Nano VNA   Slide show by K3EUI

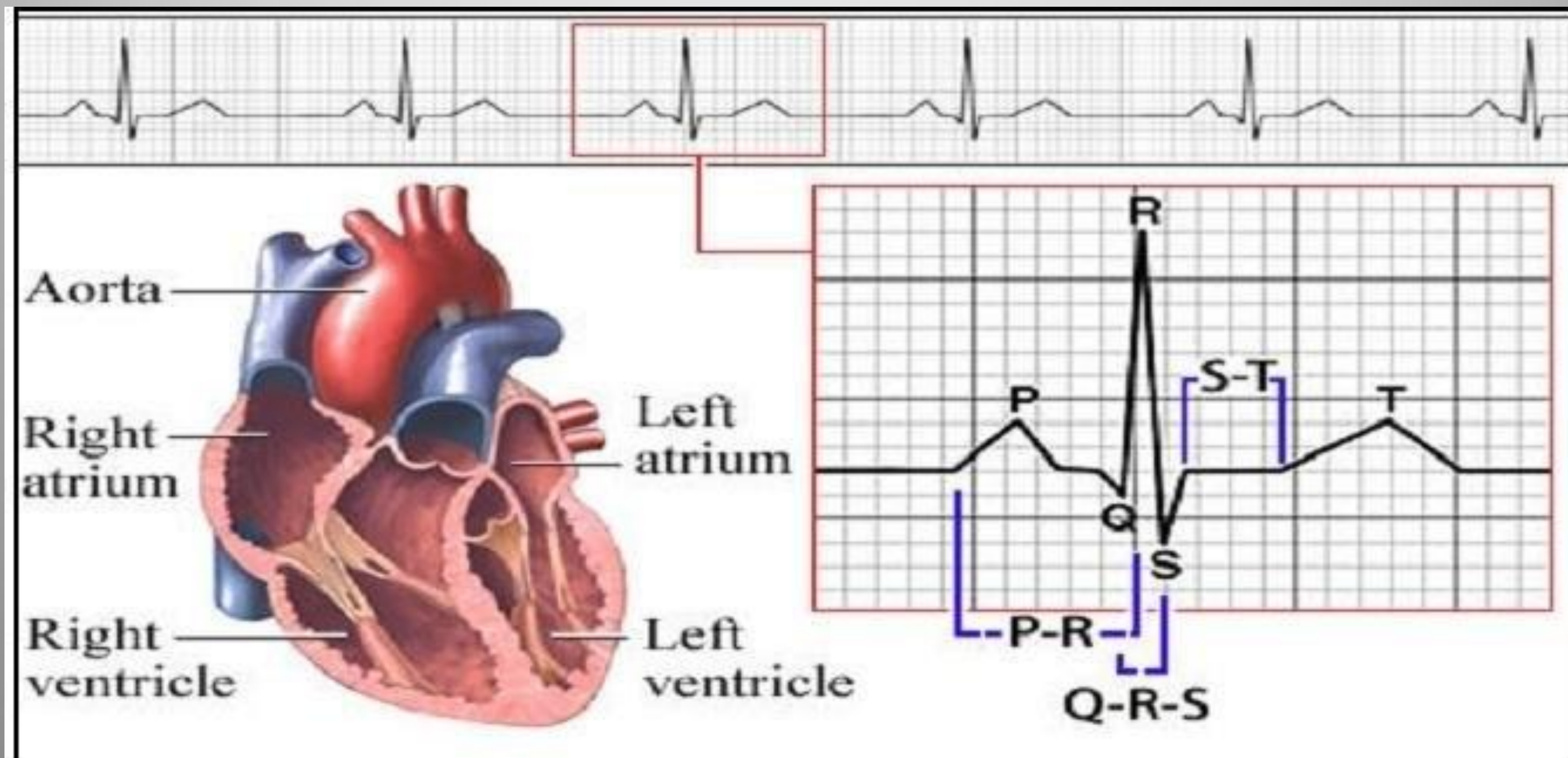
Which device would you rather have in your ham shack?
They each cost about $50

Nano VNA – your antenna stethoscope

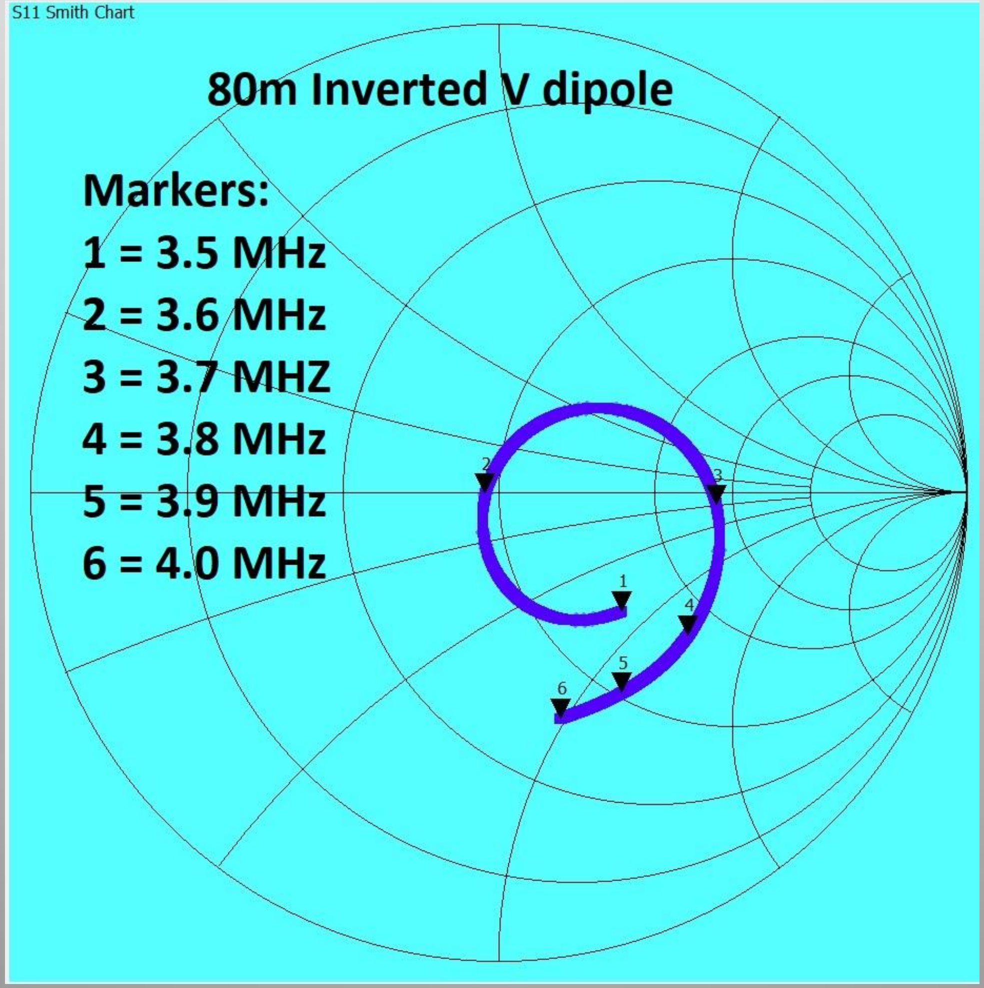
What can you conclude about the health of your heart with a stethoscope?

What can you conclude about the health of your antenna with a Nano VNA?

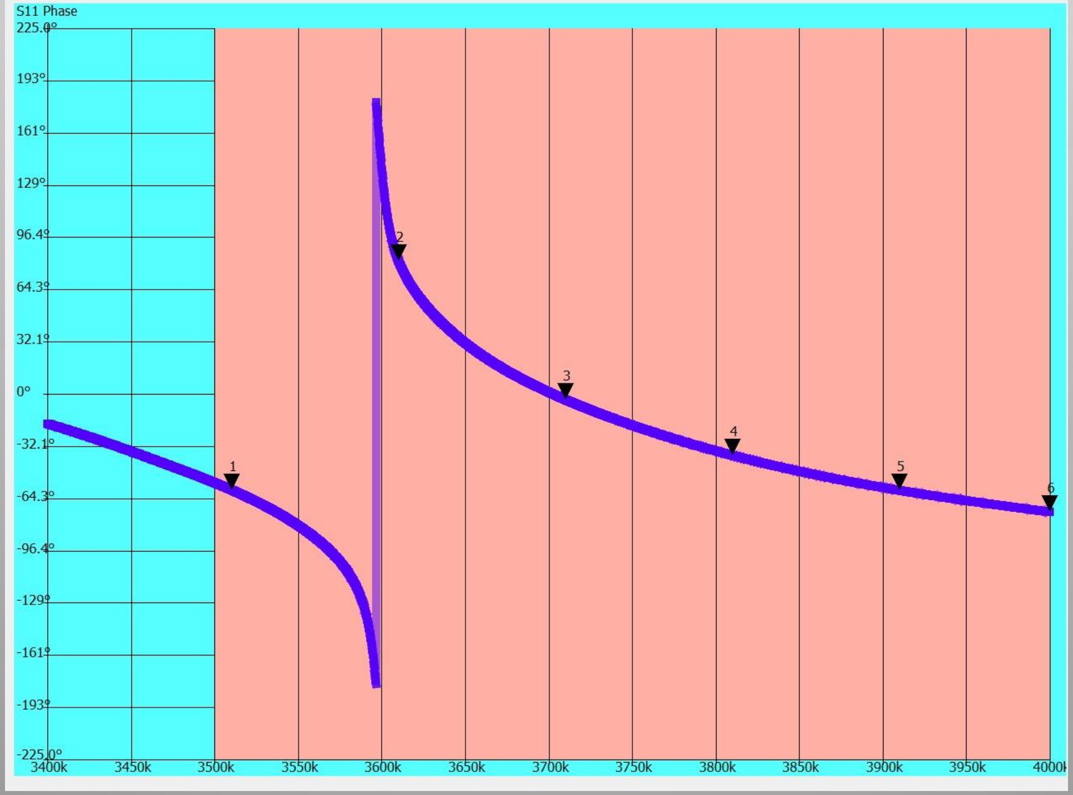
If you saw your own EKG could you interpret what it says about the state of health of your heart?



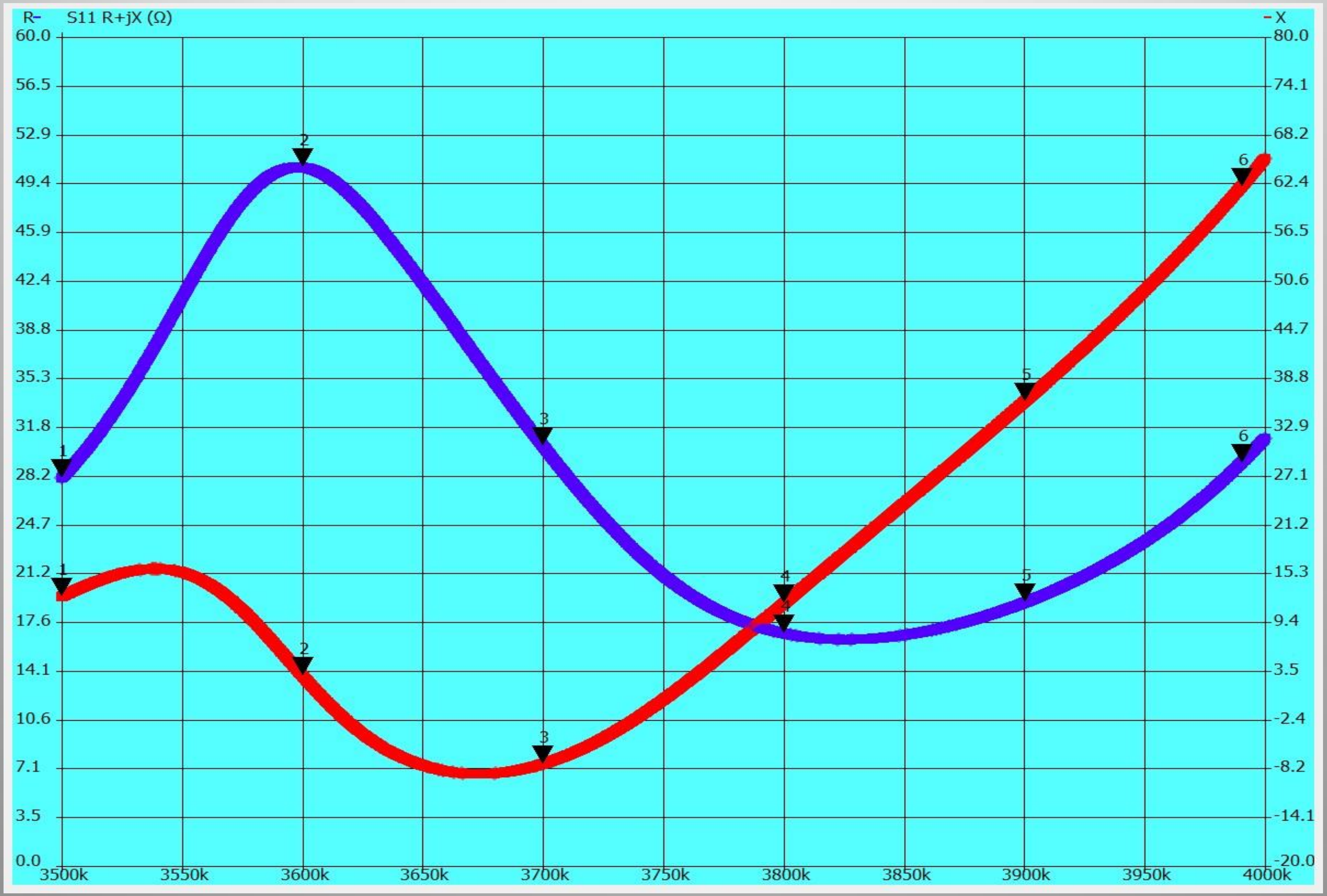
If you saw this **Smith Chart** of your 80m antenna would you know how to interpret it correctly?



Would you know what this **PHASE** graph is revealing about the antenna's resonance?



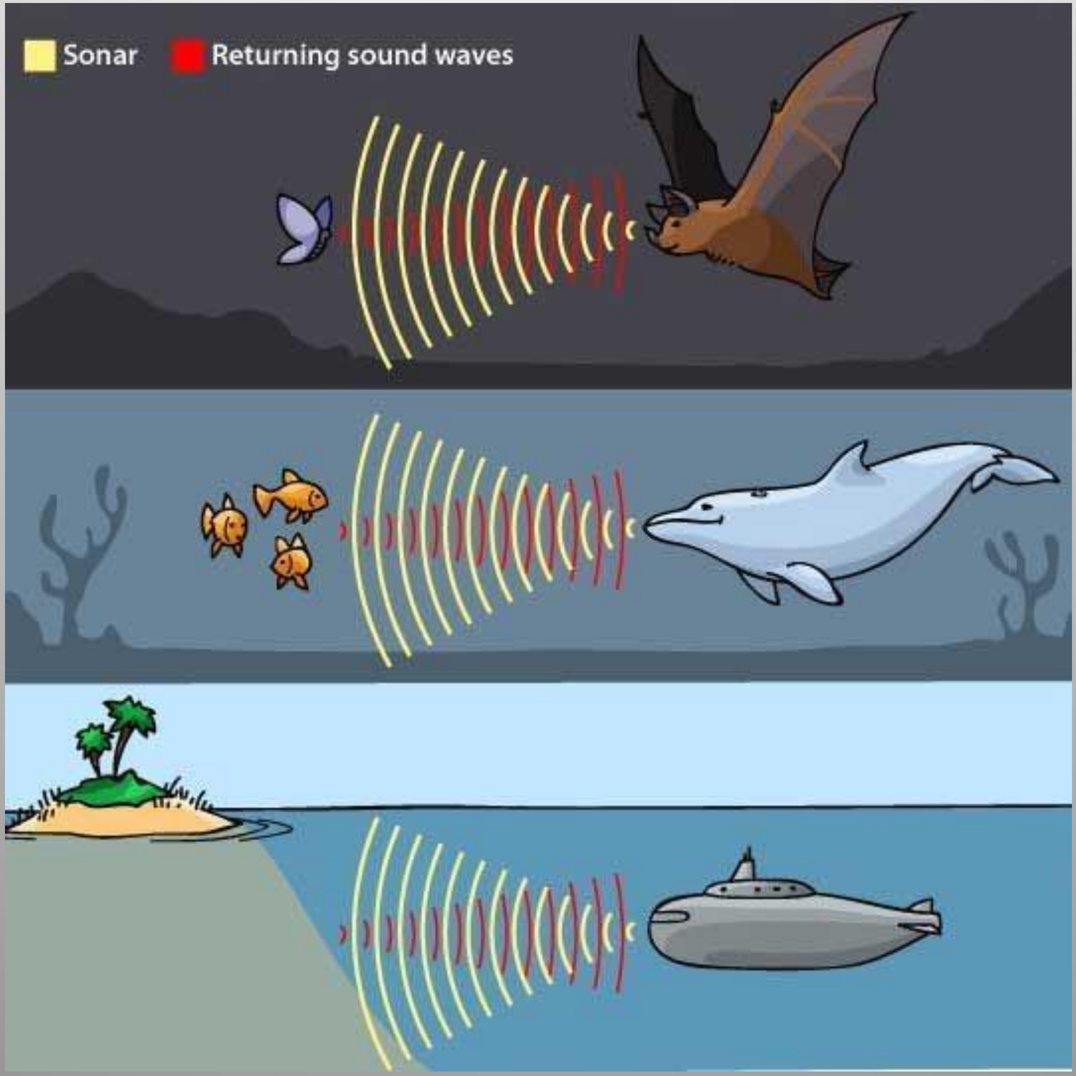
On this **Resistance** (BLUE) and **Reactance** (RED) graph
On what frequency would you expect this antenna to work best?



