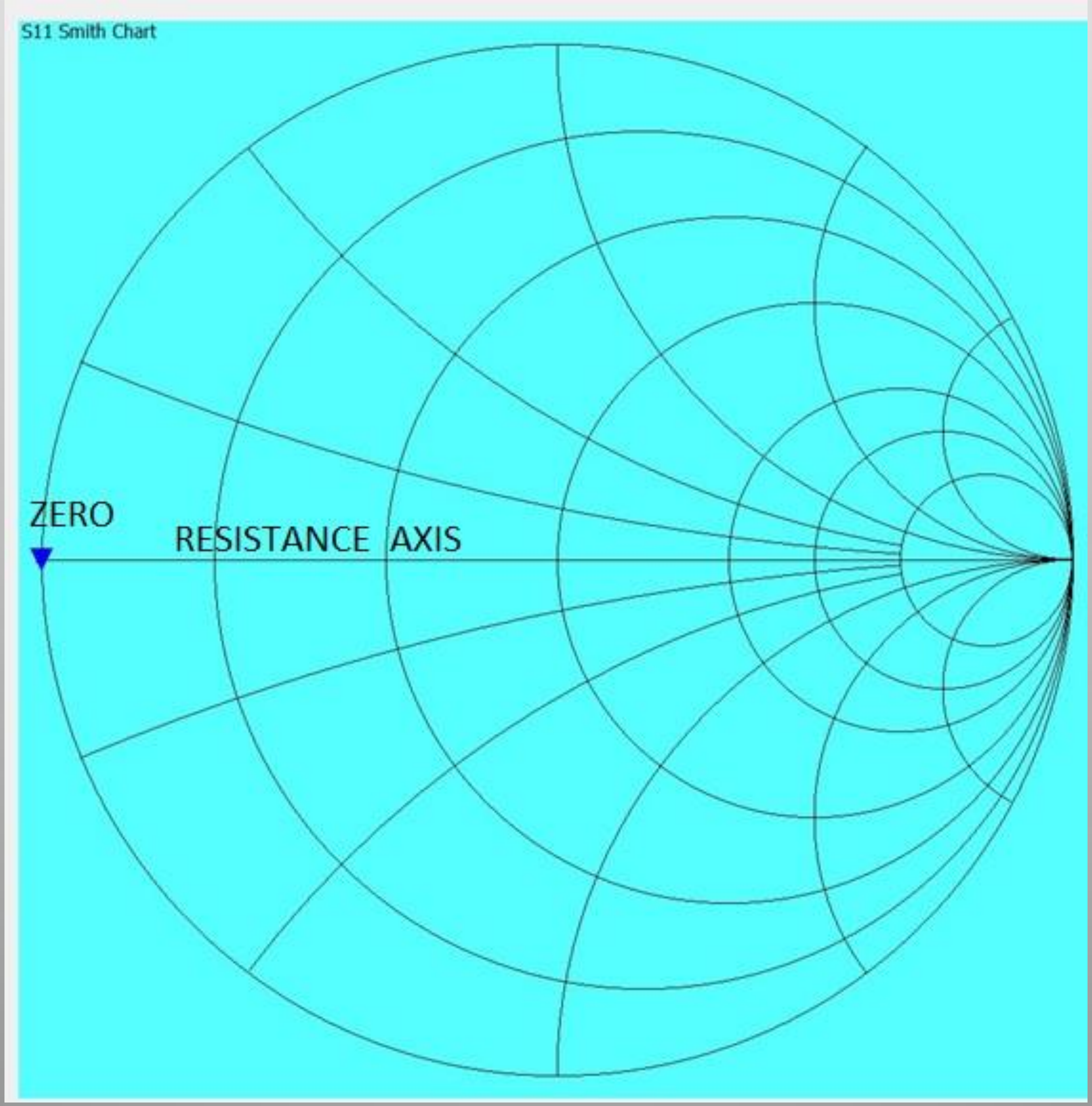
SAVE CAL files

You can use up to 5000 data points to plot

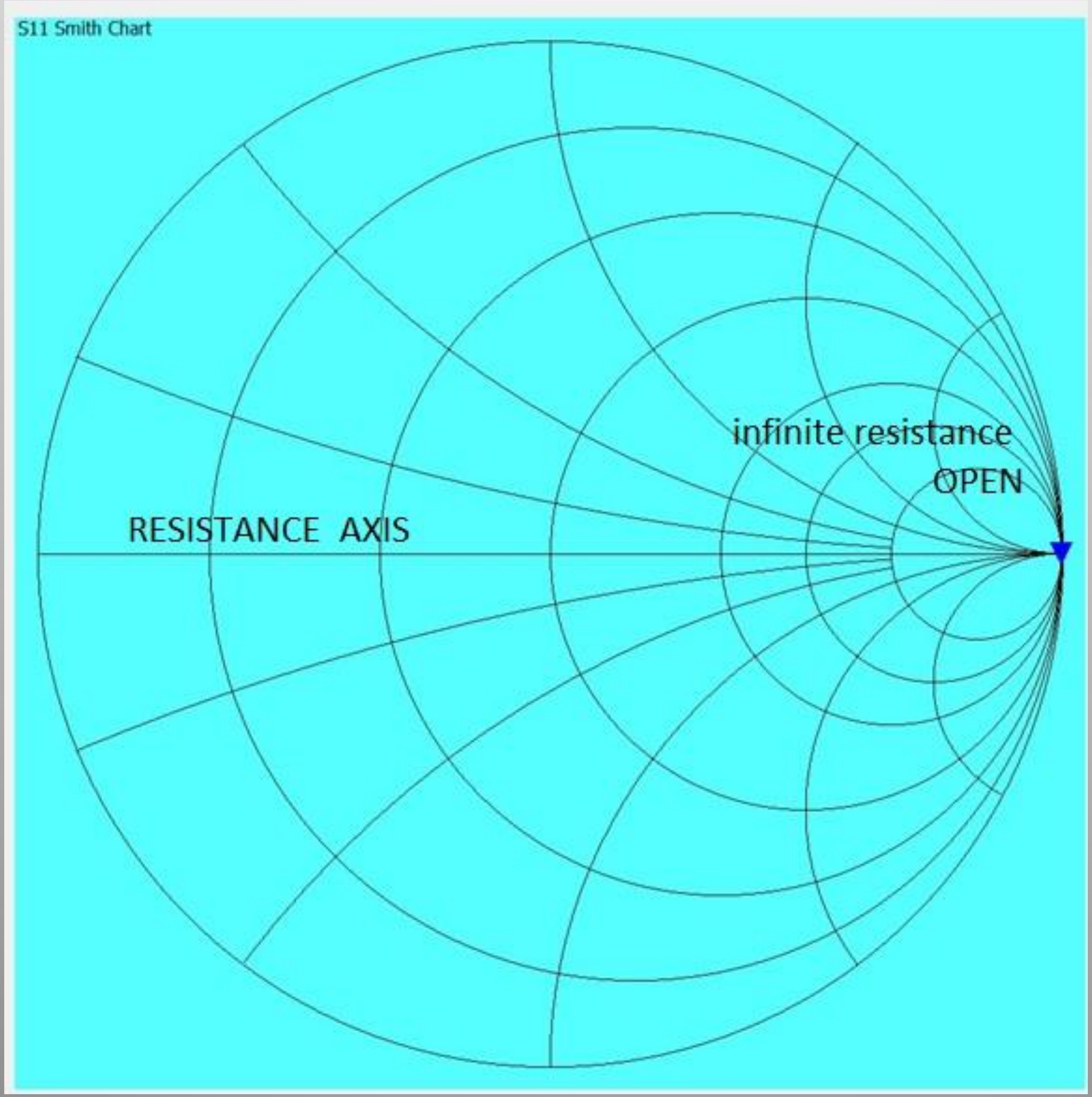


First Step: **CALIBRATE** VNA over a frequency range (MHz)
Calibration standards included as SMA connectors
Short, Open, Load (50-ohm), and Through

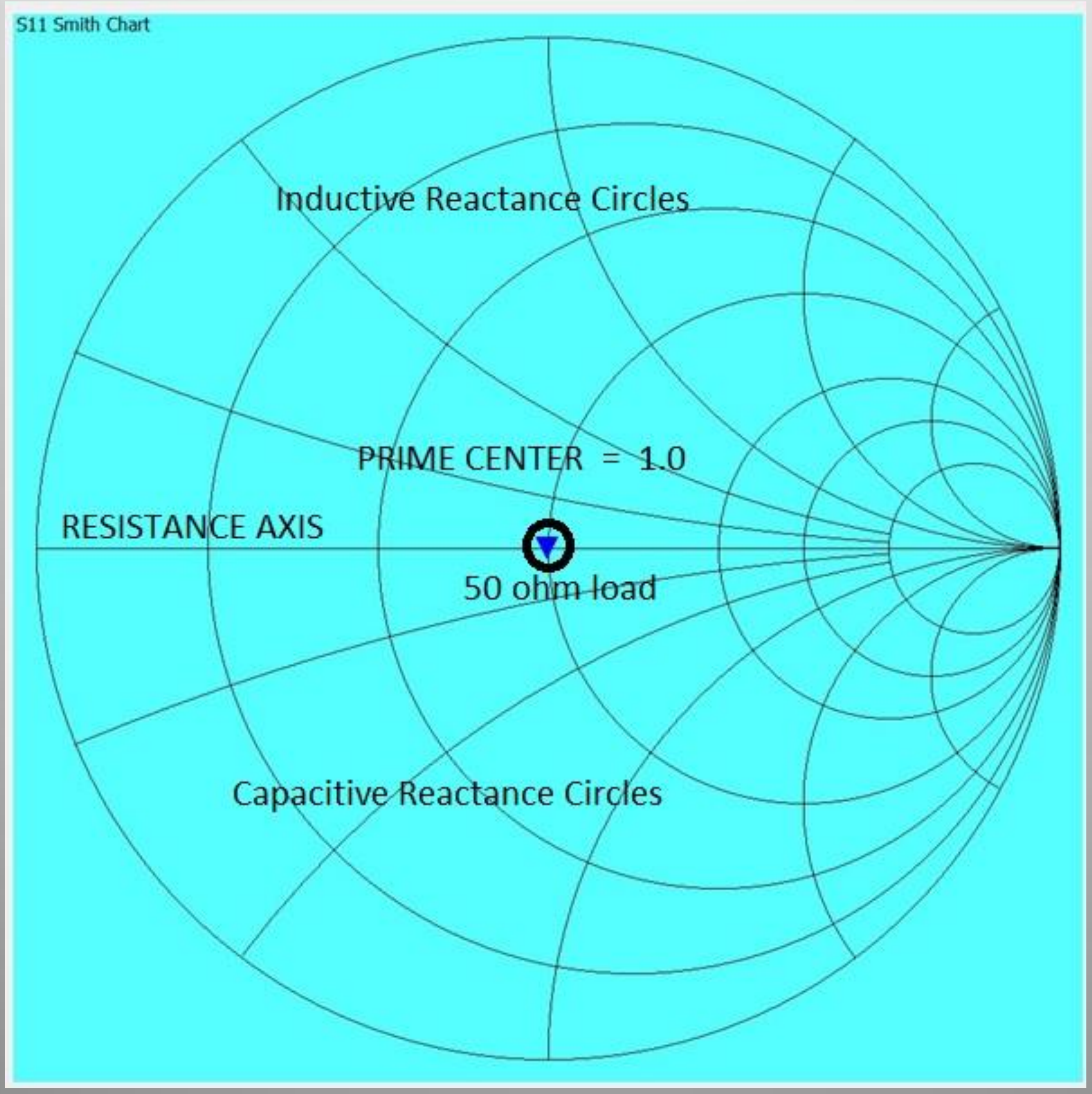
Calibration: **SHORT** circuit (ZERO R) on far left of the Smith Chart RESISTANCE axis



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



Calibration: **50-ohm** **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 <u>101 data points</u>

Measuring Antenna Characteristics

Resistance R (ohms)

Reactance X (ohms)

Impedance Z (ohms)

Phase θ (degrees)

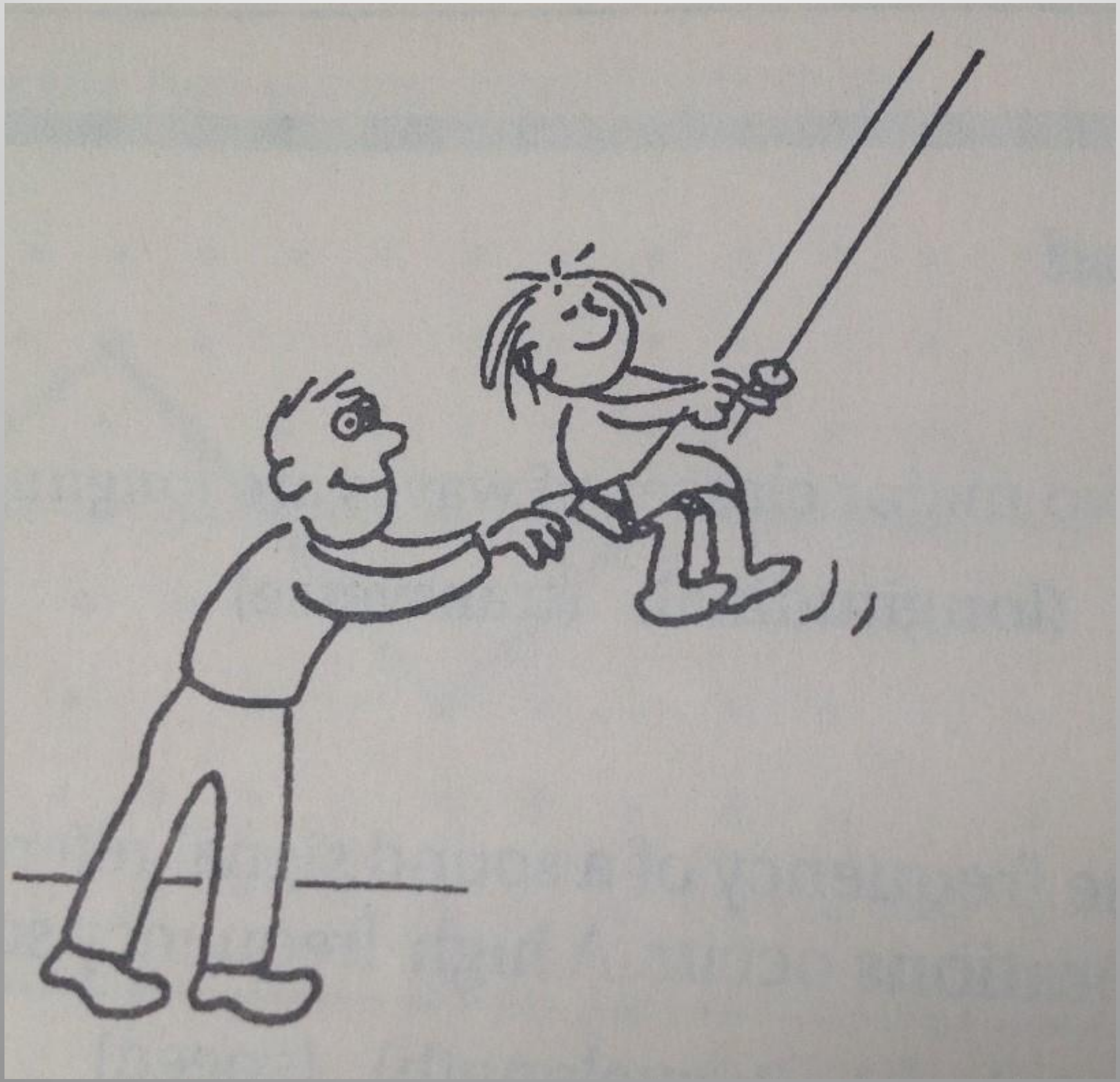
Reflection Coefficient ρ rho

RETURN LOSS (dB)

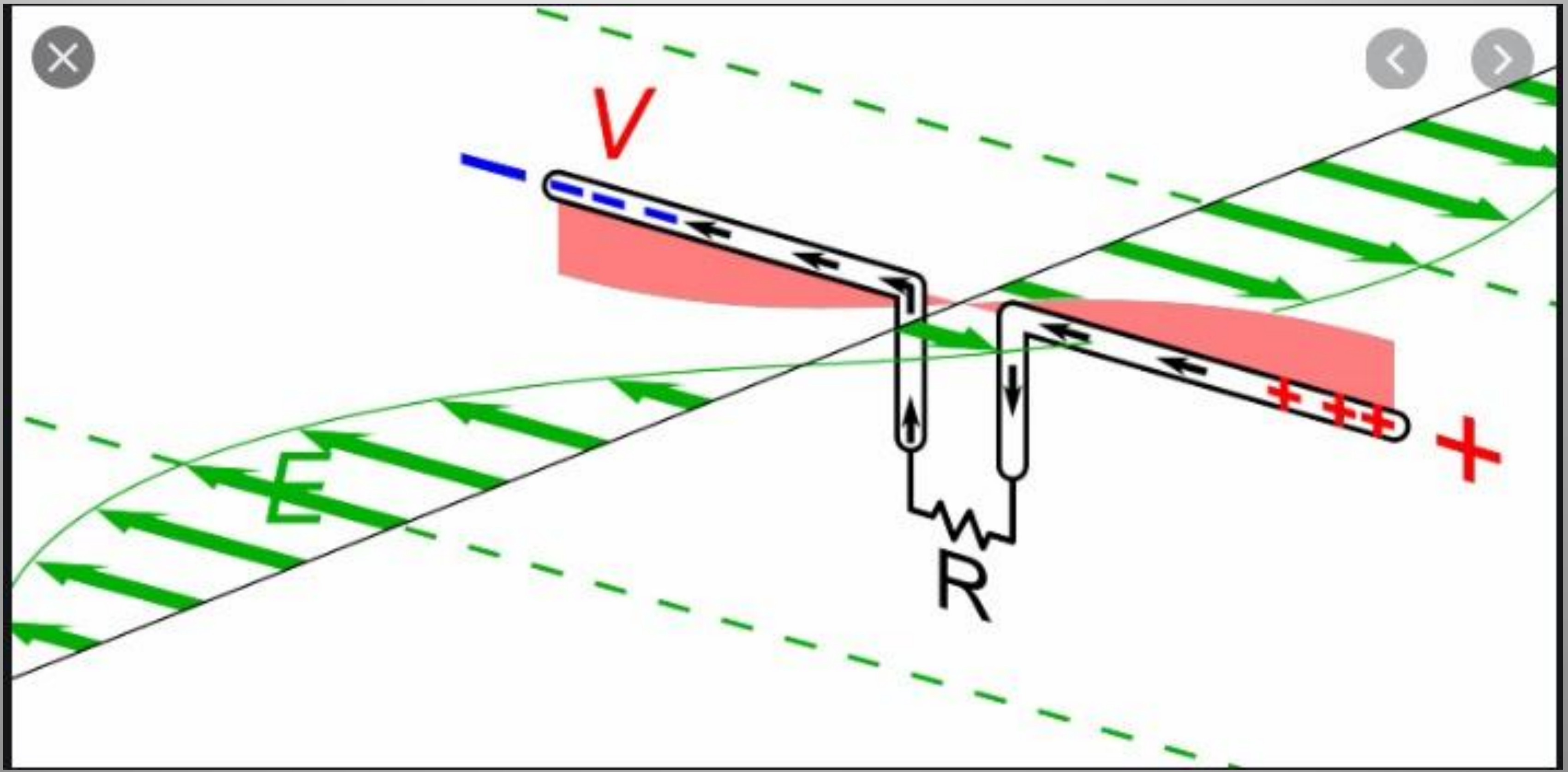
SWR

Smith Chart Analysis

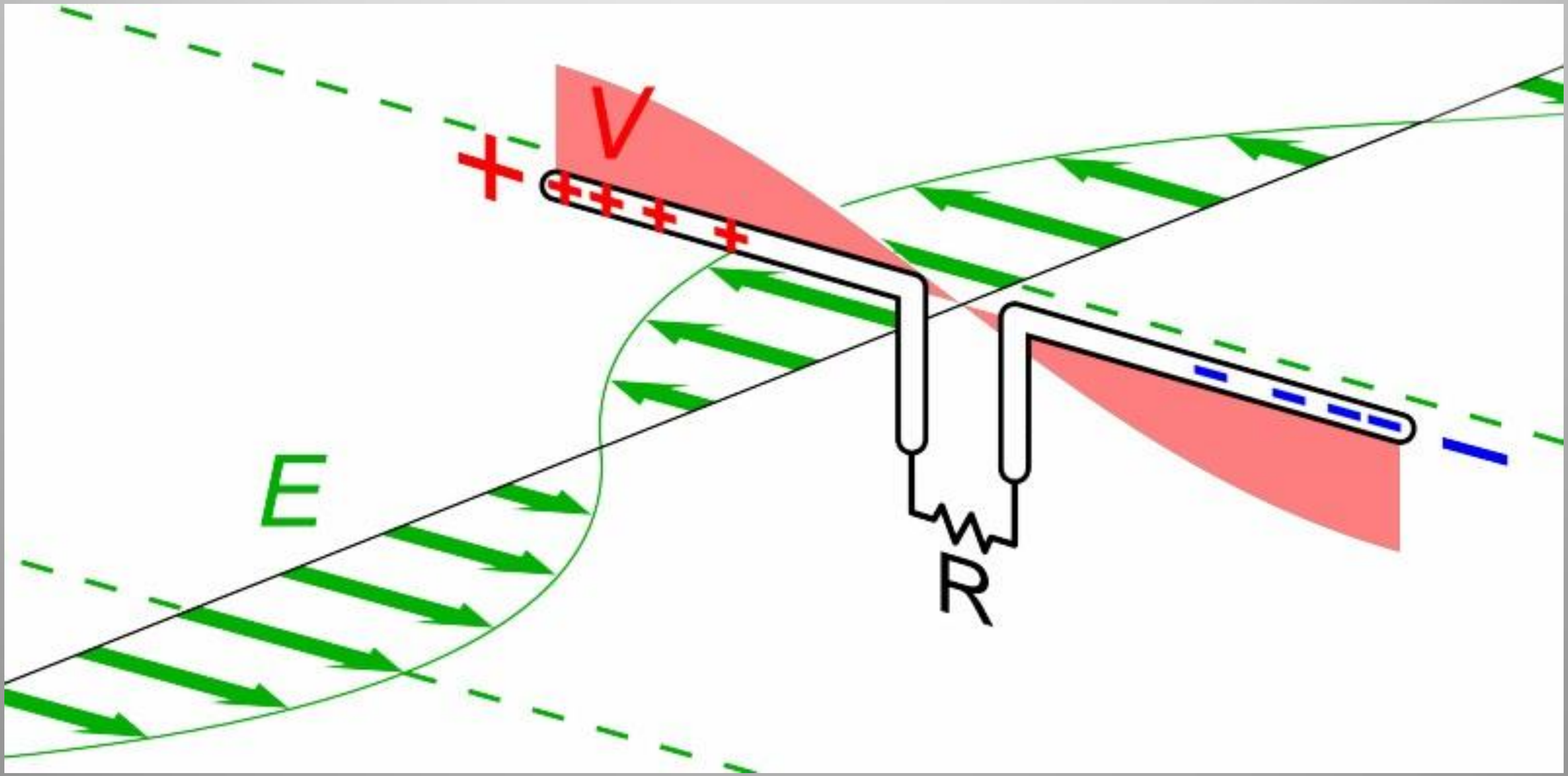
Antenna Length and Resonance
“Grampy, push <u>in phase</u> with my natural swinging please”



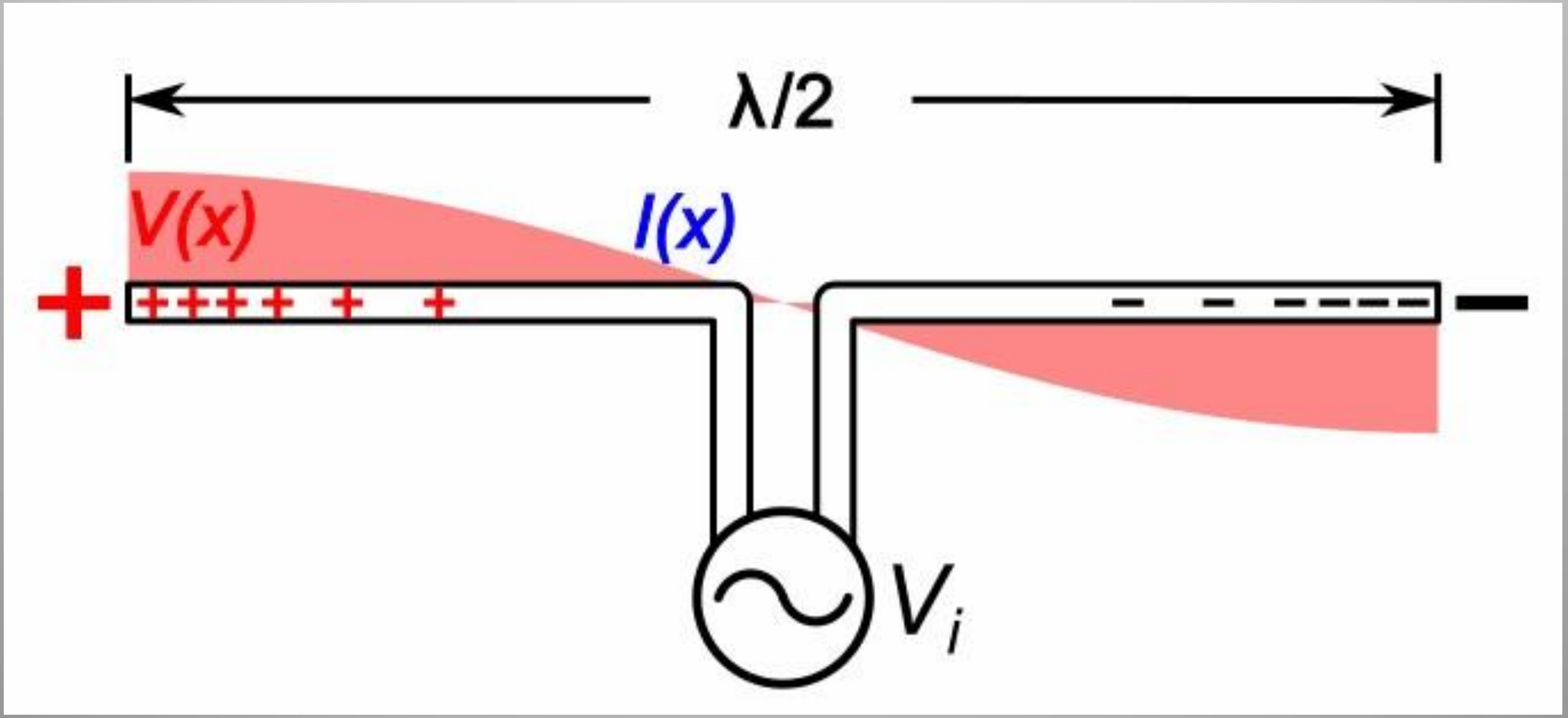
You want the feed line to “push” the electrons in rhythm with the natural vibrations of the electrons in the antenna at some frequency F



The charges at the ends of the antenna have reversed polarity in ½ cycle of RF



The electrons must travel a length of twice the dipole length in one RF cycle (period)

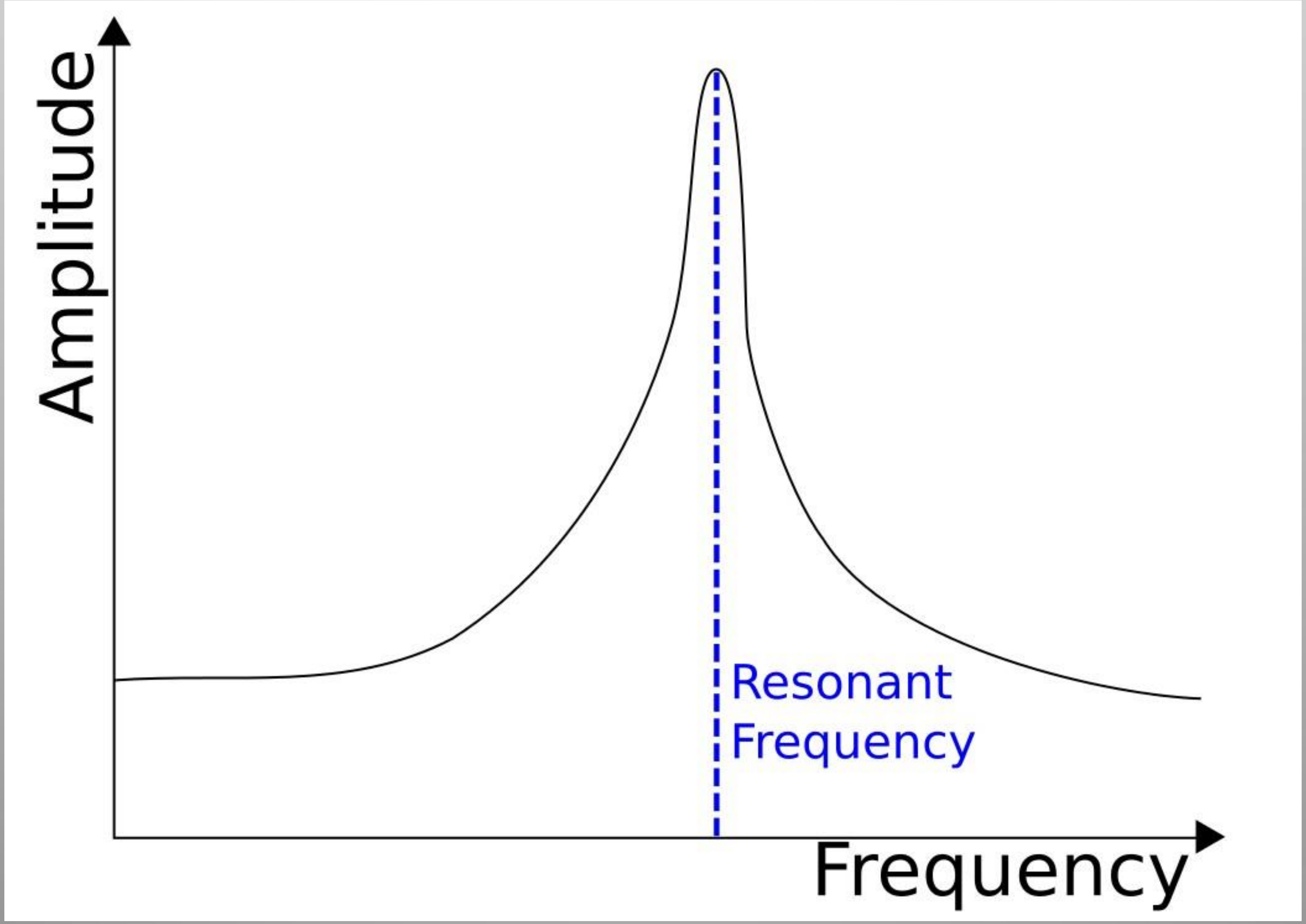


Resonant Frequency for 130 ft dipole

1) Electrons must travel 260 ft in one RF cycle
2) Current speed in wire v = **1 ft/nanosecond**
3) Time for 1 rf cycle must be about 260 nanosec
4) 260×10^{-9} seconds = the PERIOD of osc
5) Frequency = 1 / period
6) Frequency = $1 / (260 \times 10^{-9}$ seconds)

Resonant frequency = 3.8 MHz

At resonance the current and the voltage are IN-PHASE at the feed point connection



What happens if you transmit on a frequency that is NOT resonant? SWR climbs, but WHY?

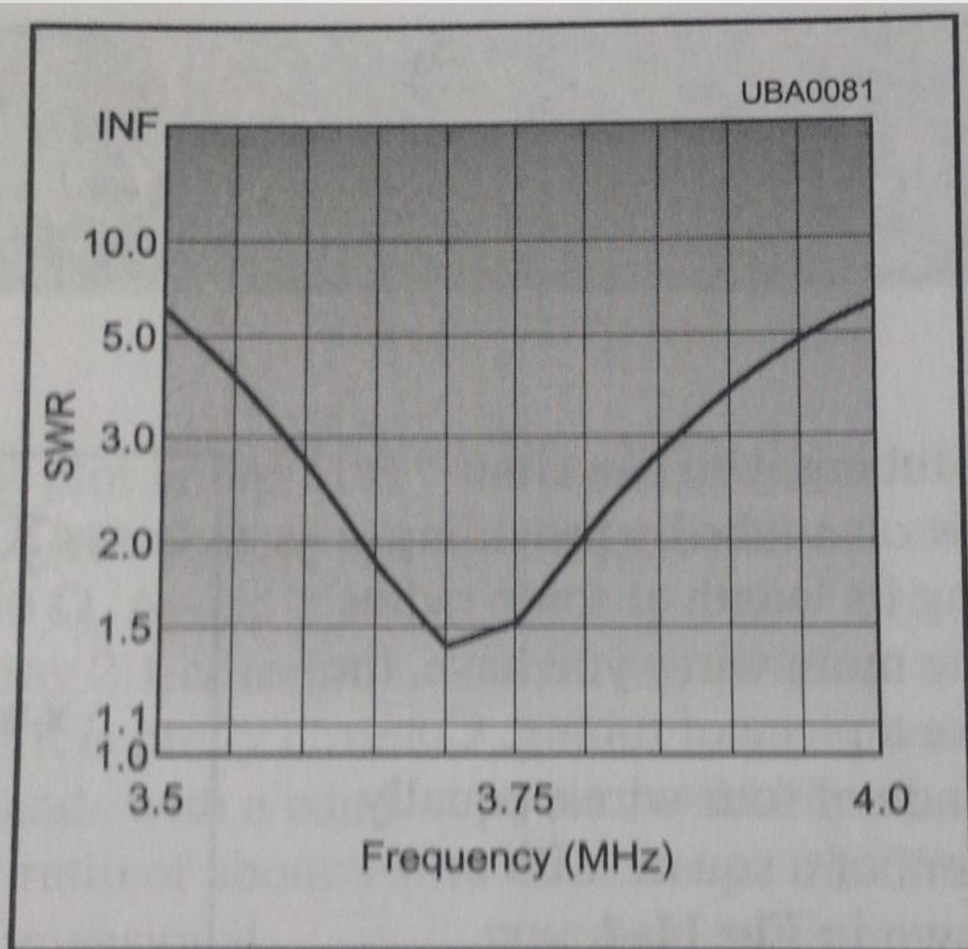
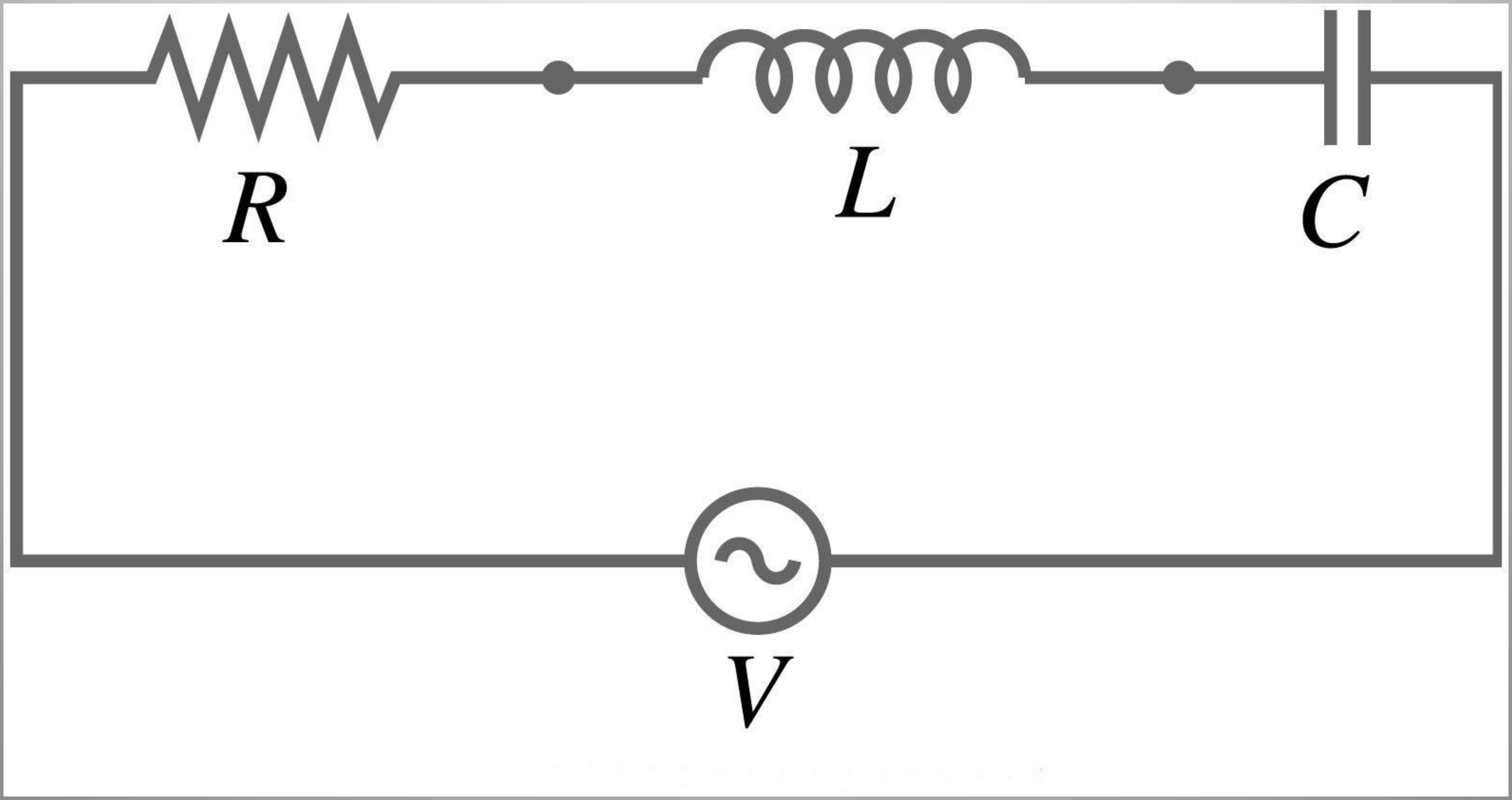
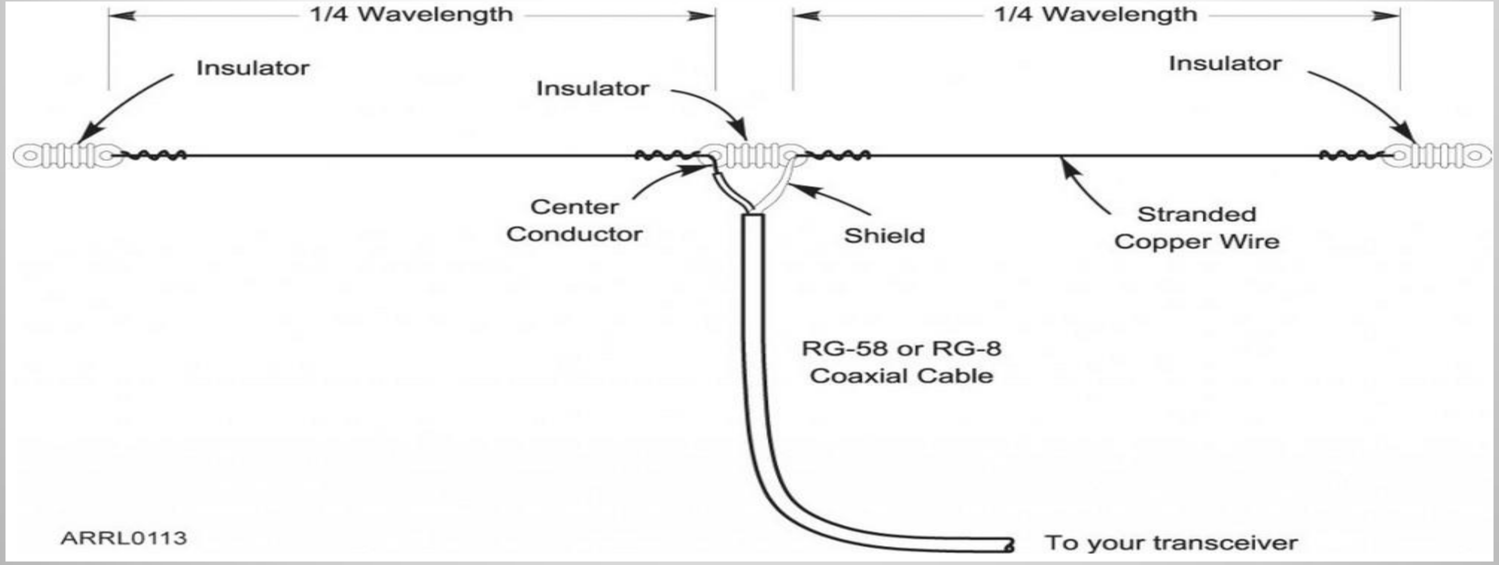


Fig 11-1 — SWR plot of 80 meter dipole of #12 wire at 50 feet.

Dipole now shows **REACTANCE (phase errors)** and behaves like a series **RLC** circuit



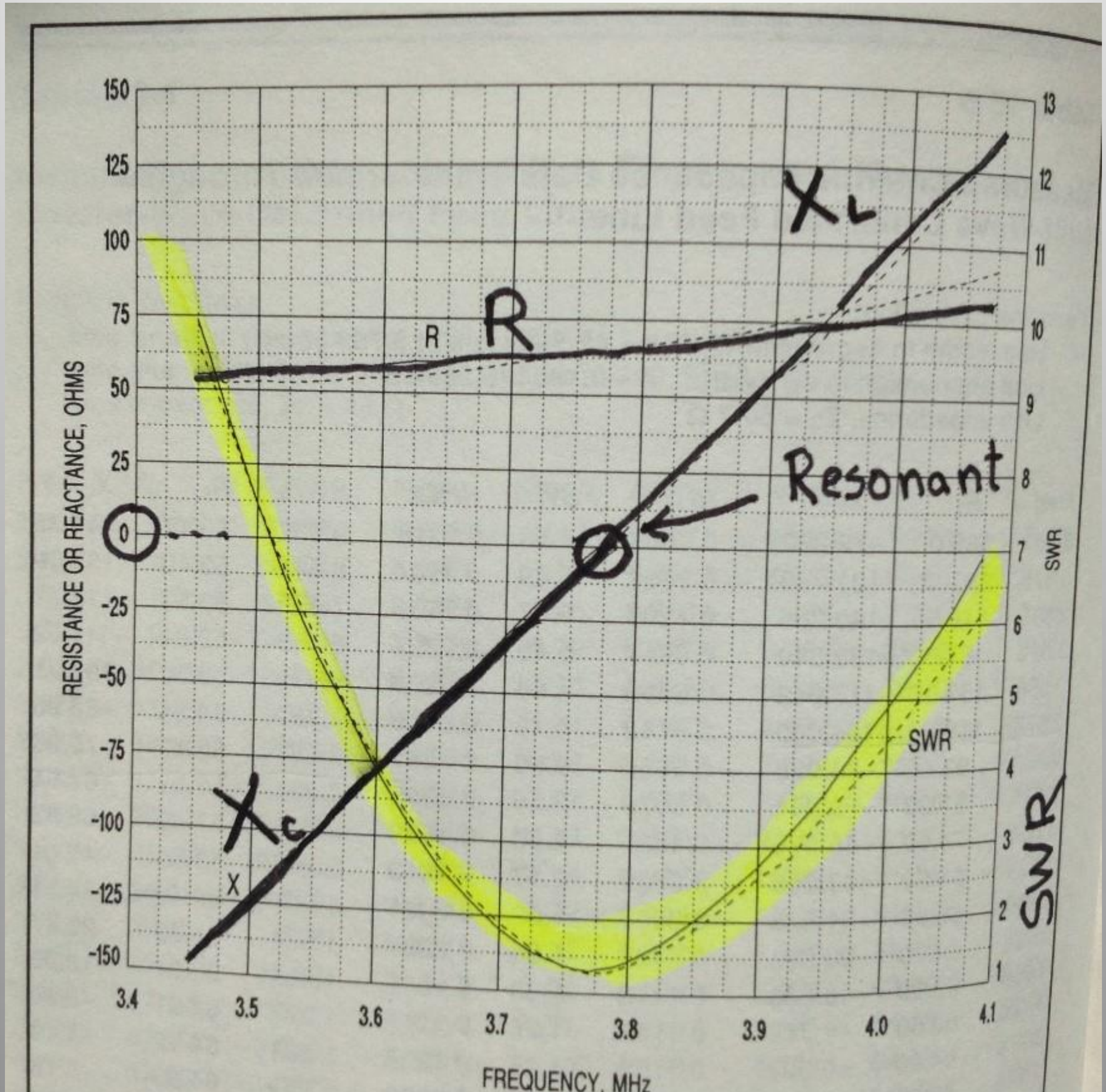


- Below resonance: the dipole is too short and the current leads the driving voltage (capacitive reactance)

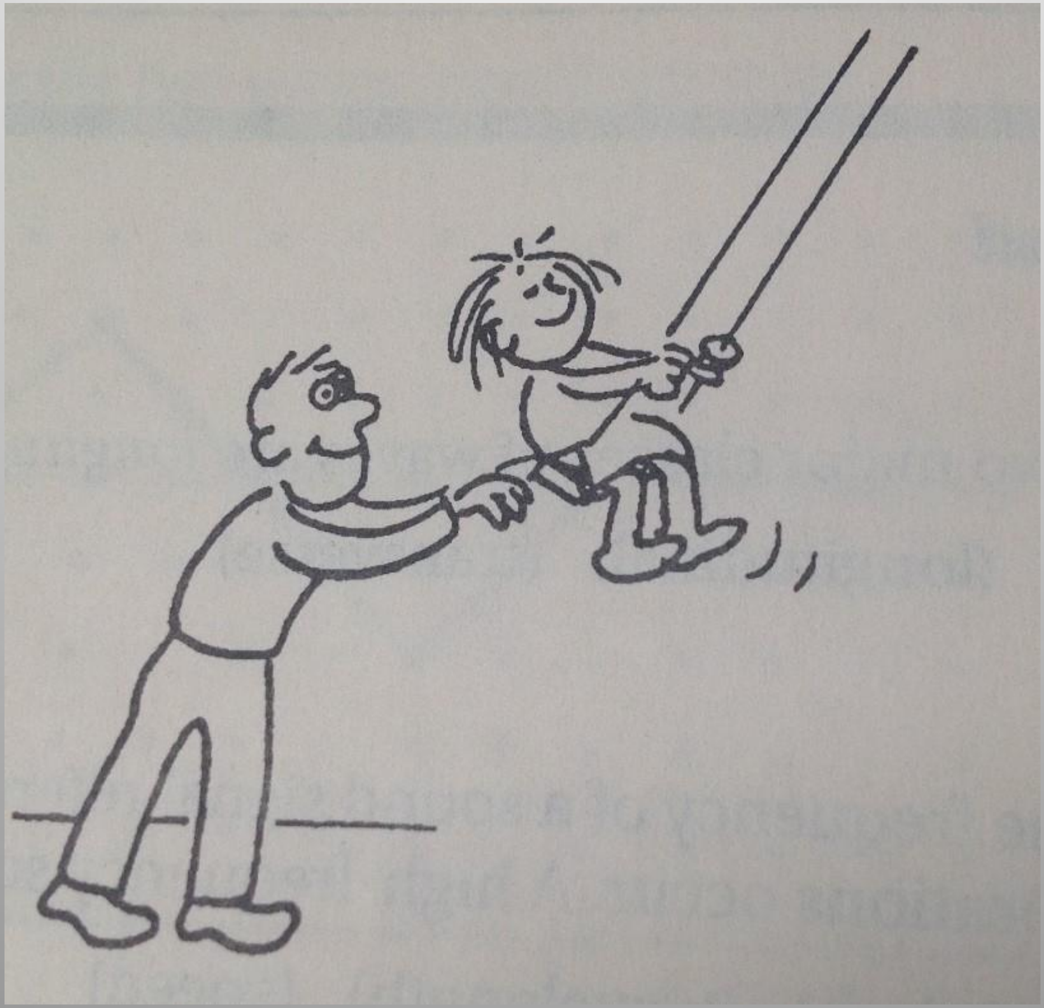
- Above resonance: the dipole is too long, and the current lags the driving voltage (inductive reactance)

ELI the ICE man

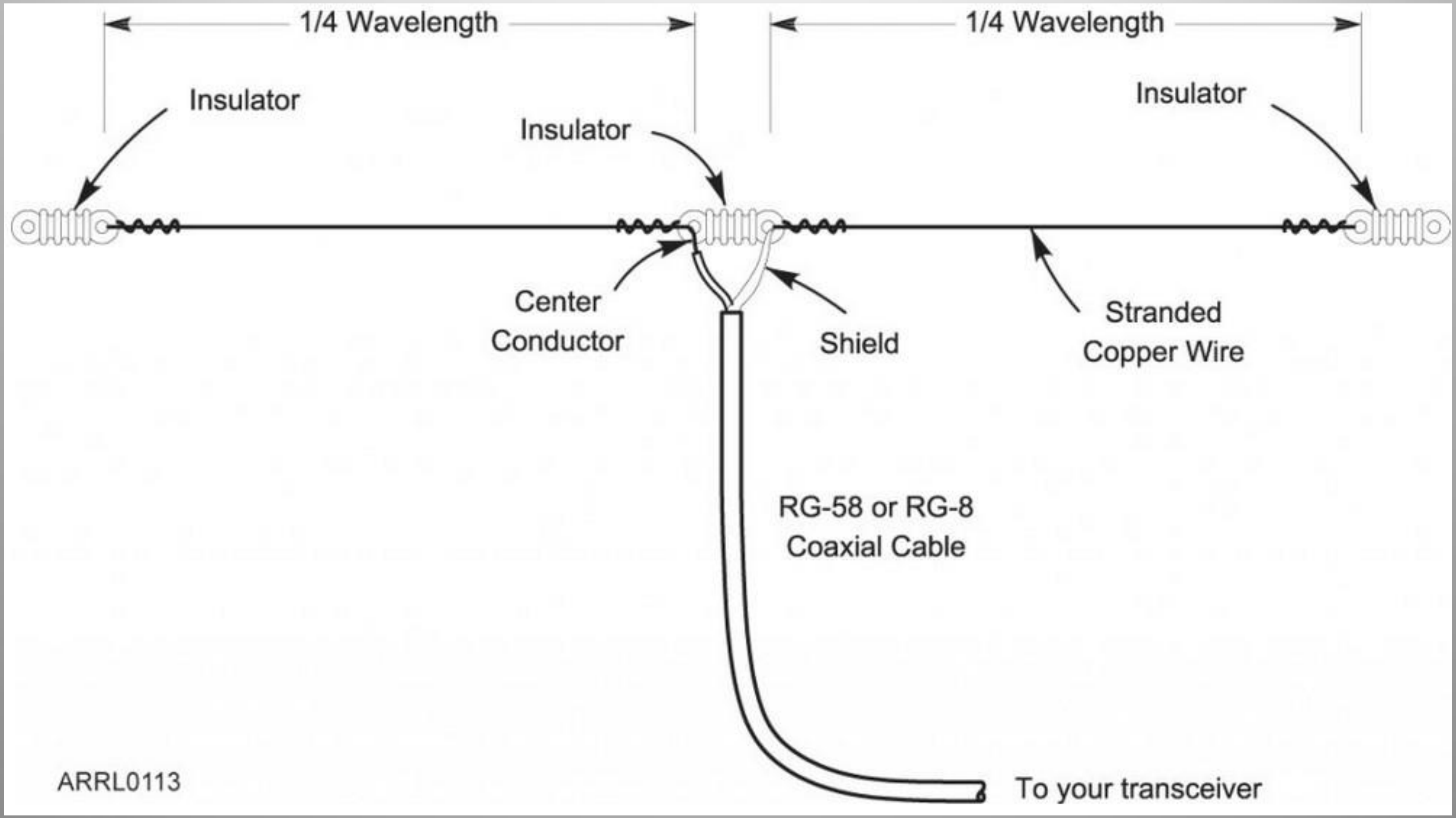
SWR climbs off resonance due to big changes in REACTANCE



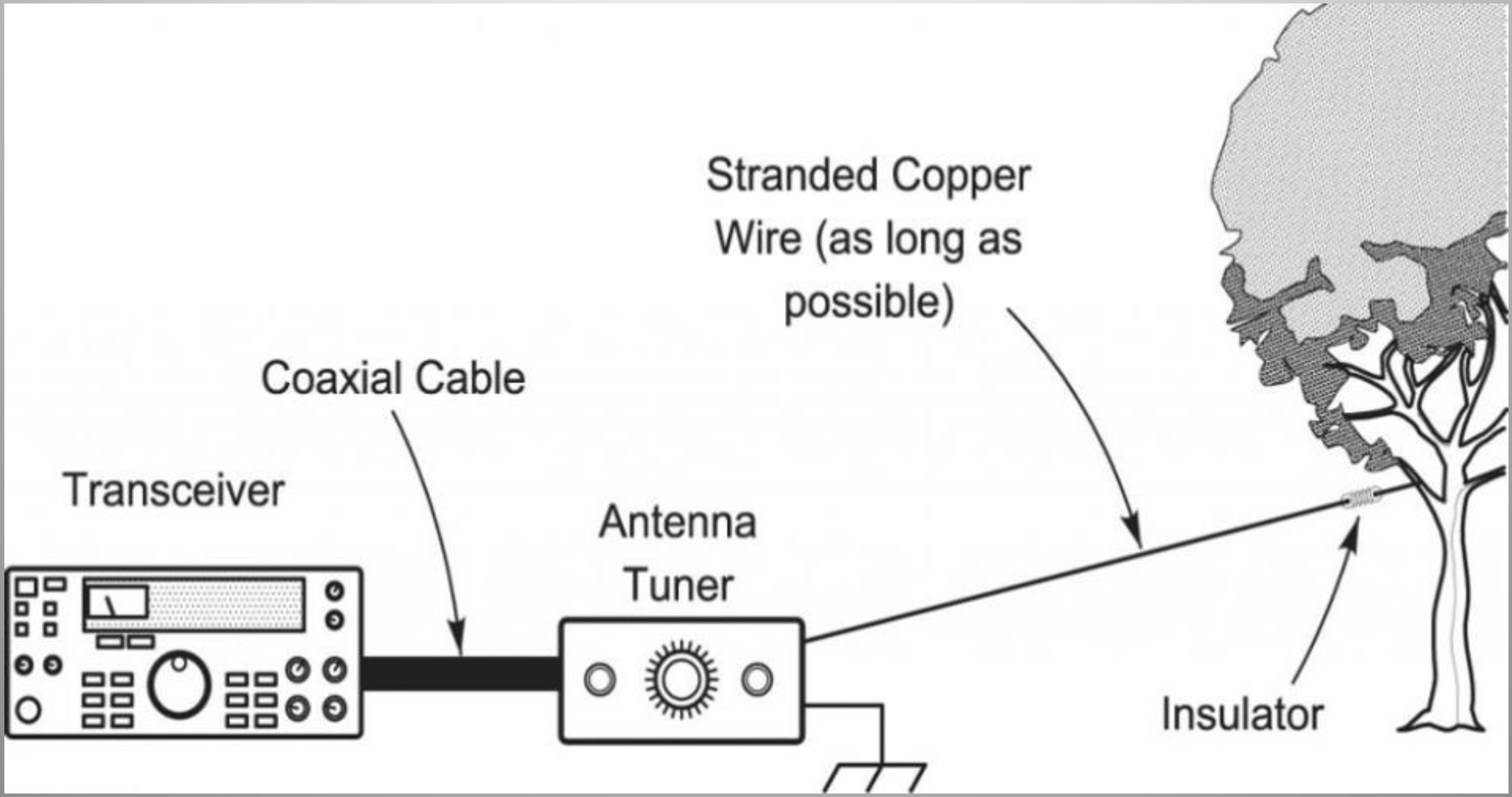
We all want RESONANCE to make our grandkids happy



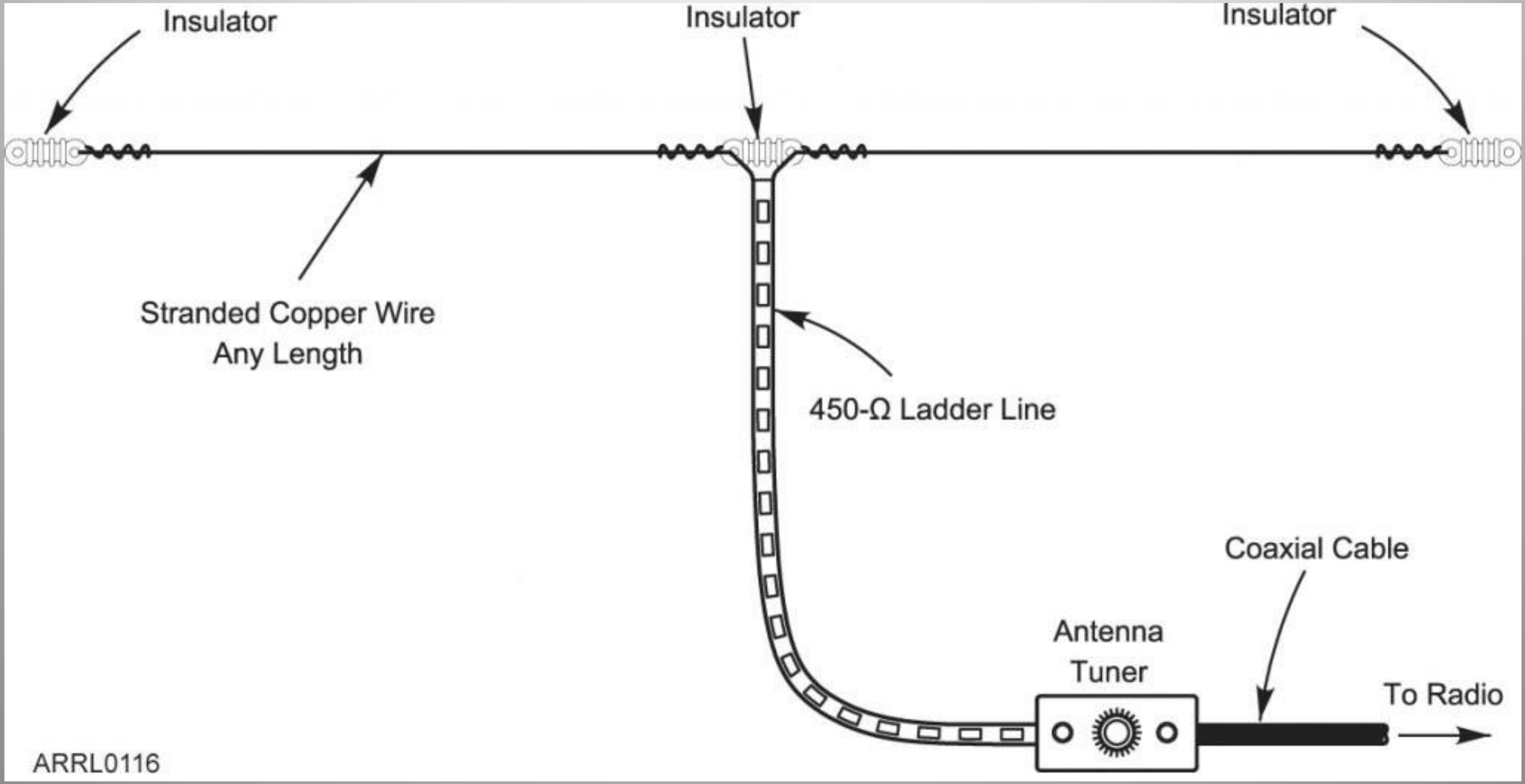
But does the antenna itself need to be at its resonant frequency to work well?