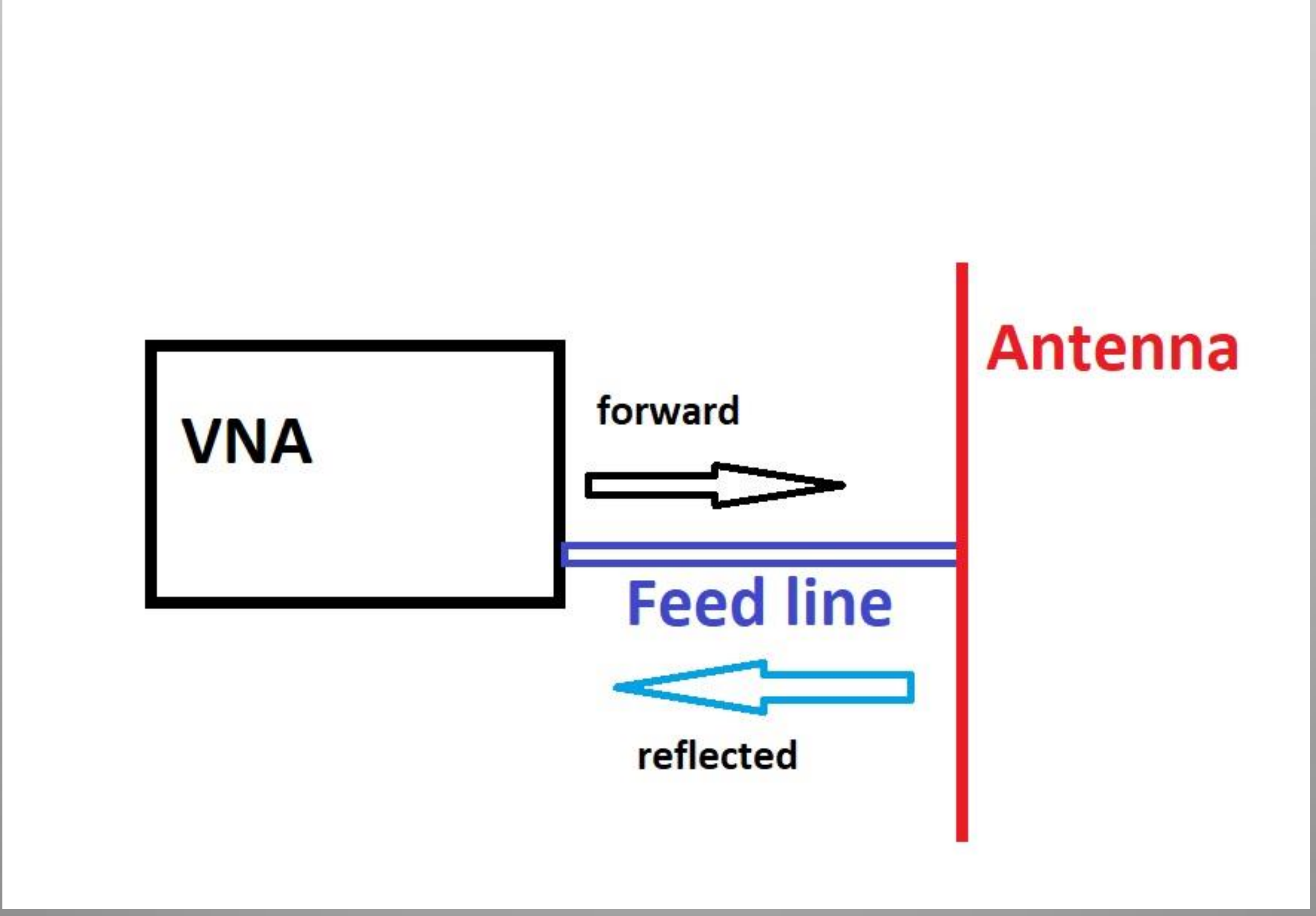
Goals of this presentation

Learn about the various ways that a VNA can be a useful tool in your toolbox

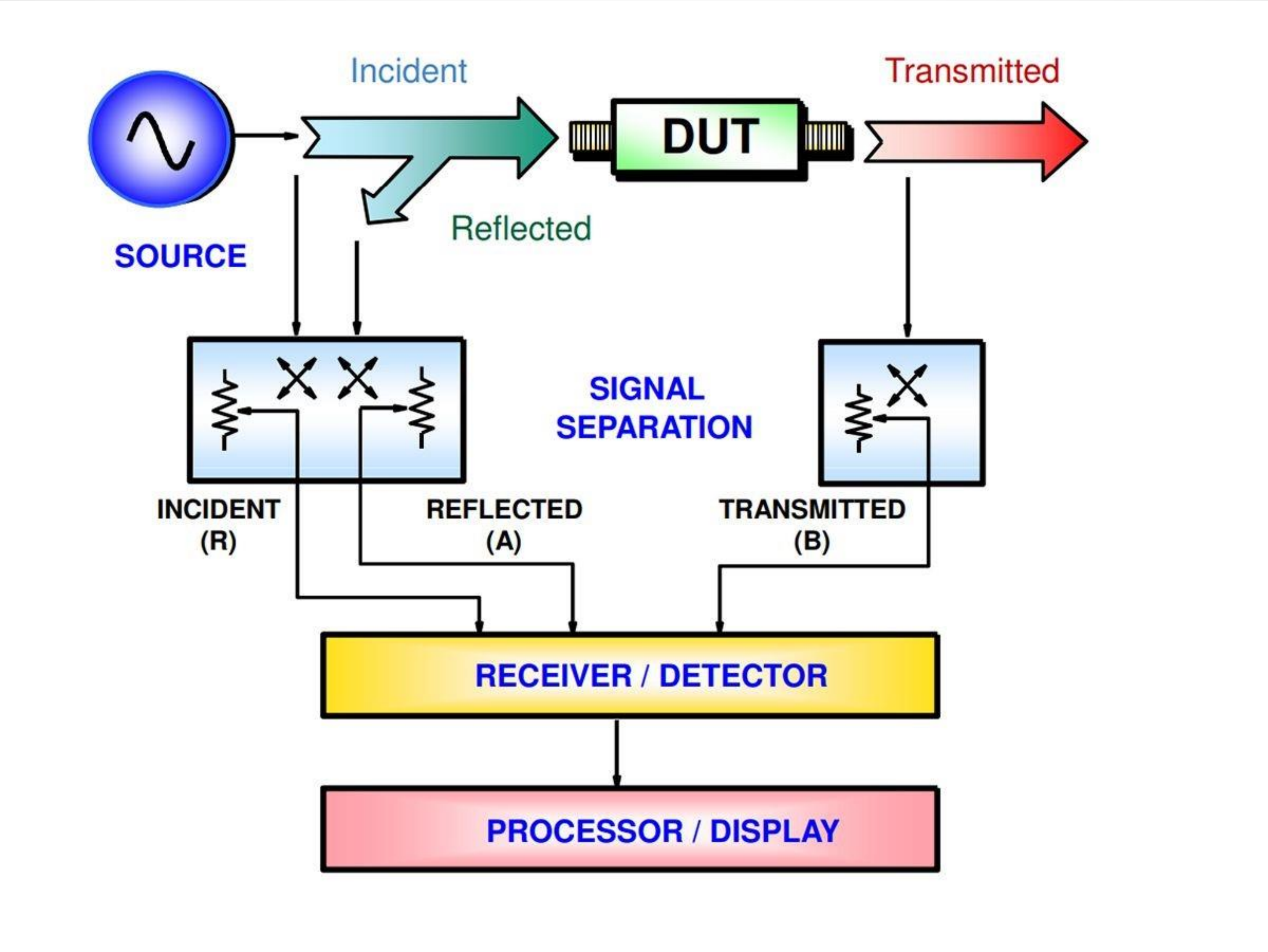
How is a VNA like an active SONAR?



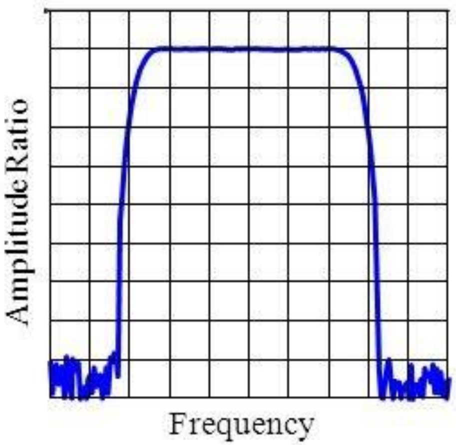
The **VNA** sends a pulse of RF out on a feedline and measures the V(forward) and V(reflected) at various frequencies (both **<u>magnitude and phase</u>**)

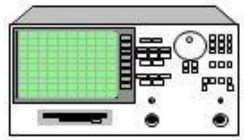


Flow Chart: Vector Network Analyzer

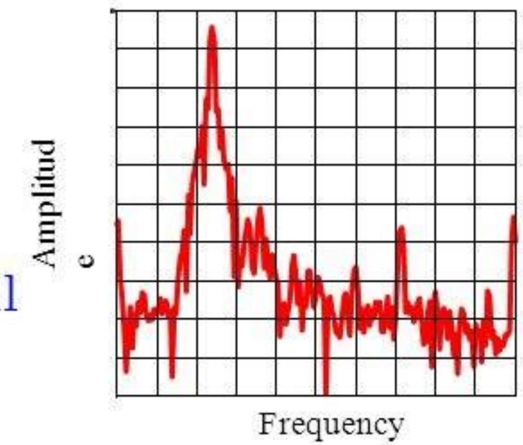


Network Analyzers Vs Spectrum Analyzers





Measures known signal



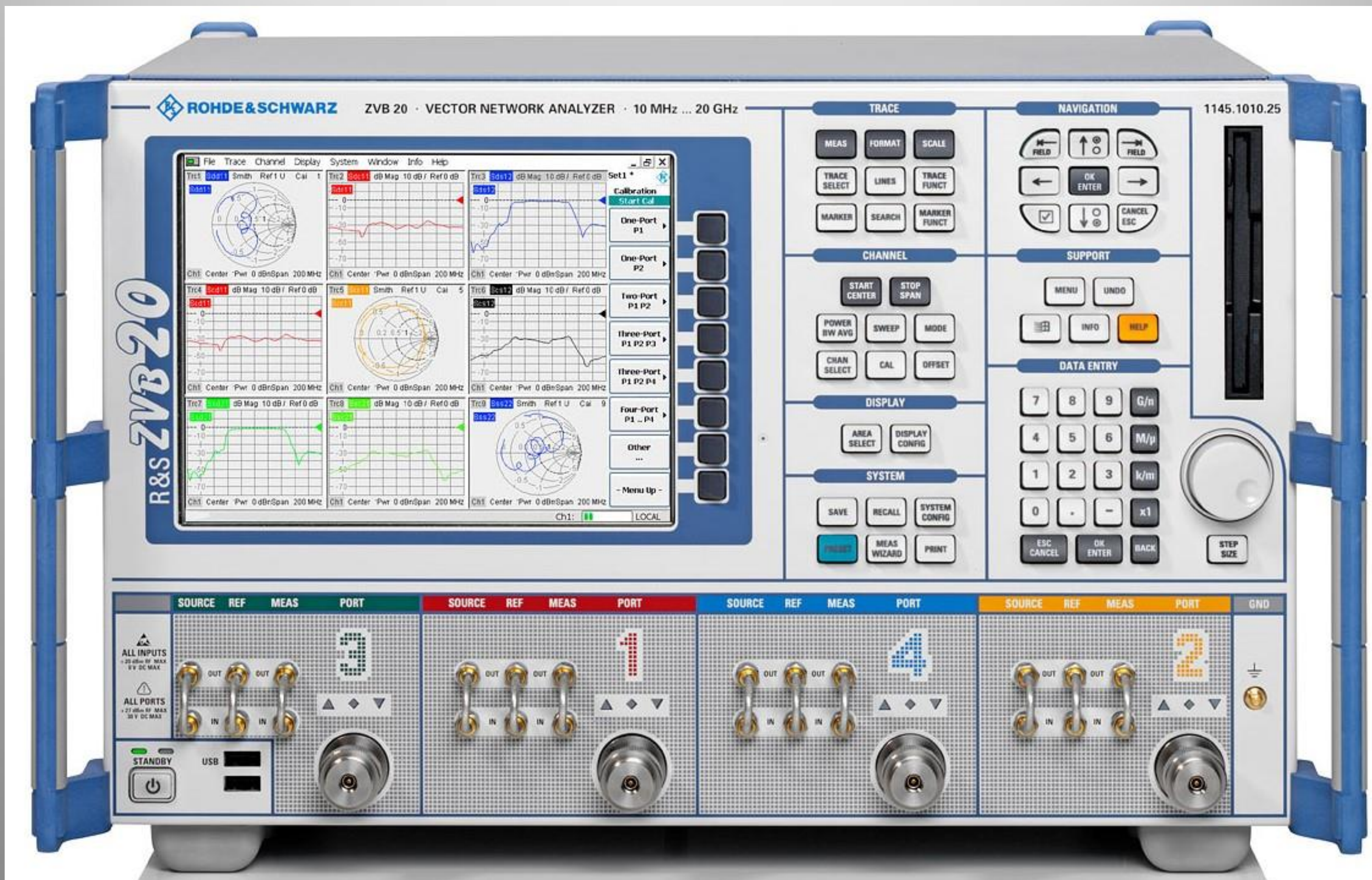
Measures unknown signals

Network analyzers:
- measure components, devices, circuits, sub-assemblies
- contain source and receiver
- display ratioed amplitude and phase (frequency or power sweeps)
- offer advanced error correction

Spectrum analyzers:
- measure signal amplitude characteristics carrier level, sidebands, harmonics...)
- can demodulate (& measure) complex signals
- are receivers only (single channel)
- can be used for scalar component test (*no phase*) with tracking gen. or ext. source(s)

The “high-end” Vector Network Analyzers

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



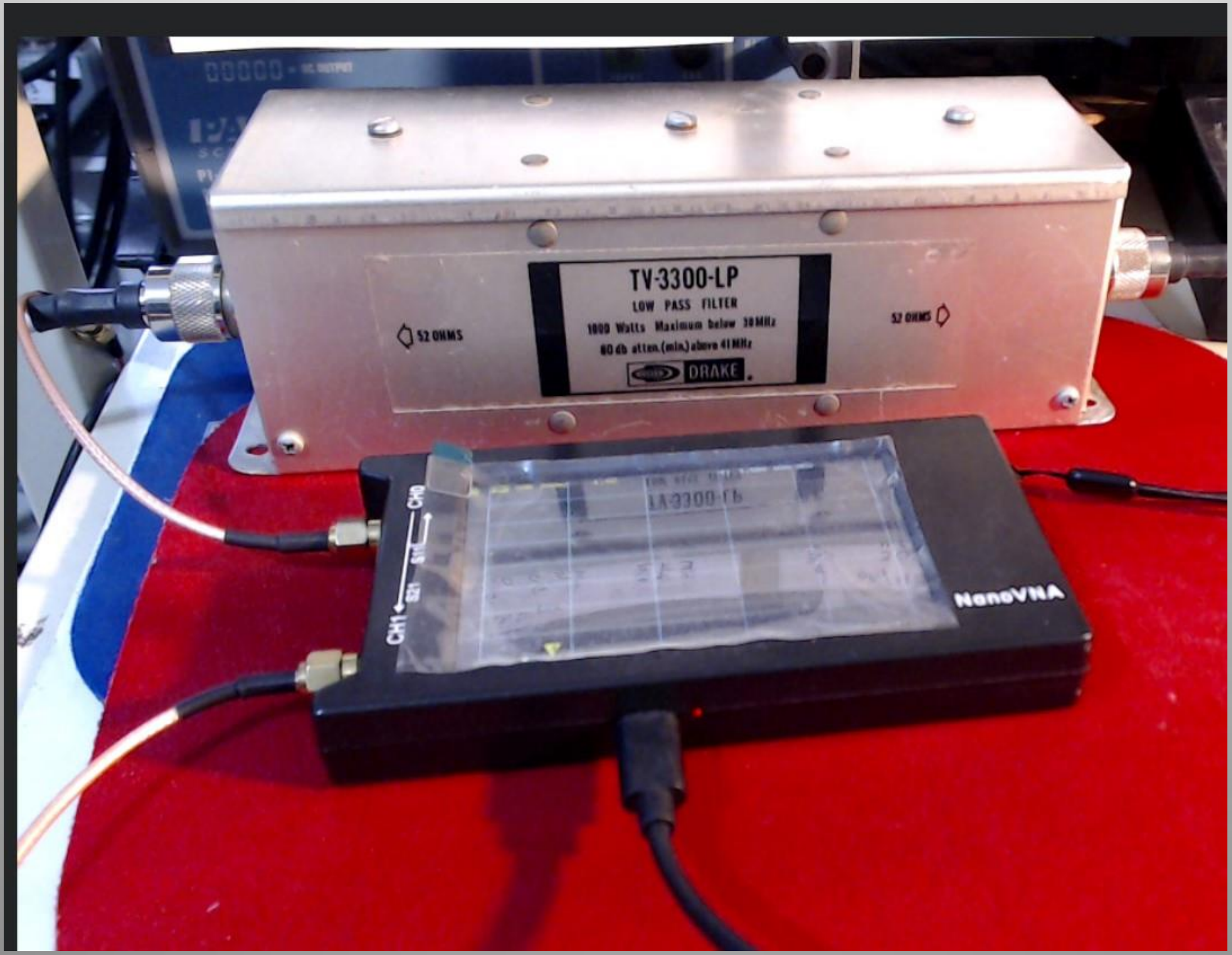
Some practical uses for a VNA

Check out bandpass and band stop filters

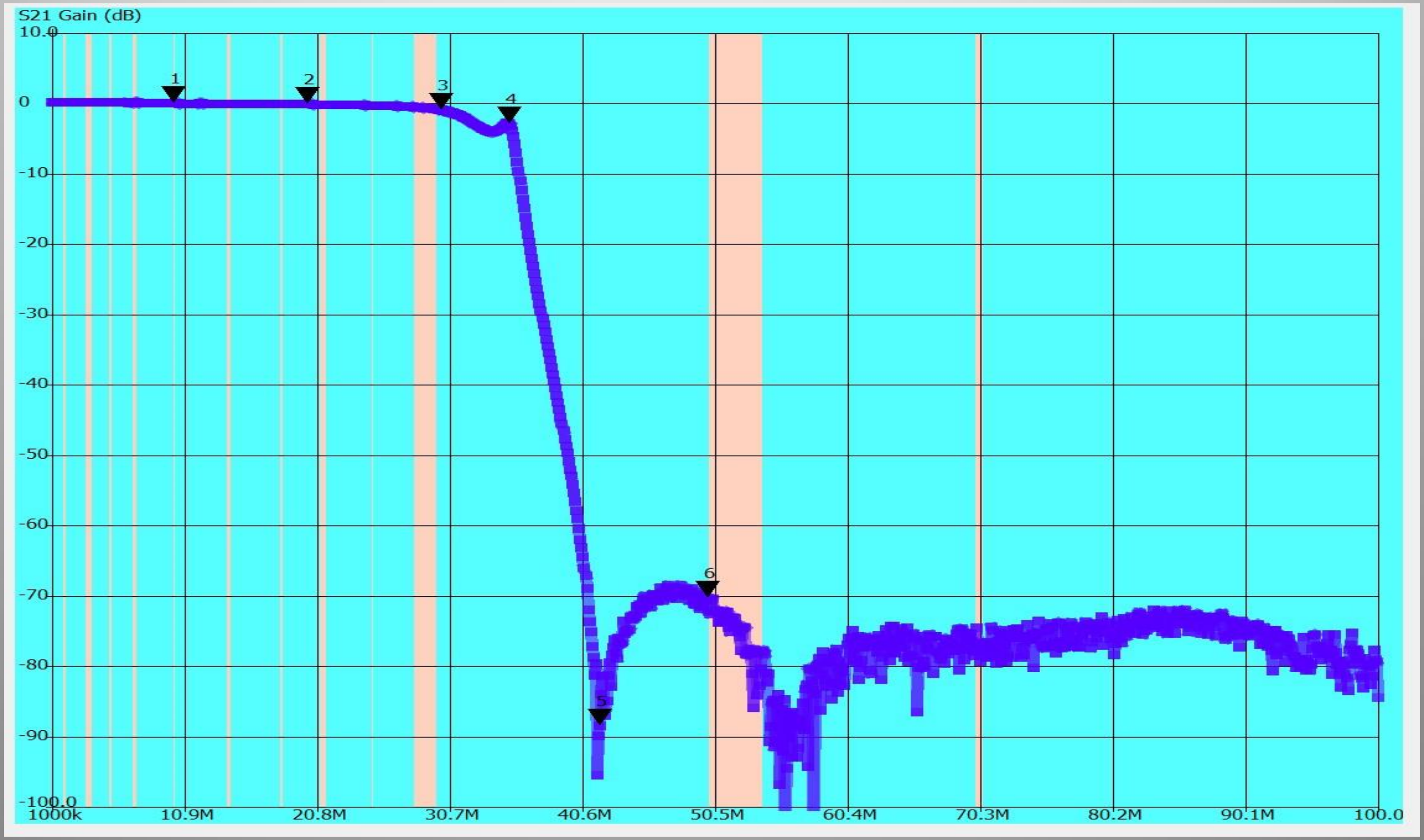
Check out long lines of coax for attenuation

Check out your antenna system

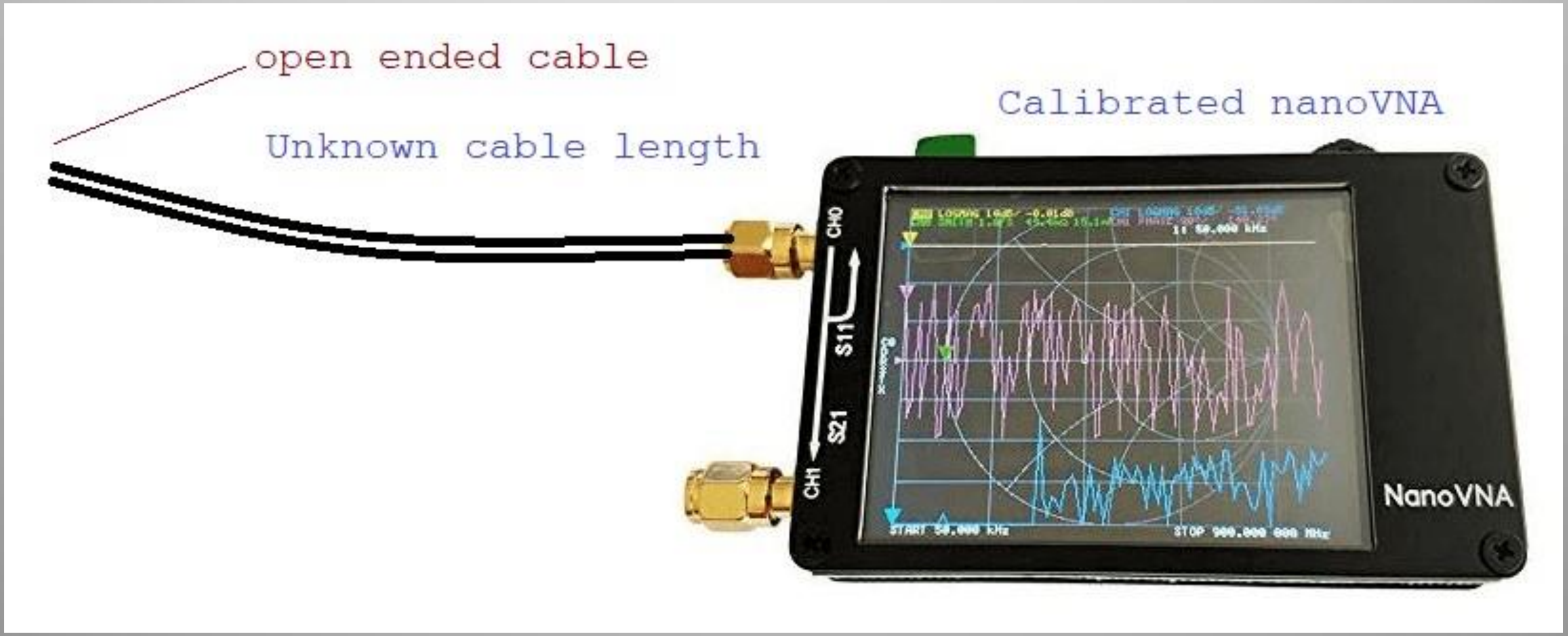
Check out the bandpass of a "low-pass" filter using BOTH ports of the VNA Drake: 52 ohm, 80 dB attenuation above 41 MHz