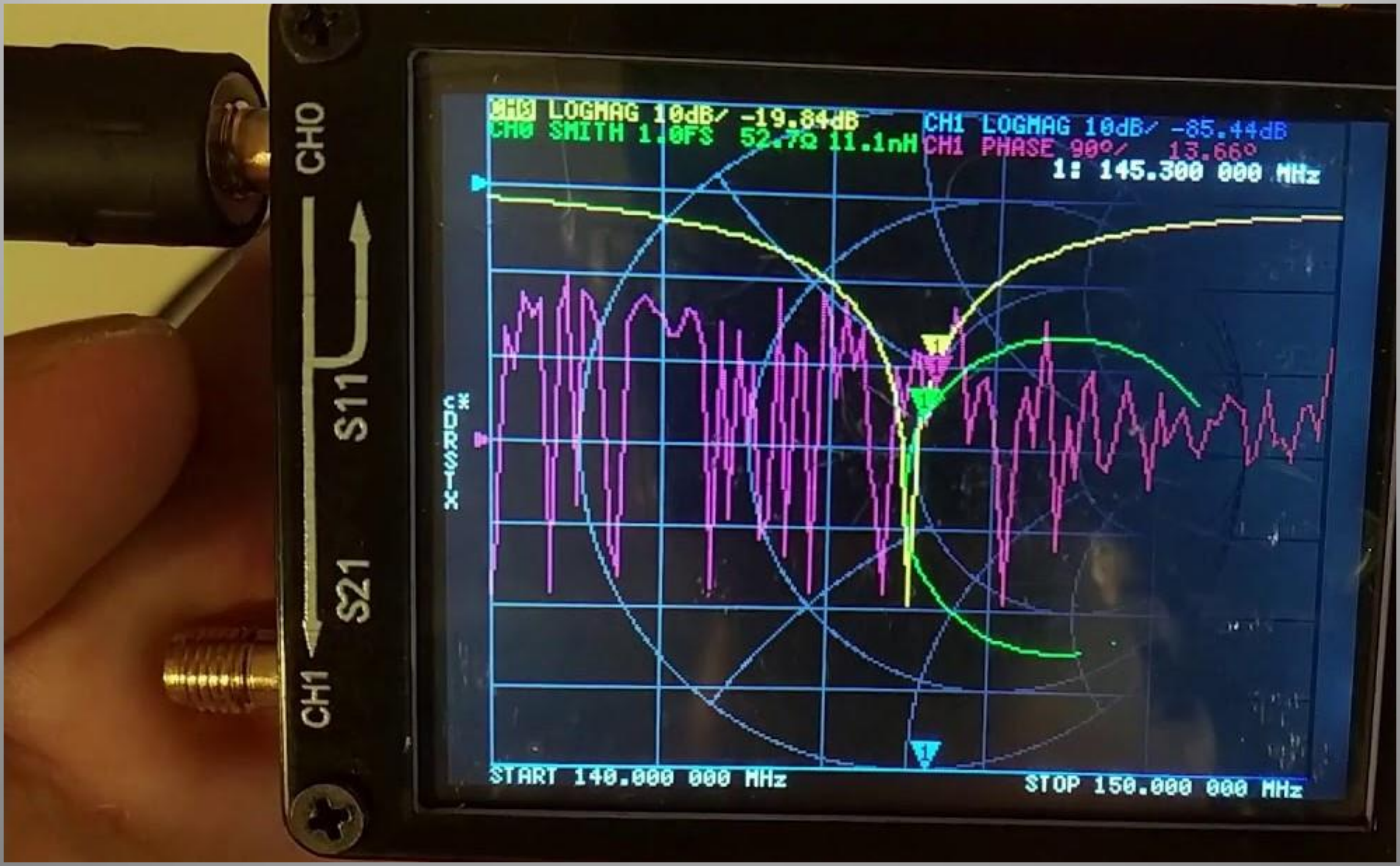
This "random" length wire can work well with some help from an antenna "tuner"



Center Fed dipole with Low-Loss BALANCED Line can work on all HF bands with TUNER in the shack



Let’s put the Nano VNA to work testing real antennas
S11 = Signal goes out Ch0 and returns via same port



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

We are measuring the HF signals returning to shack after

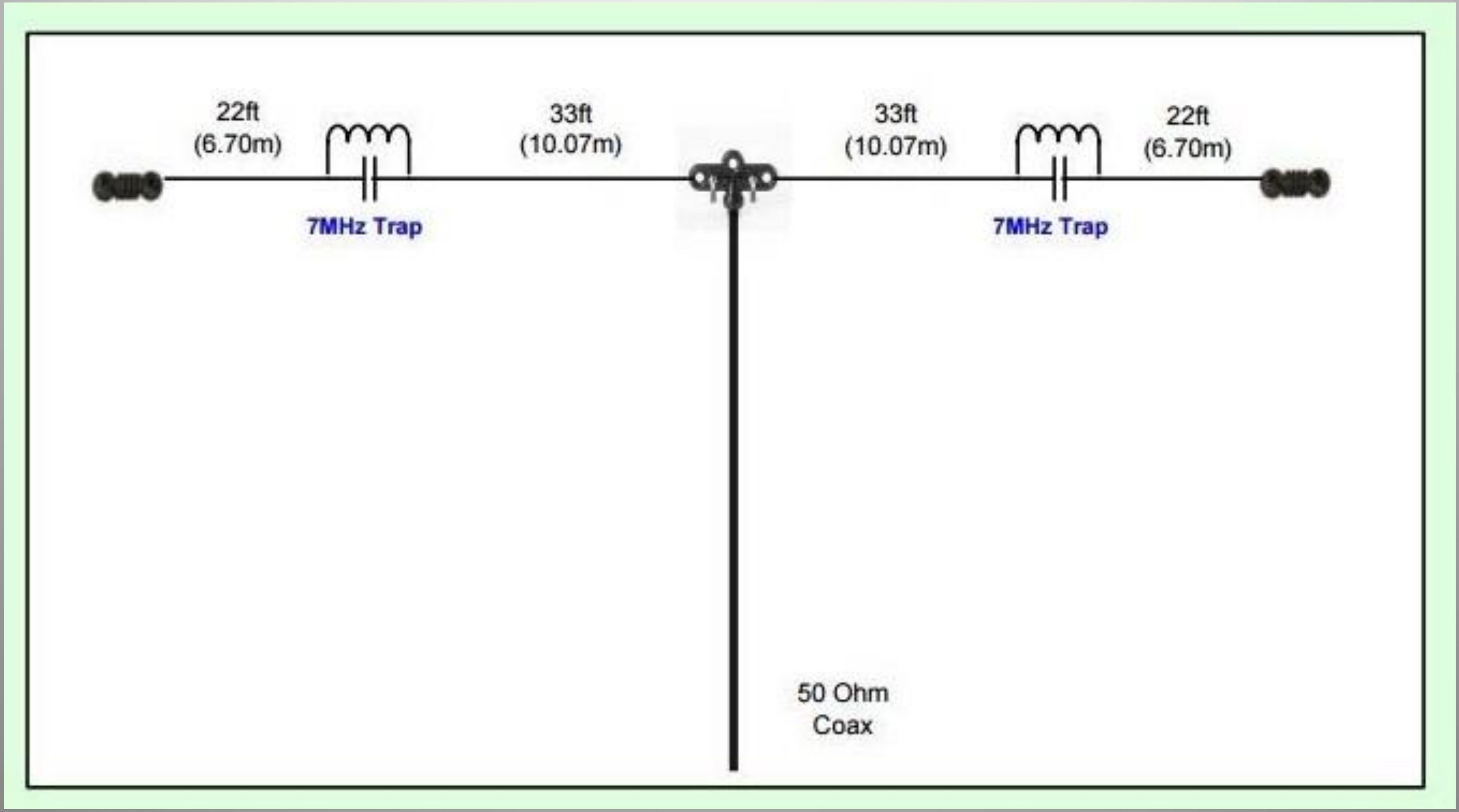
100 -150 ft

RG213 50-ohm coax

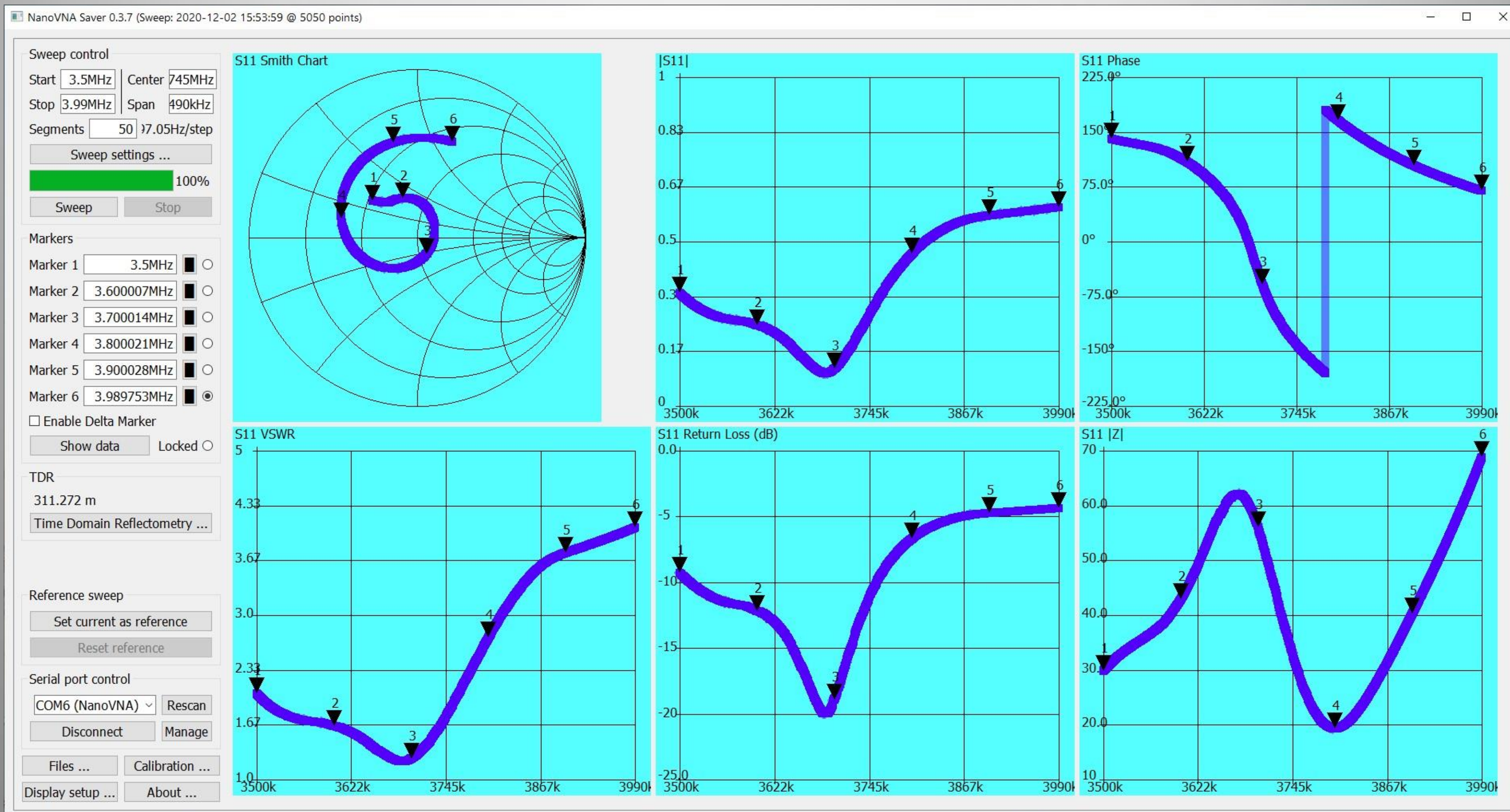
80 and 40 meter **TWO-BAND TRAP DIPOLE**

Trap is high-impedance LC circuit tuned to 7 MHz

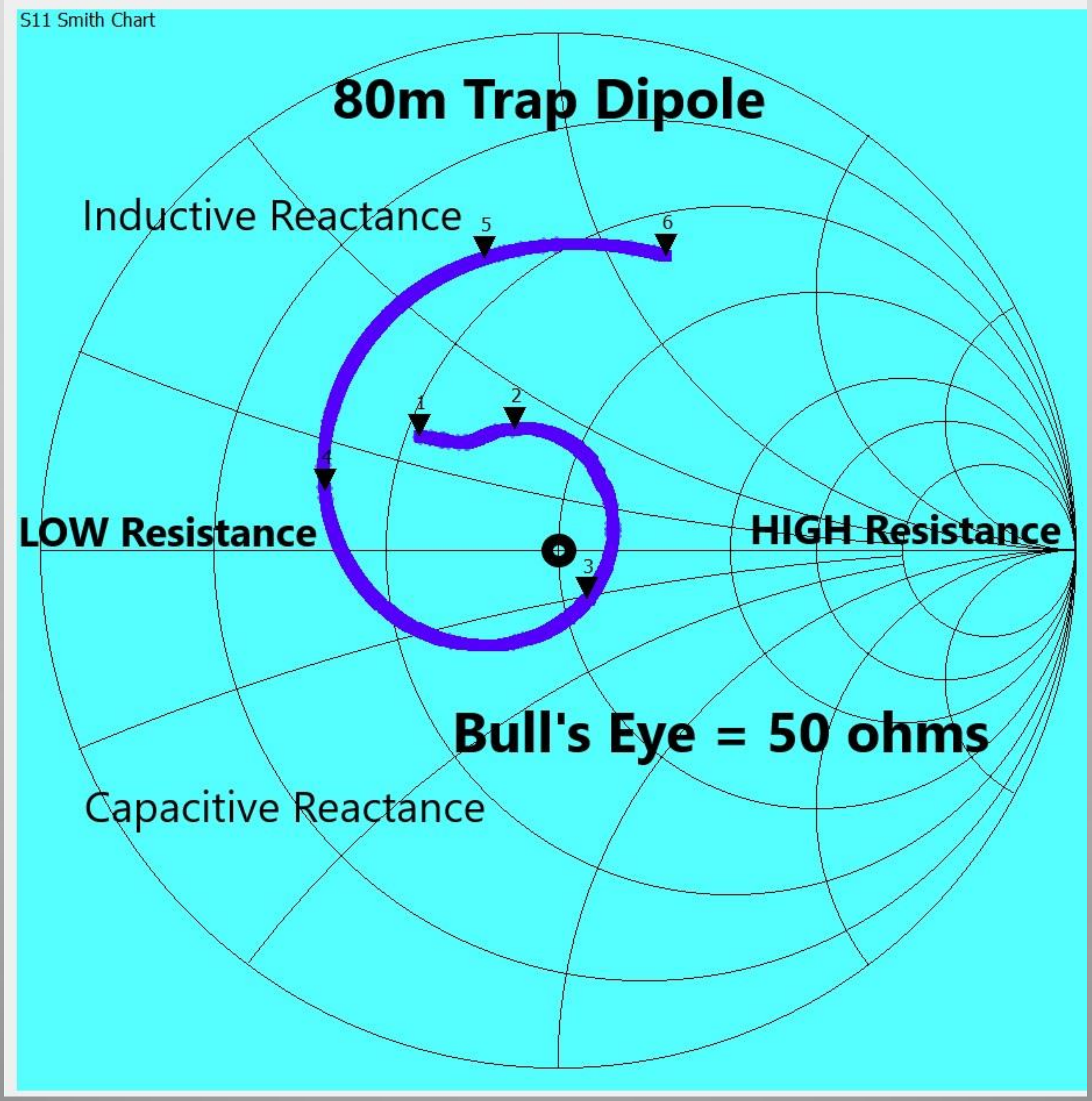
Overall length about 110 feet: height 25 feet (NVIS)



Trap Dipole 80m all graphs
markers at 3.5, 3.6, 3.7, 3.8, 3.9, 4.0 MHz

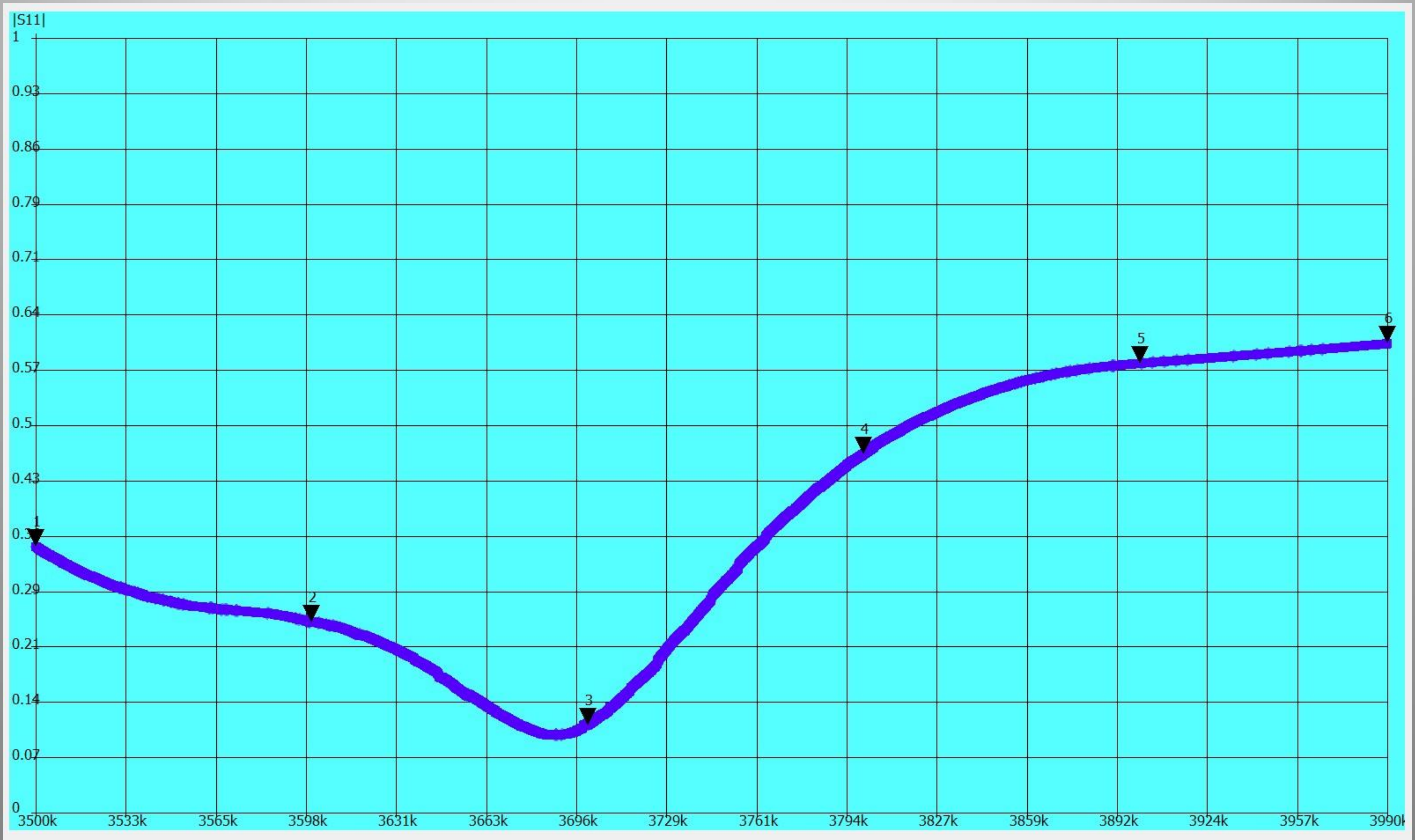


80m Trap Dipole Smith Chart



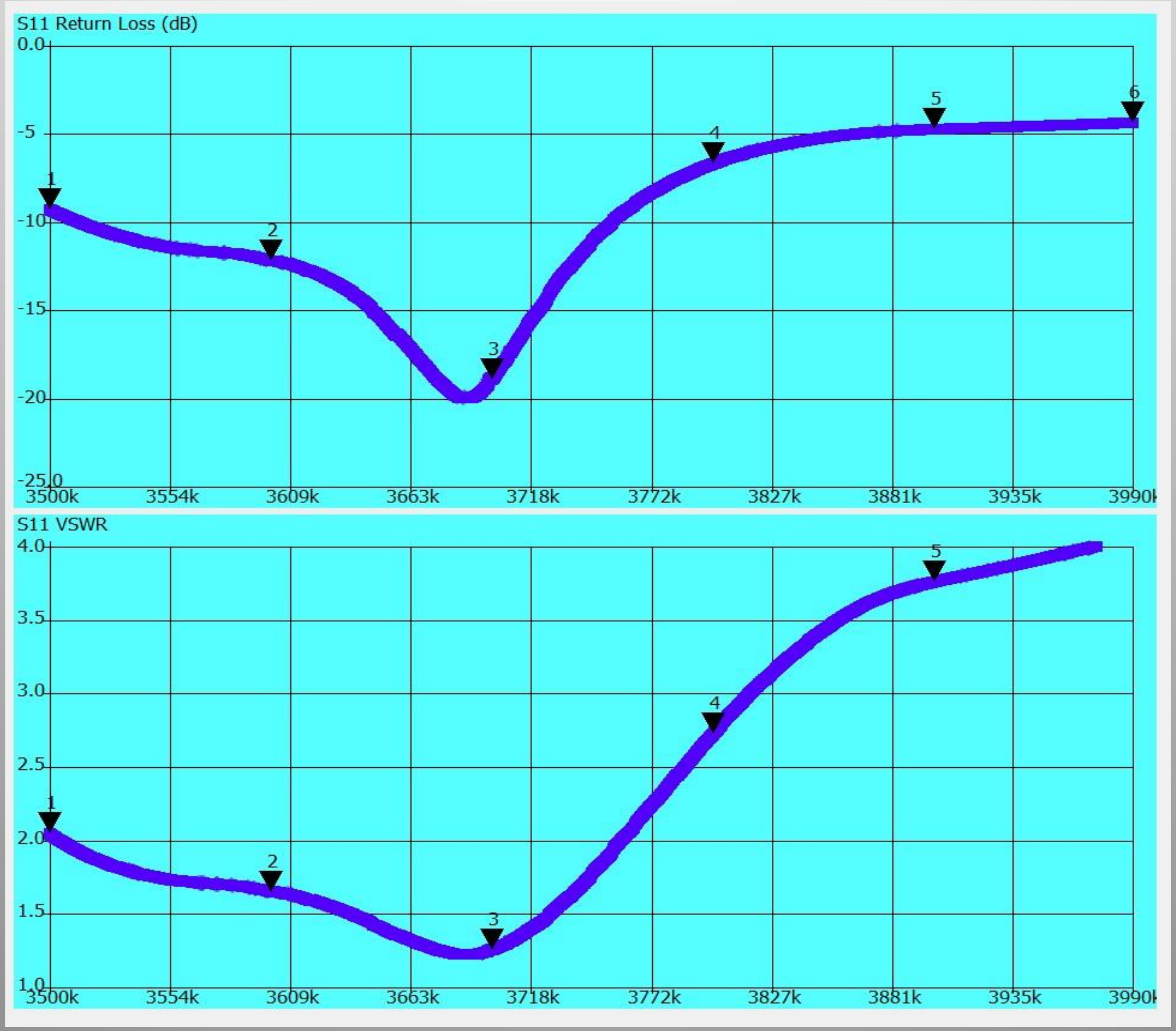
80m Trap Dipole: Reflection Coefficient (RHO) ρ = V(ref) / V(forward)

0 = no reflection 1 = total reflection



80m Trap Dipole

RETURN LOSS = (20 log ρ) = 20 dB and SWR = 1.2:1

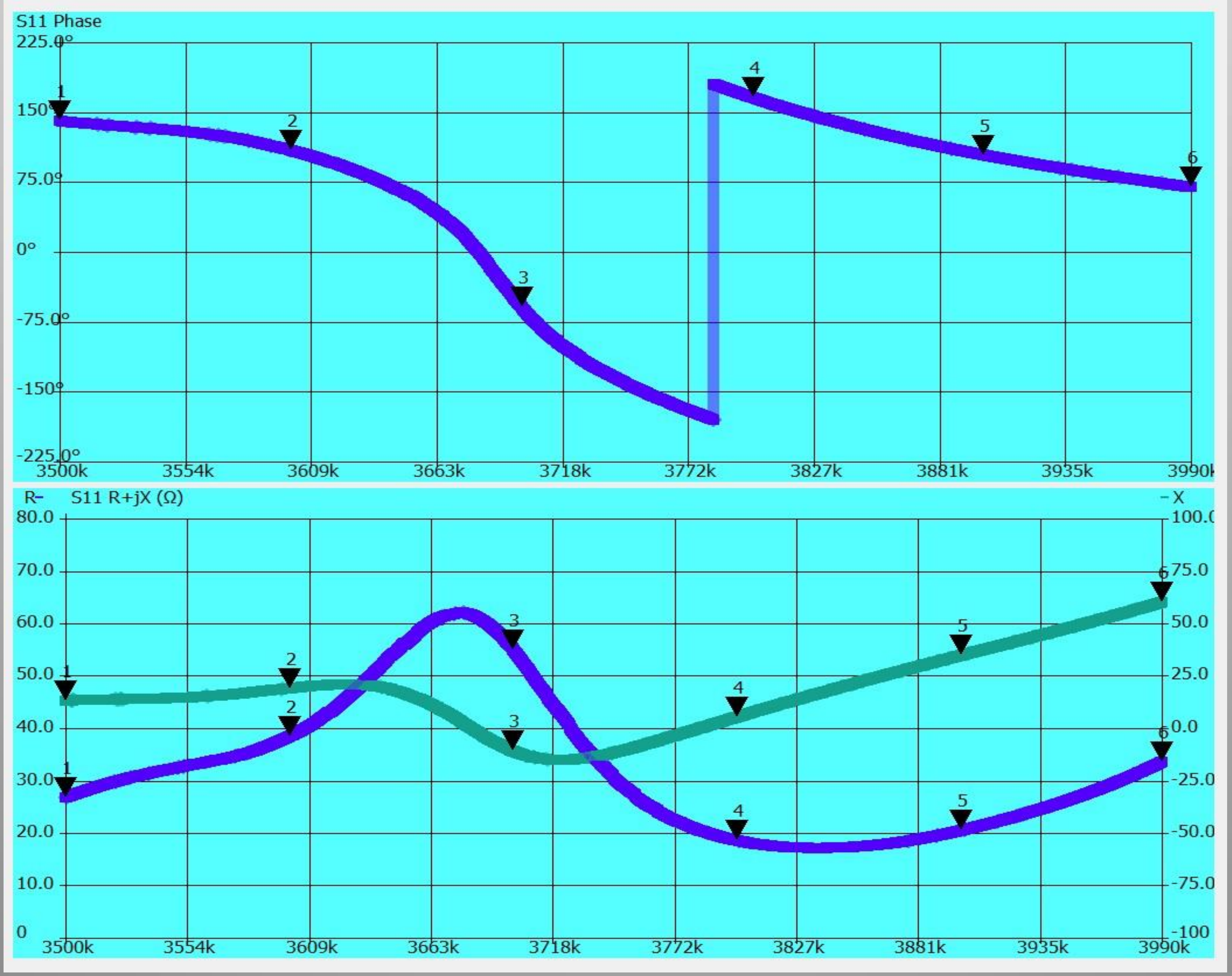


Trap Dipole 80 meters **PHASE** and **R,X** graphs

Resistance R blue trace (left scale 0 to 80 ohms)

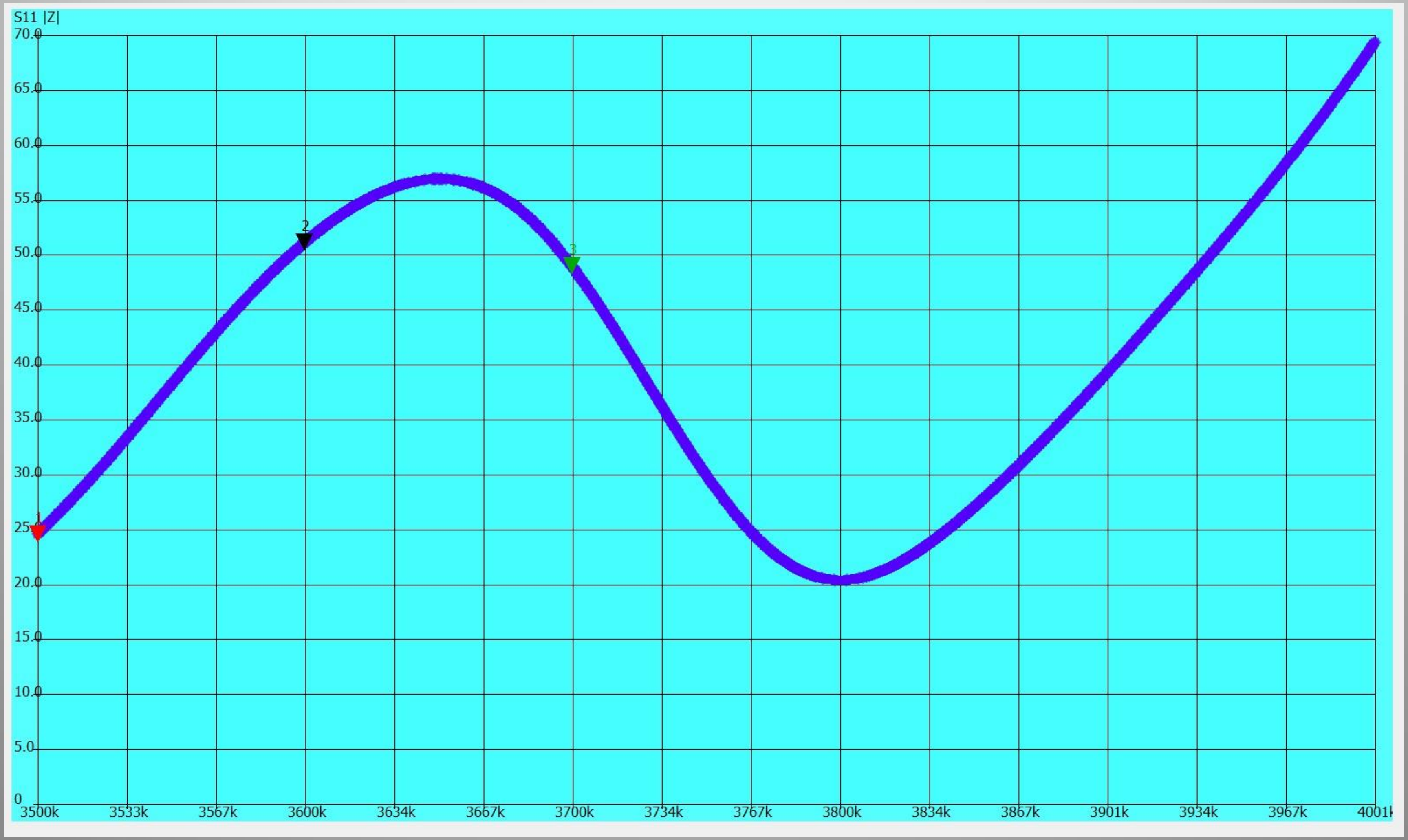
Reactance X (right scale -100 to +100 ohms)

Note TWO locations where REACTANCE X is zero (resonance)



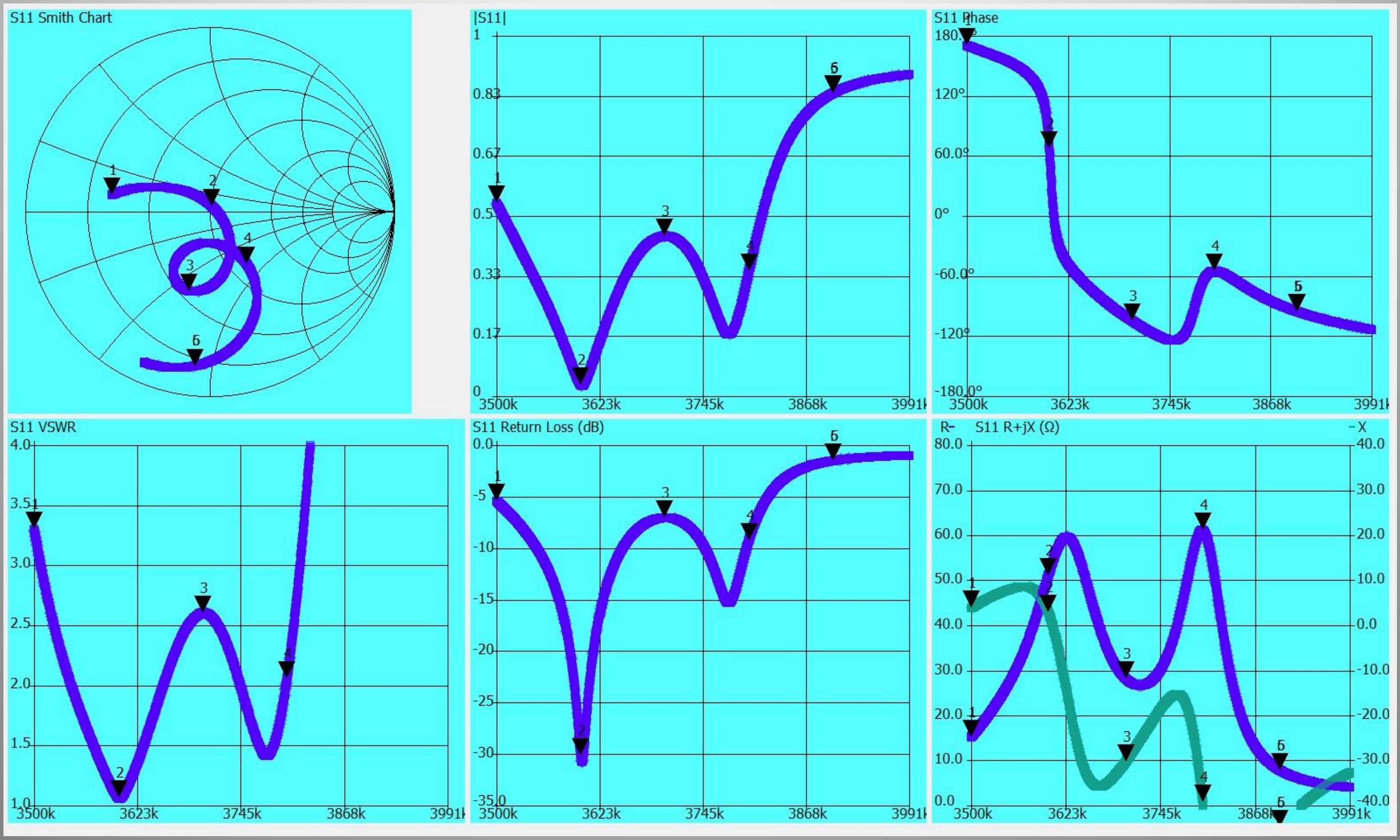
Impedance (Z) 80m trap dipole

Ideal **Z = 50 ohms R** to match 50 ohm coax Marker 2

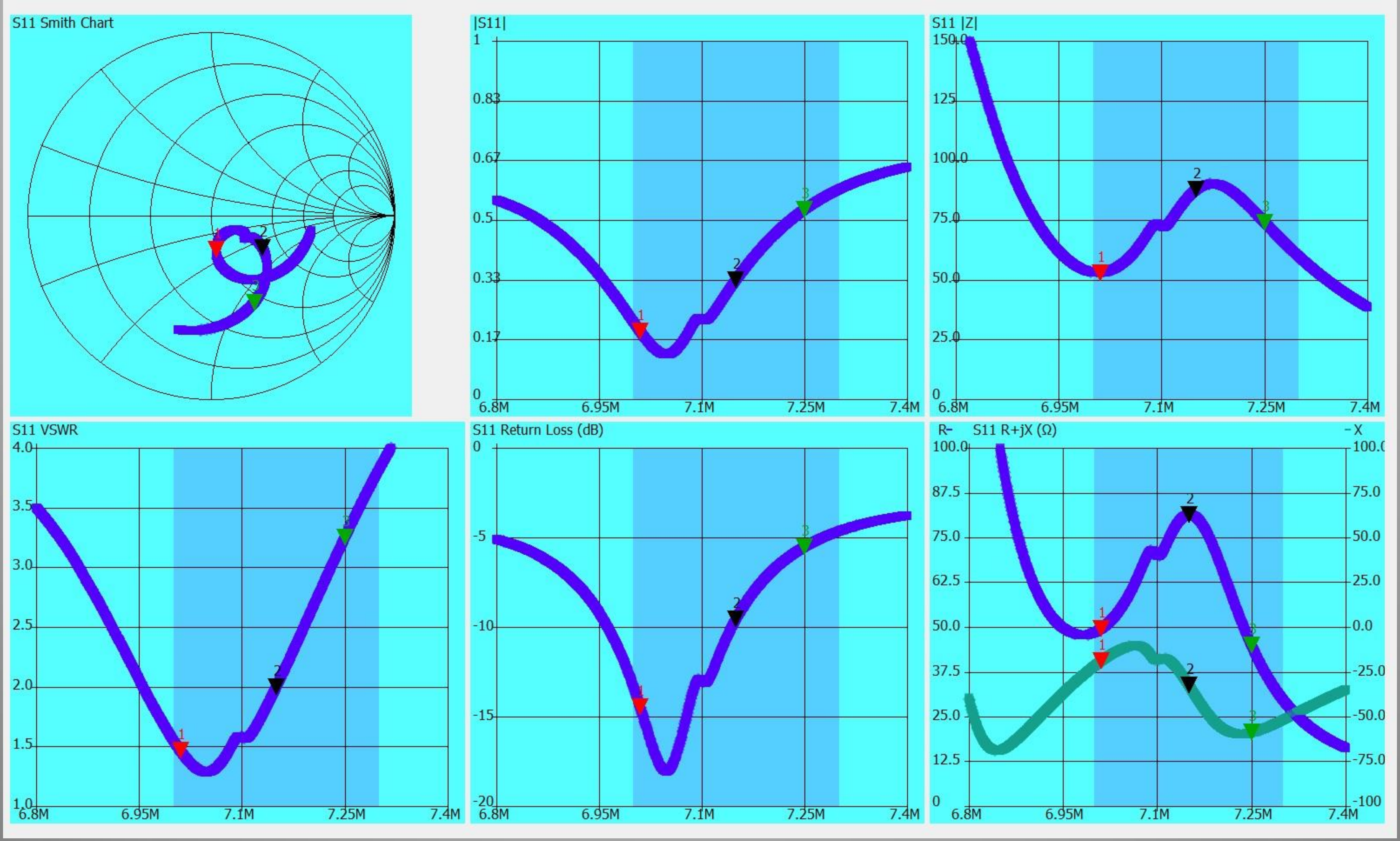


Enter: Antenna Tuner in shack
Tuned for minimum SWR at 3600 kHz

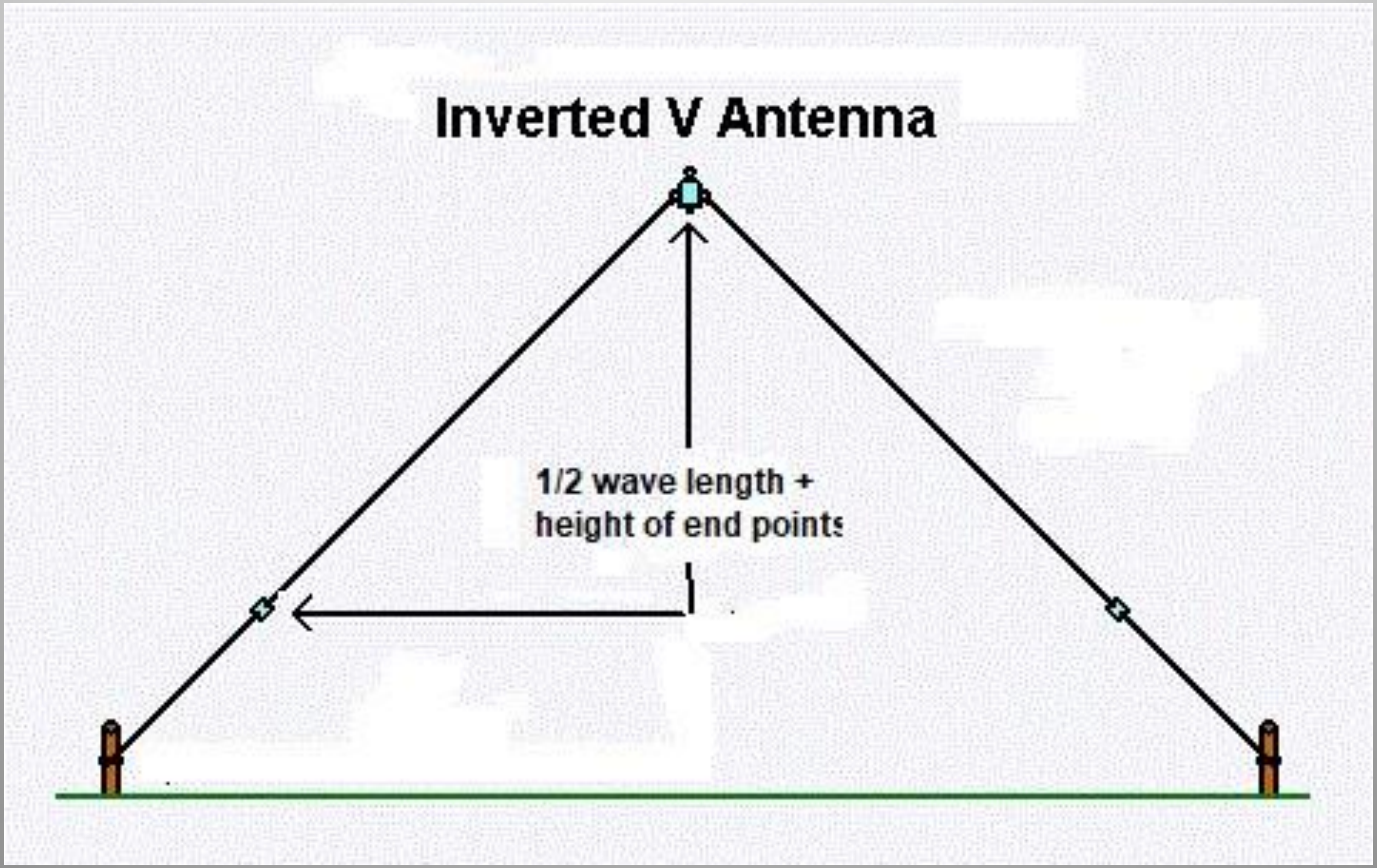
Note changes in shack – post ANTENNA TUNER tuned for lowest SWR at 3600 kHz



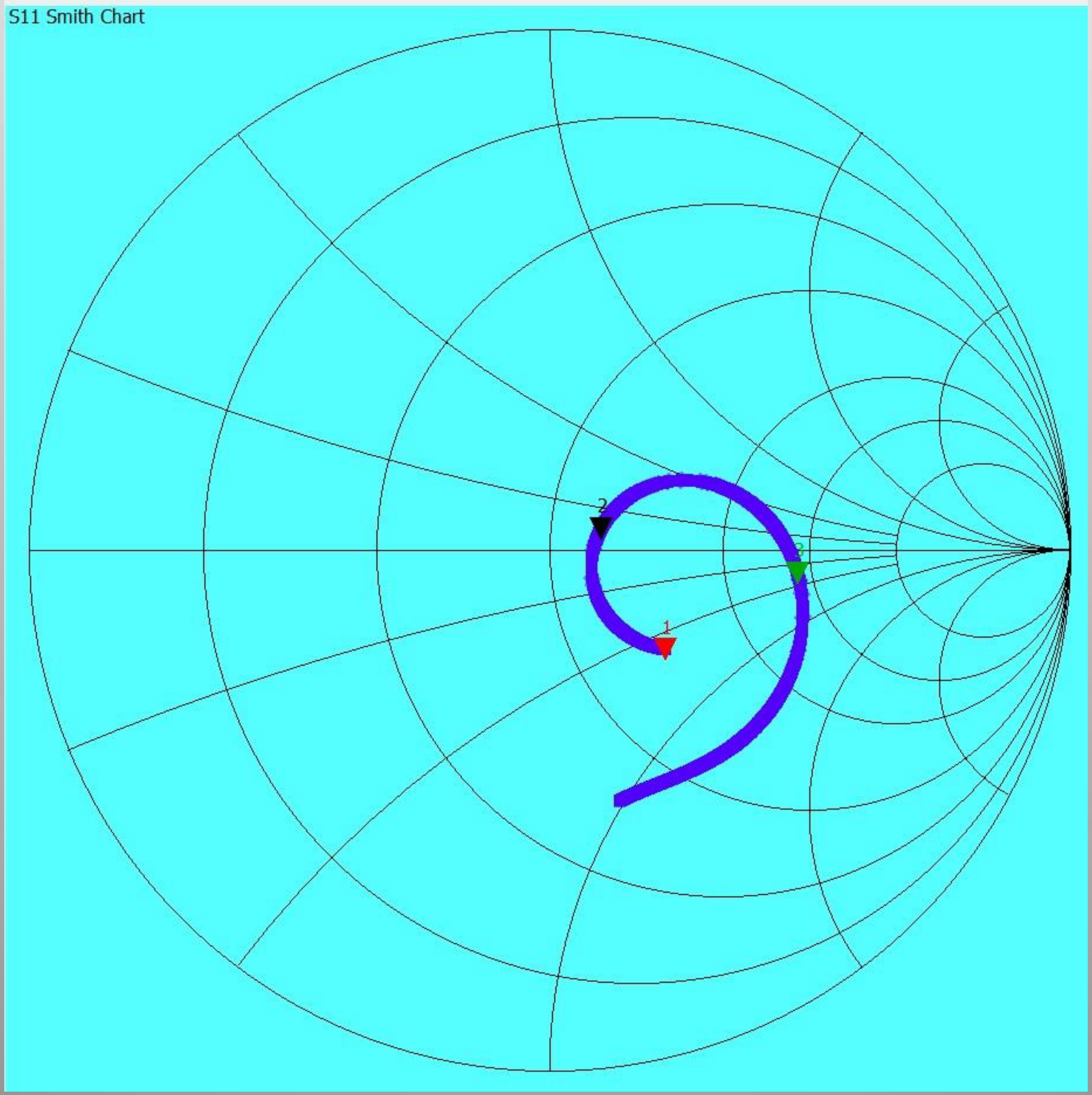
Trap dipole on 40 meters: 7.0 - 7.3 MHz
(cut to the low end of band)



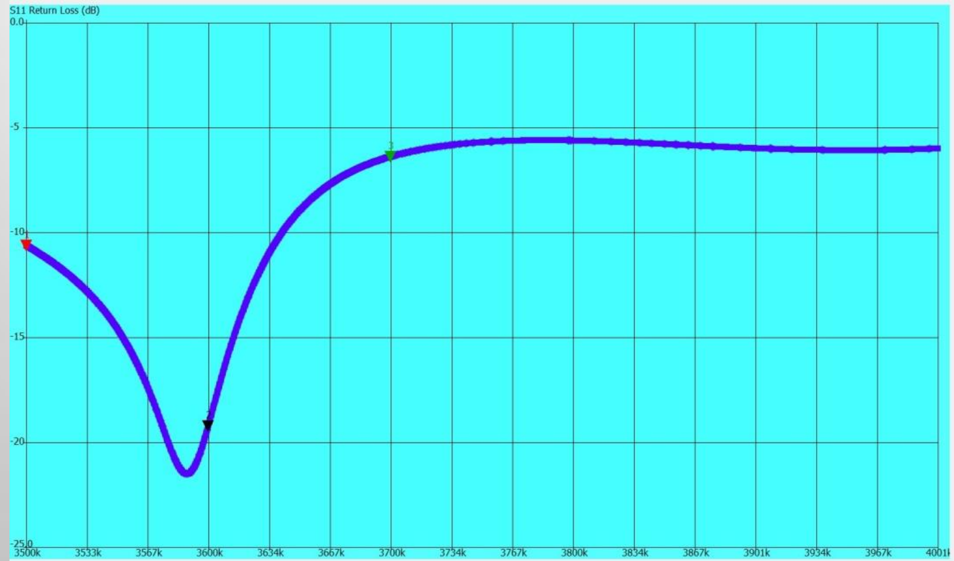
80 meter Inverted V (single band)
fed with 100 ft RG213 and W2DU current balun

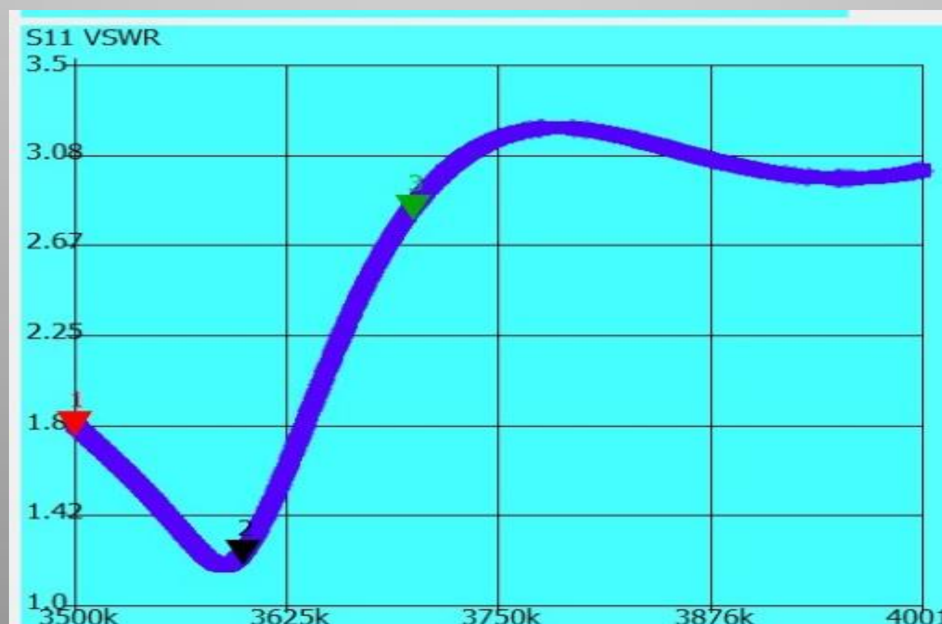


80m Inverted V antenna   Smith Chart
Can you tell where the SWR is minimum?

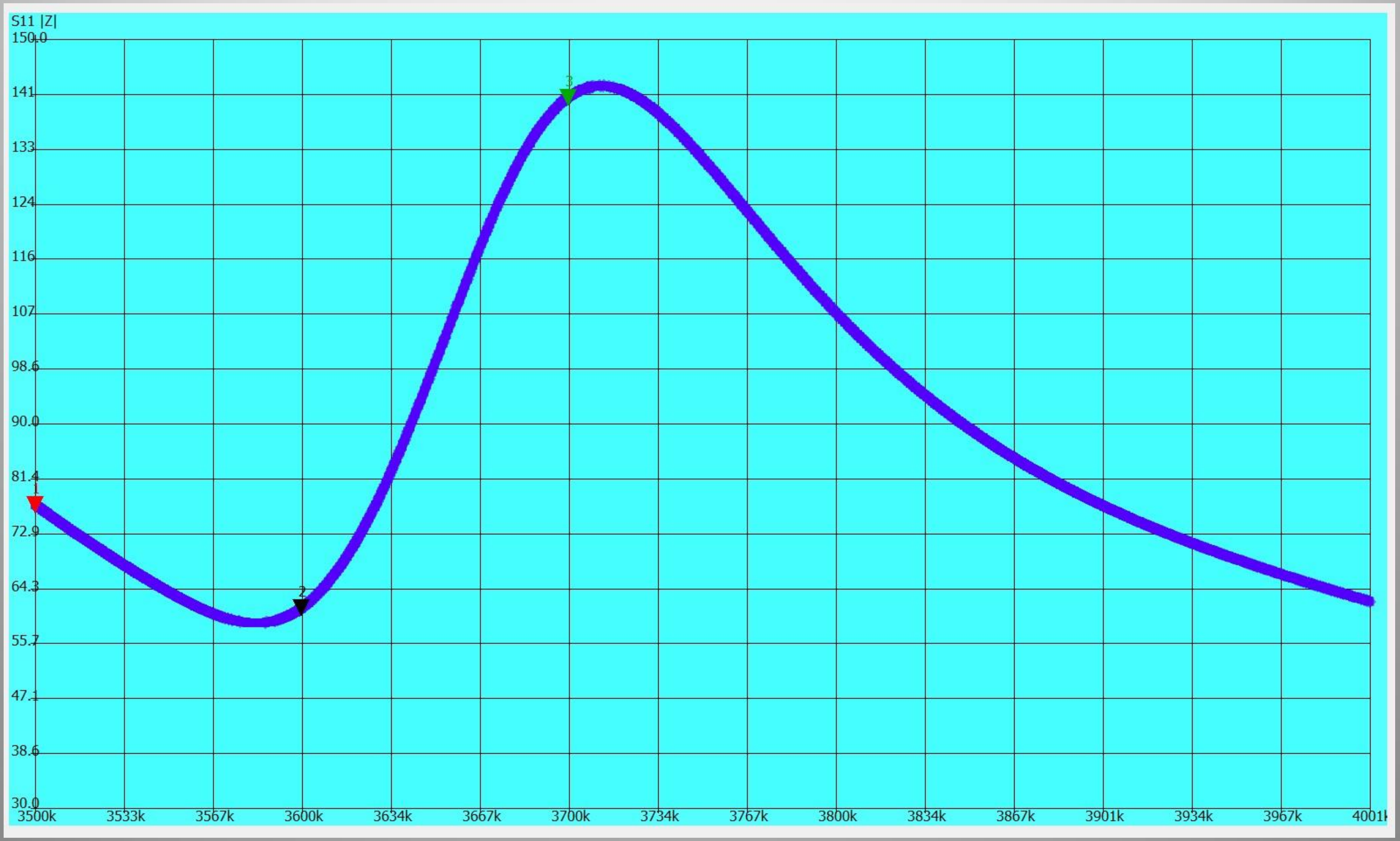


80 m Inverted V Dipole: Return Loss (dB) 22 dB and SWR



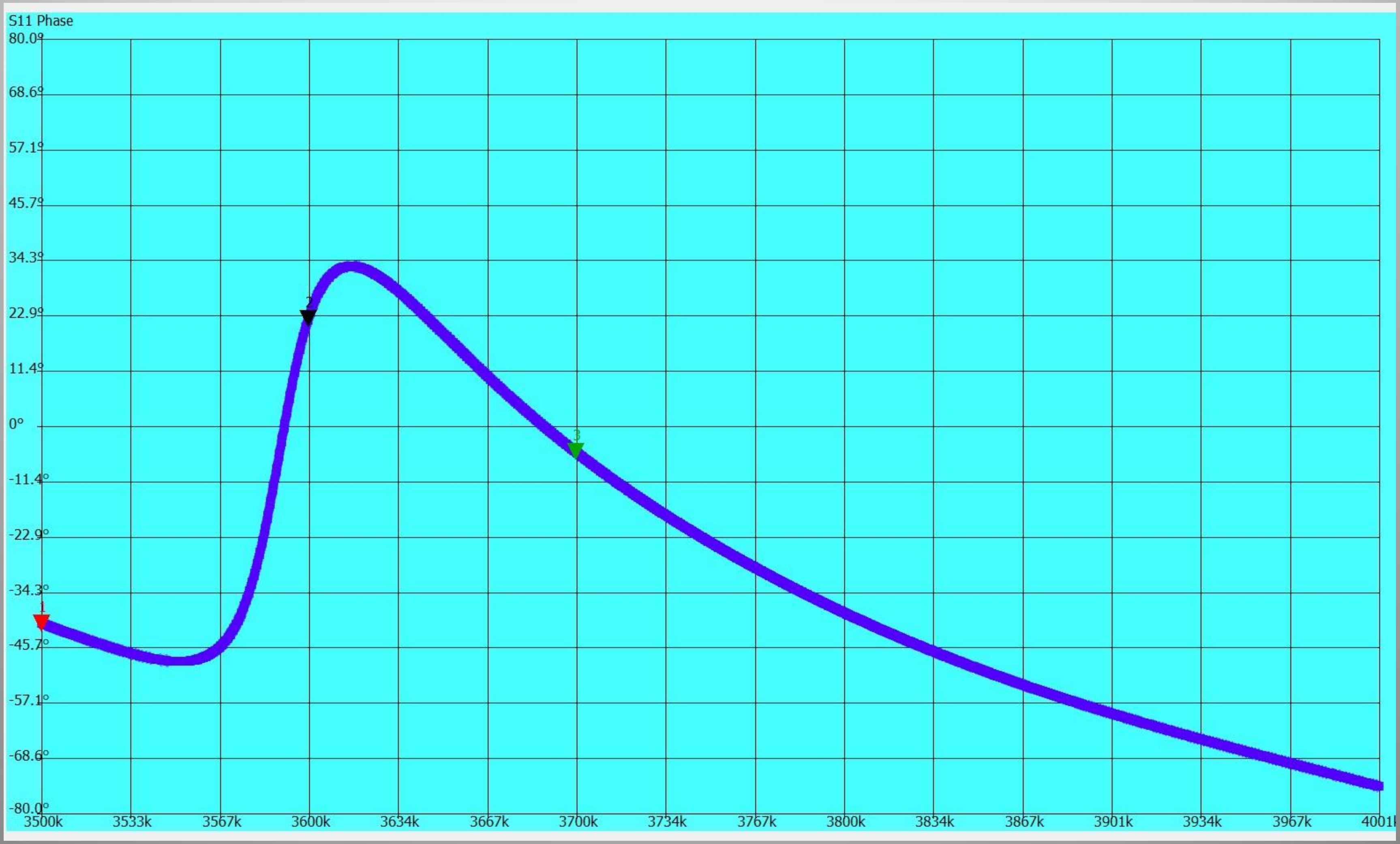


80m Inv V Impedance Z (ohms)

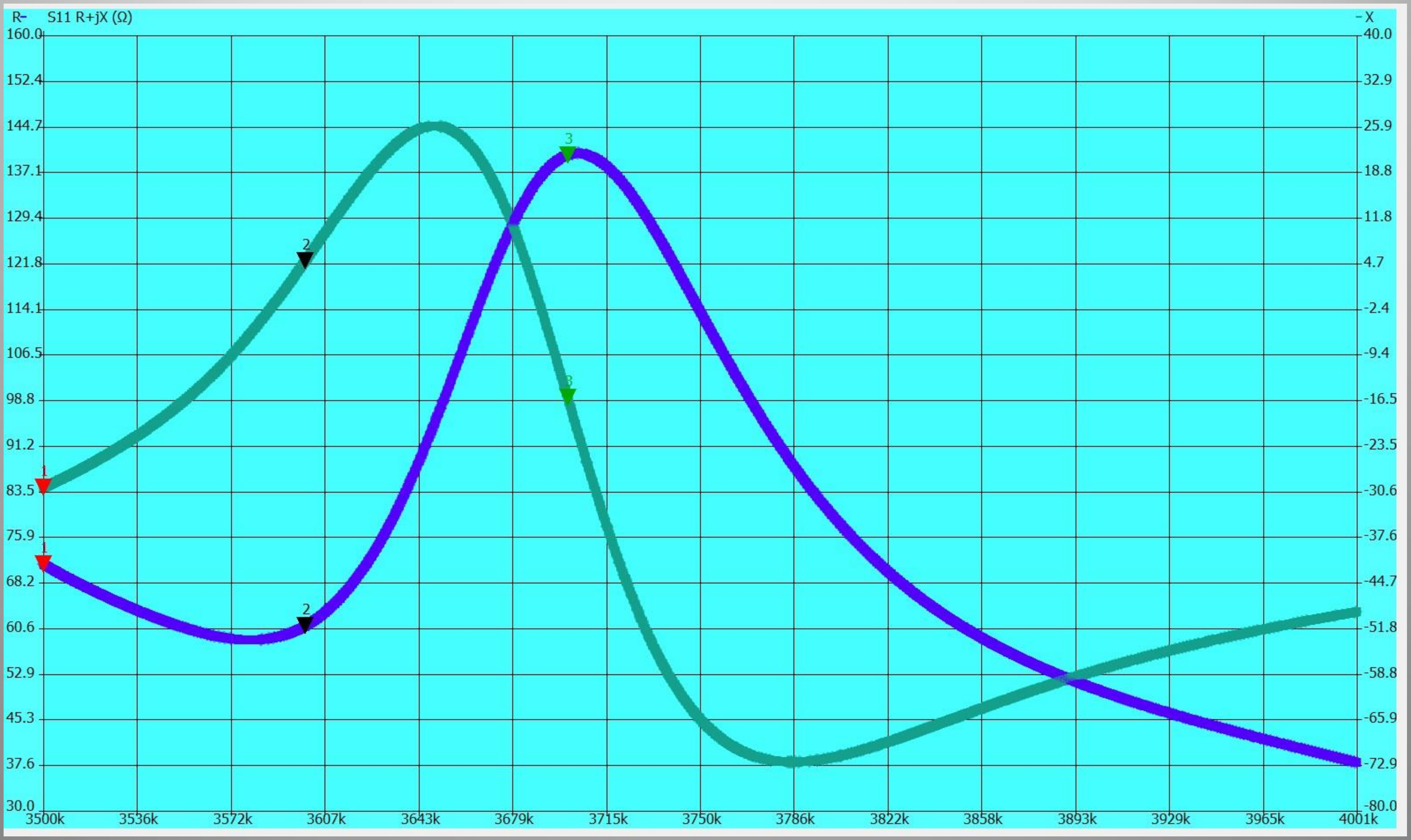


80m Inv V PHASE

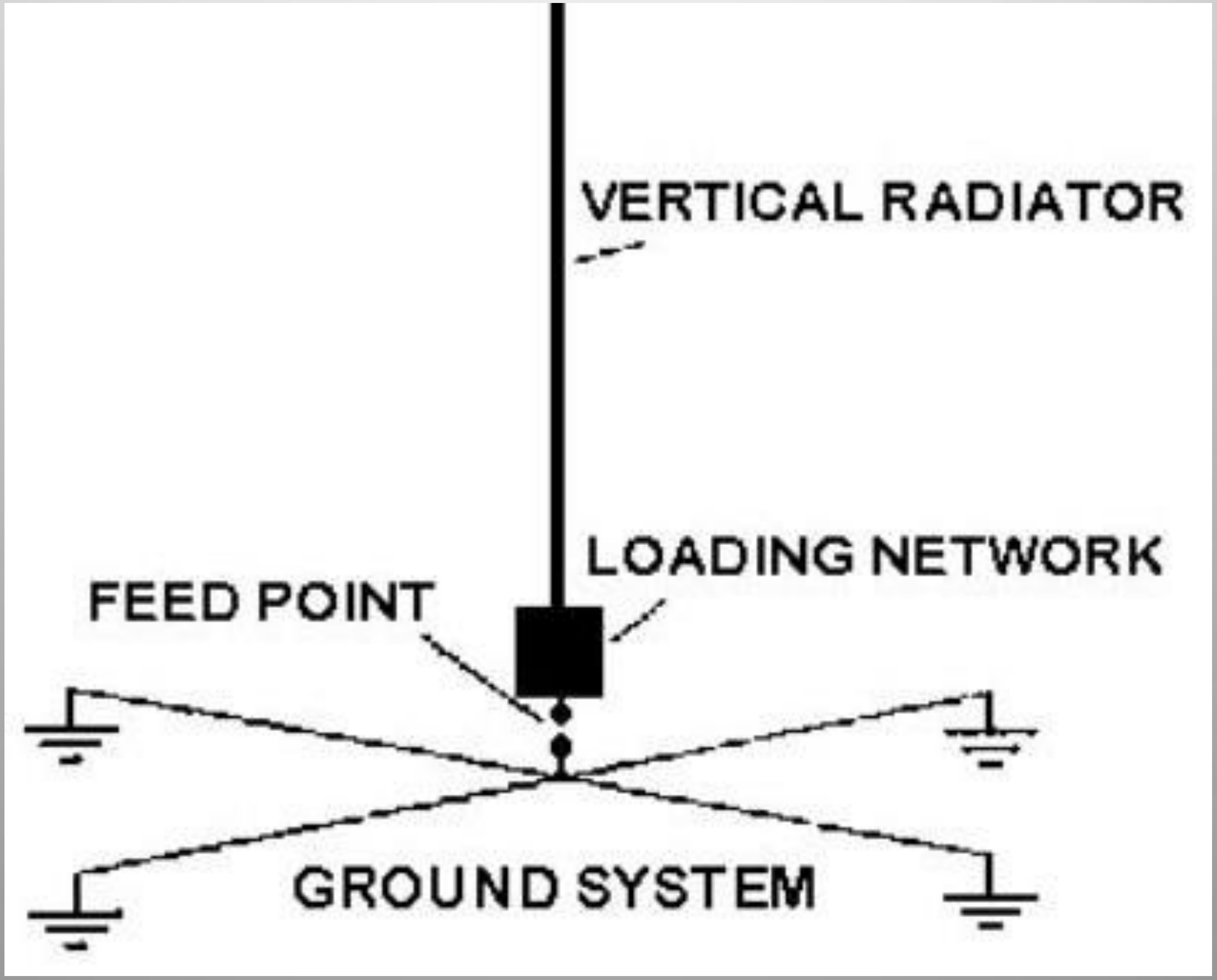
At resonance: phase = 0 degrees



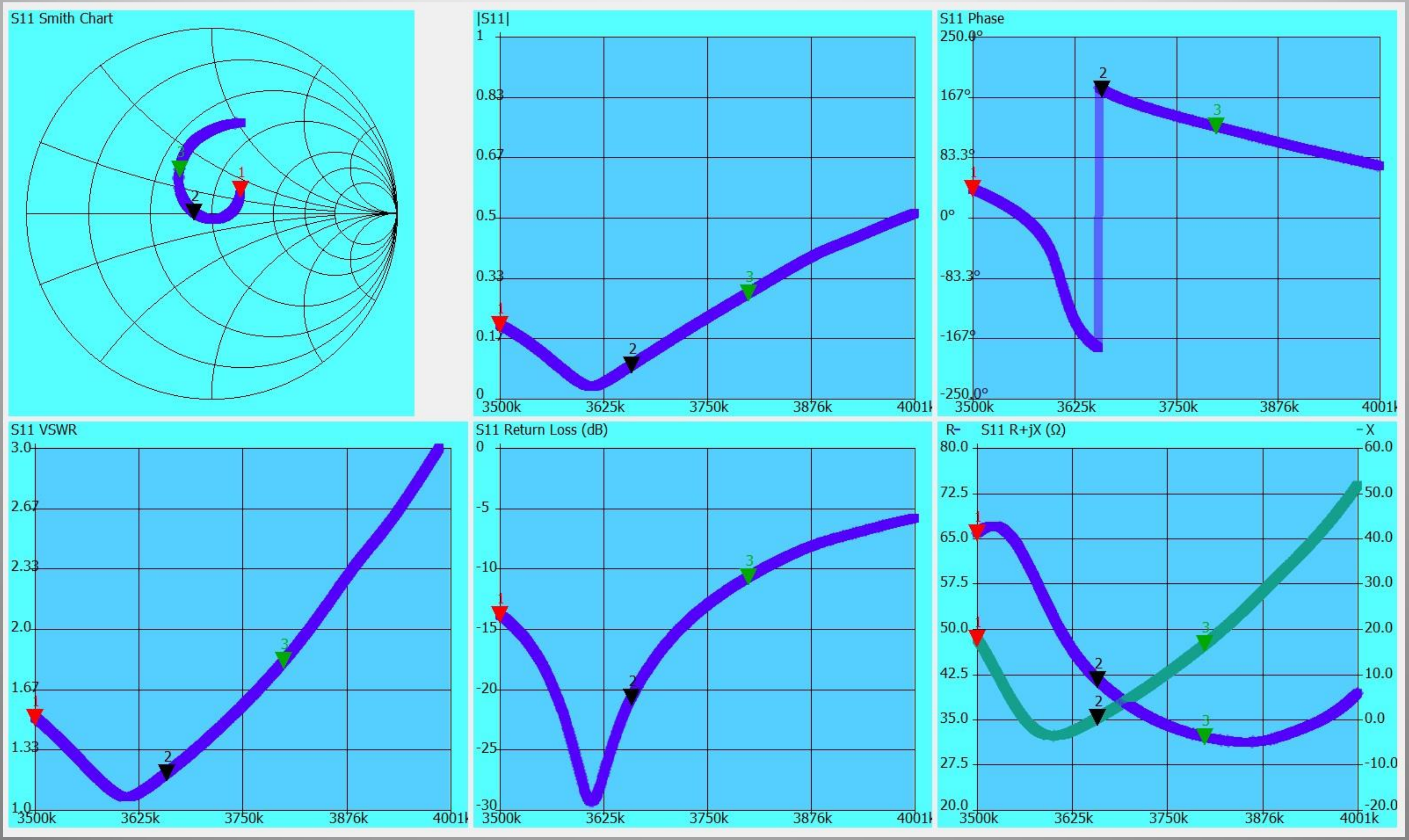
80m Inv V: R = Resistance blue (30-160 ohms) LEFT
X = Reactance (-80 to +40 ohms) RIGHT