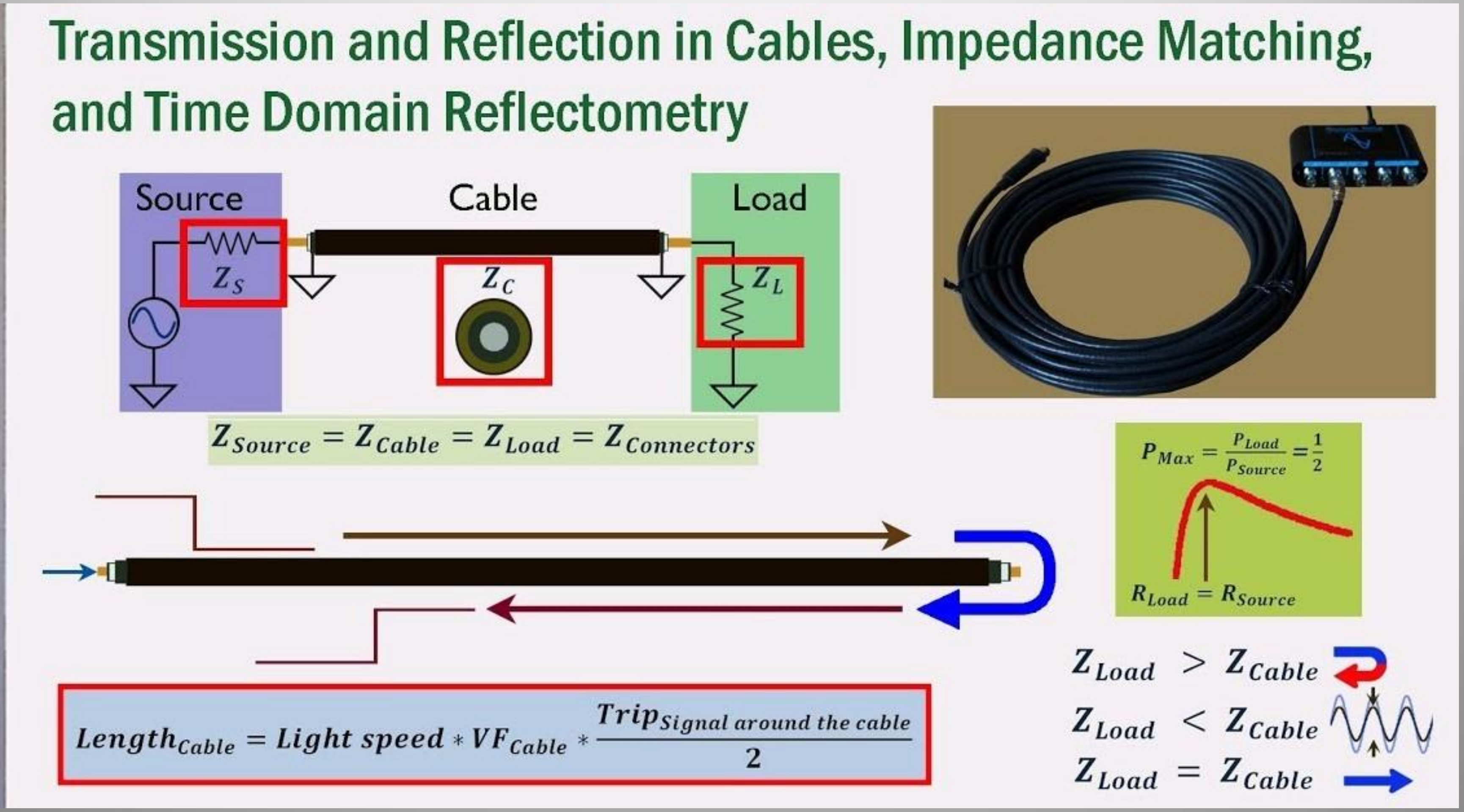
Low-pass filter - attenuate "harmonics" above 30 MHz
to **avoid TVI in VHF/UHF bands**
(television interference)



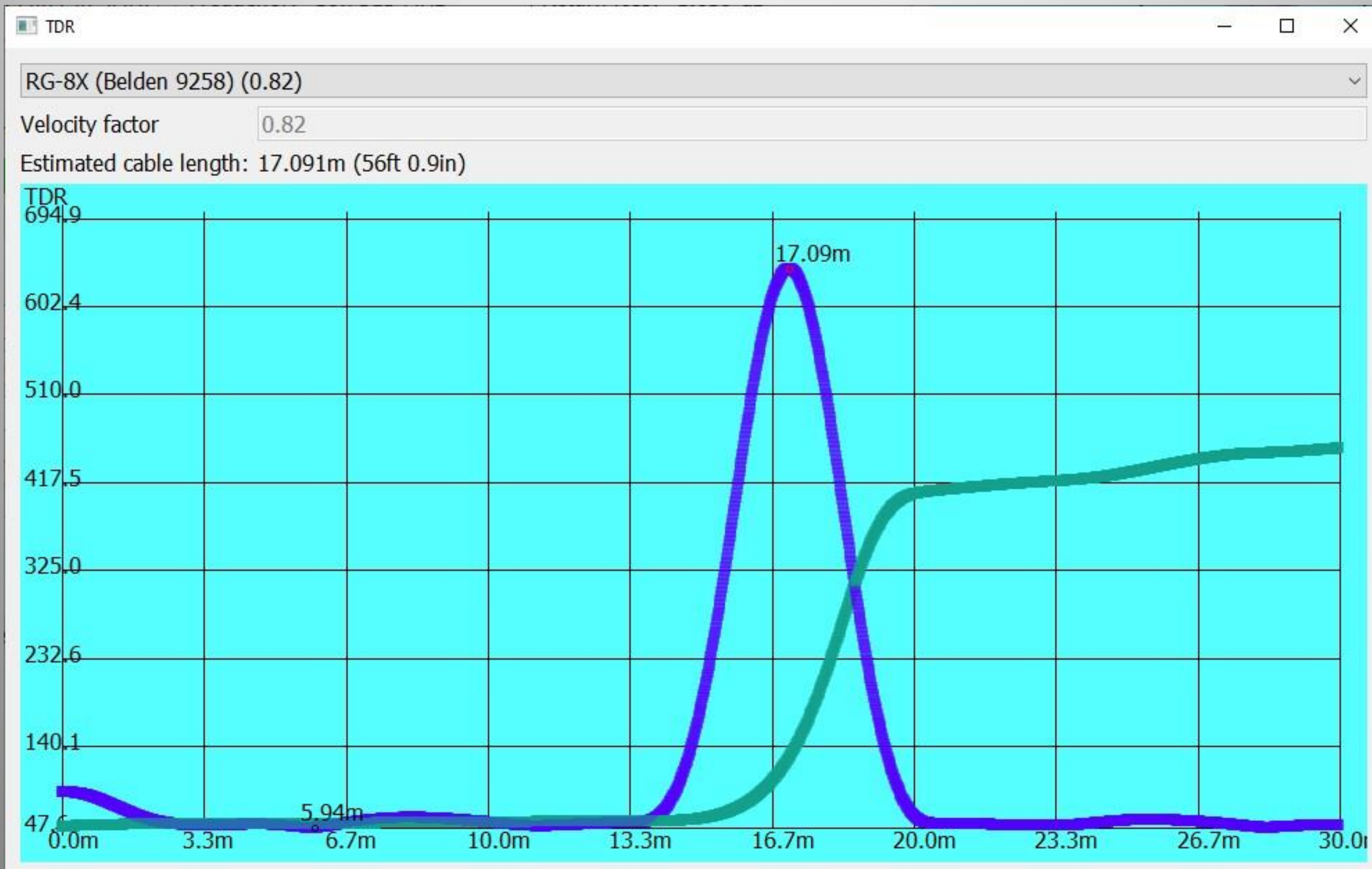
Measure Cable Length and Attenuation



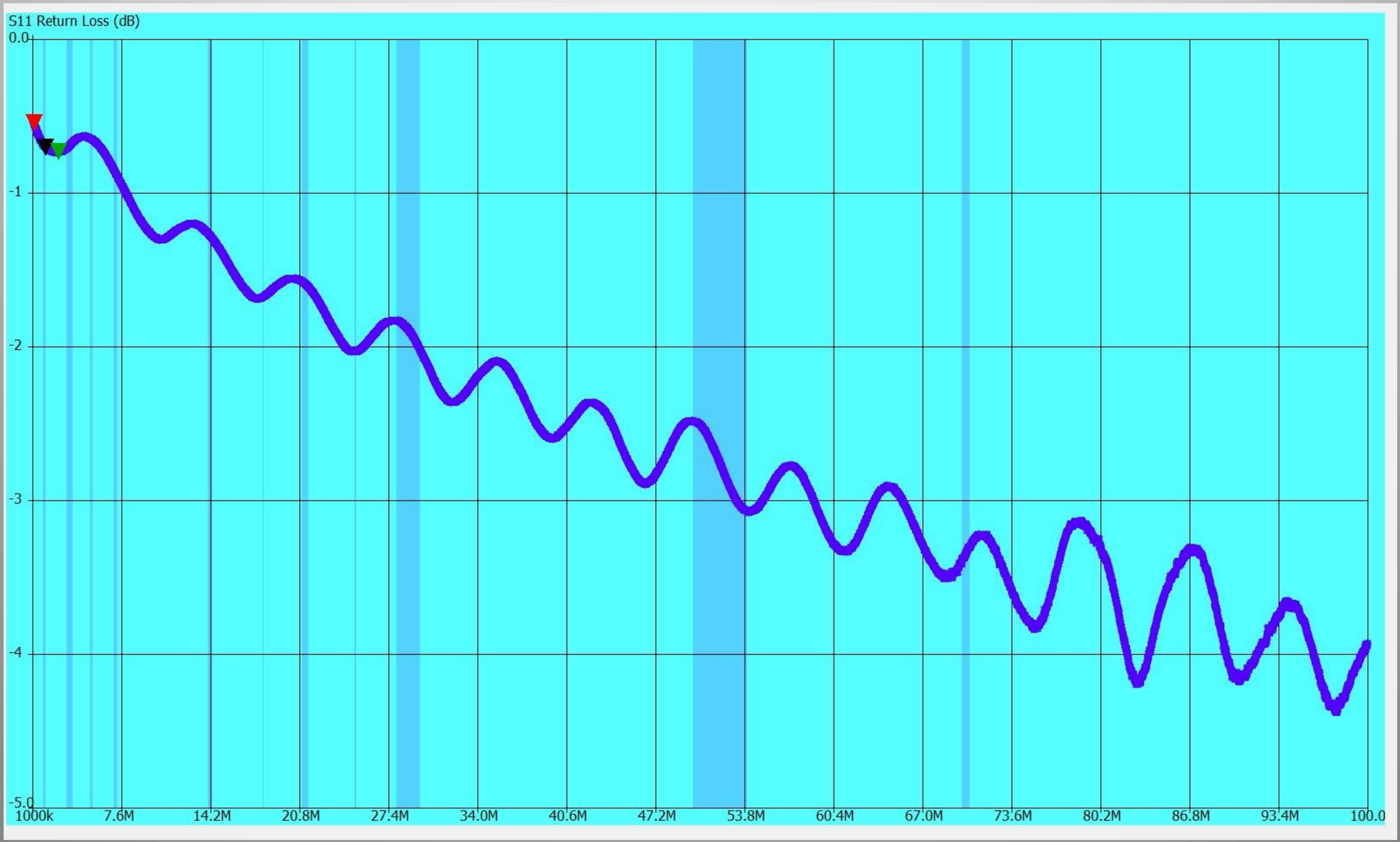
Measure TIME from a sharp pulse sent into cable
to reflected pulse from far end of cable



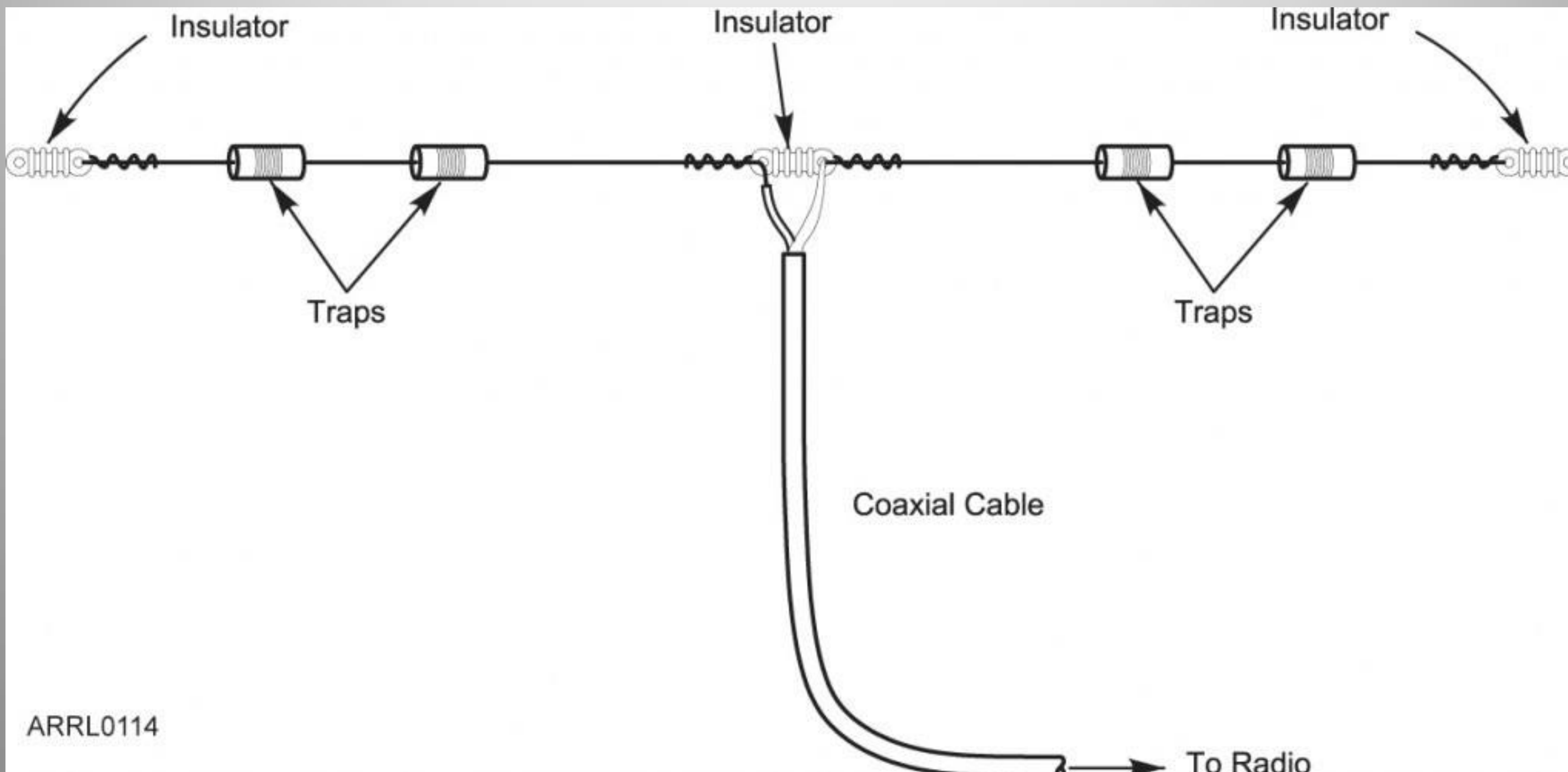
TDR display: Belden RG8X cable (**VF = 0.82**)
Determine coax **LENGTH** from time and check for breaks in cable



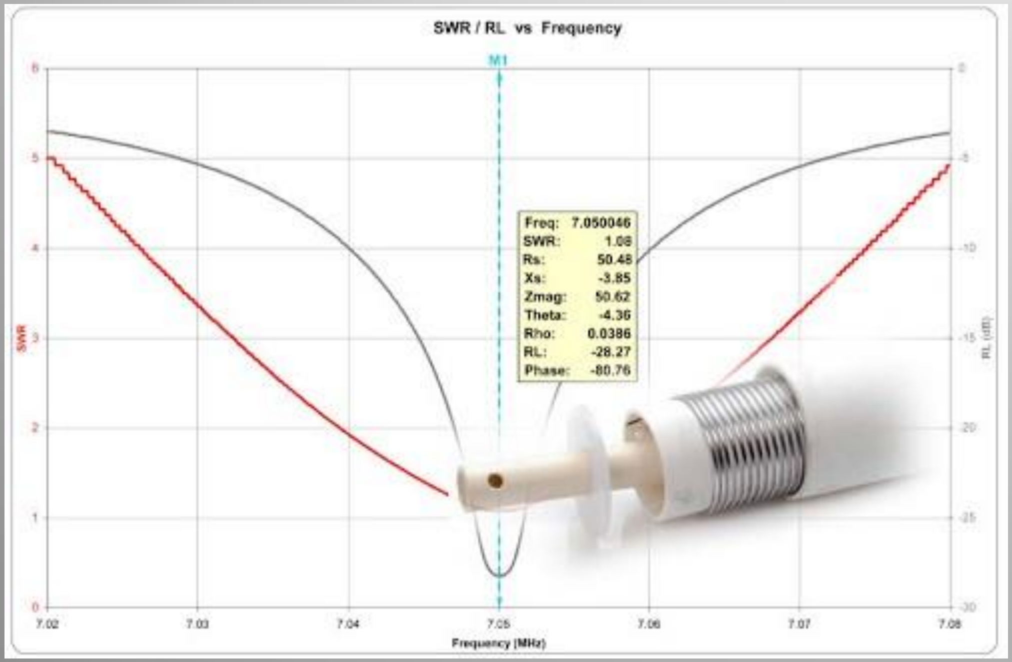
Measure the attenuation (dB loss) of the cable from 0.1 to 100 MHz as a “sweep” graph
note: -3 dB (50% power loss) at 50 MHz



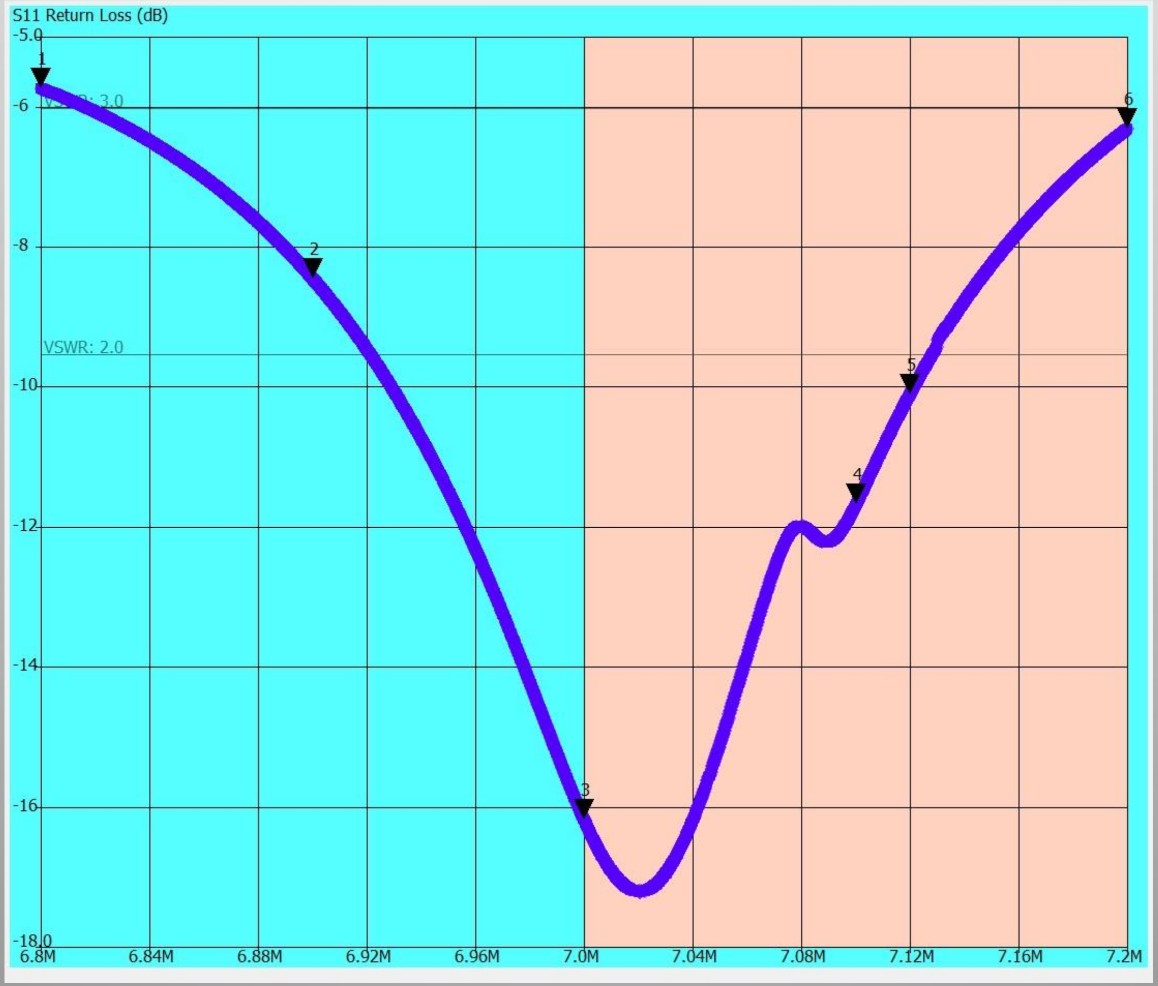
Two or Three band TRAP dipole
Check how well TRAPS are isolating different bands



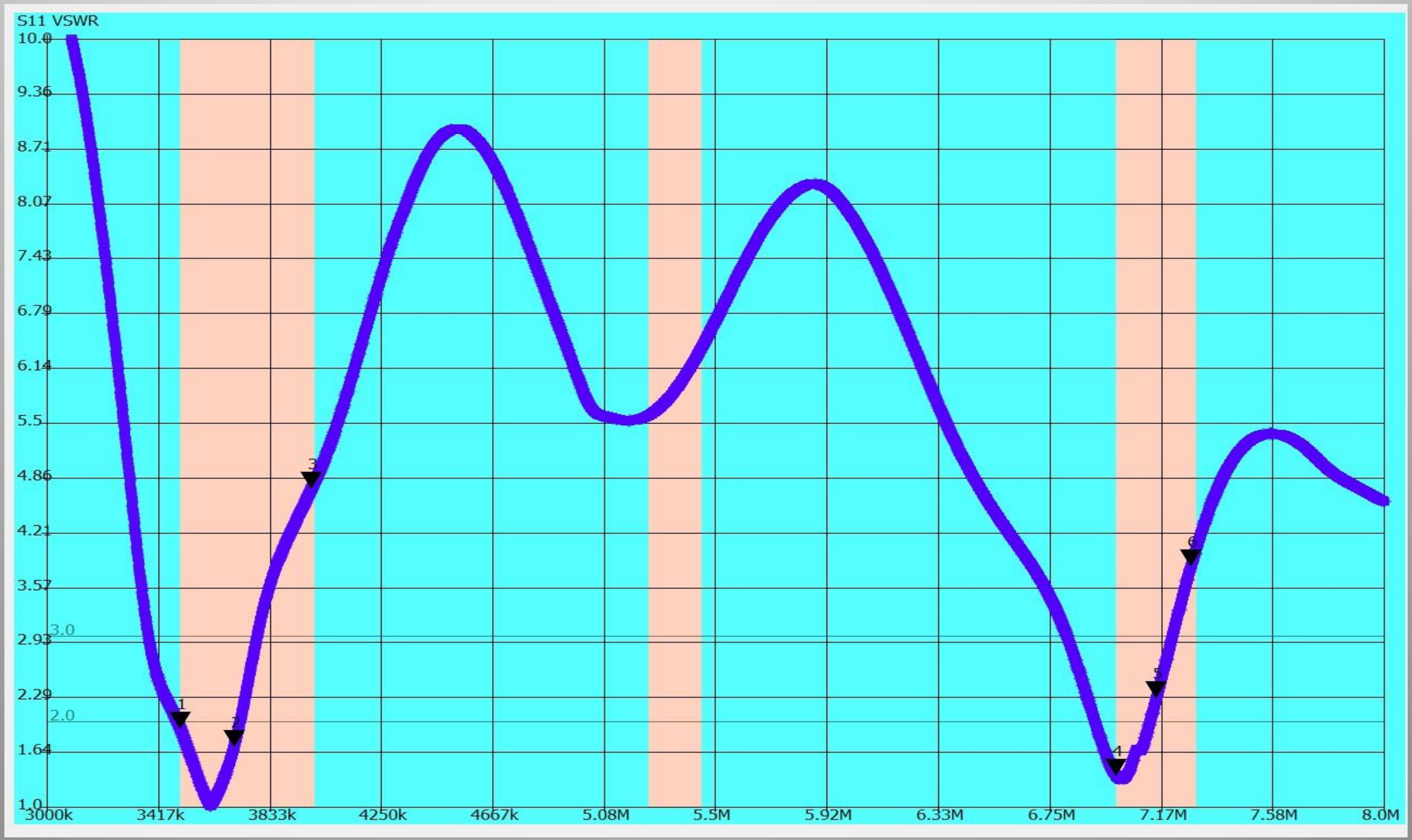
Traps act as HIGH-IMPEDANCE parallel resonant LC circuit to isolate two bands in one antenna



80/40m Trap Dipole: Return Loss plot looking at the trap resonance 7 MHz



This is designed as a “dual-band” 80/40m dipole Resonance (SWR) check on both 80m and 40m



What instruments can we use to analyze our antennas?

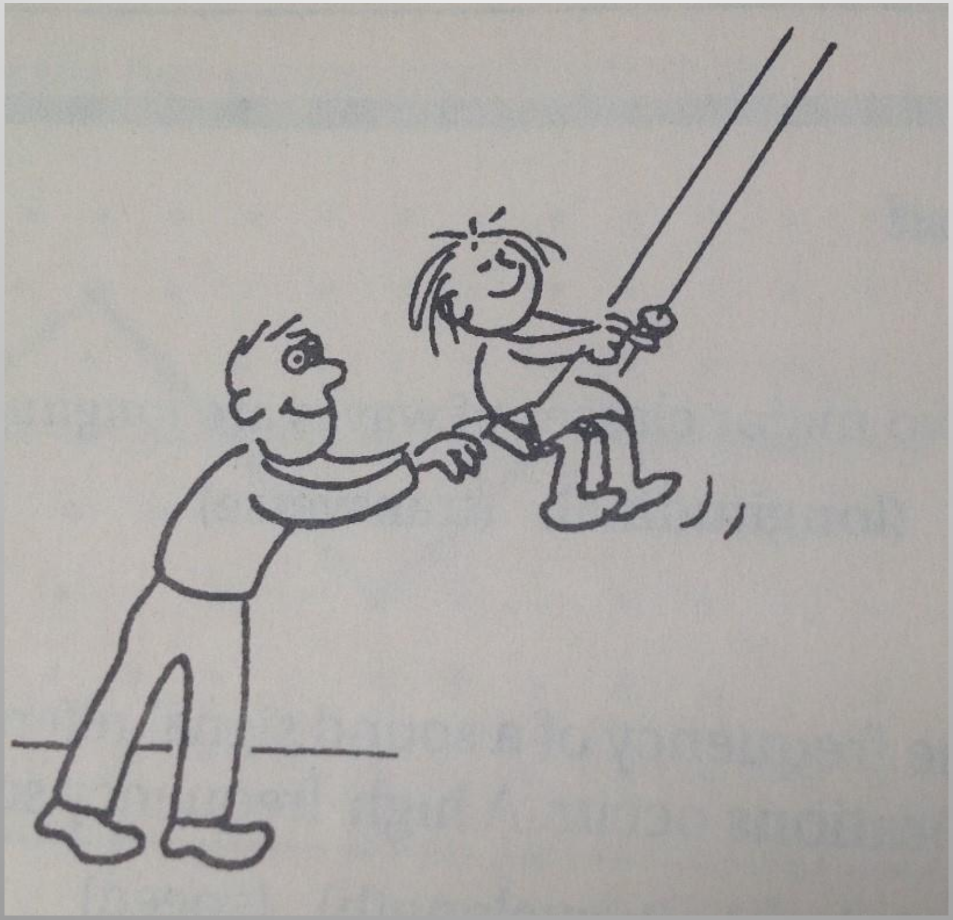
Antenna Analyzers

come in various sizes, shapes, displays, and **COST**

RF POWER and SWR meters
What do they share in common?
What do they NOT measure?

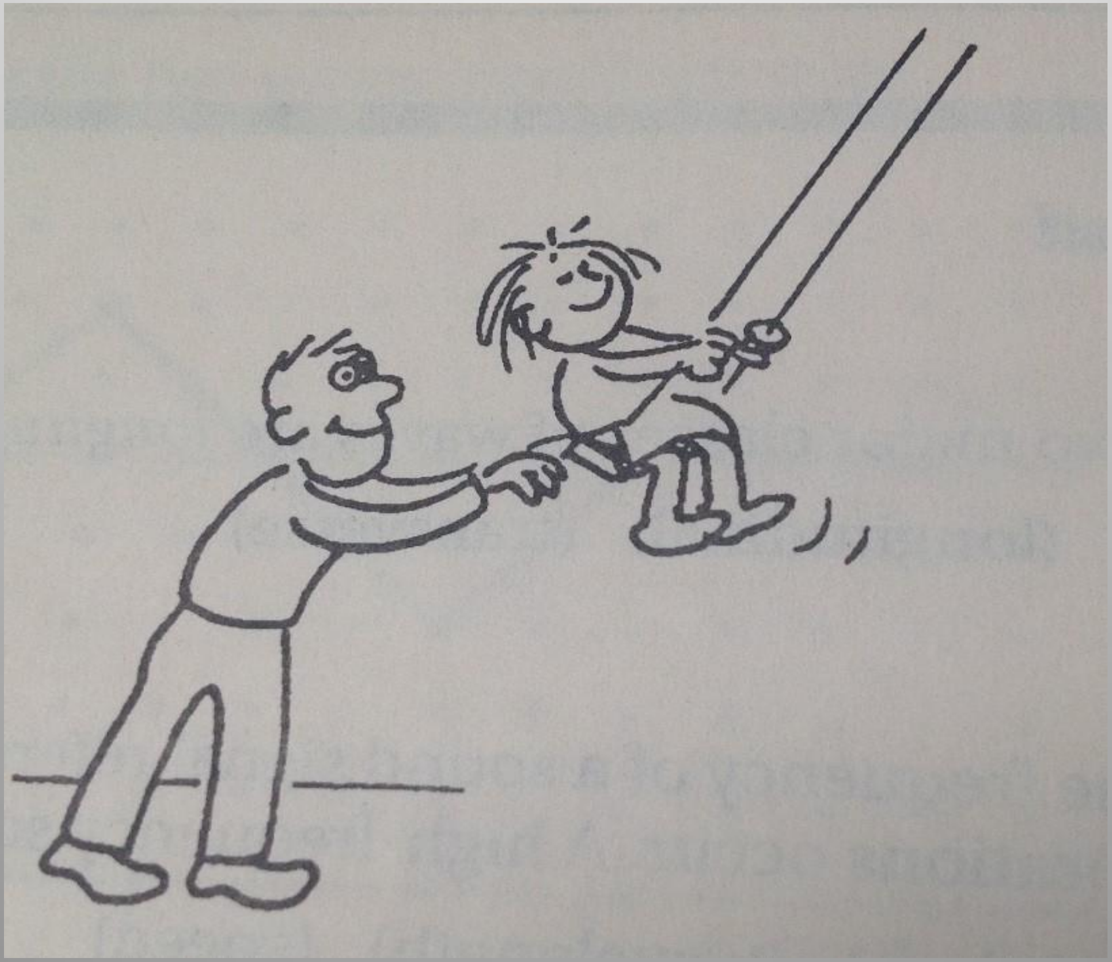
Why would I want a VNA to analyze my antenna?

This looks like an “end-fed” dipole but how does Grampy know WHEN to push?



Even young kids know this

"Grampy, please push <u>in-phase</u> with my natural swinging to increase my amplitude"



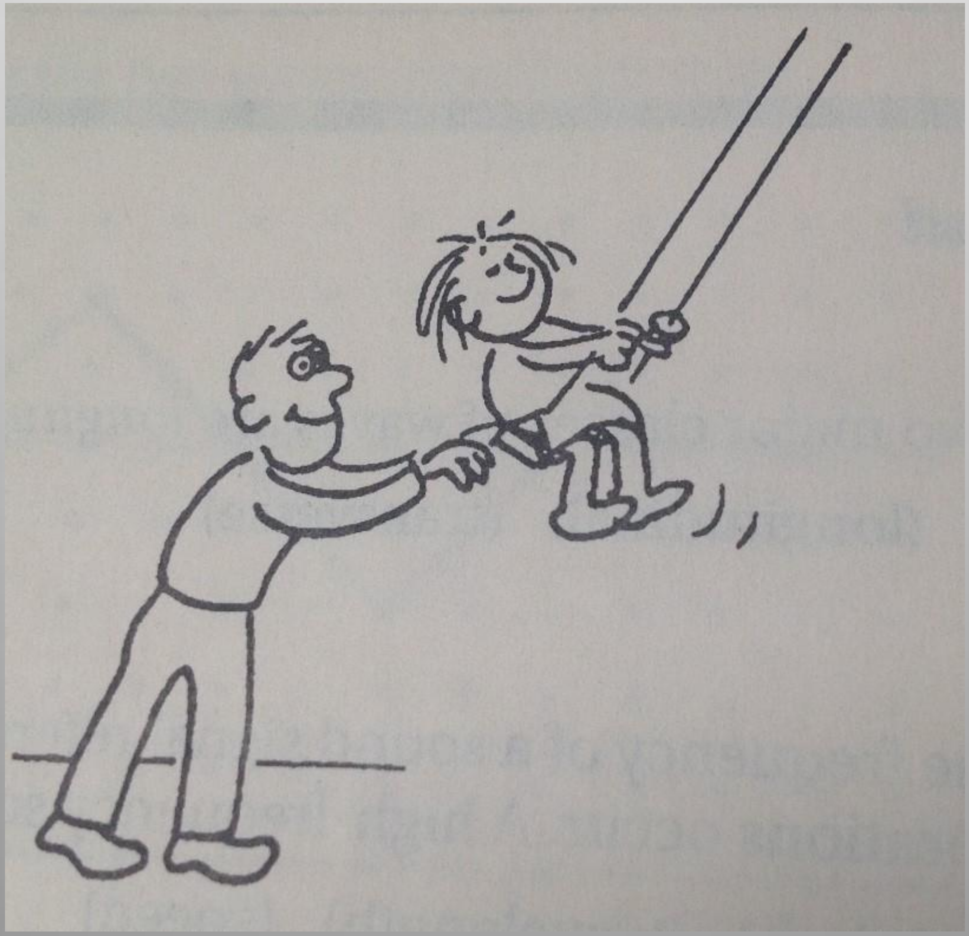
Antennas work the same way

The input “push” from the feed line needs to be **in-phase** with the natural vibrations of current in the antenna conductors

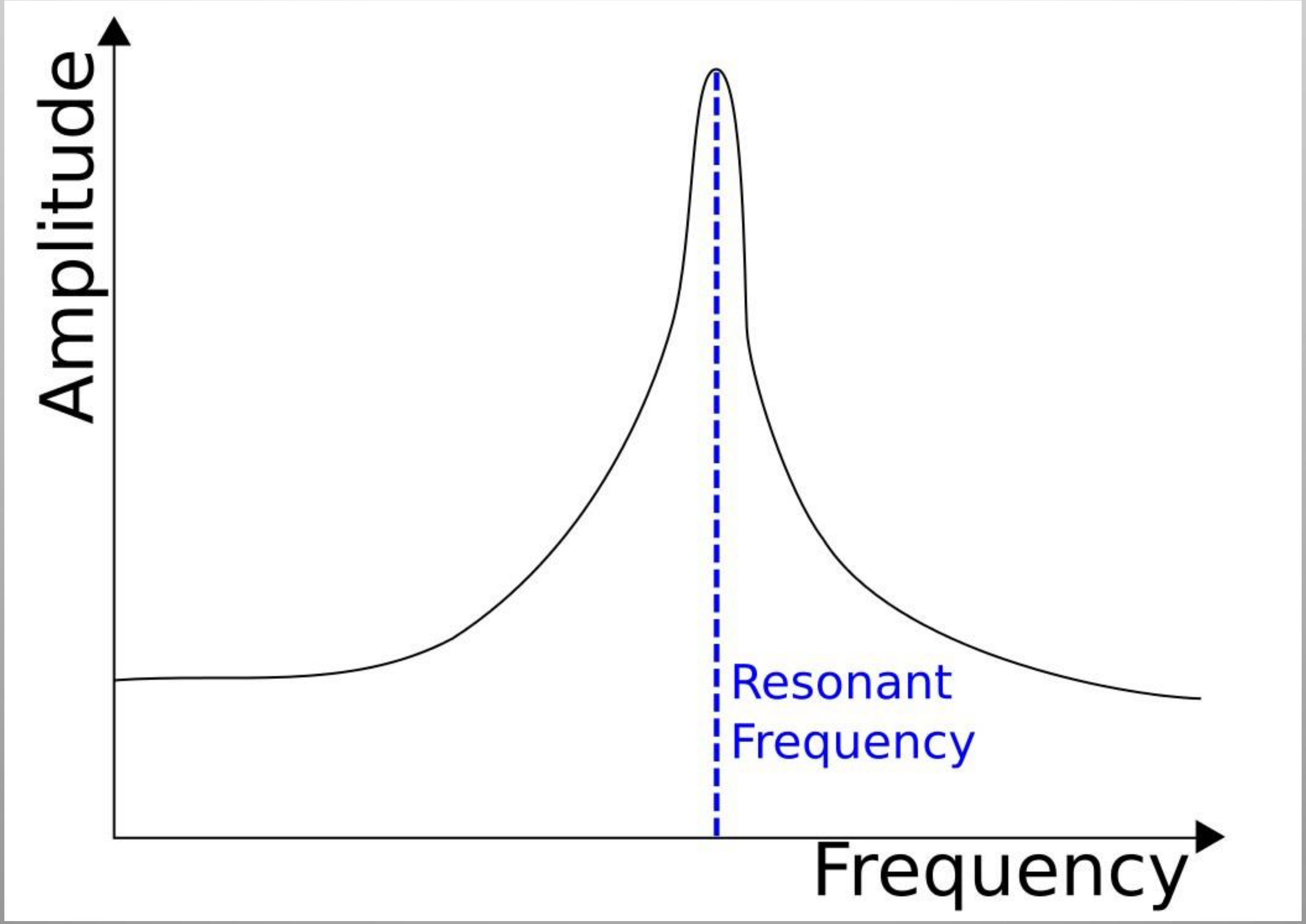
We call this “**resonance**”

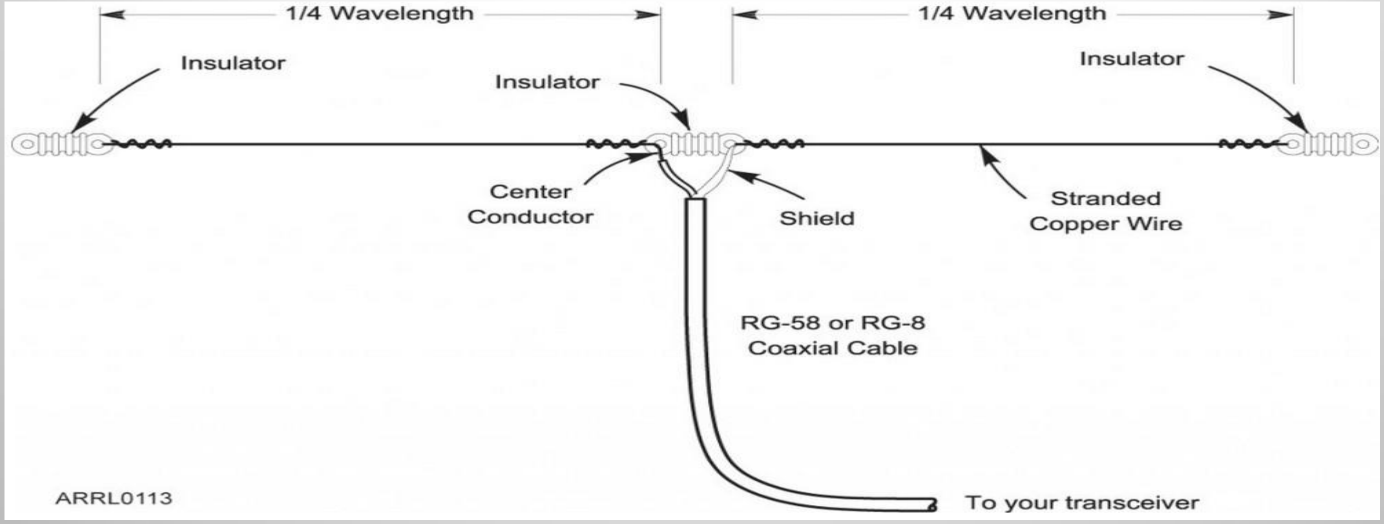
Can the Nano VNA determine resonance frequencies?