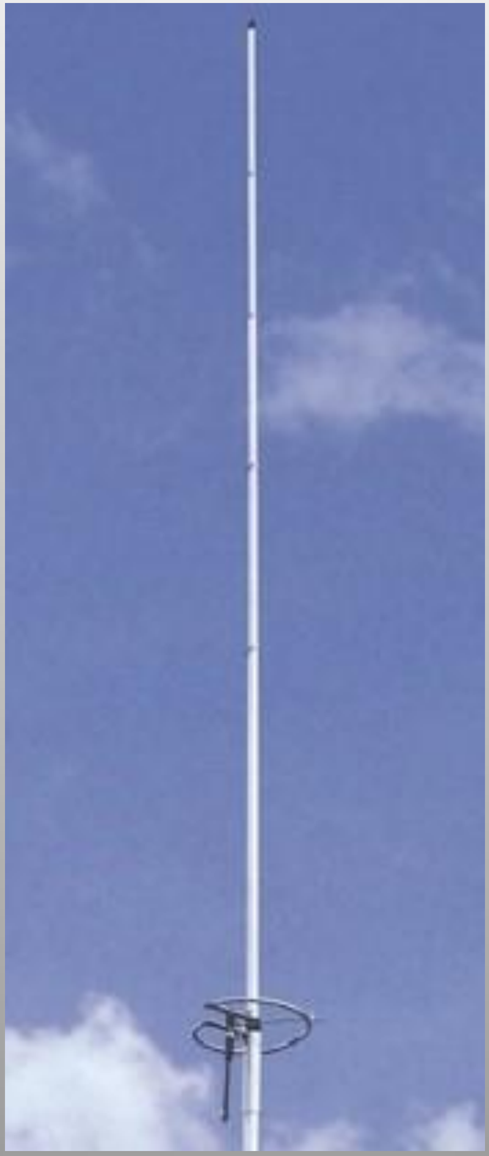
80m Vertical: 40 ft tall with “loading coil” at base and two 65 ft radials 10 ft above ground



80m Vertical with loading coil and two above ground 65 ft radials (cut for low end of band)



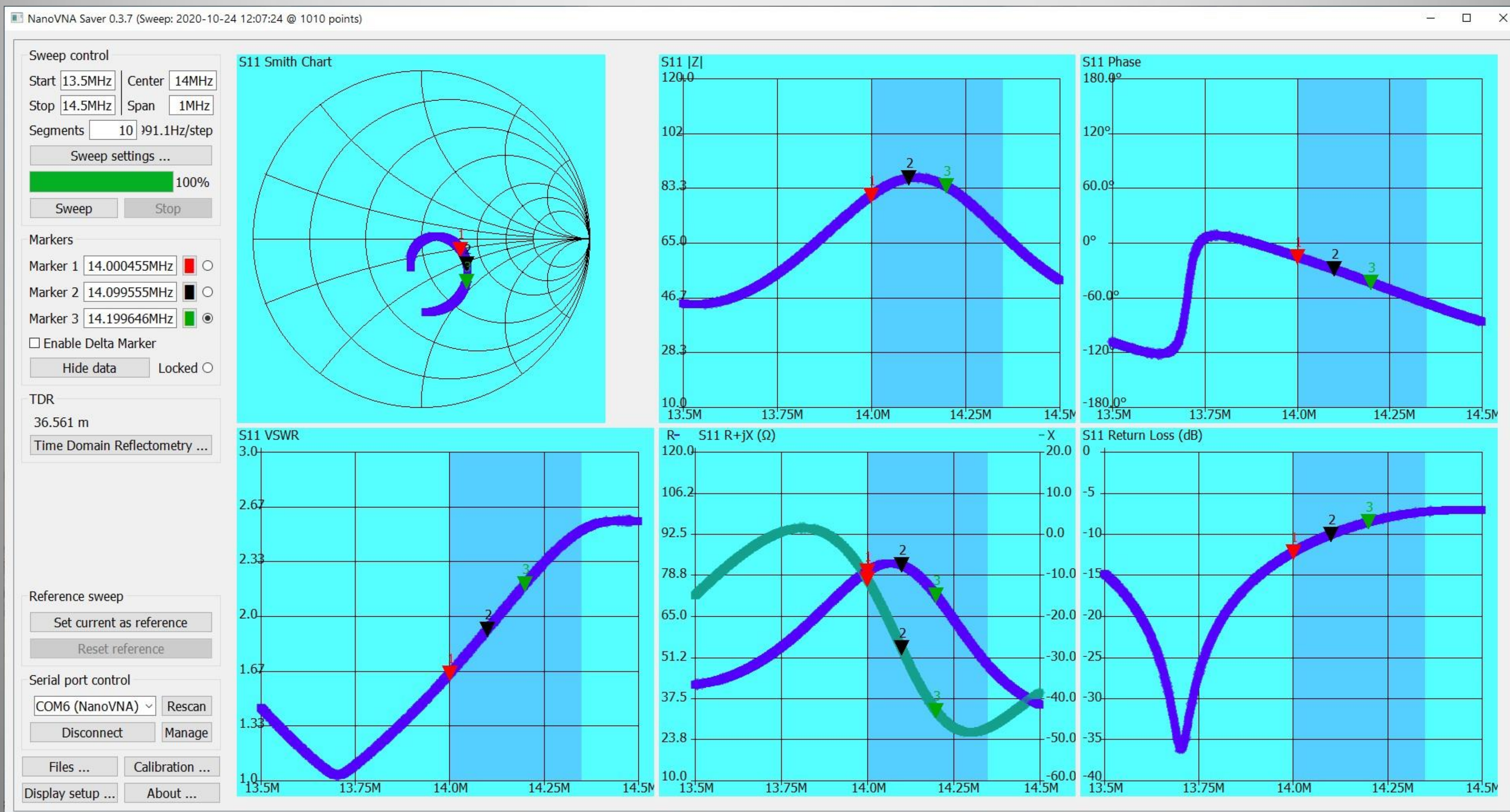
20 m Vertical with four 17 ft radials
Cushcraft A10 one-half wave without base matching coil/capacitor



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

this is obviously **mis-tuned** to 13.7 MHz

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



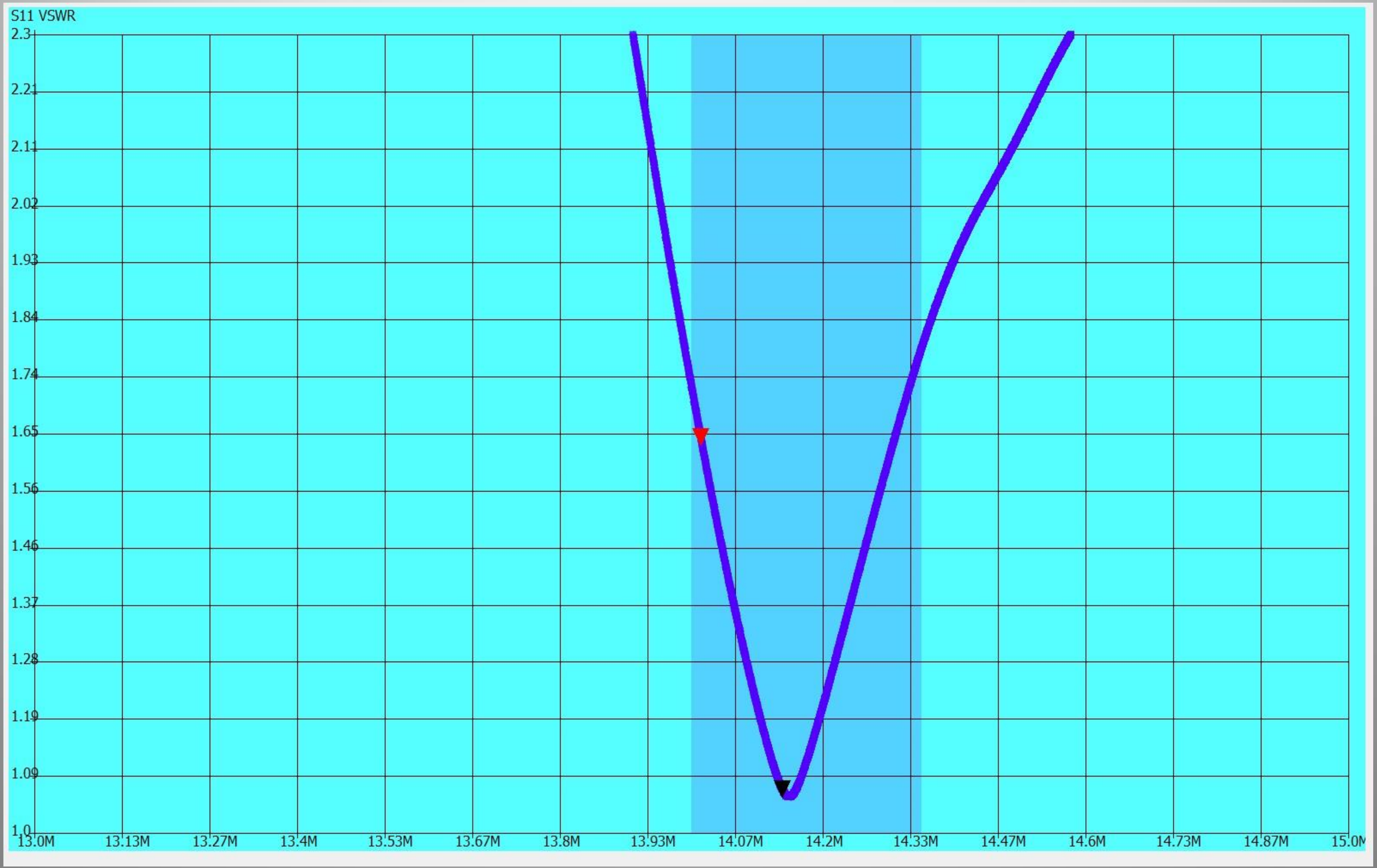
OR -- Insert Antenna Tuner in shack

This makes rig happy – RIG sees 50 ohm Z and SWR=1:1 at rig's port

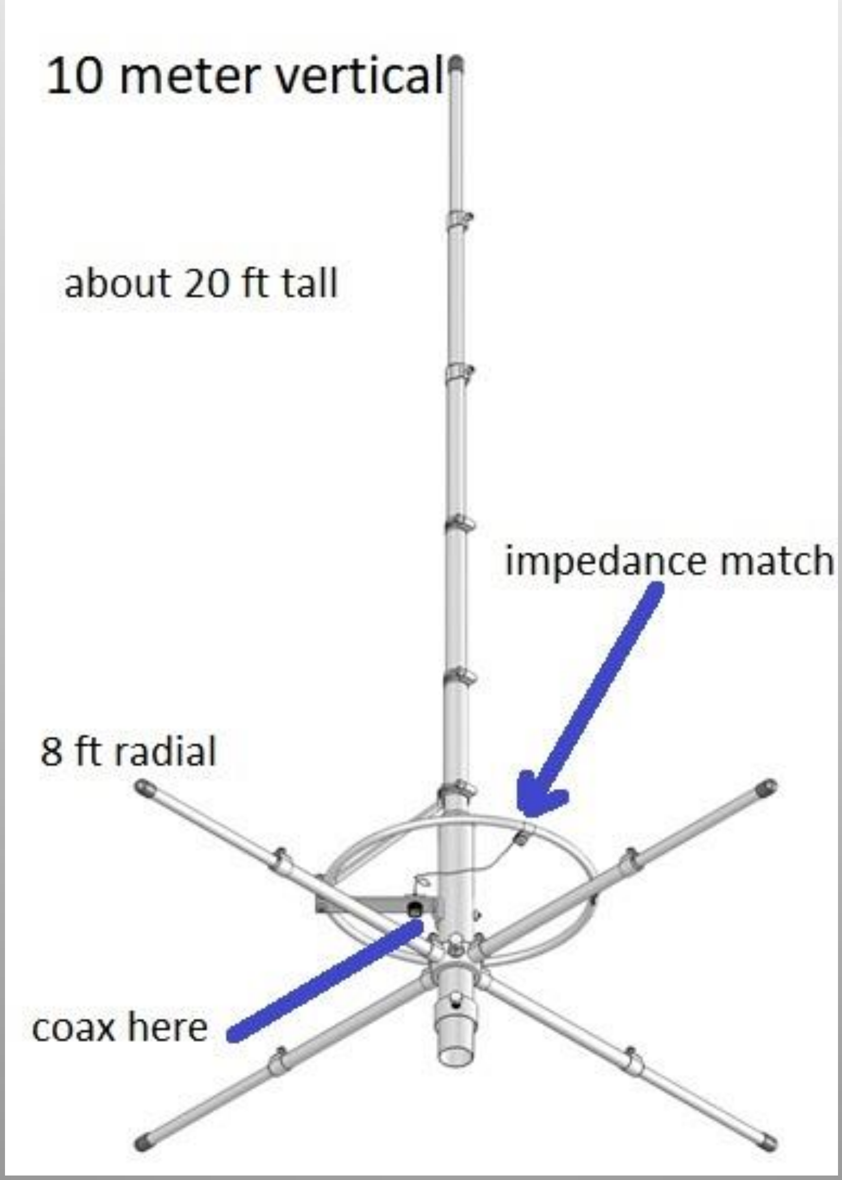
but tuner in shack does NOT change SWR on line

New SWR across 20m looks great < 1.7 : 1 across band

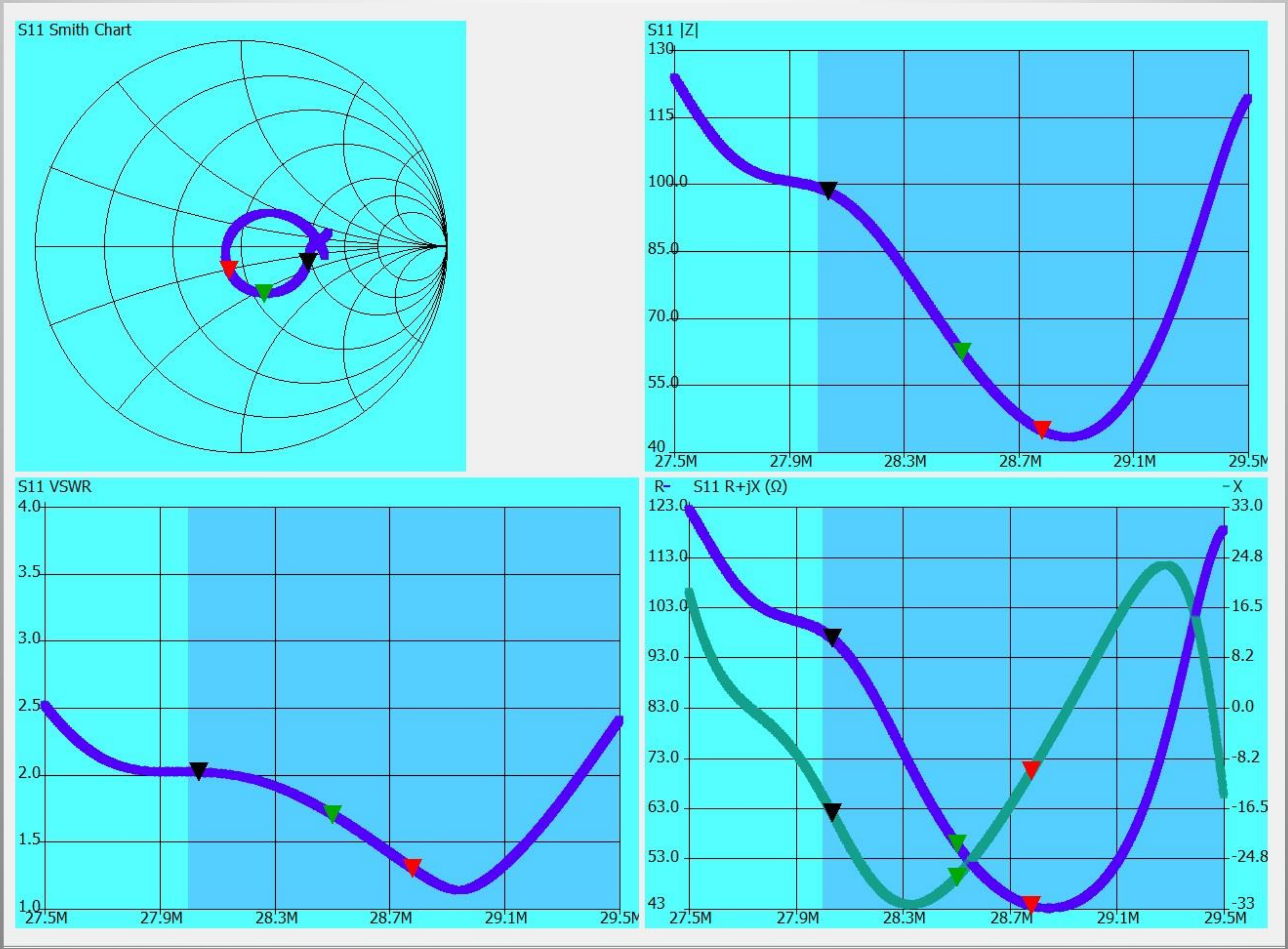
So do we now have more power radiated by antenna?



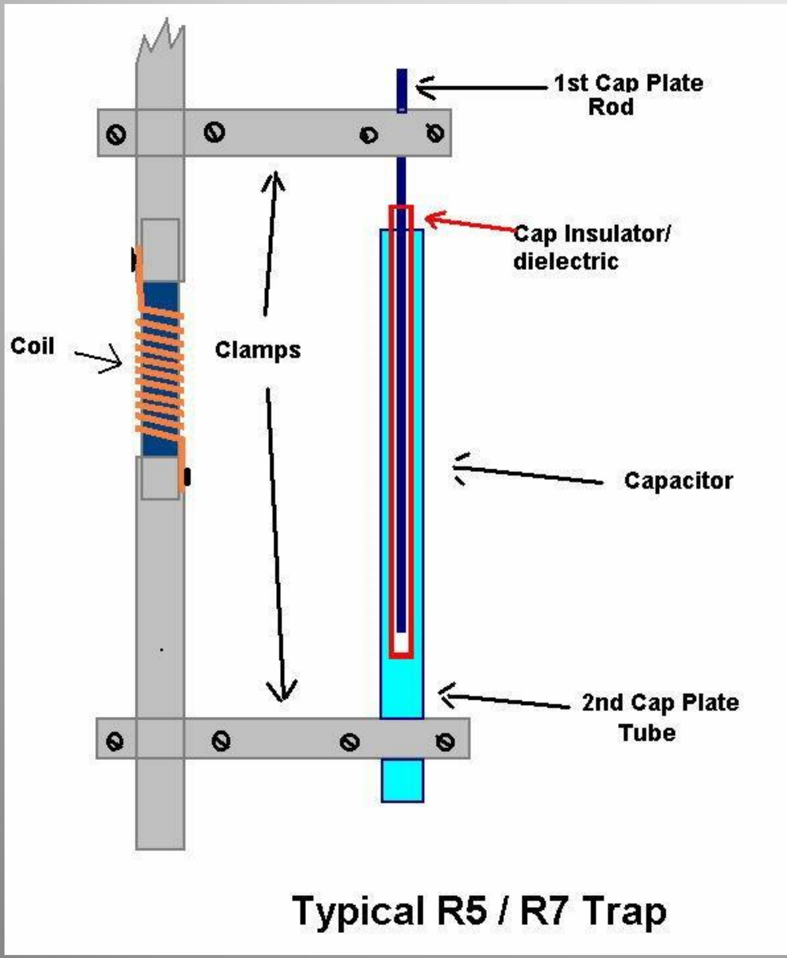
Jetstream 10m vertical: 5/8 wave
Gain about 3 dB over ¼ wave vertical

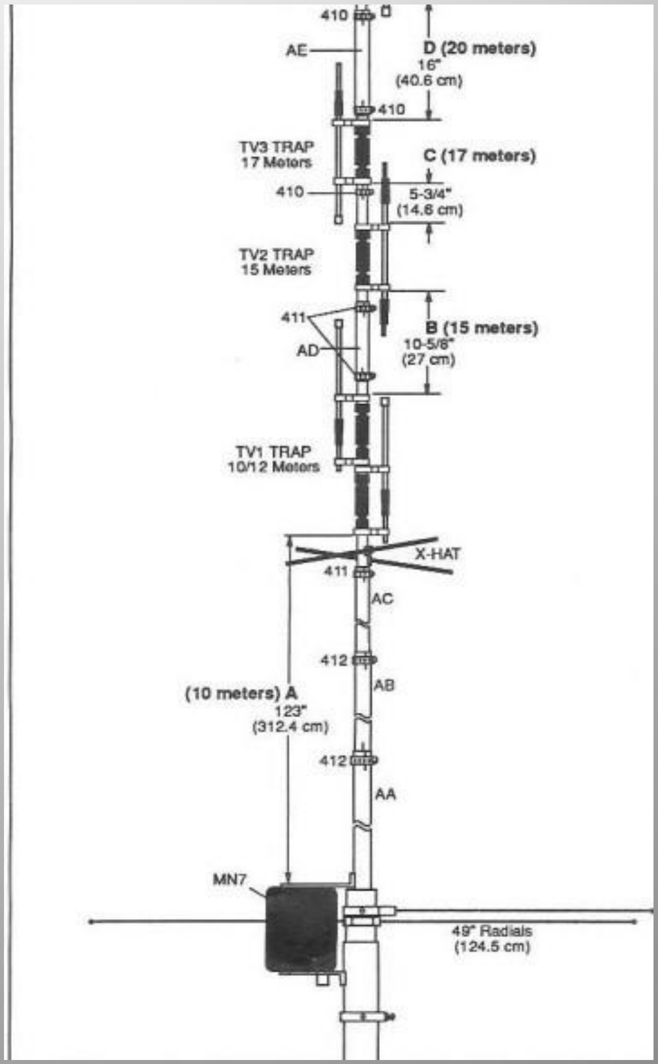


10m Jetstream
SWR < 2:1 from 28.0 to 29.3 MHz

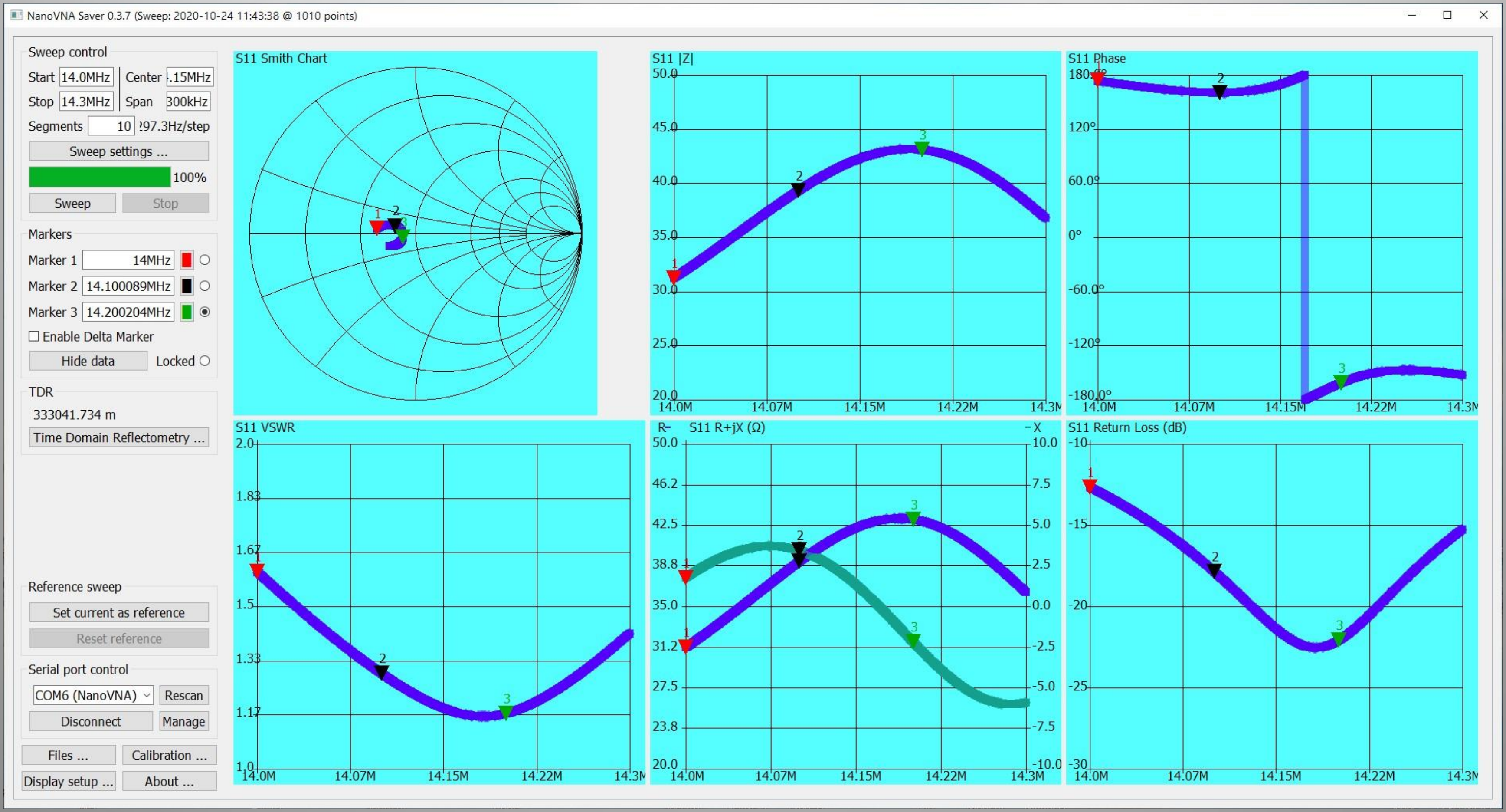


Cushcraft **R5** Vertical (5 bands)
with four "traps" for 10/12/15/17 m bands
(Traps act as parallel tuned High-Z circuits to isolate each band)