What happens if Grampy pushes
too soon? too late?
These will make grandchild quite unhappy!



At resonance the current and the voltage
are IN-PHASE at the feed line connection
and maximum current occurs in the antenna





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

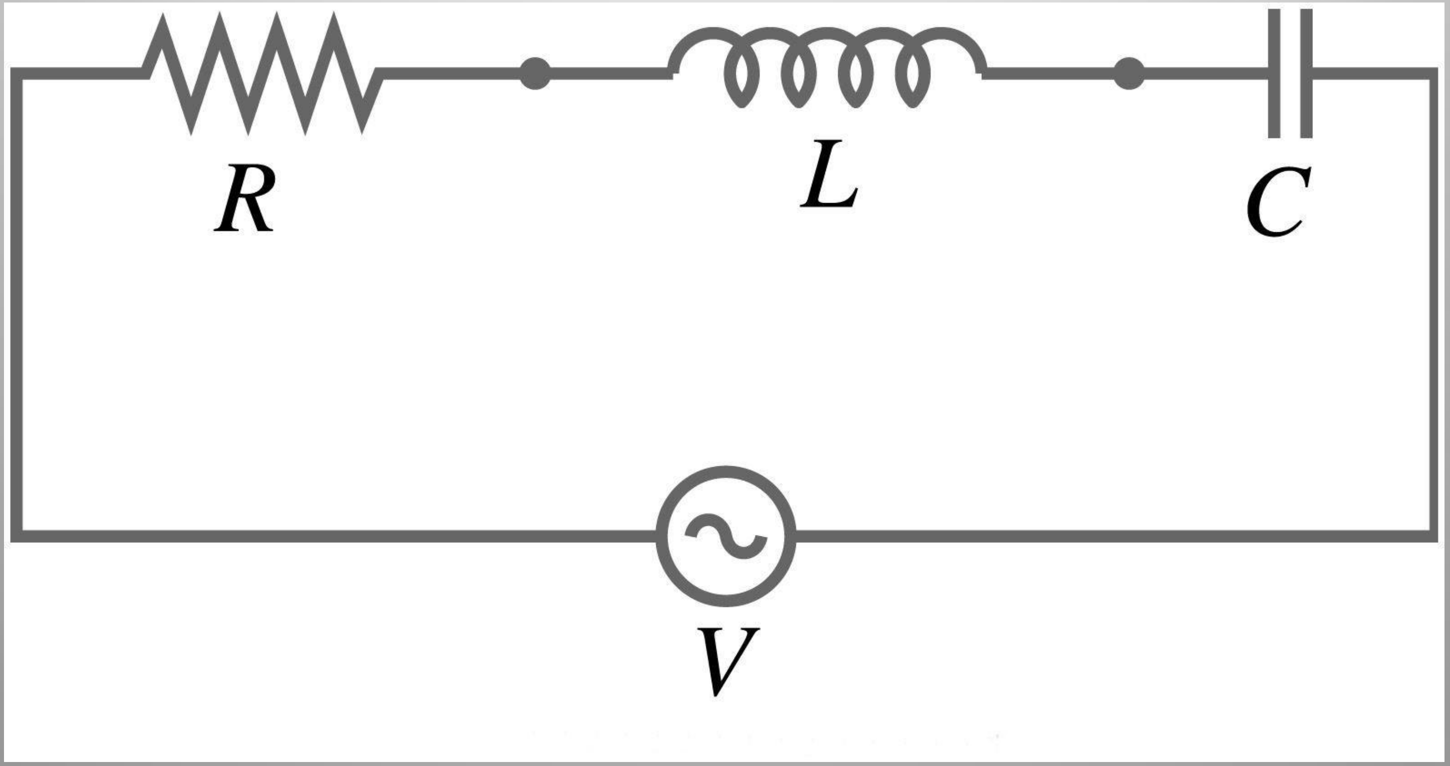
- Above resonance: the dipole is too long, and the <u>current lags the driving voltage</u> (inductive reactance)

ELI the ICE man

L = inductance C = capacitance

I = current E = voltage (emf)

Off resonance a dipole now shows
REACTANCE (phase errors)
and behaves like a series **RLC** circuit



Resonance will make your grandkids happy so CANCEL that antenna REACTANCE

How can my antenna analyzer tell me if my antenna is "resonant" ?

Antenna Characteristics that a VNA can measure or calculate

Resistance R (ohms)

Reactance X (ohms)

Impedance Z (ohms)

Phase θ (degrees)

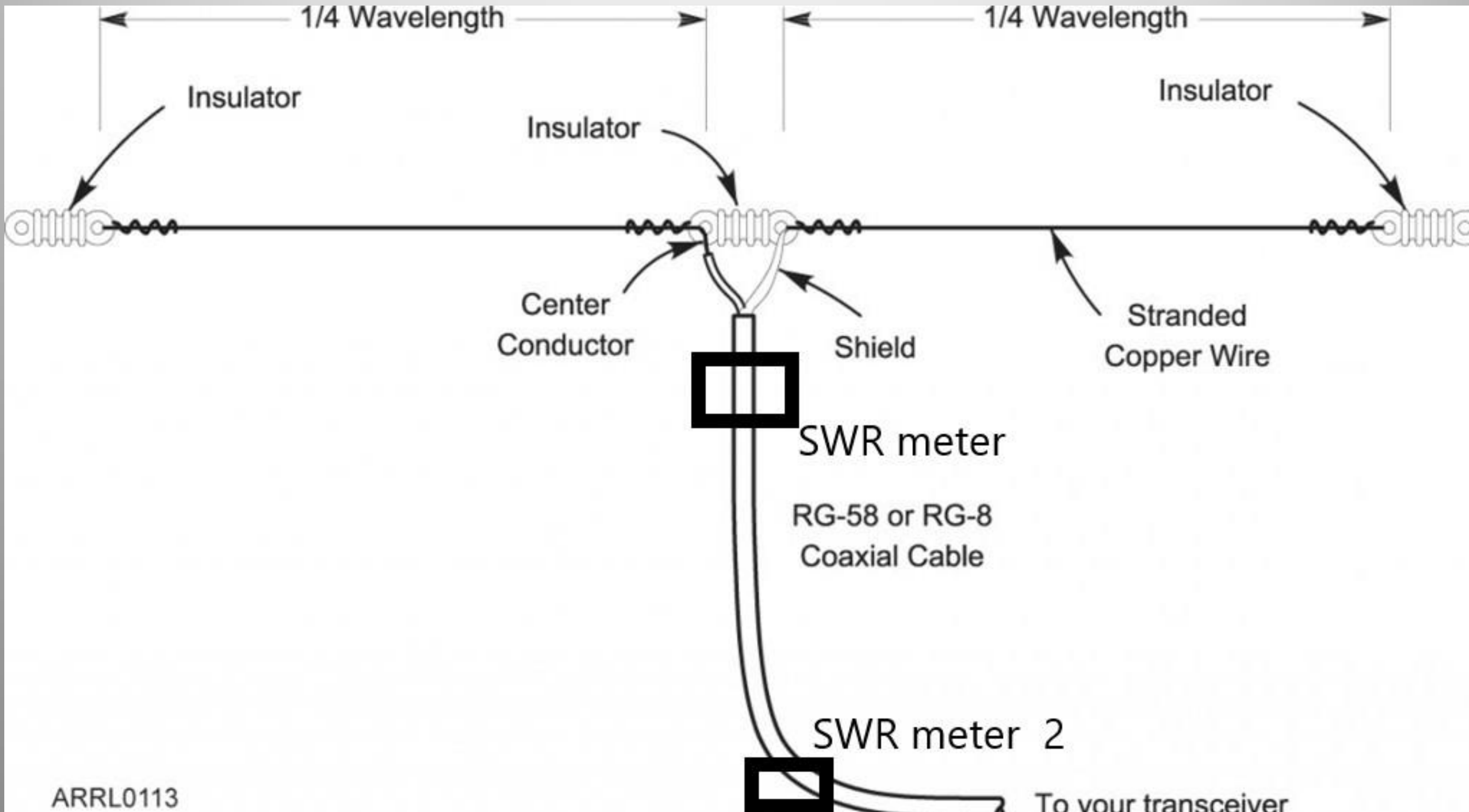
Reflection Coefficient (ρ)

RETURN LOSS (dB)

SWR

Smith Chart

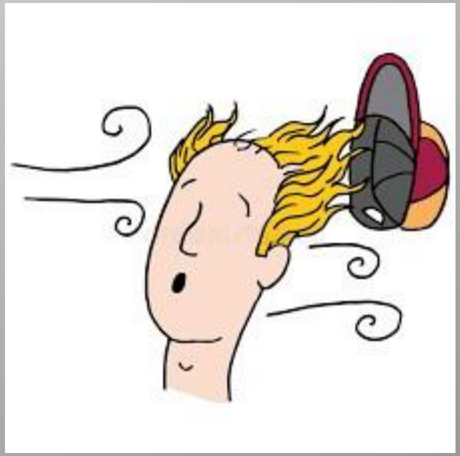
If SWR meter at feedline/antenna junction reads 2:1
What will SWR meter 2 read closer to shack?



REALLY important concept

We are measuring the FORWARD and REFLECTED voltages recorded by the VNA in the shack and **NOT AT THE ANTENNA**

So what?



Feed Line alters impedance measured at different locations from antenna

As you change the LENGTH of feed line

The magnitude of voltage and current changes

The impedance (R and X) changes

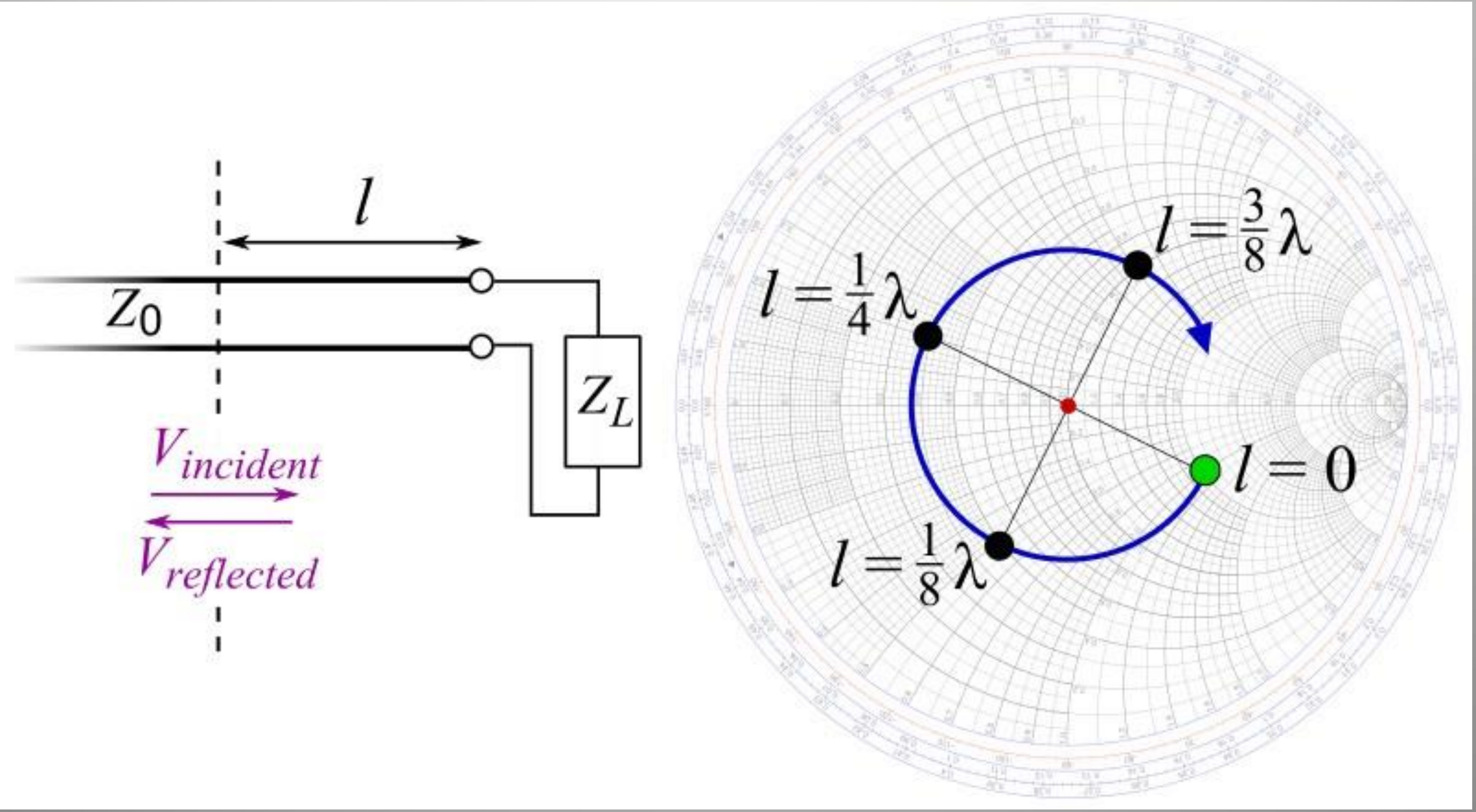
The PHASE changes

But

The SWR does <u>not</u> change

(other than small attenuation changes)

Impedance Z changes as resistance R and reactance X change over the course of ½ wavelength of feed line (if SWR not 1:1)



The measured **RESISTANCE**, **REACTANCE**, **IMPEDANCE** and **RESONANT FREQUENCY** of the antenna system will not be the same in the shack and at the antenna

…. UNLESS

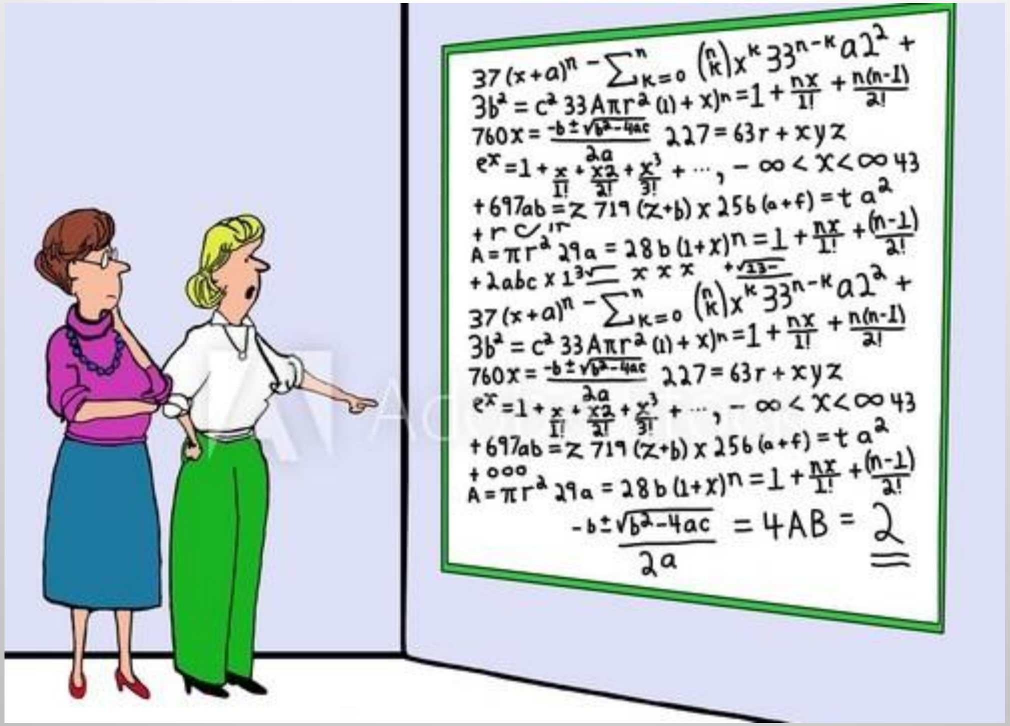
the feed line is ½ λ or an integer multiple of ½ λ

or the antenna and feed line are a perfect 1:1 match with zero attenuation

HOWEVER
assuming very low-loss feed line
and that the shield is not part of the antenna

The **REFLECTION COEFFICIENT**, **RETURN LOSS**, and the measured **SWR** will be (almost) the same value in the shack and at the antenna itself, regardless of the length of feed line.