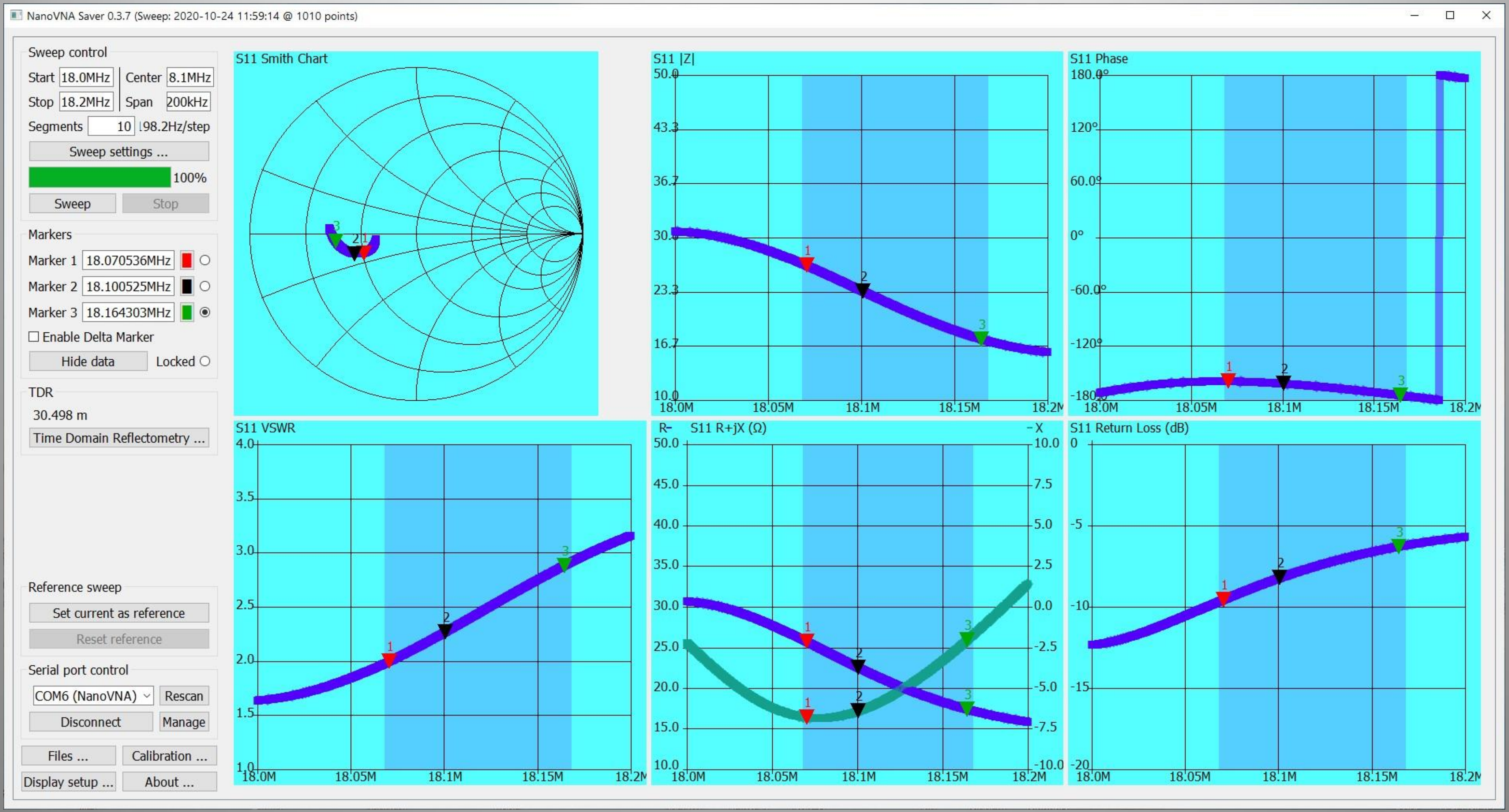




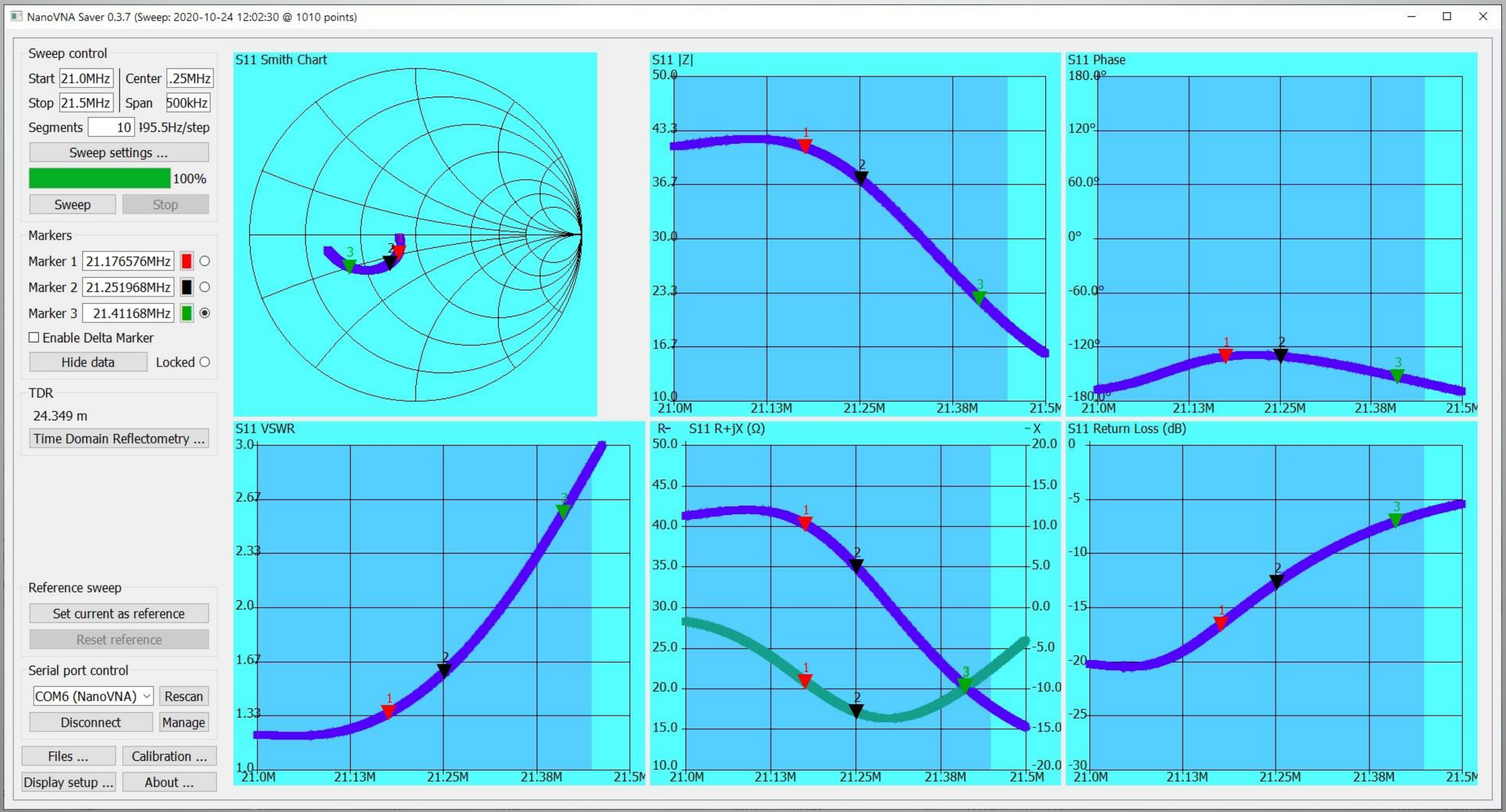
Cushcraft R5: 20m only



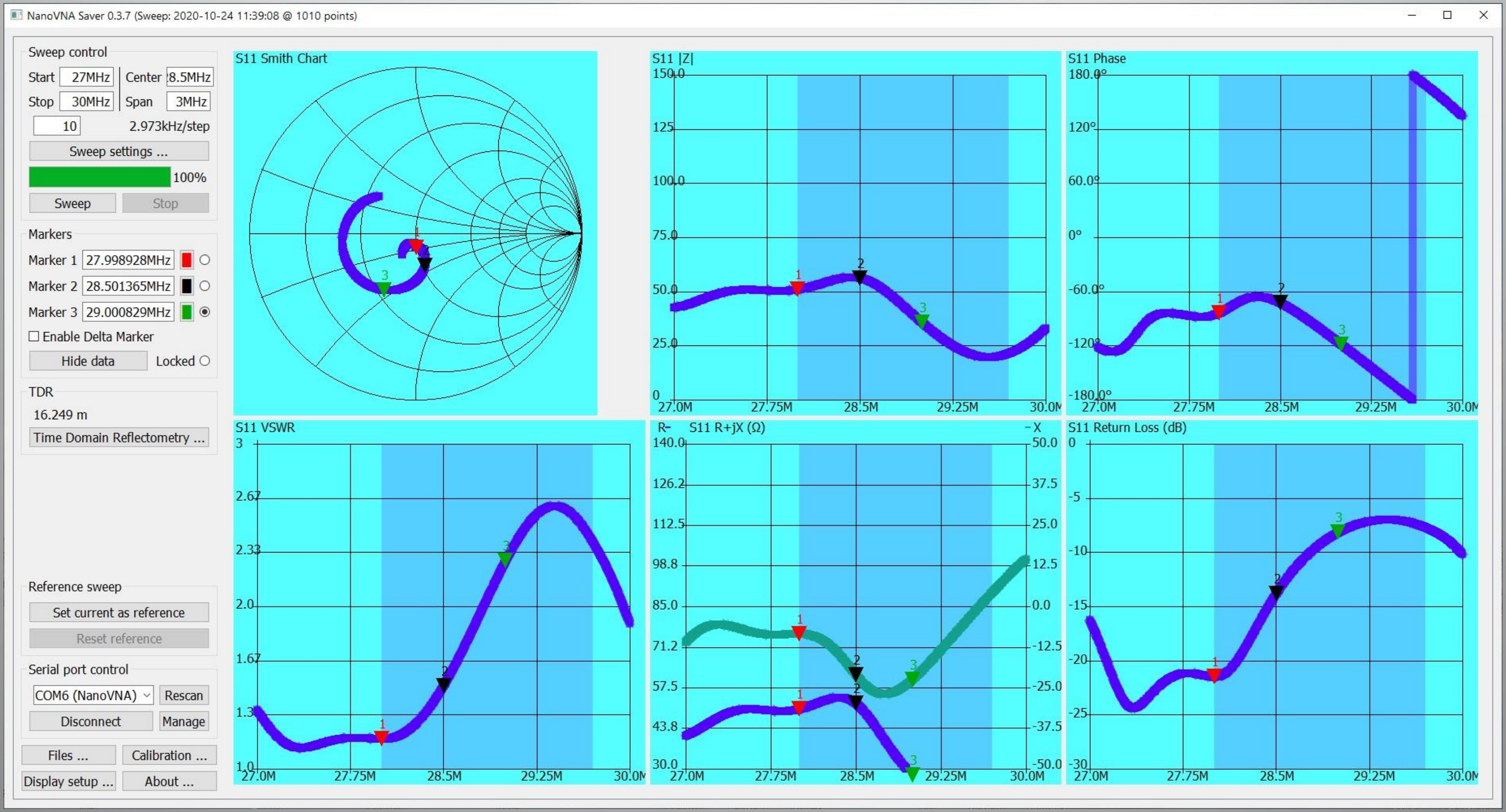
Cushcraft R5 17 meters



Cushcraft R5 15m only

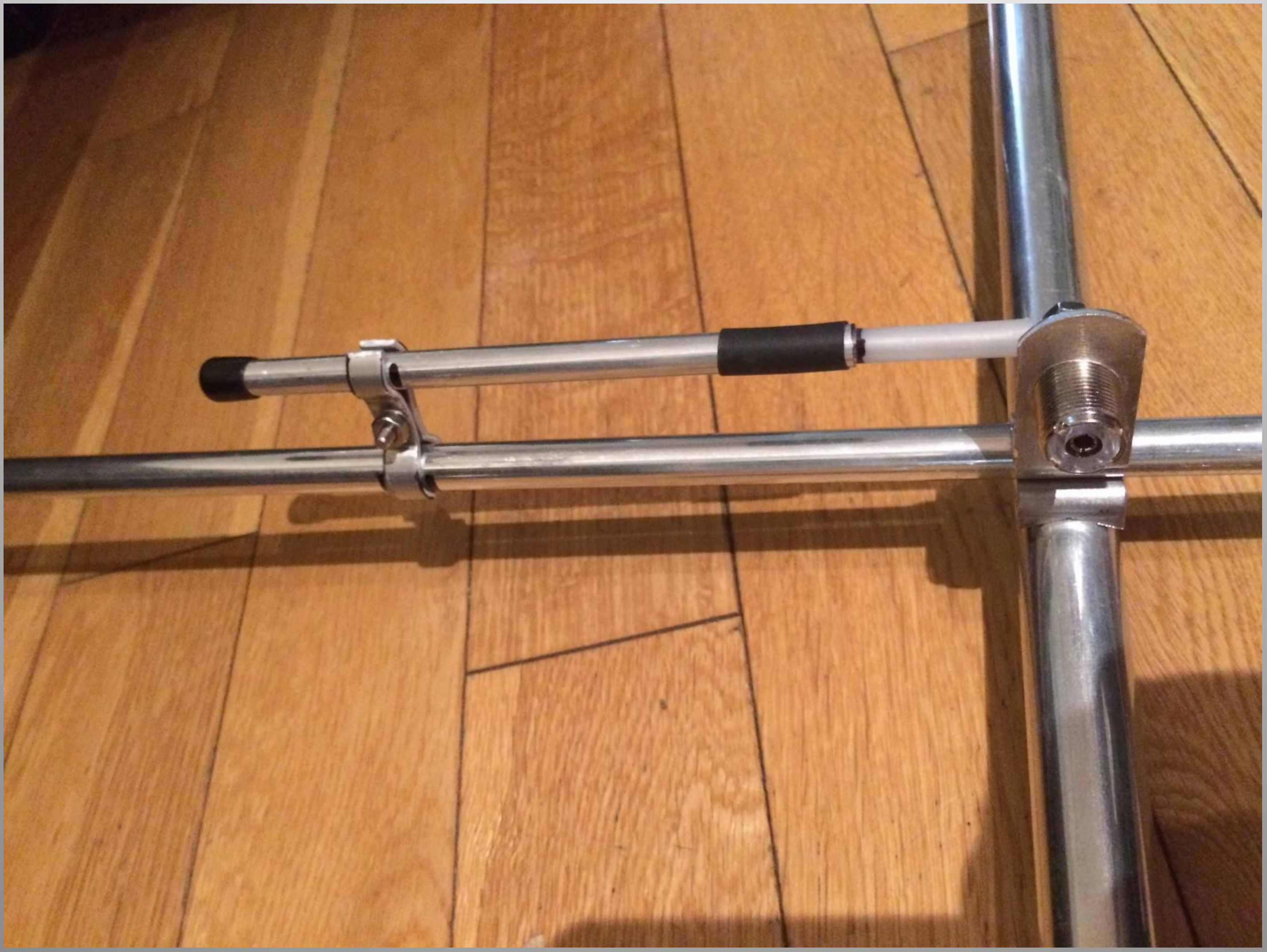


Cushcraft R5 10m only

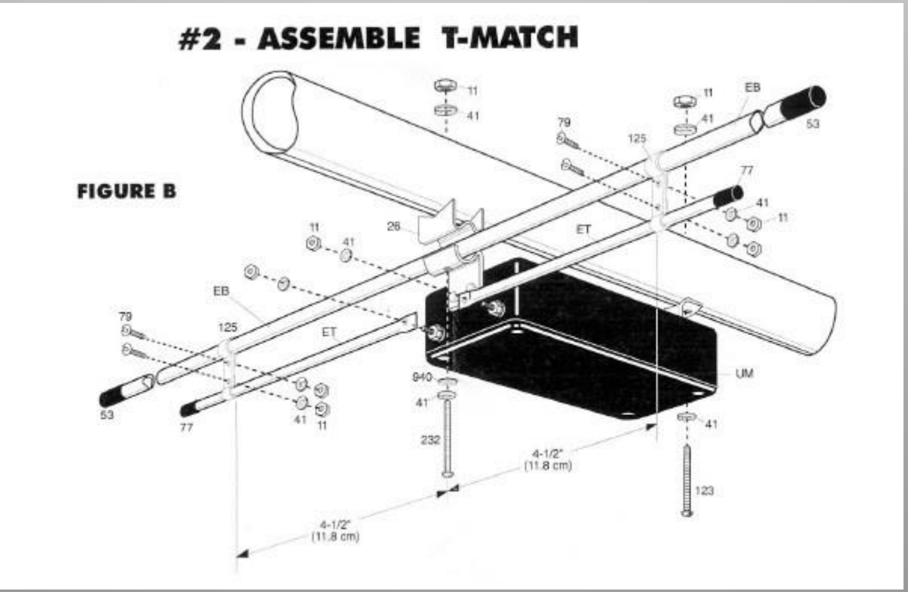


Cushcraft 10 element 2m beam

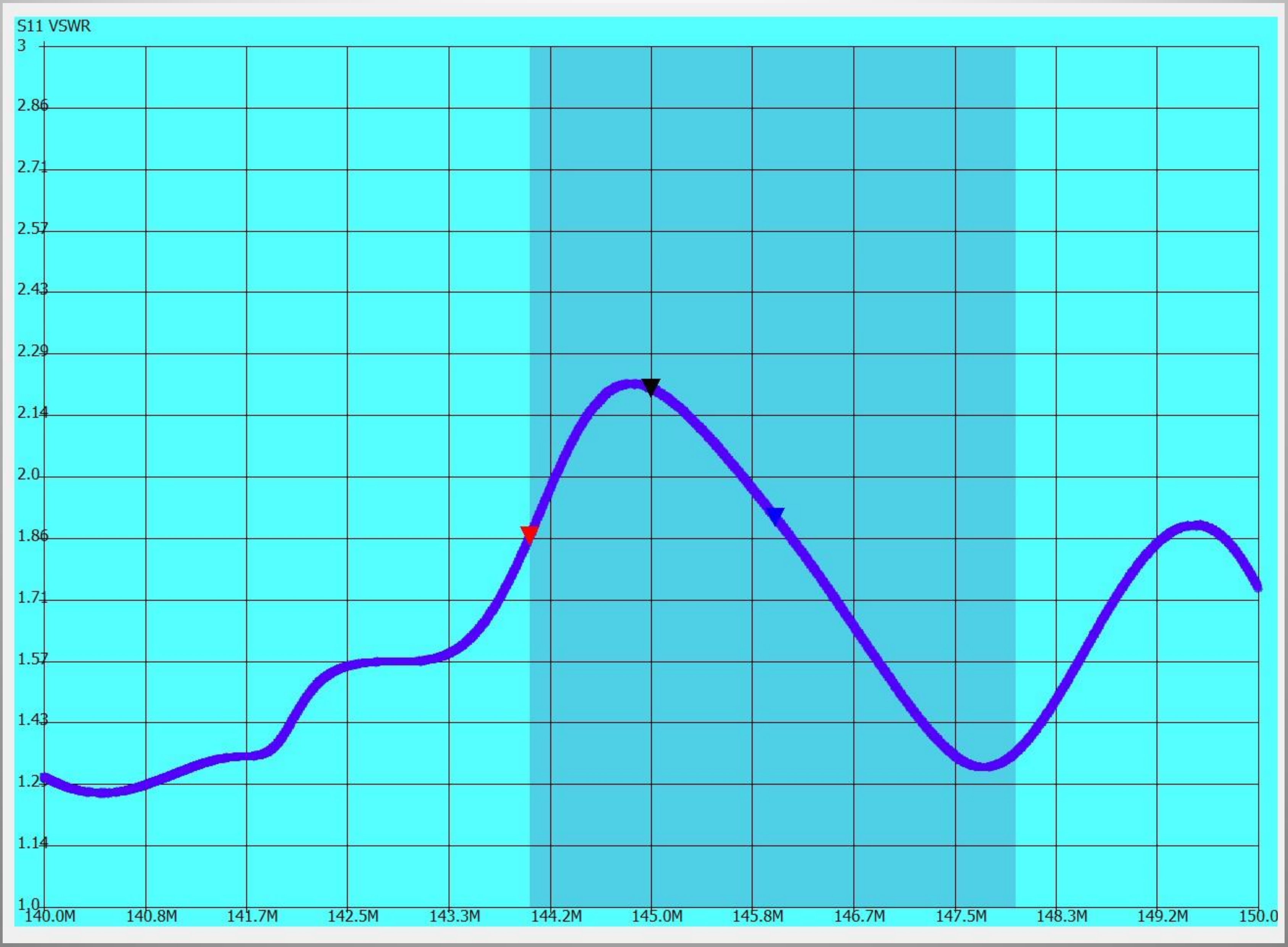
The “**Gamma Match**” is an UN-BALANCED circuit used to match the low impedance of beam to 50 ohms for coax



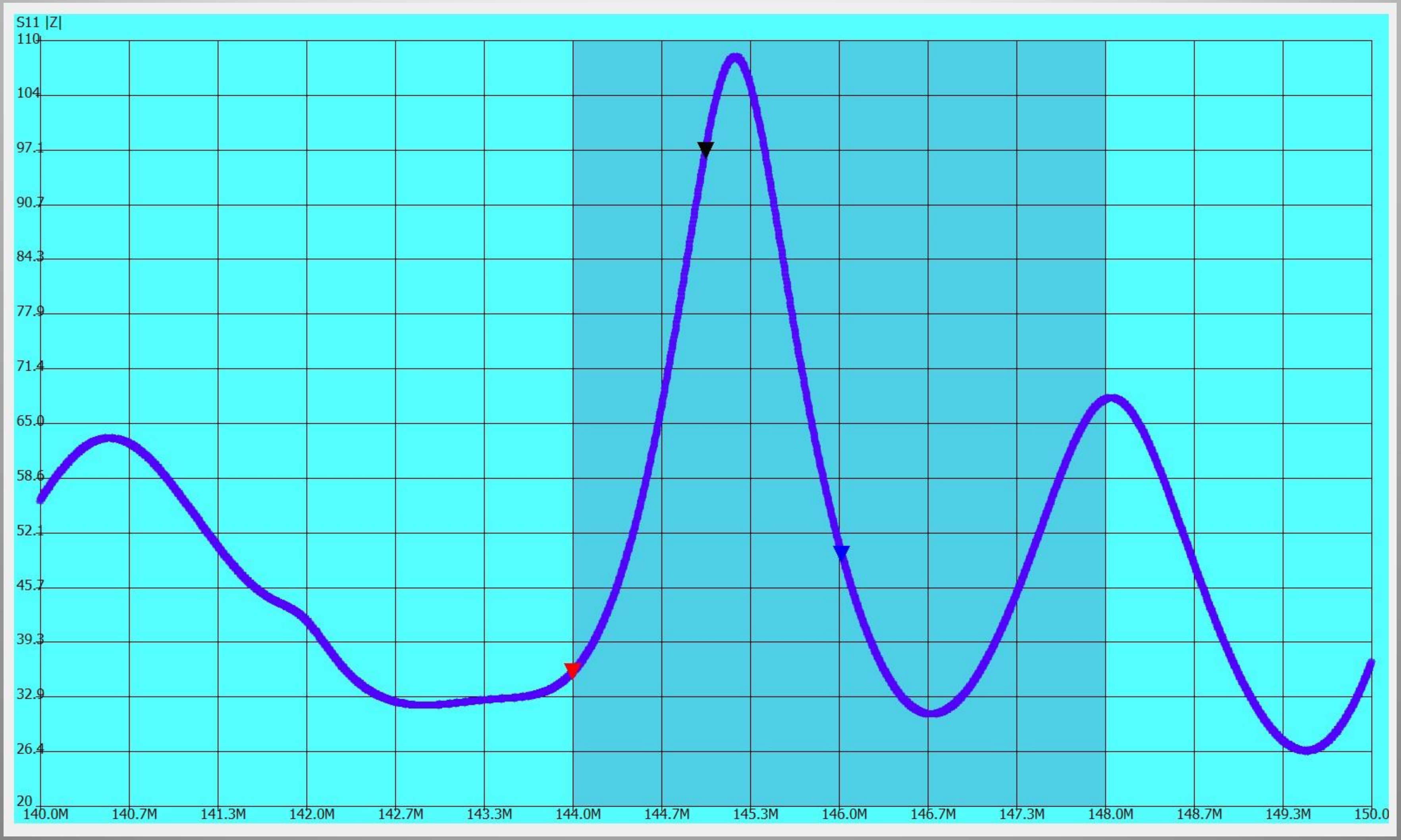
Cushcraft "**Ultra-Match**" is just two Gamma matches but provides a <u>BALANCED</u> approach relative to ground



SWR Cushcraft 10 element 2m BEAM

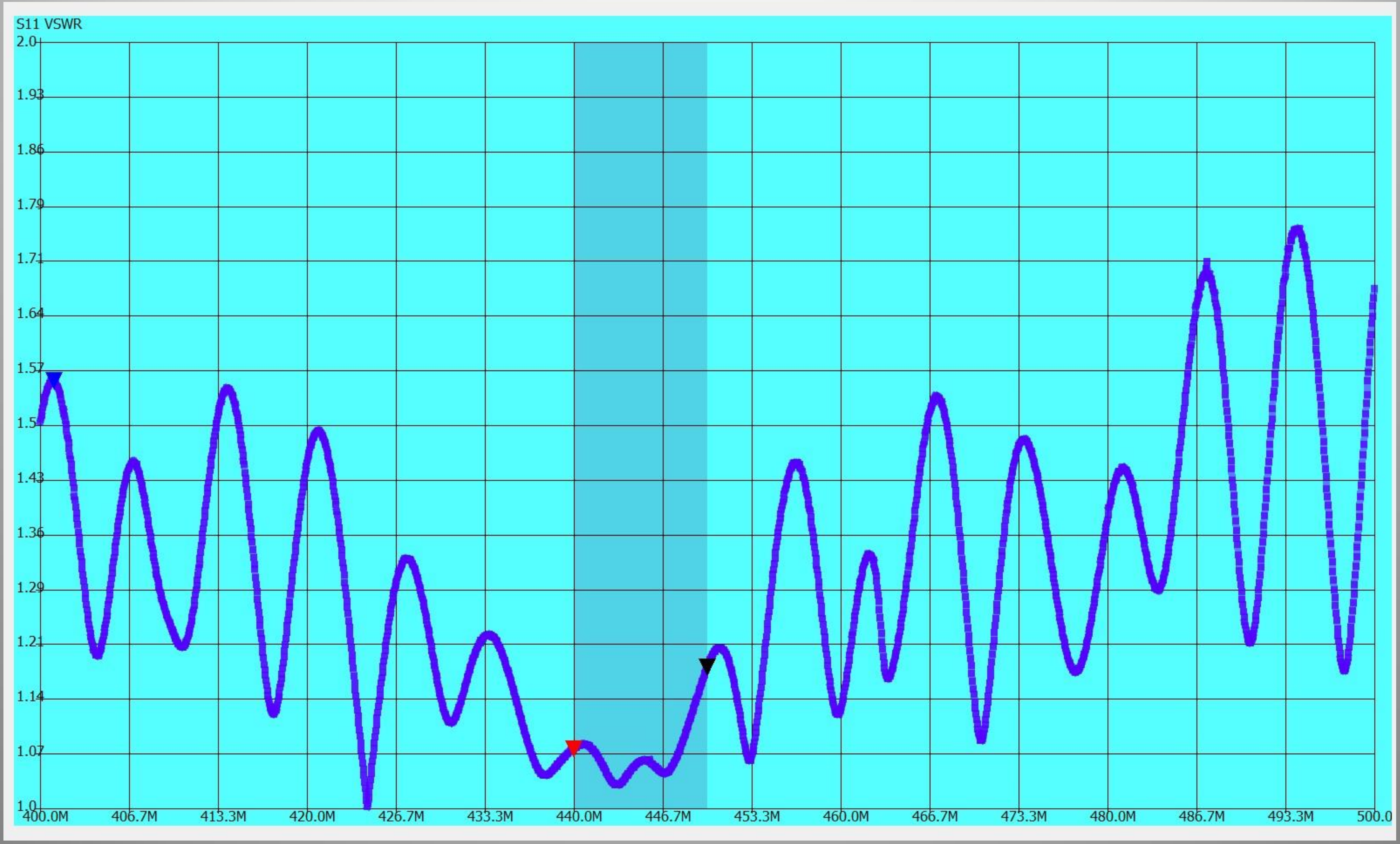


Impedance Cushcraft 2m BEAM

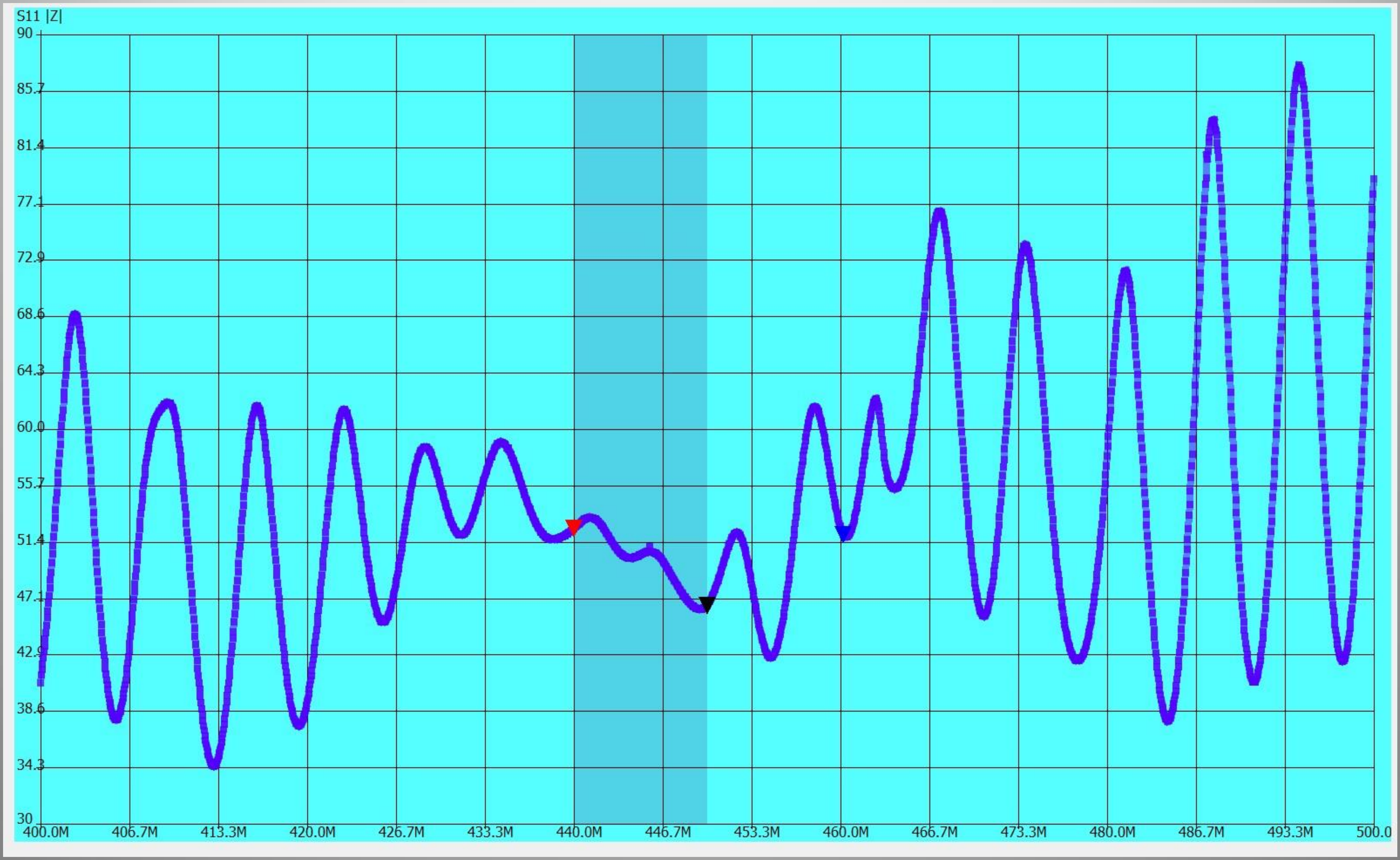


Cushcraft 11 element 70cm BEAM
now SWR is getting to be critical - why?