The SWR does <u>not</u> change with a small change in feed line length



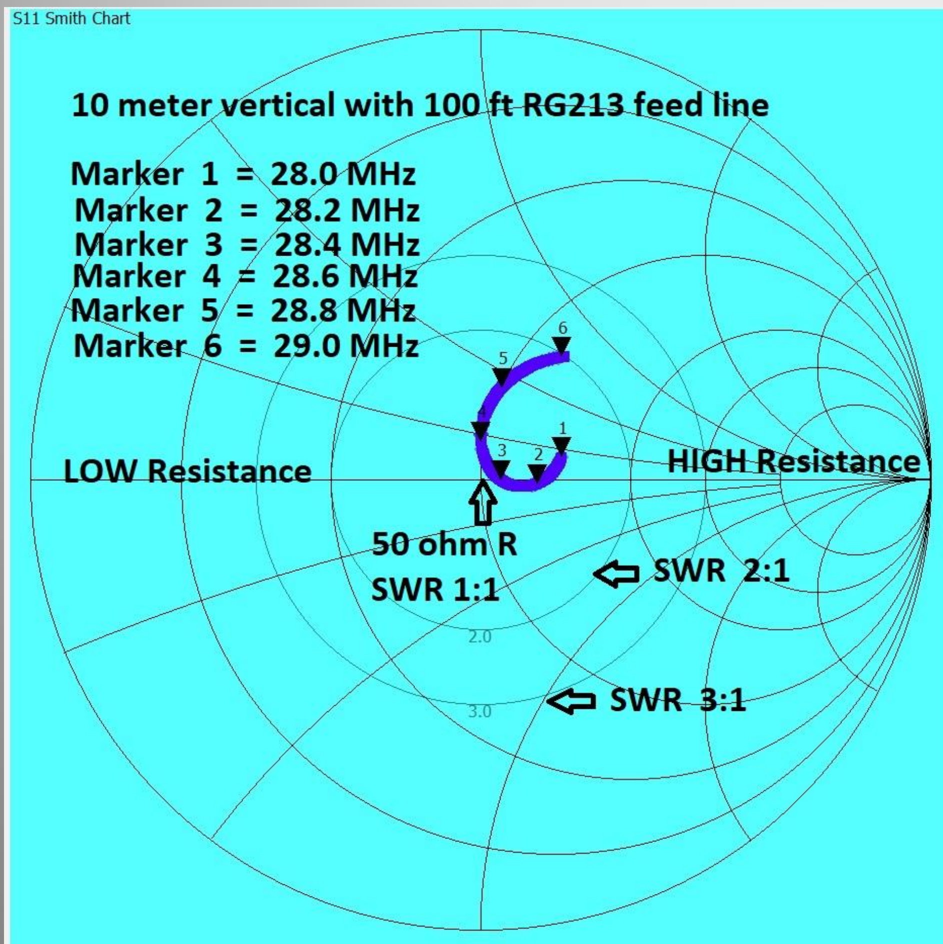
If we are clever

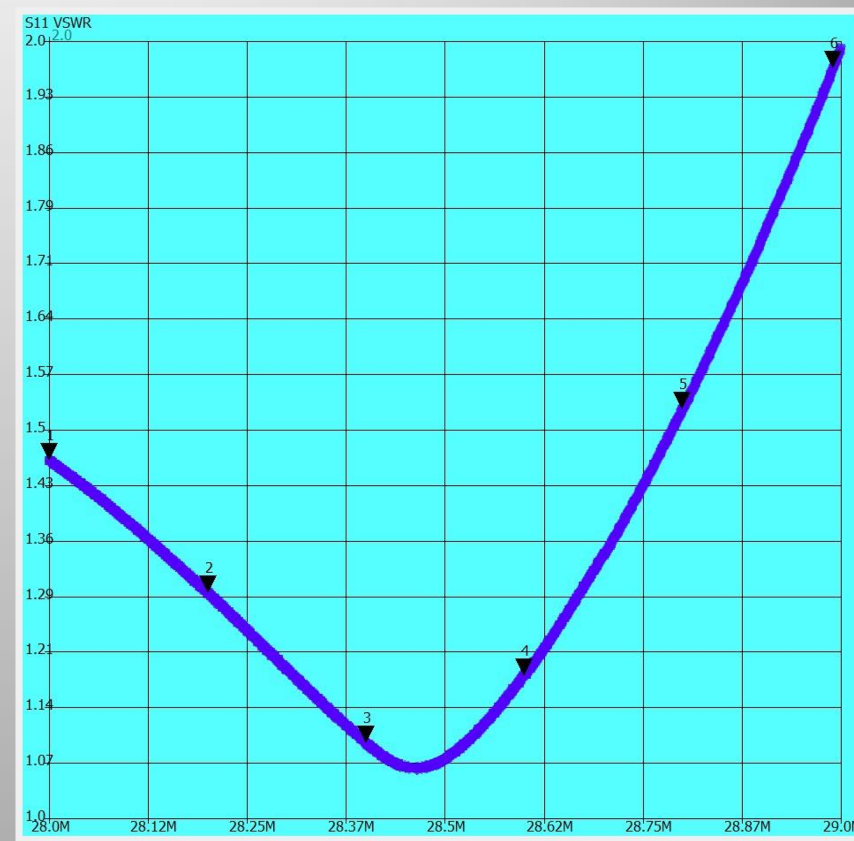
we can take measurements with the VNA

in the shack

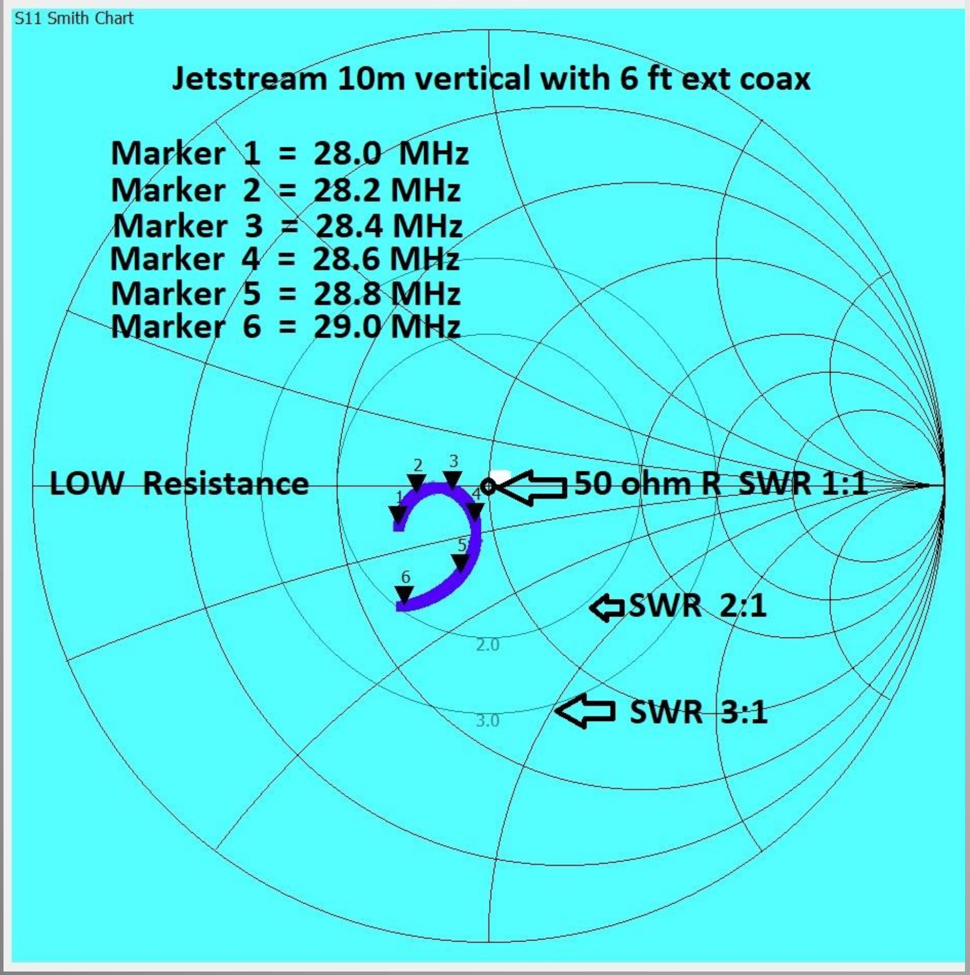
And calculate what these measurements would be **<u>if taken at the antenna</u>**

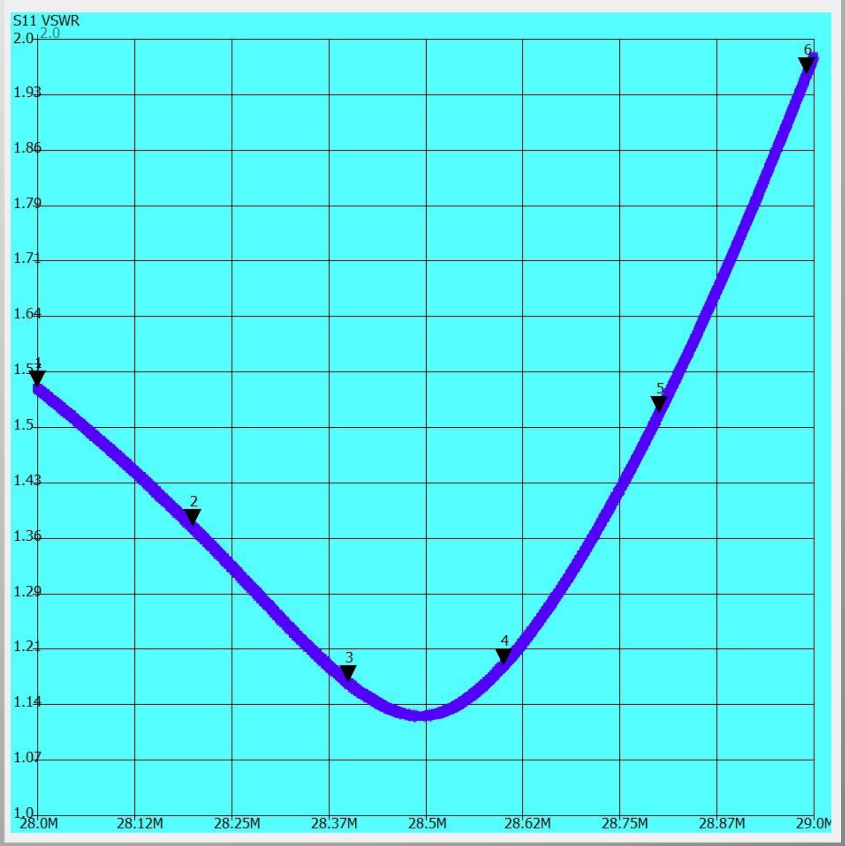
10 meter Vertical: 100 ft RG213 50-ohm feed line
Smith Chart and   SWR   <u>measured in shack</u>





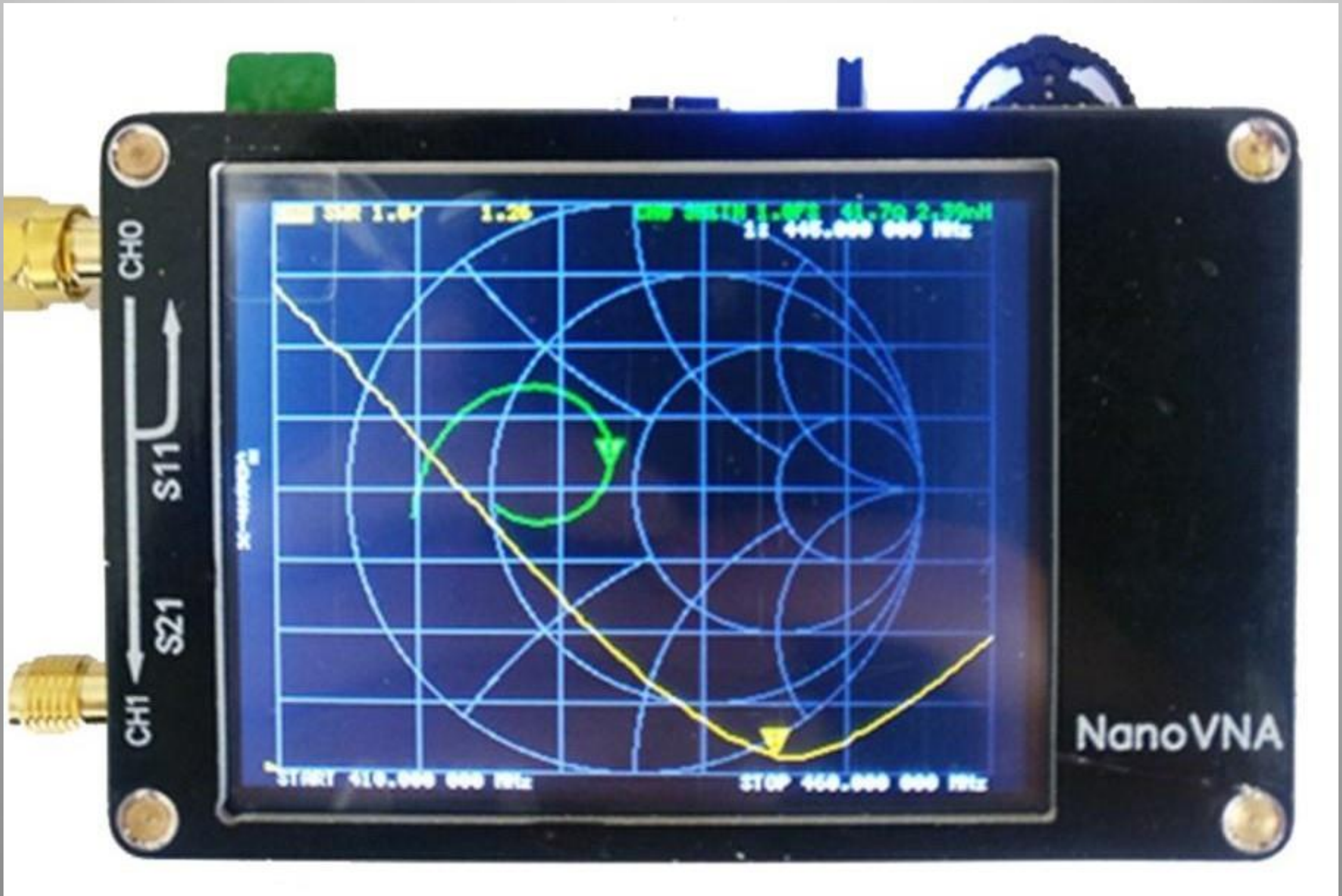
10 meter Vertical with **6 feet** extra 50-ohm coax (1/4 wave)
Smith Chart has "rotated" 180 degrees (different impedance)
but SWR of each marker has not changed





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

Important Parameter Definitions

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

Γ (gamma) = a complex number

absolute value |gamma| = **ρ** (rho)

$$\mathbf{0 < \rho < 1}$$

RETURN LOSS (dB) = - 20 log (ρ)

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

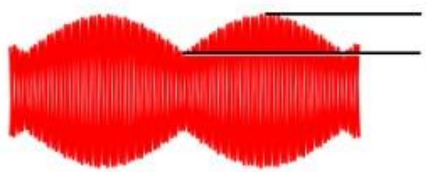
SWR = (1 + ρ) / (1 – ρ) = V(max) / V (min)

REFLECTION Parameters (Agilent Tech great resource)

Reflection Parameters

Reflection Coefficient $\Gamma = \dfrac{V_{reflected}}{V_{incident}} = \rho \angle \Phi = \dfrac{Z_L - Z_o}{Z_L + Z_o}$

Return loss $= -20 \log(\rho)$, $\rho = |\Gamma|$



Voltage Standing Wave Ratio

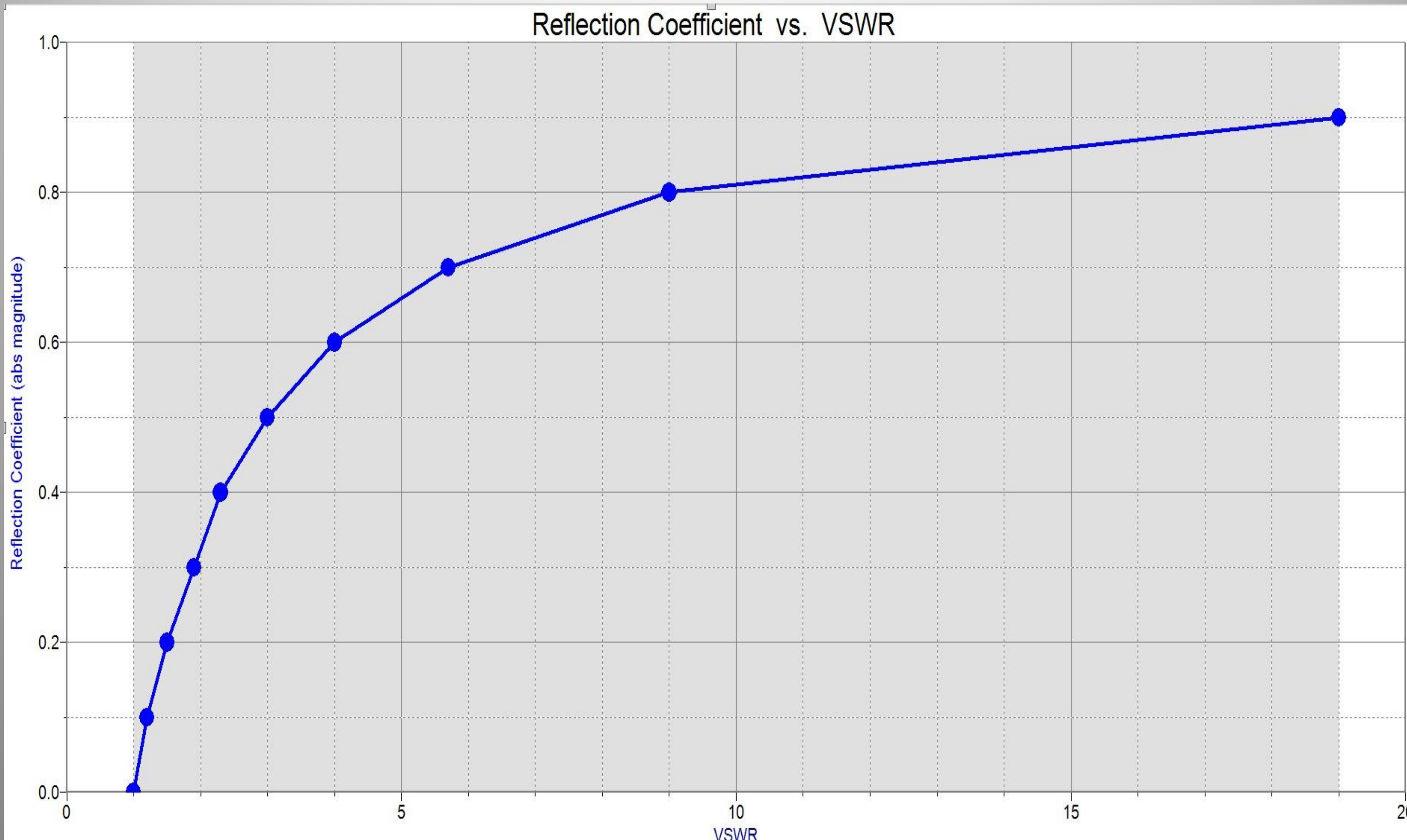
$$\textbf{VSWR} = \frac{V_{max}}{V_{min}} = \frac{1 + \rho}{1 - \rho}$$

No reflection ***($Z_L = Zo$)***		***Full reflection*** ***(Z_L = open, short)***
0	ρ	1
∞ dB	**RL**	0 dB
1	**VSWR**	∞

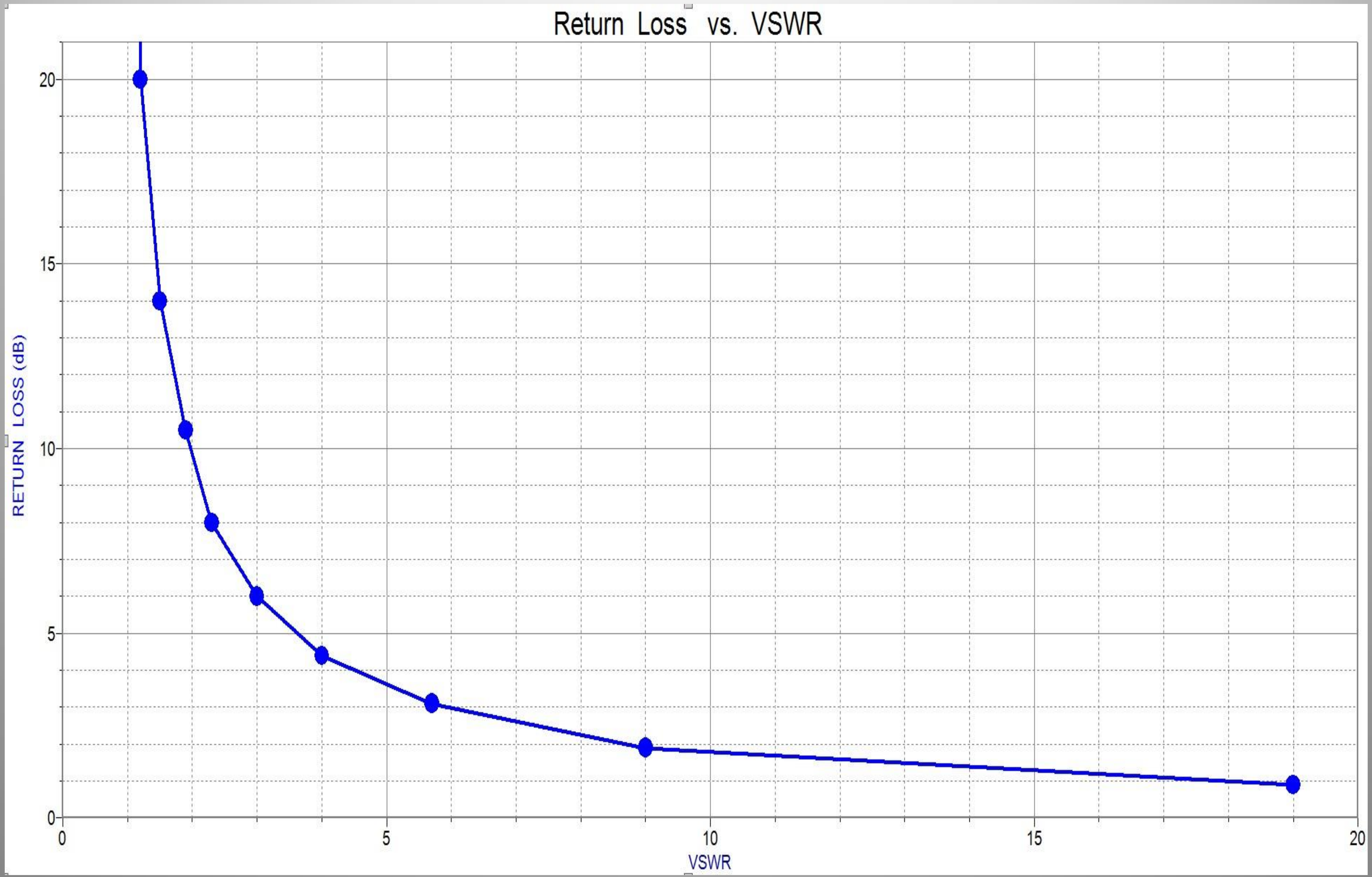
Agilent Technologies

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)