SWR Cushcraft 11 element 70 cm BEAM
note SWR < 2:1 from 400 – 500 MHz

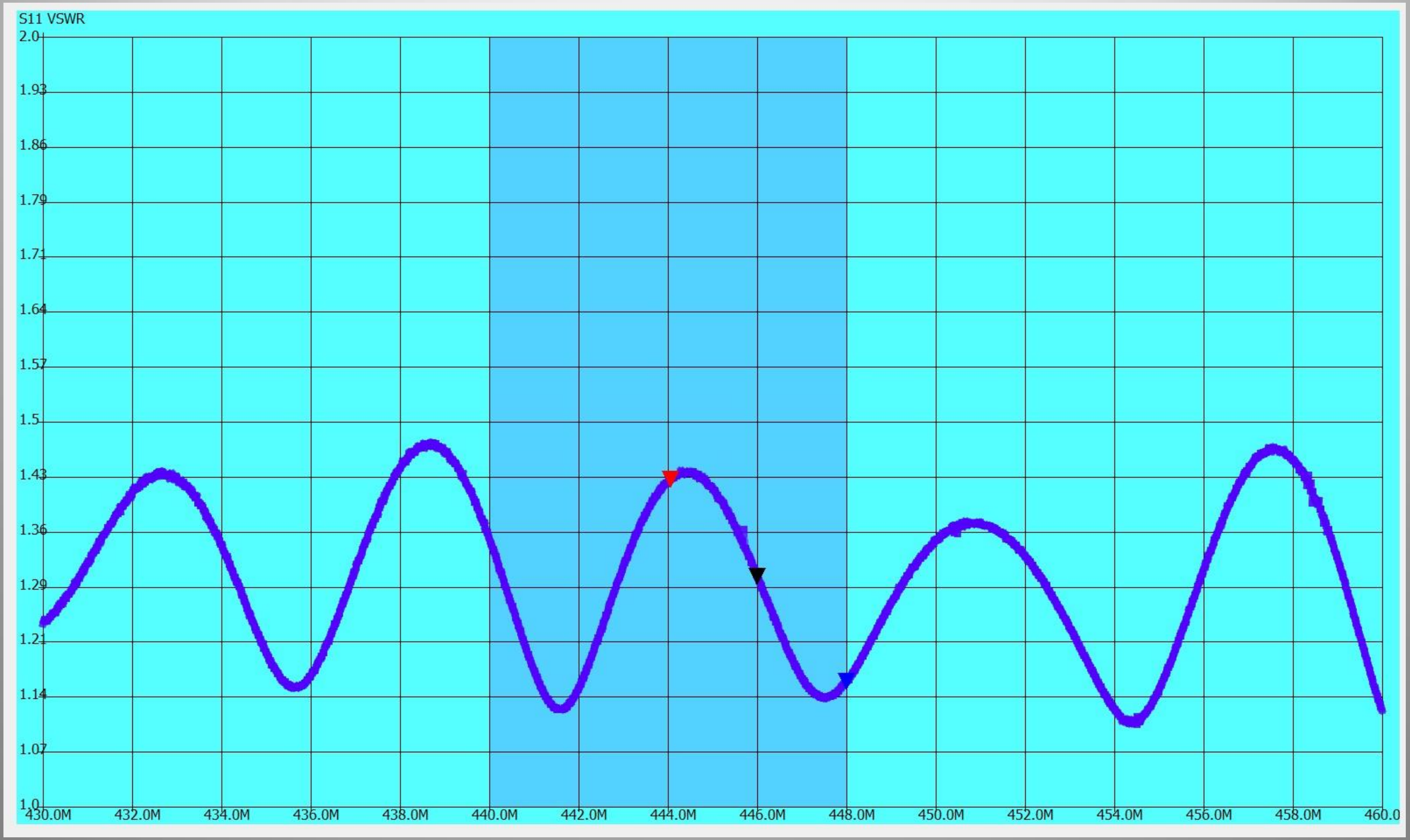


Impedance Cushcraft 70cm BEAM



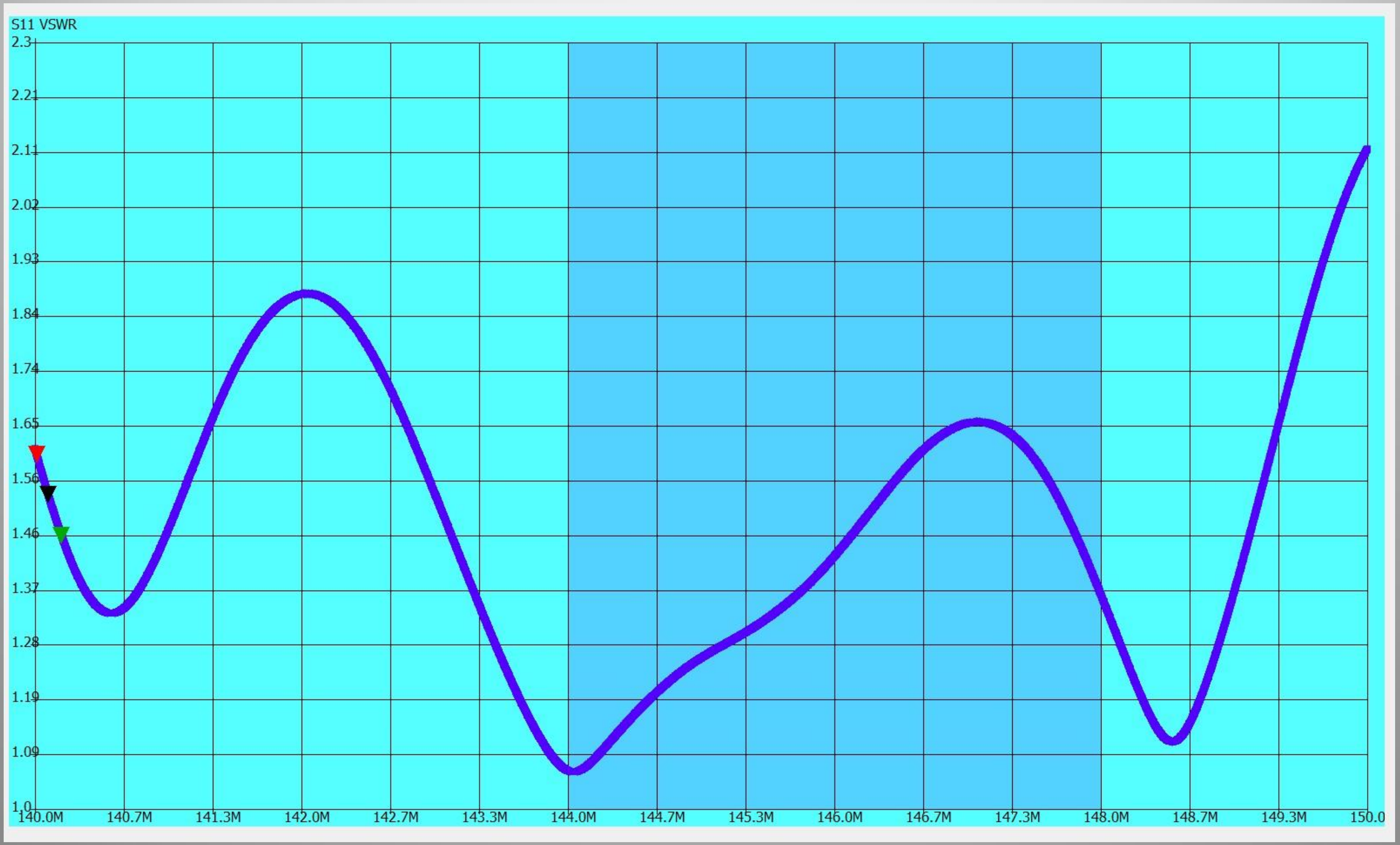
Diamond 70cm Vertical

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

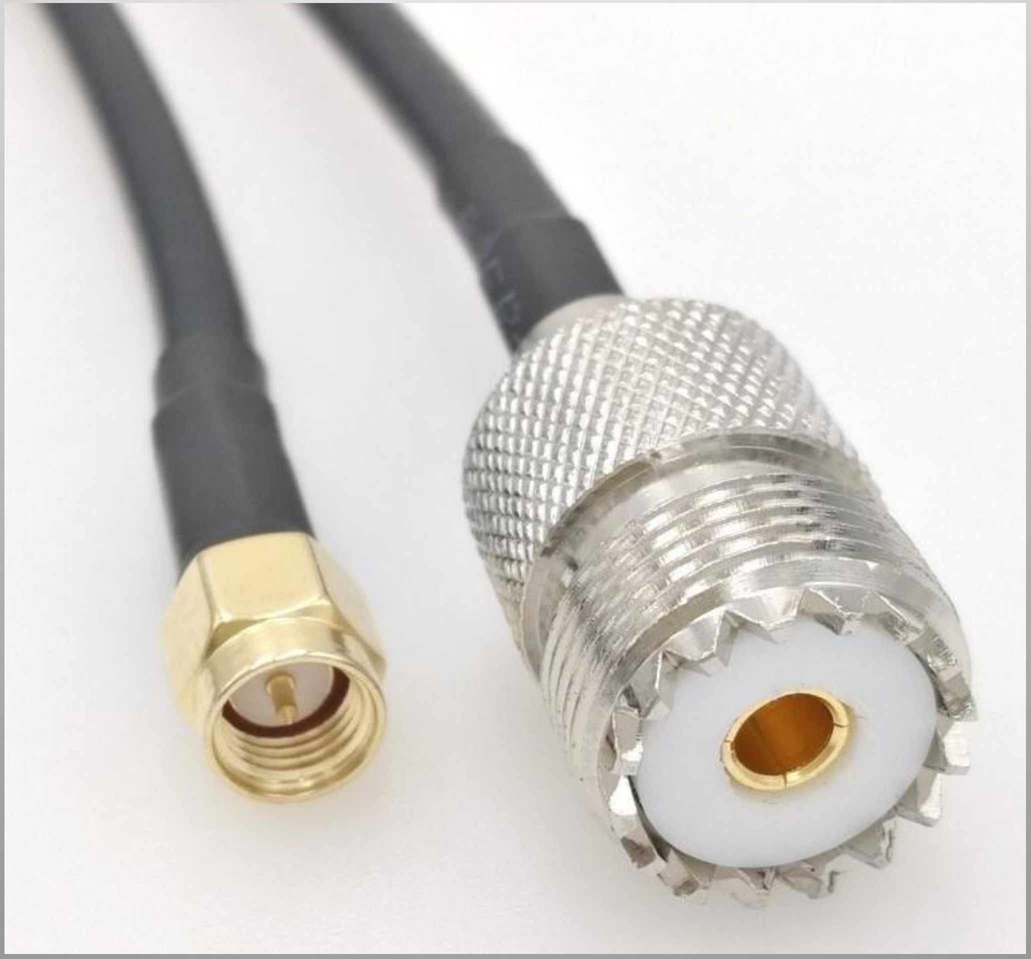
Measure the inductance L of a coil

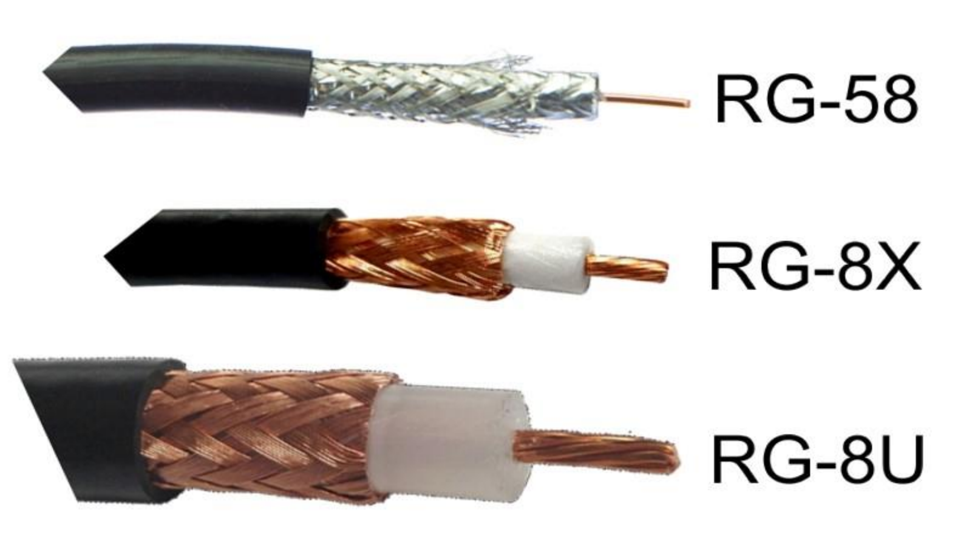
Measure the capacitance C of a capacitor

Measure the impedance Z of a RLC circuit

Measure PHASE ANGLES

Useful Adapter: SMA to SO239
but is the impedance still **50** ohms in the SO239 socket?





Attenuation (dB per 100 feet)

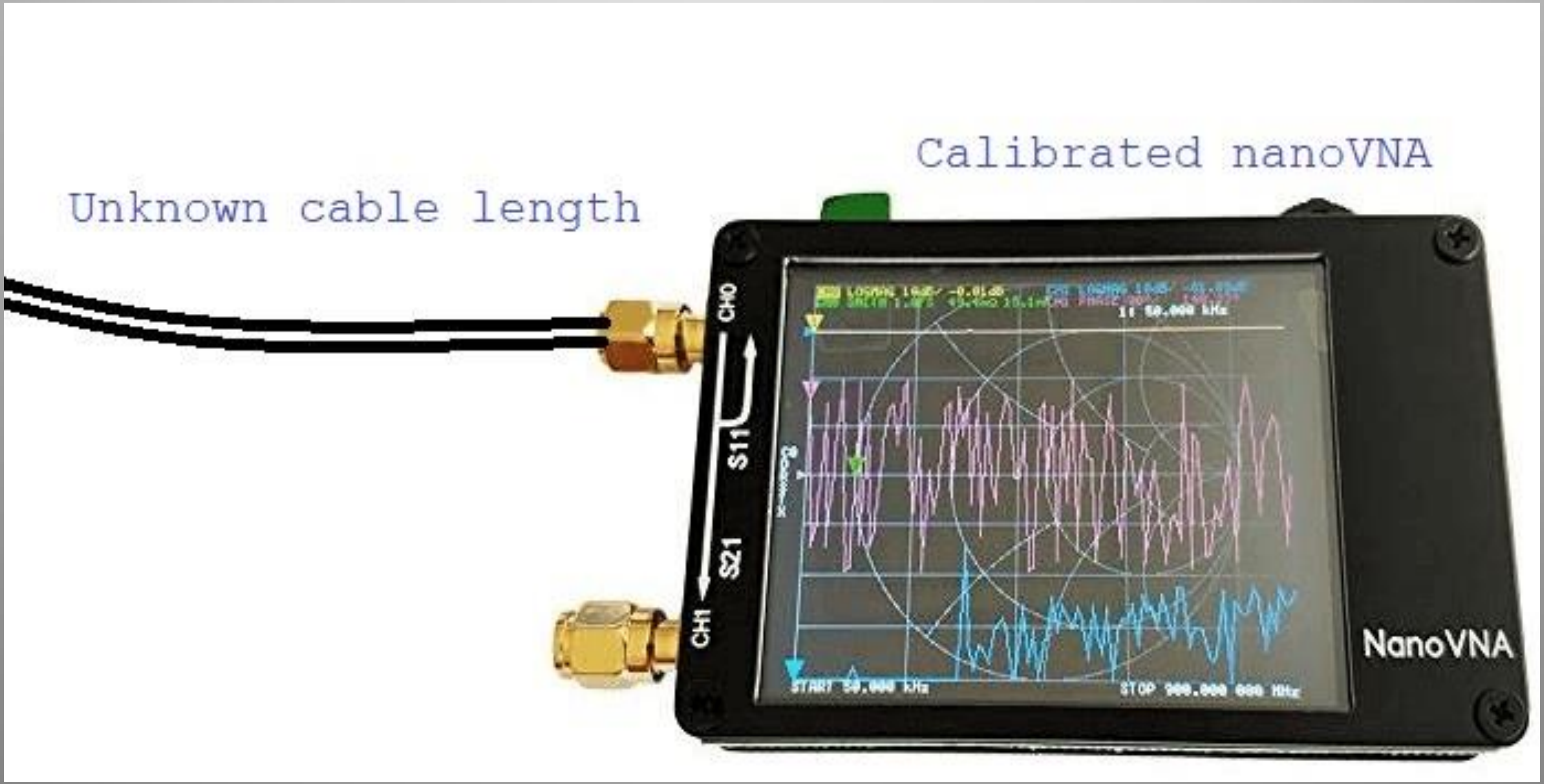
Coax Cable Signal Loss (Attenuation) in dB per 100ft*								
Loss*	RG-174	RG-58	RG-8X	RG-213	RG-6	RG-11	RF-9914	RF-9913
1MHz	1.9dB	0.4dB	0.5dB	0.2dB	0.2dB	0.2dB	0.3dB	0.2dB
10MHz	3.3dB	1.4dB	1.0dB	0.6dB	0.6dB	0.4dB	0.5dB	0.4dB
50MHz	6.6dB	3.3dB	2.5dB	1.6dB	1.4dB	1.0dB	1.1dB	0.9dB
100MHz	8.9dB	4.9dB	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

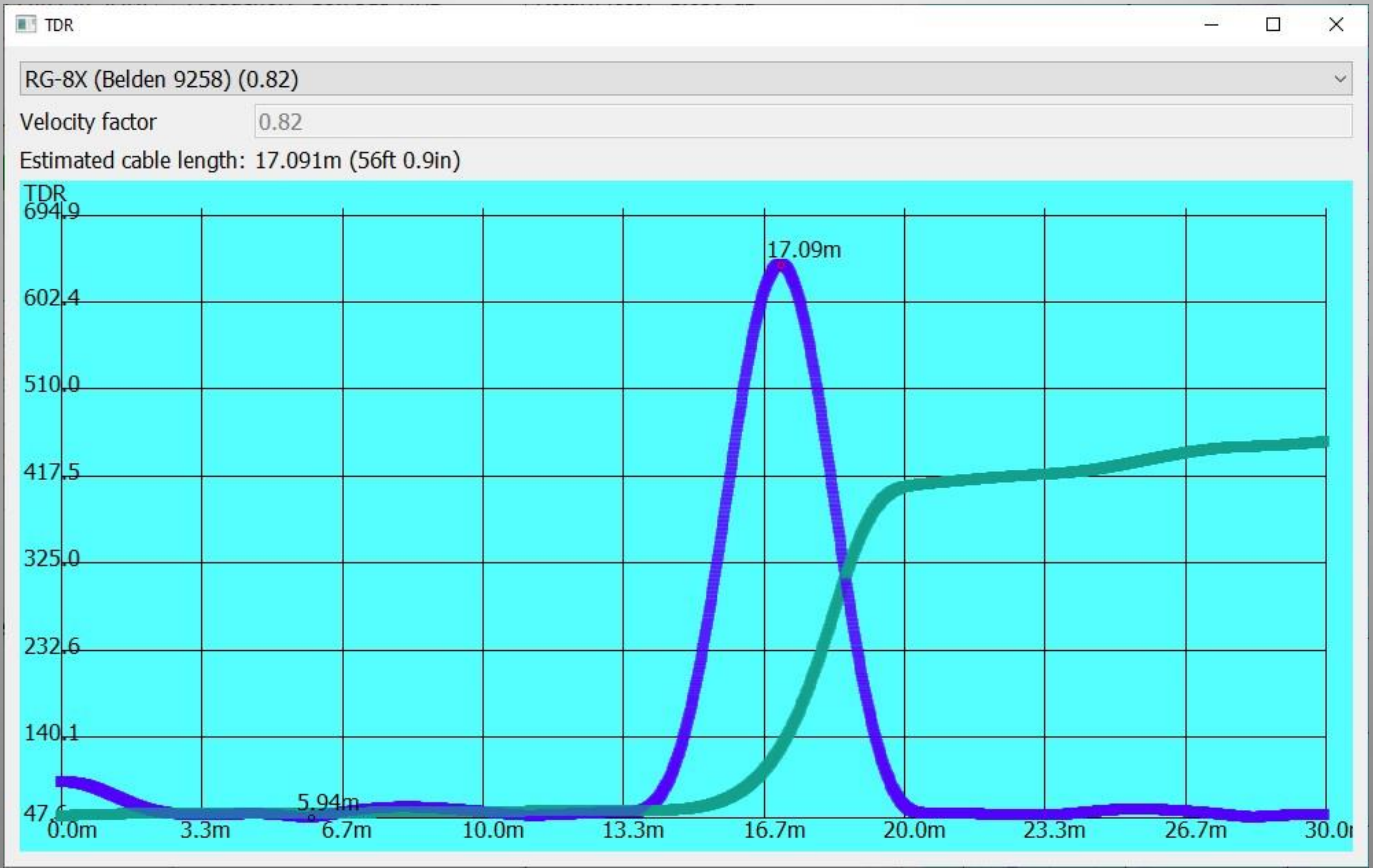
Set the TDR display function to ON

What "should happen"

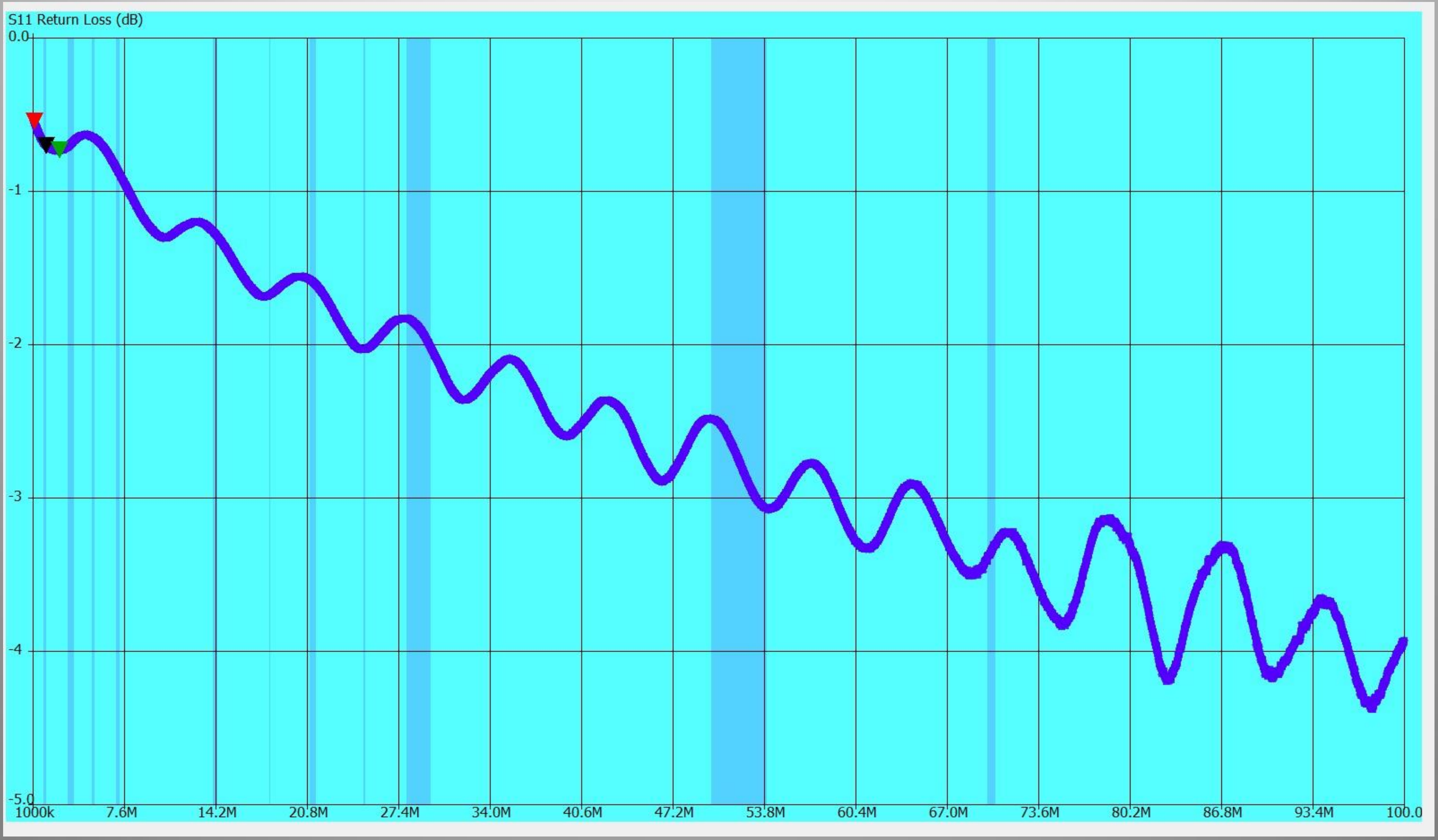
When the RF gets to the shorted end of the coax, impedance = 0

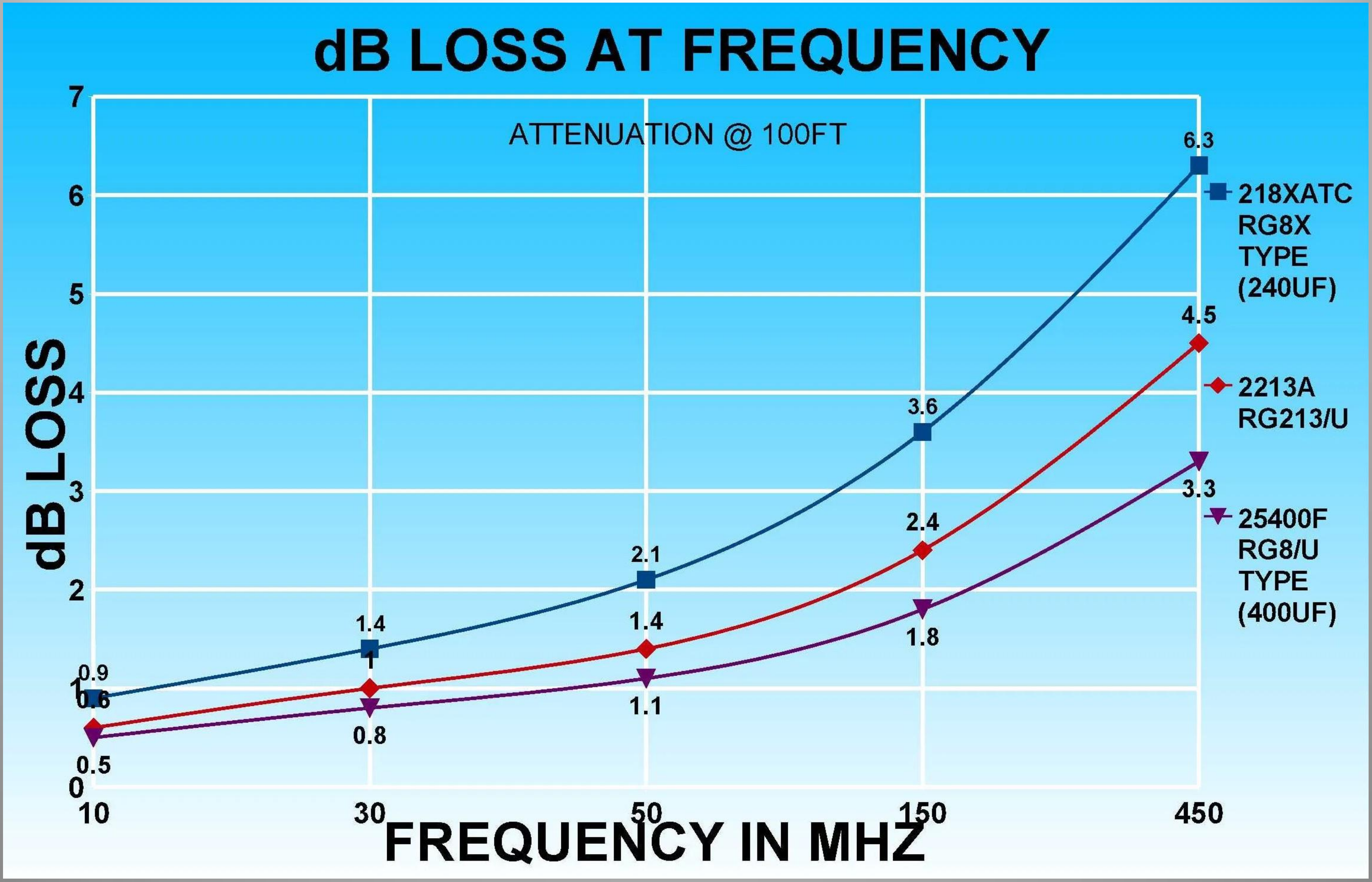
100% of the RF should reflect back to Ch0 (SWR is infinite)

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

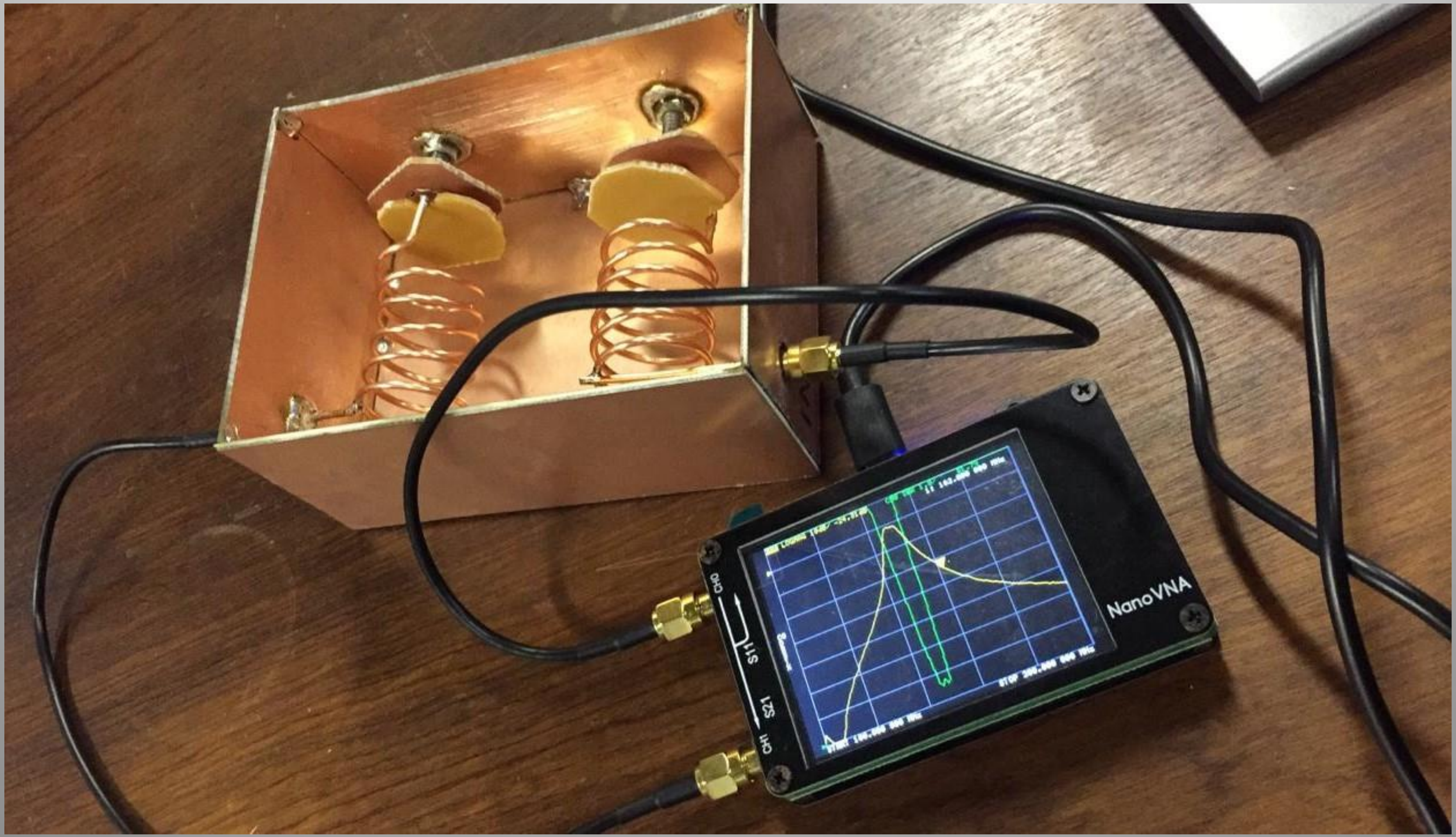


Attenuation (dB) of 50 ft **RG8X** vs. **Frequency** (1-100 MHz)
At what frequency is the "heat" loss = 50% of the power?
Why does the attenuation increase with frequency?




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

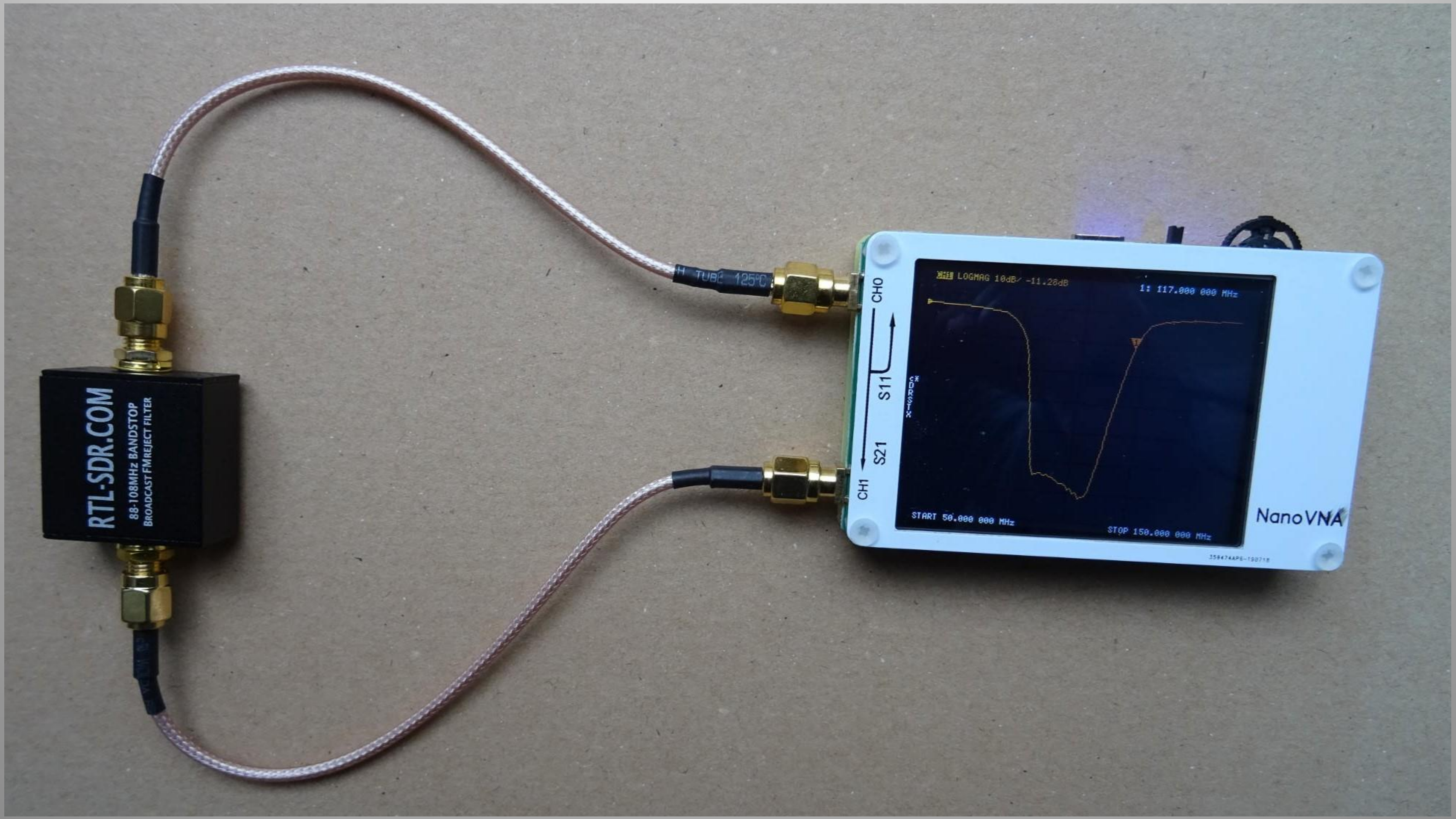
Measure the frequency response of a LC filter by measuring the “THRU” response: Ch0 to Ch1



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

Advanced: measure trap Q by use of TWO Channels

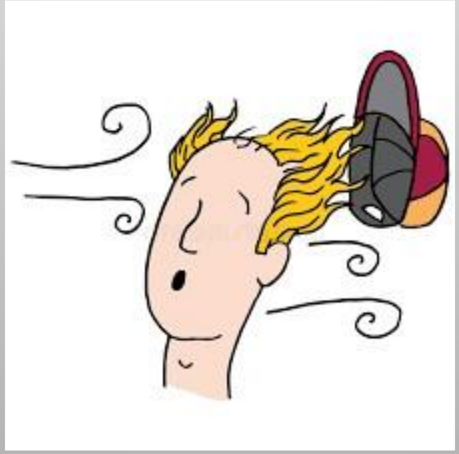
A FM broadcast band-stop "filter"
Use the S21 mode (two ports)



Ready for a closer look at

Smith Charts

Hold on



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

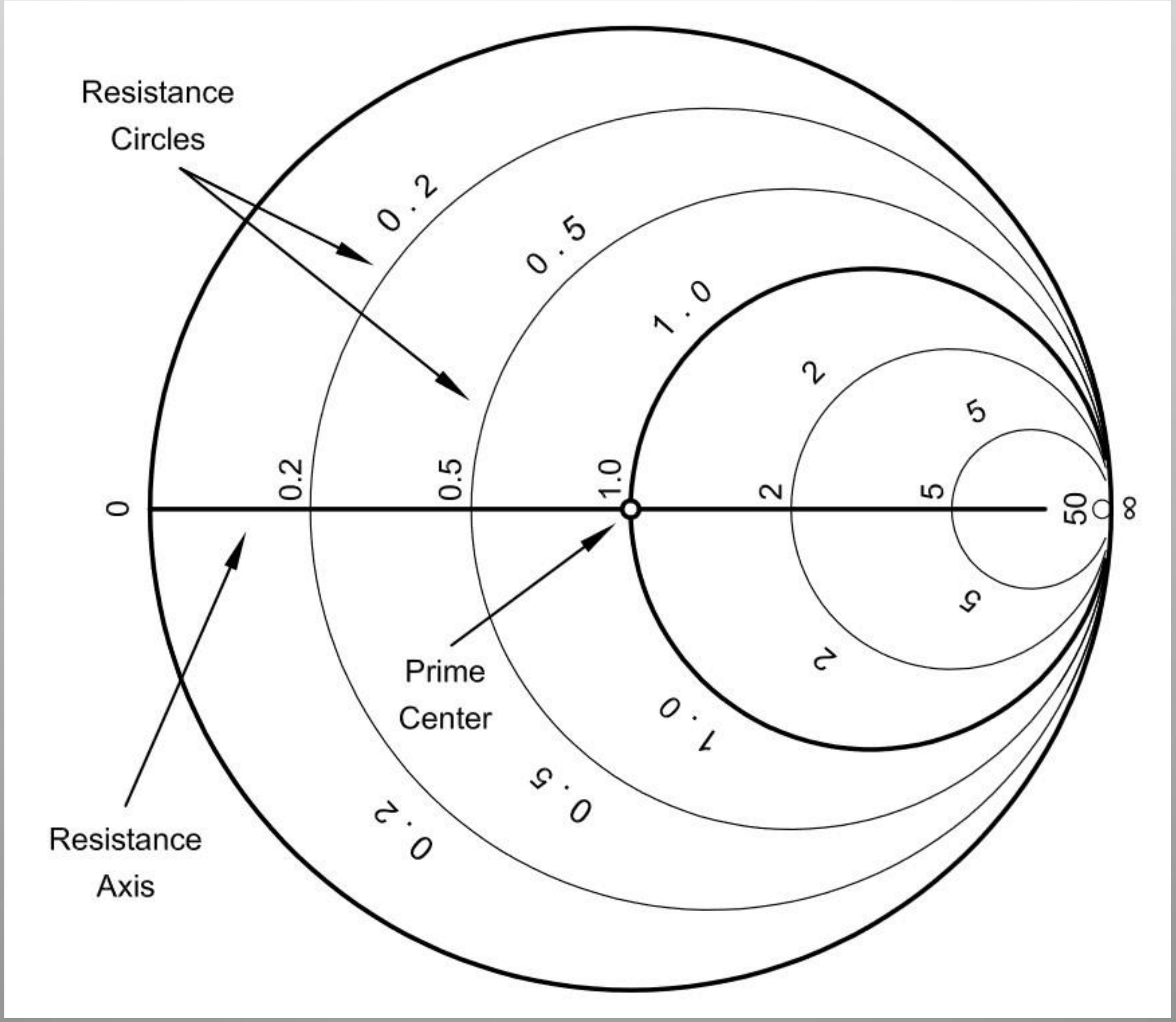
Smith Chart

to guide our thinking

ENTER the **Smith Chart**

Resistance is plotted on **horizontal** axis from 0 to infinity

Often the PRIME **center** is normalized to 1.0 (for scale)



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

Inductors produce **POSITIVE** reactance

Capacitors produce **NEGATIVE** reactance

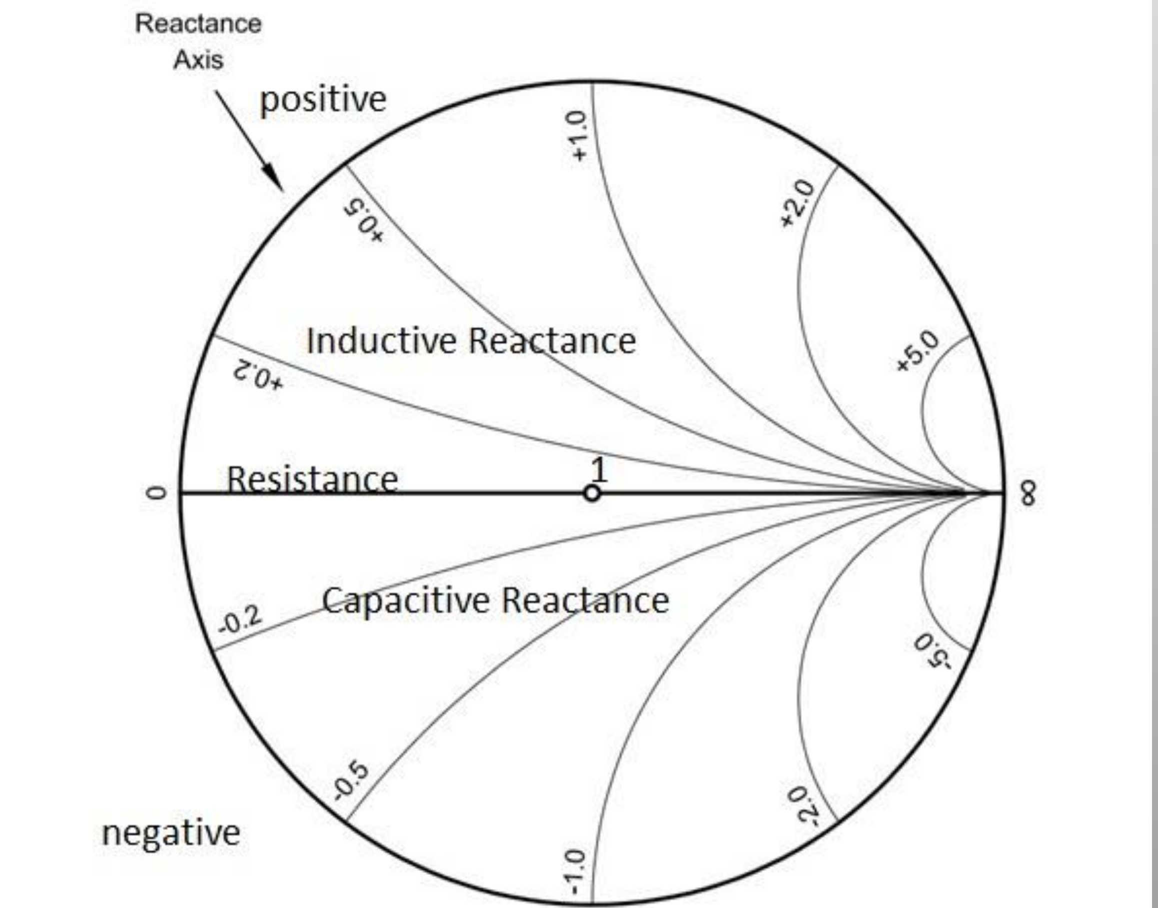


Fig 2—Reactance circles (segments) of the Smith Chart coordinate system.

Every impedance (R +/- j X) has a **unique location** on this graph

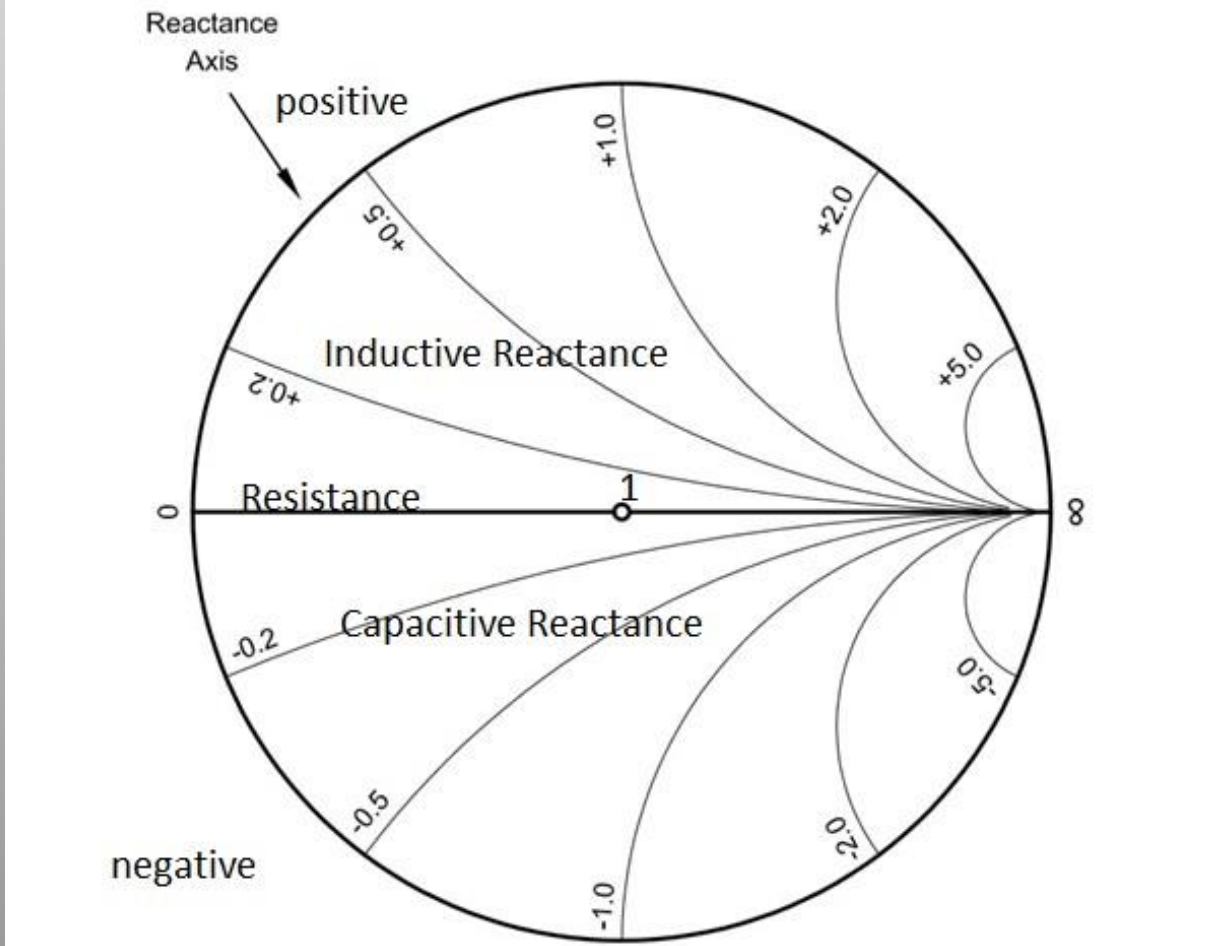


Fig 2—Reactance circles (segments) of the Smith Chart coordinate system.

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

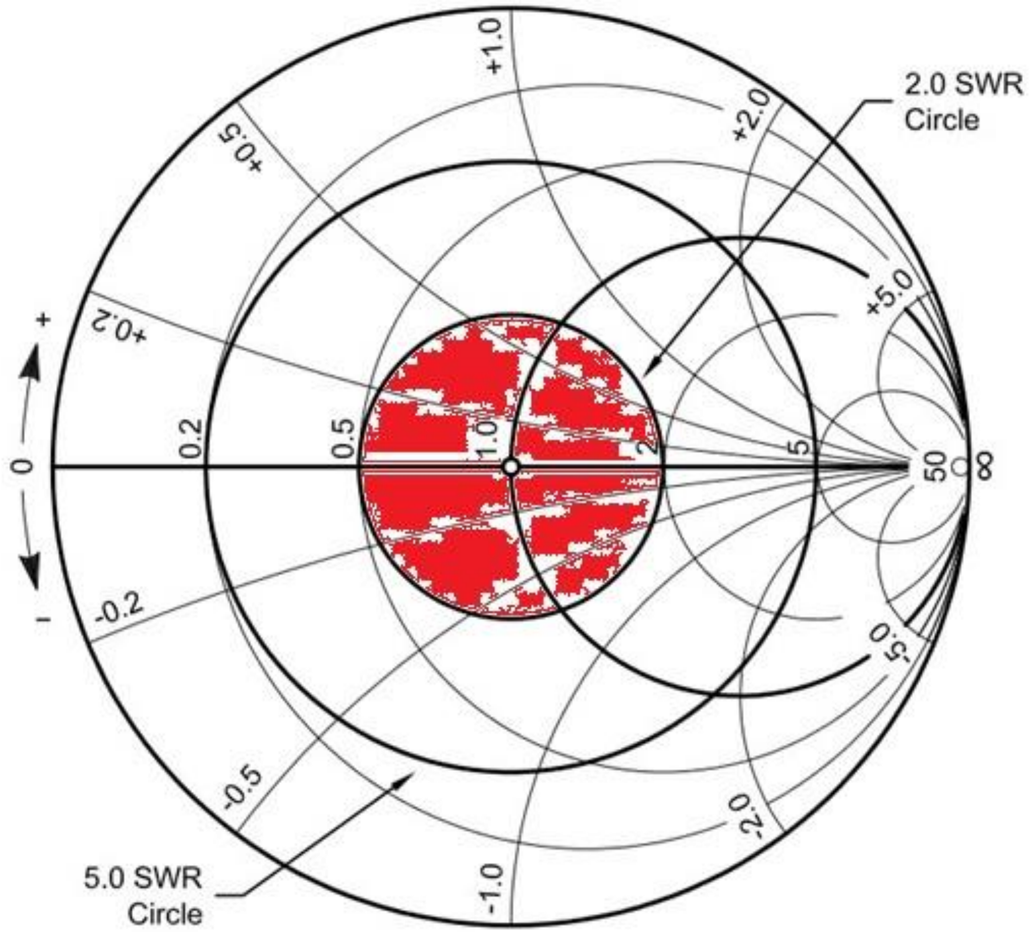
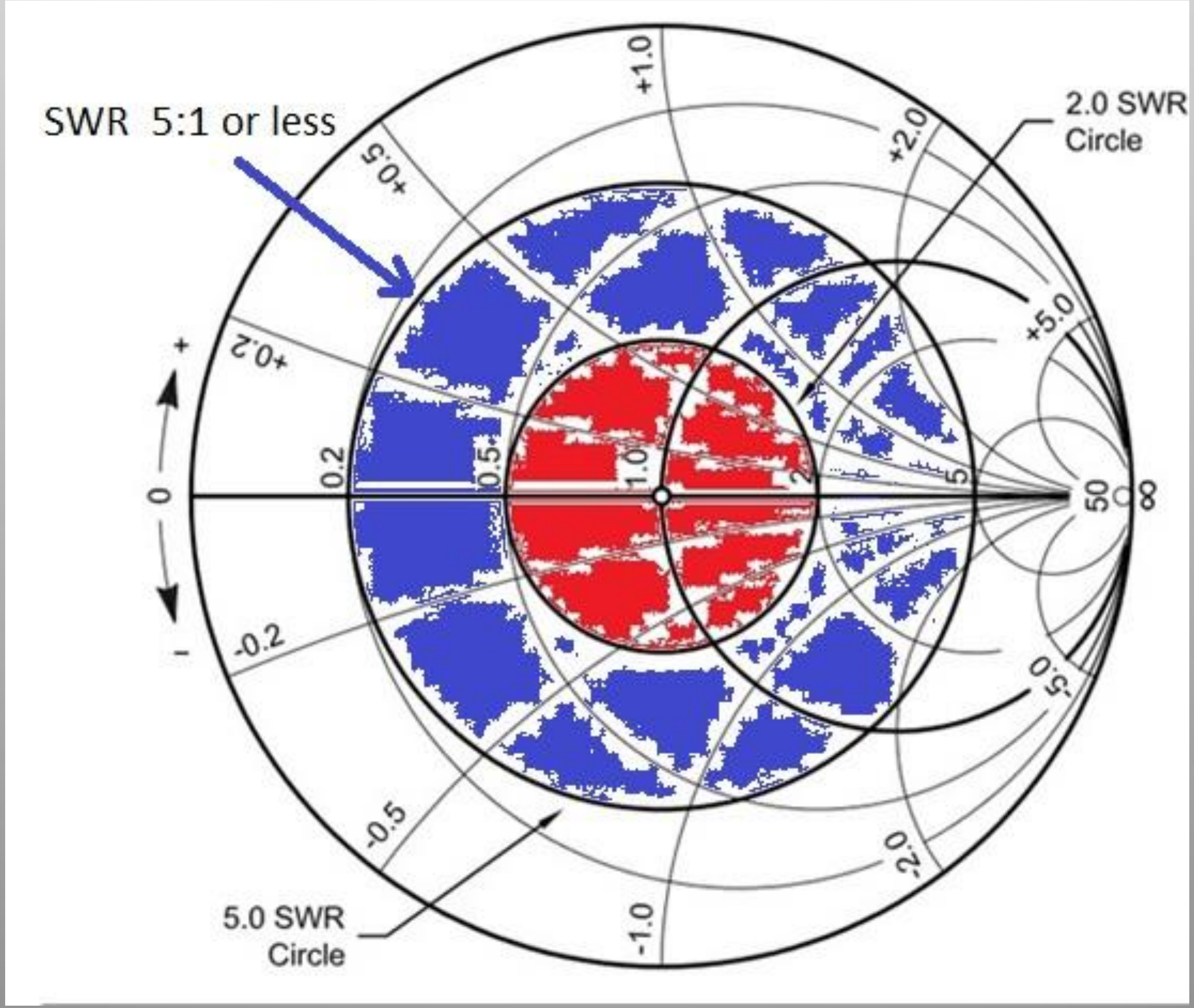


Fig 4—Smith Chart with SWR circles added.

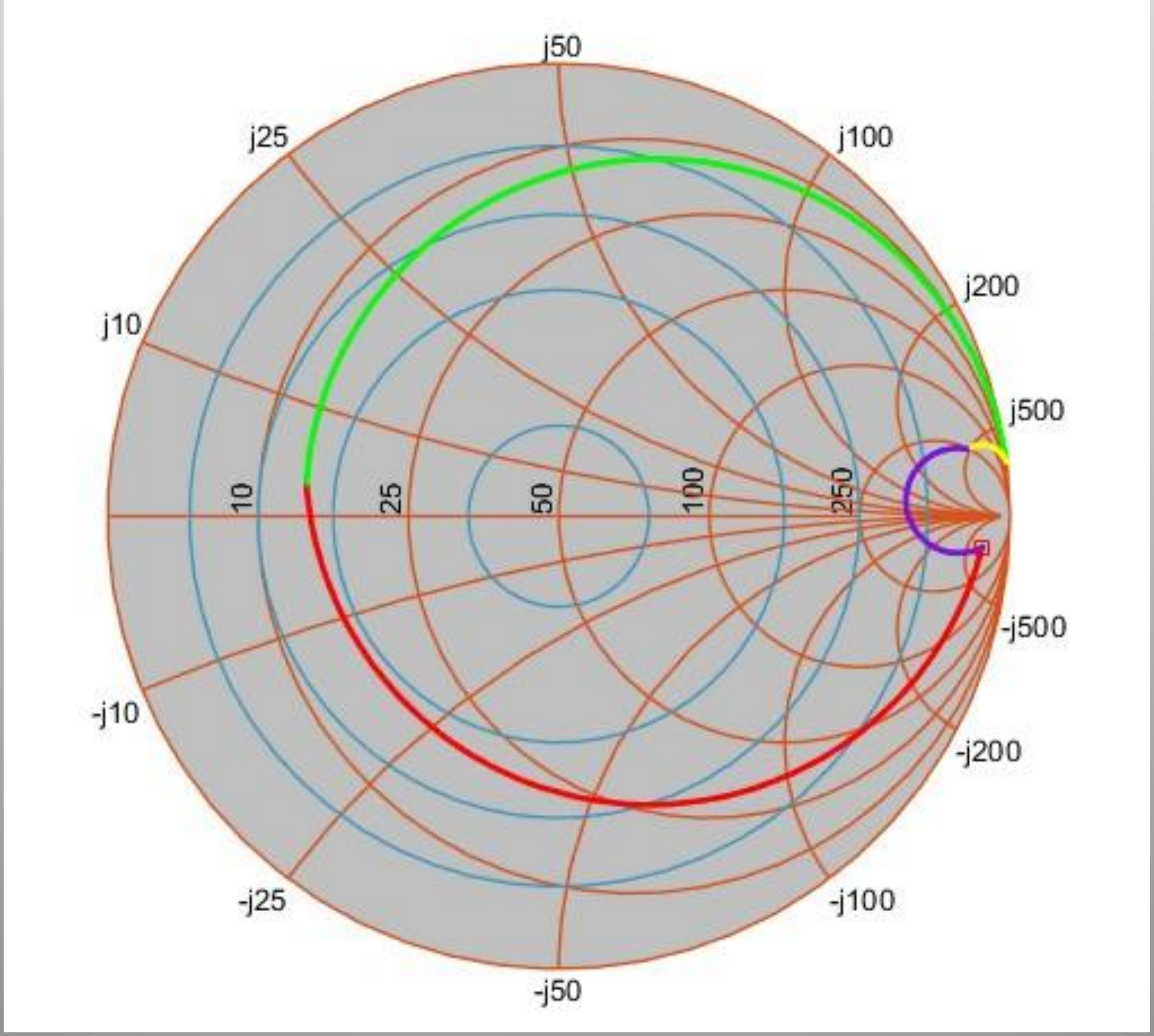
Constant SWR circles

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

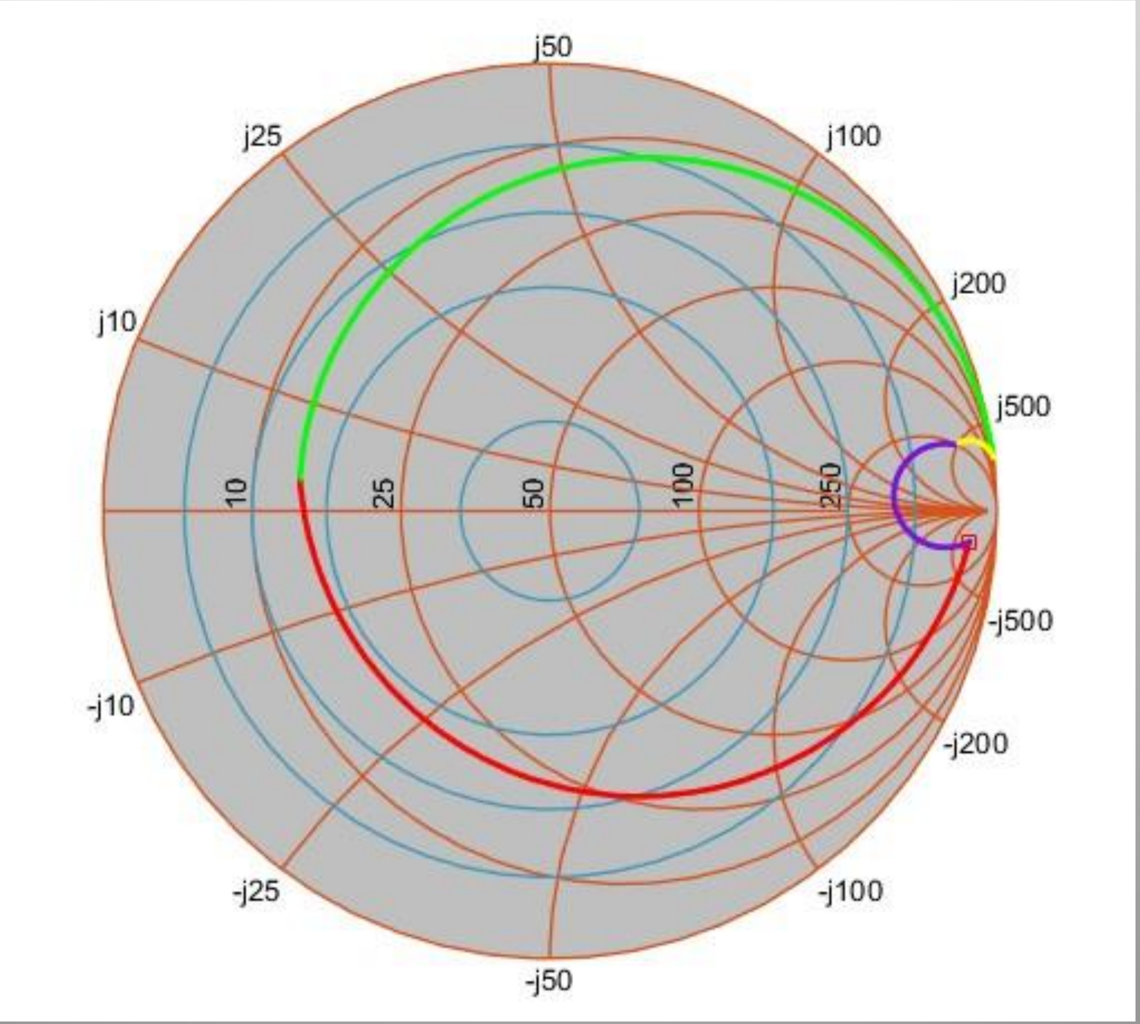
(remember 1:1 is the single point at center)



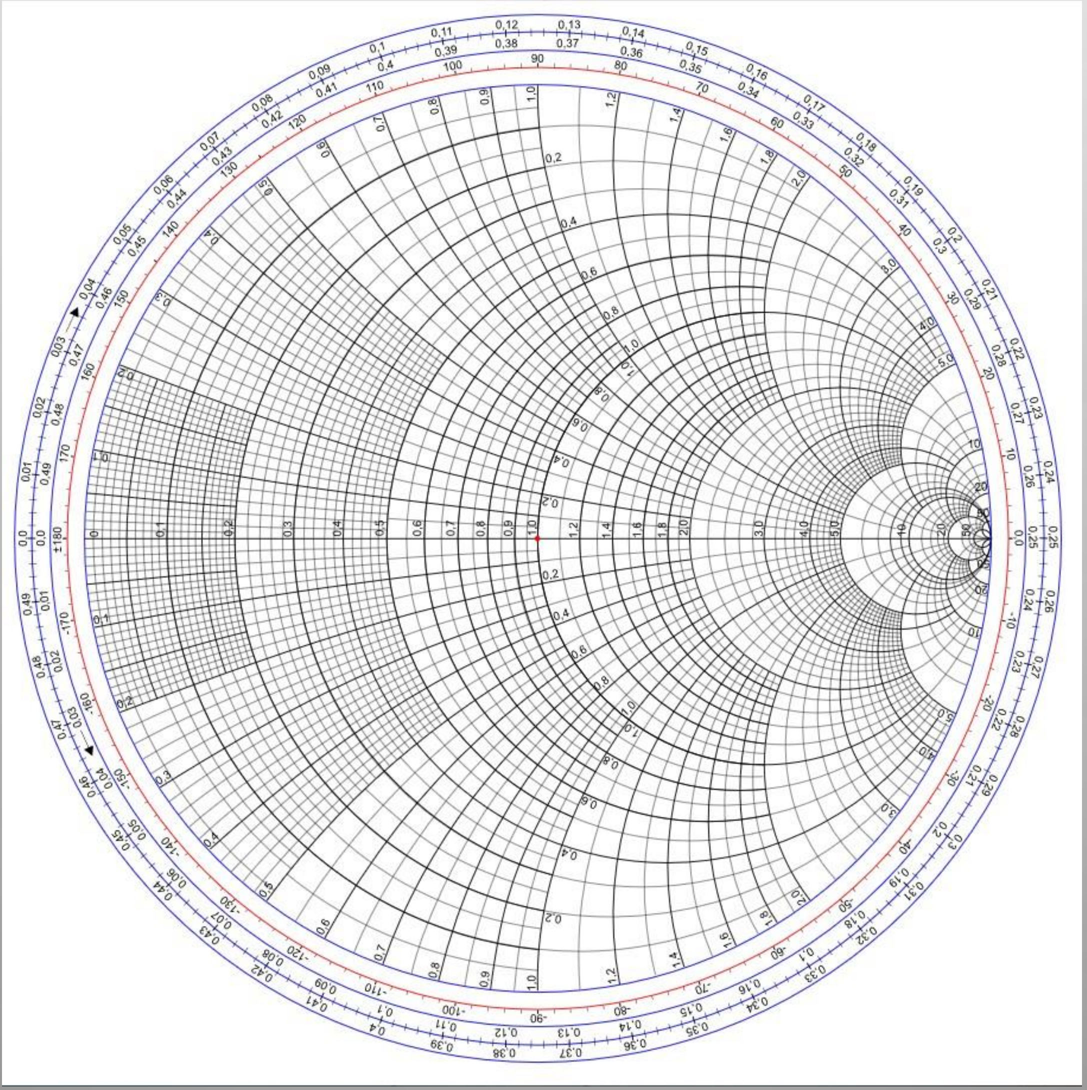
Smith Chart: conjugate match location
prime center now **normalized** to **50 ohms** for convenience



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 Smith Chart Slide Rule