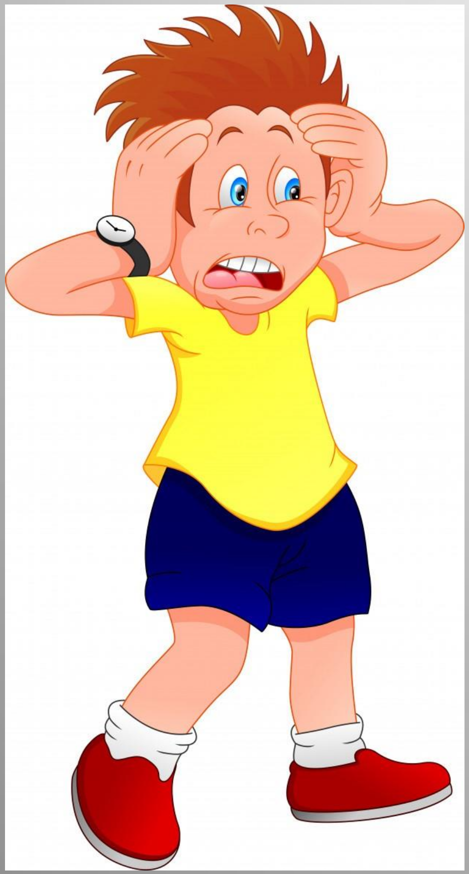
Reflection Coefficient ρ vs. VSWR

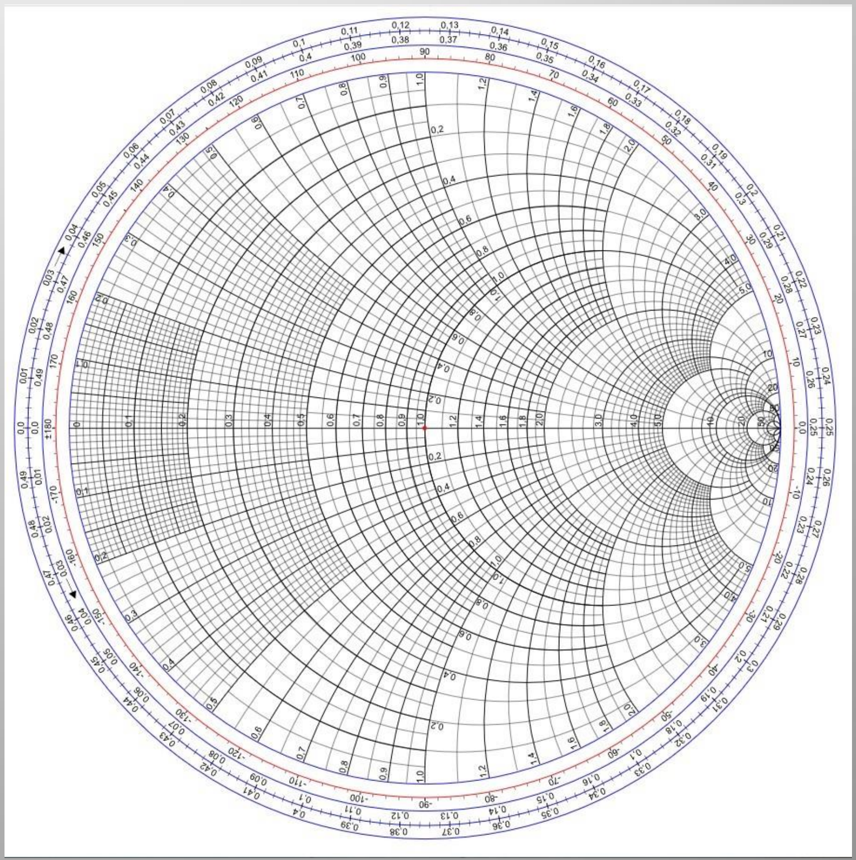


RETURN LOSS (dB) vs. VSWR
(you want a high RETURN LOSS)

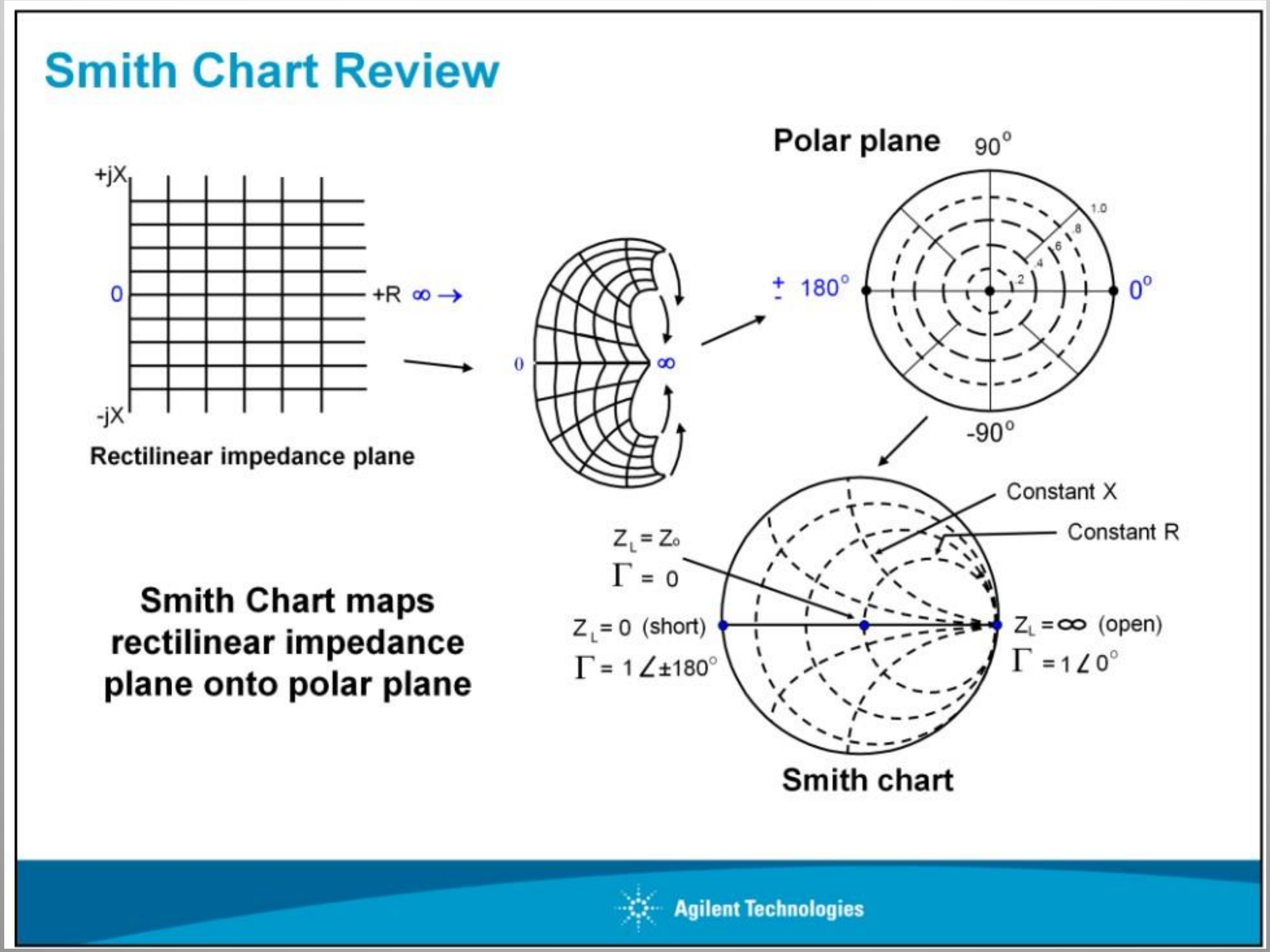


Take a deep breath
We are now entering into the
SMITH CHART realm

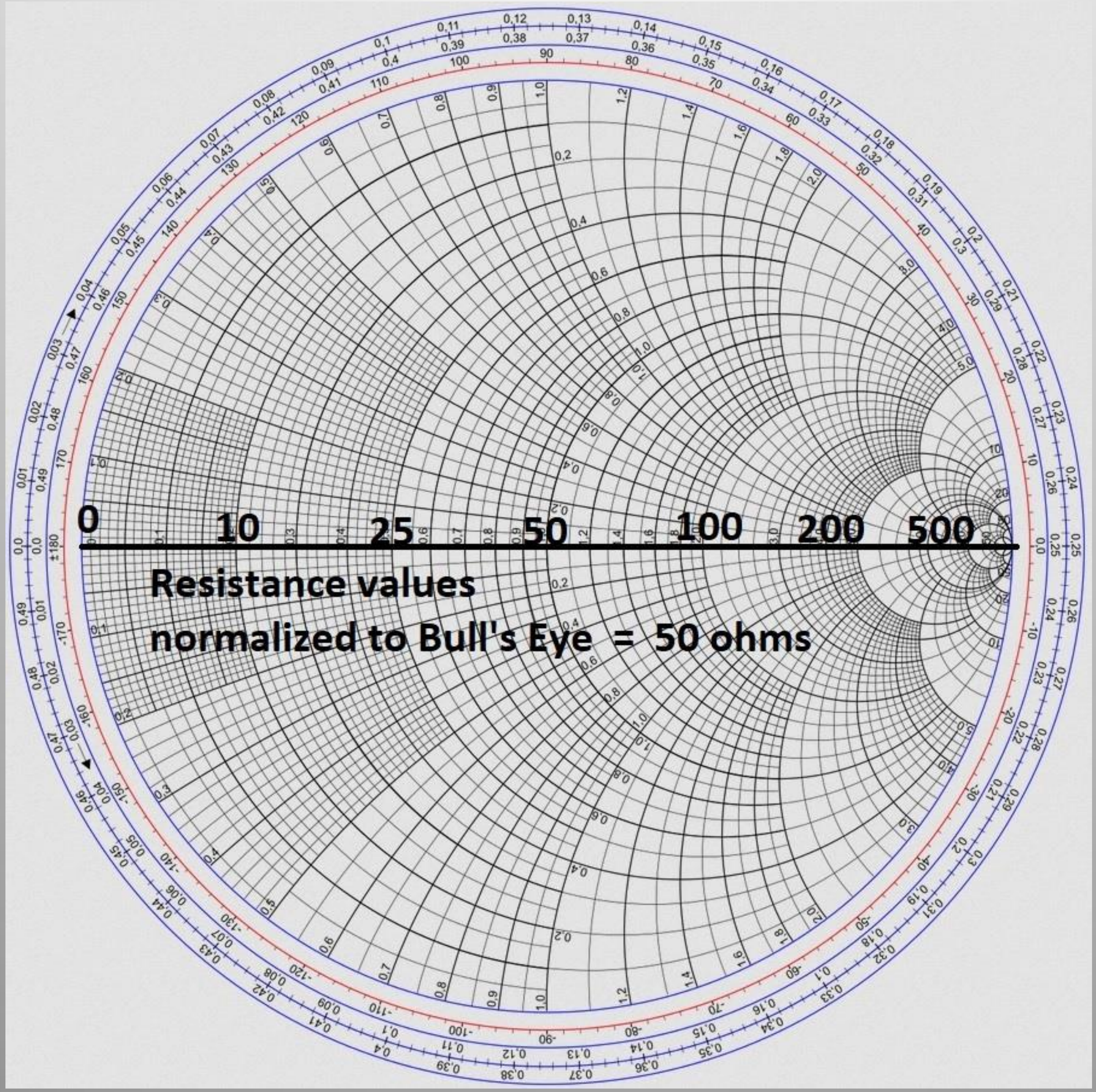




Smith Chart is just expressing values of resistance **R** and reactance **X** in a **“polar” coordinate system**

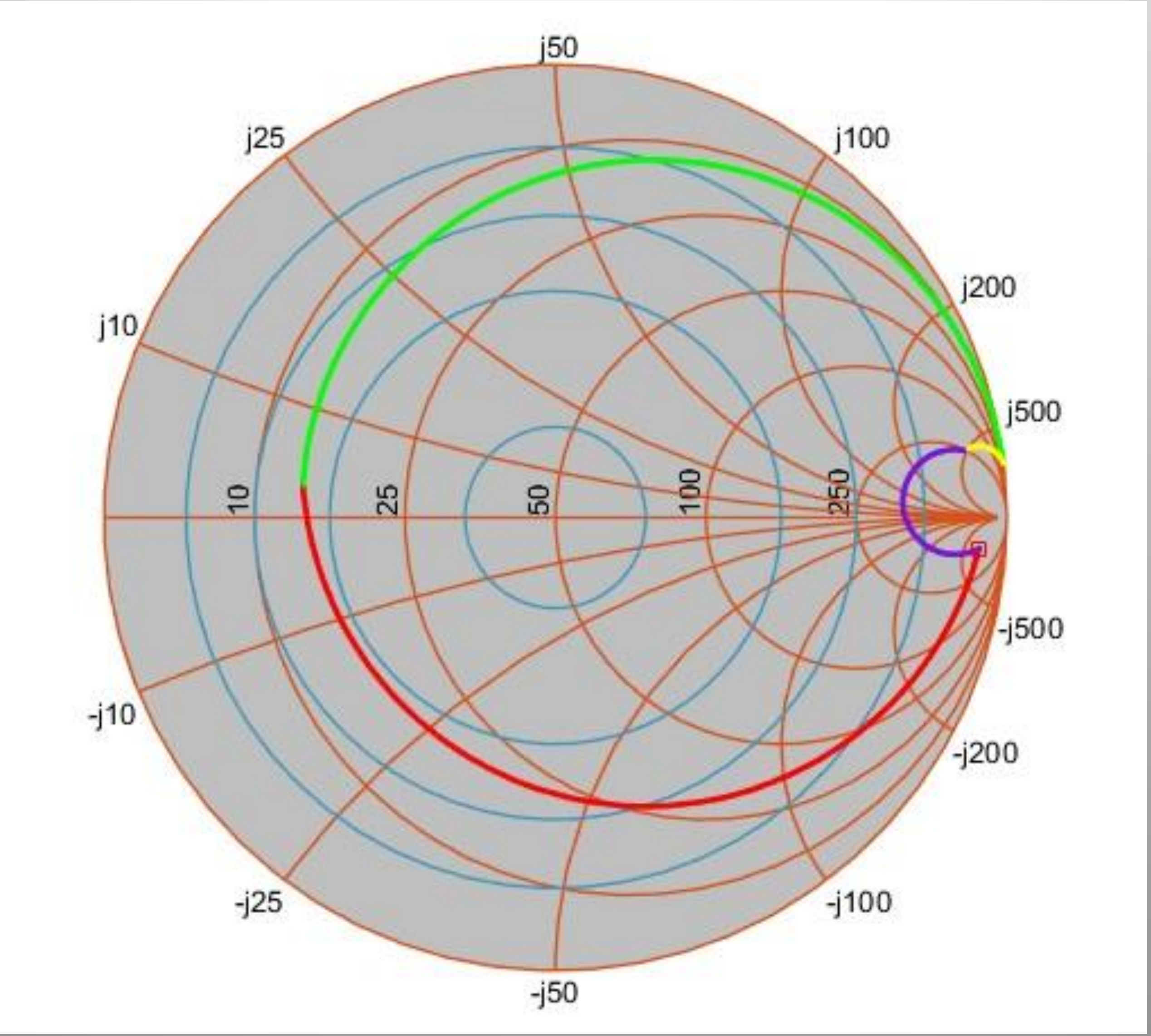


Resistance values are plotted on the **horizontal axis in a non-linear scale**
Usually **50** ohms is plotted at dead-center (Bull's Eye)

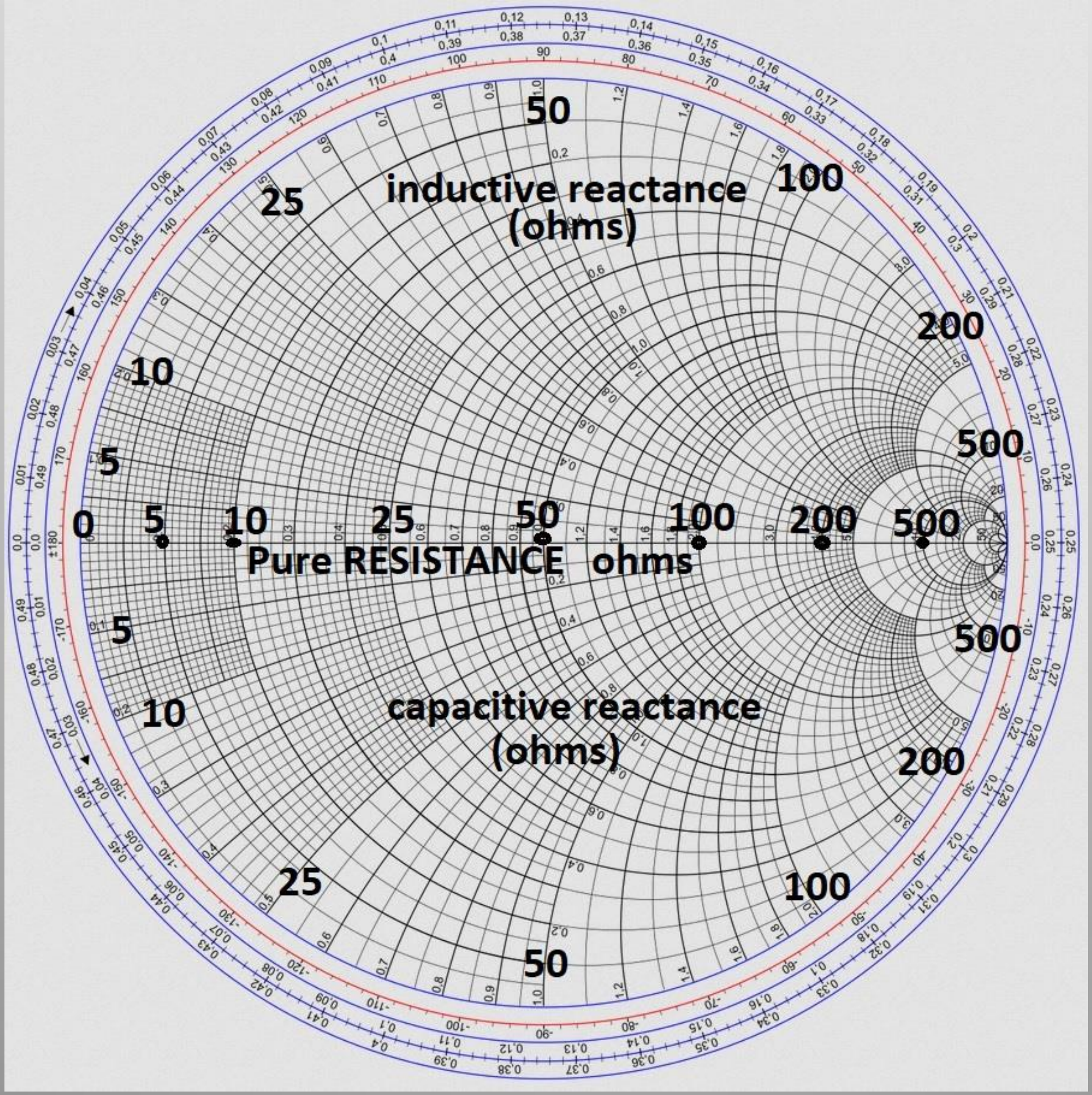


Every impedance consists of $Z = R \pm jX$

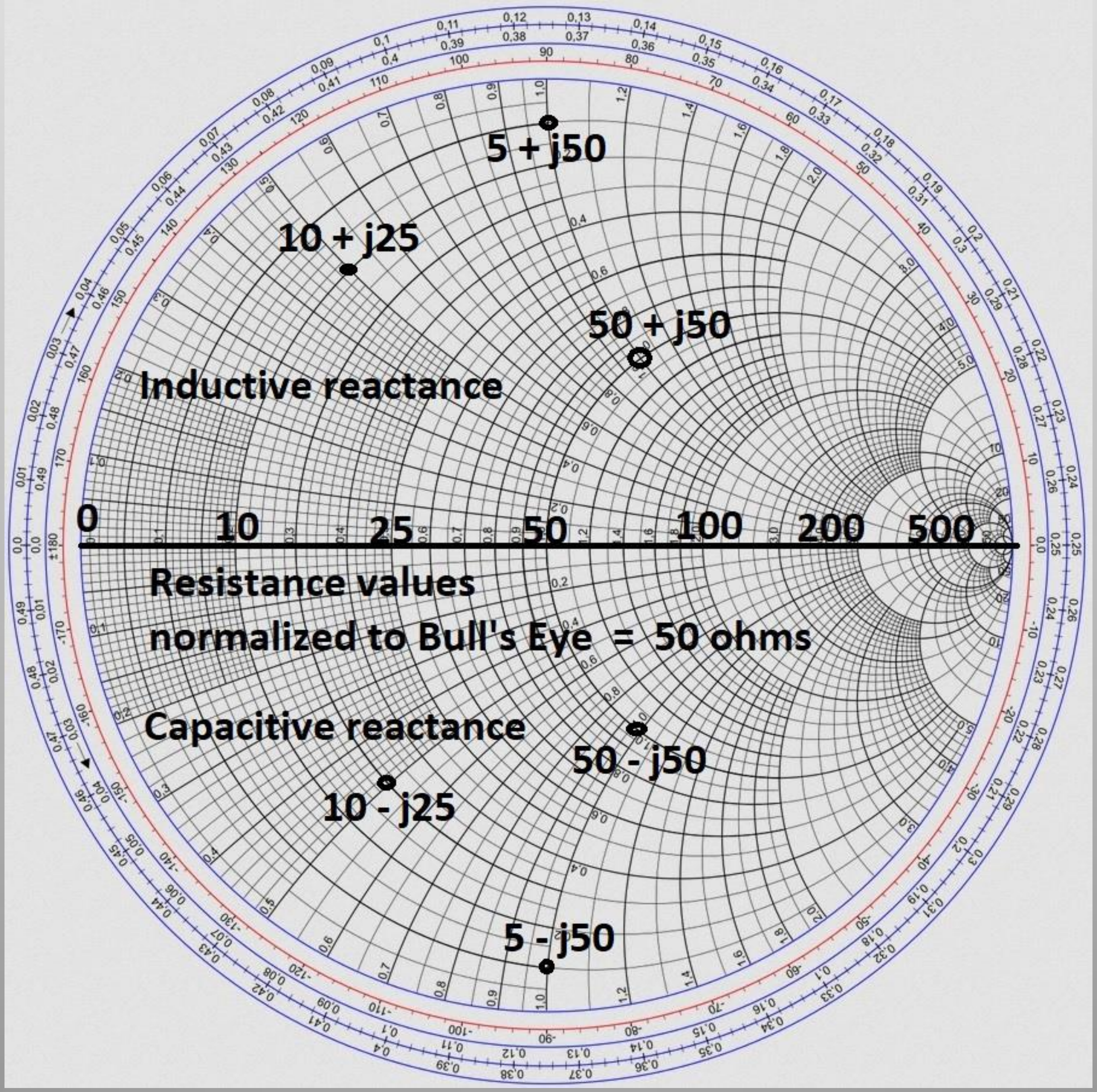
Resistance value R and reactance value X



Capacitive reactance X_c (ohms) curves are plotted BELOW X axis
Inductive reactance X_L (ohms) curves are plotted ABOVE X axis



Every impedance Z has a unique location: R + jX
Where is (50 + j0) located on the chart?

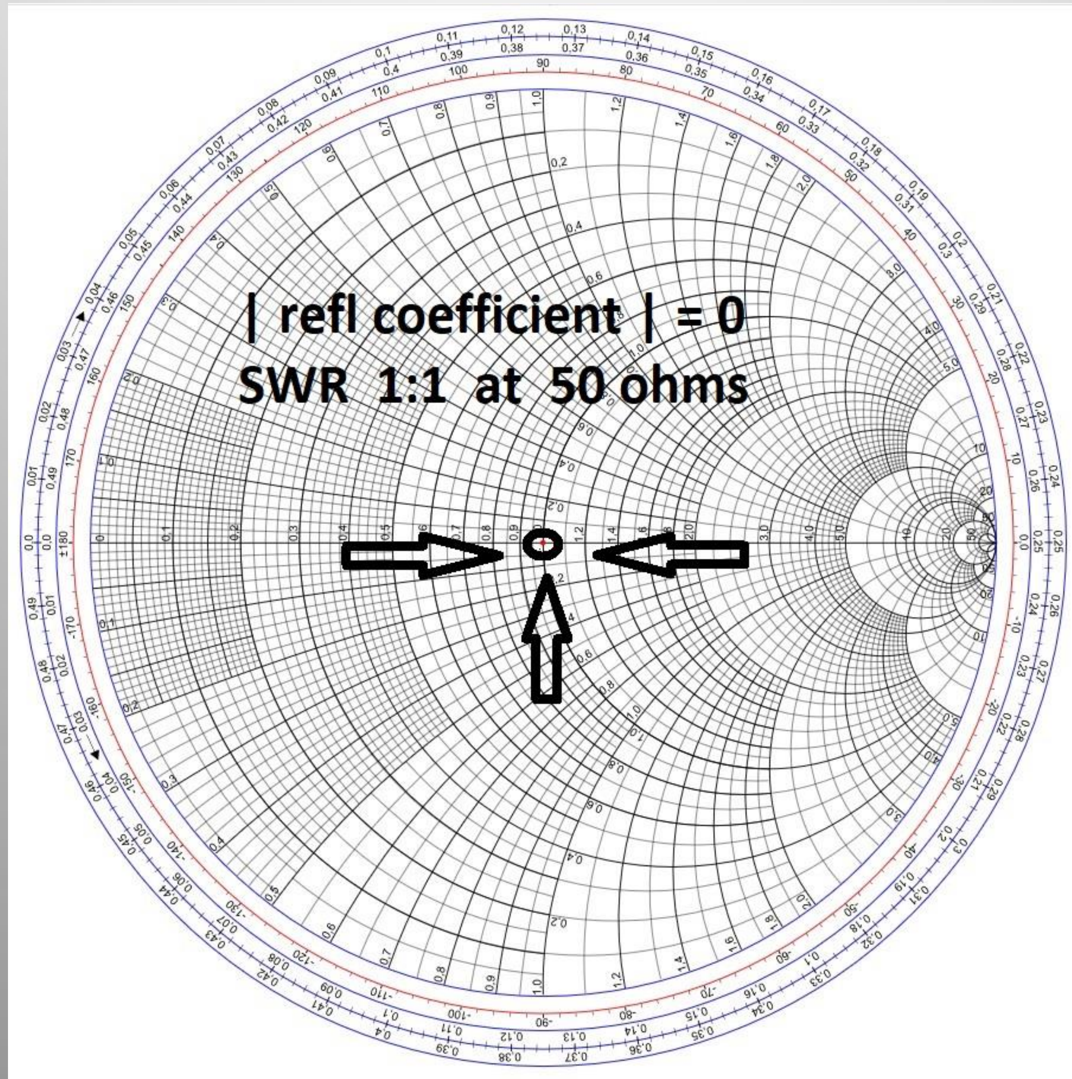


Remember: we want our antenna to land in the Smith Chart "Bull's Eye" where impedance is 50 ohms to match 50 ohm coax

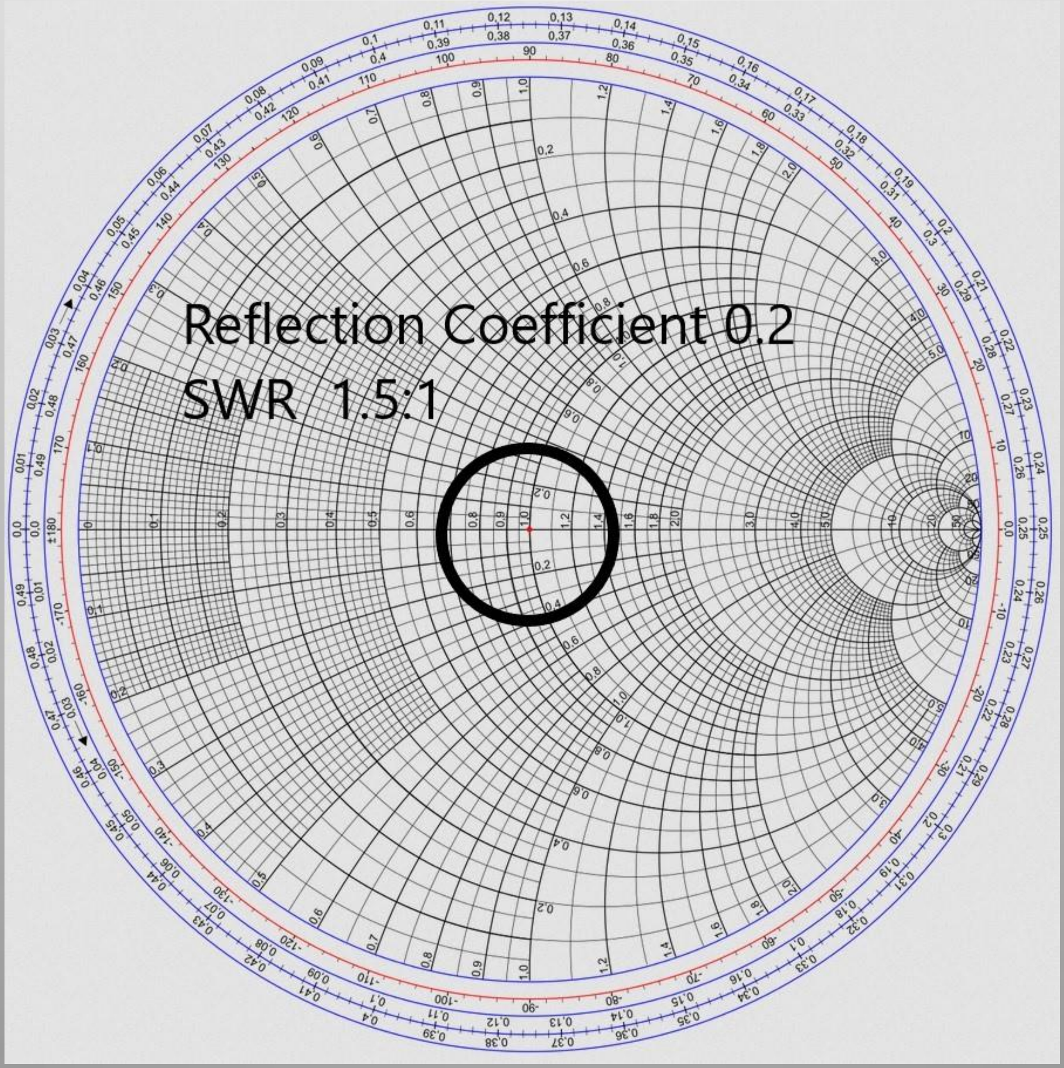
Smith Chart (think DART BOARD)

reflection coefficient ρ and SWR

Bull’s Eye = perfect match to **<u>50 ohms</u>** with zero reflected power

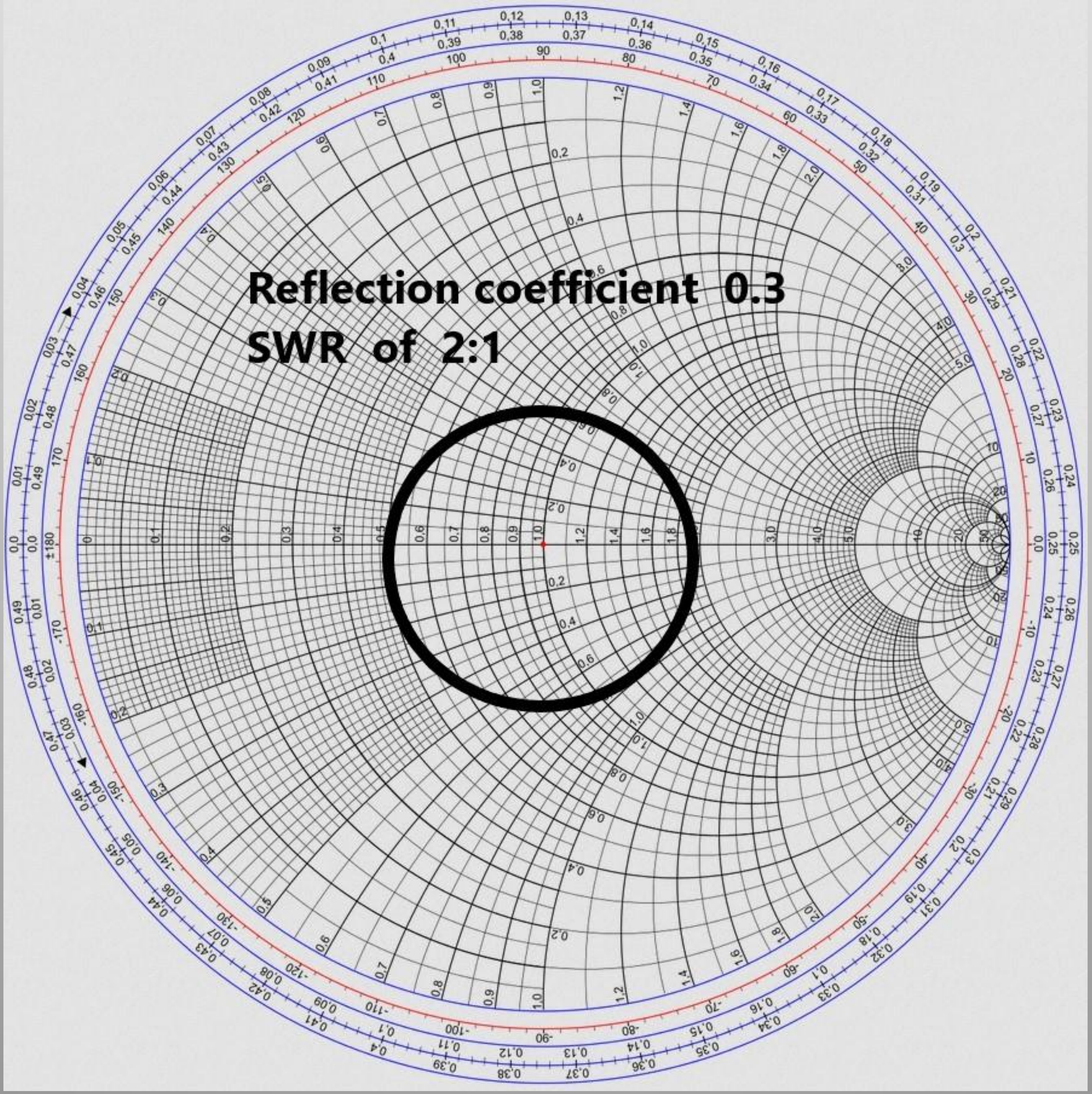


20% of incident voltage is reflected
All points on the circle represent impedances with
ρ = 0.20 and SWR = 1.5:1

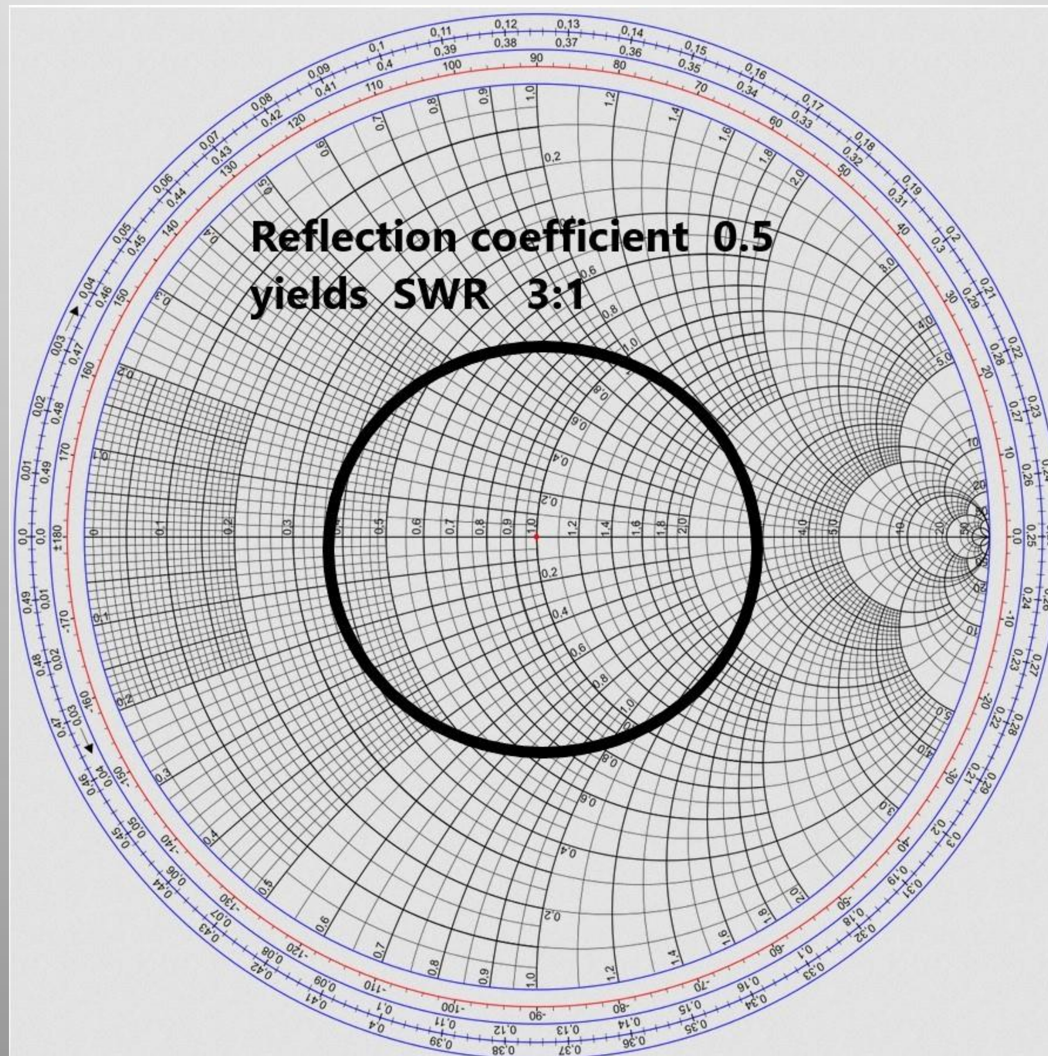


If 33% of incident voltage is reflected

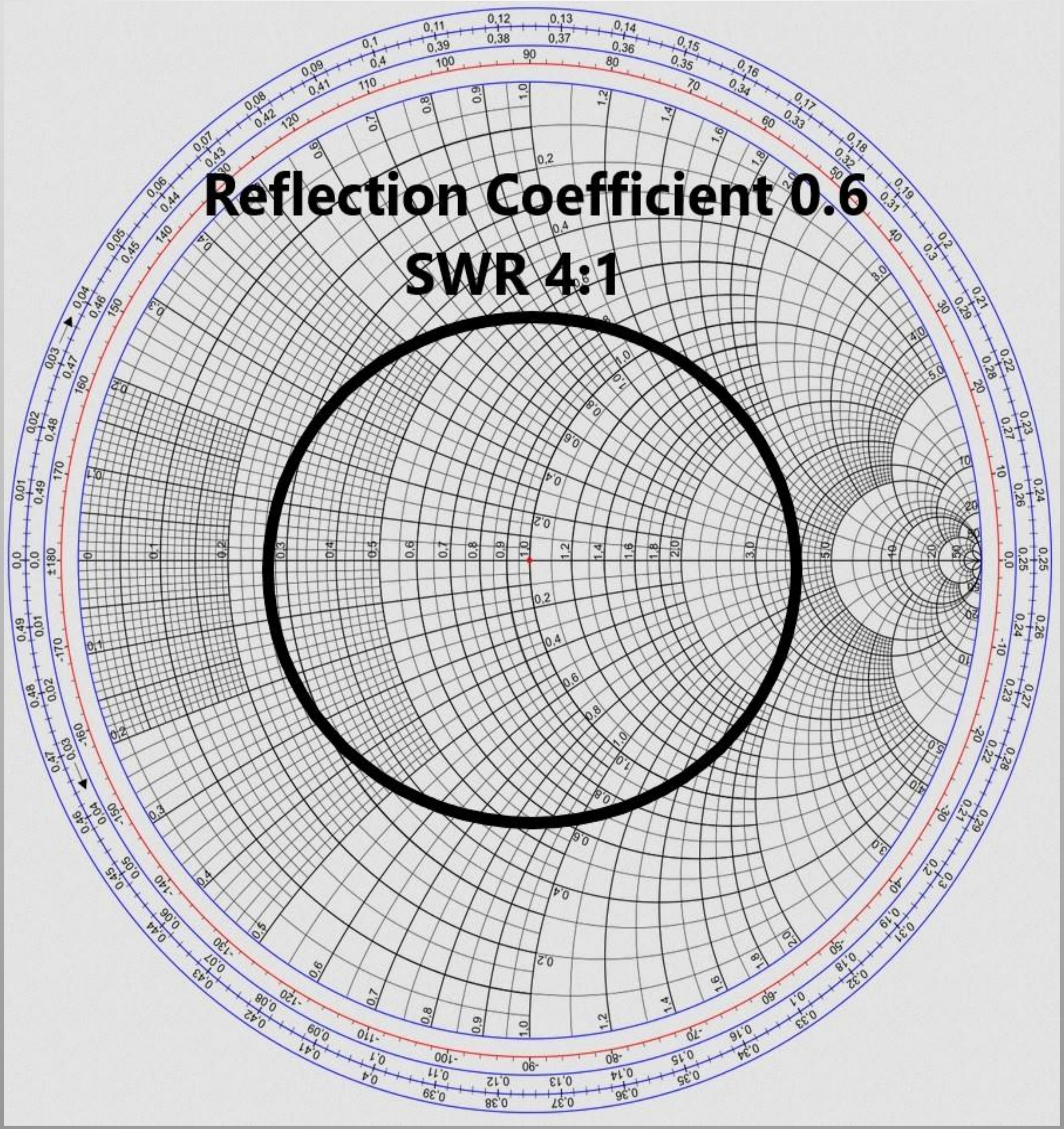
ρ = 0.33 and all locations on circle have an SWR 2:1



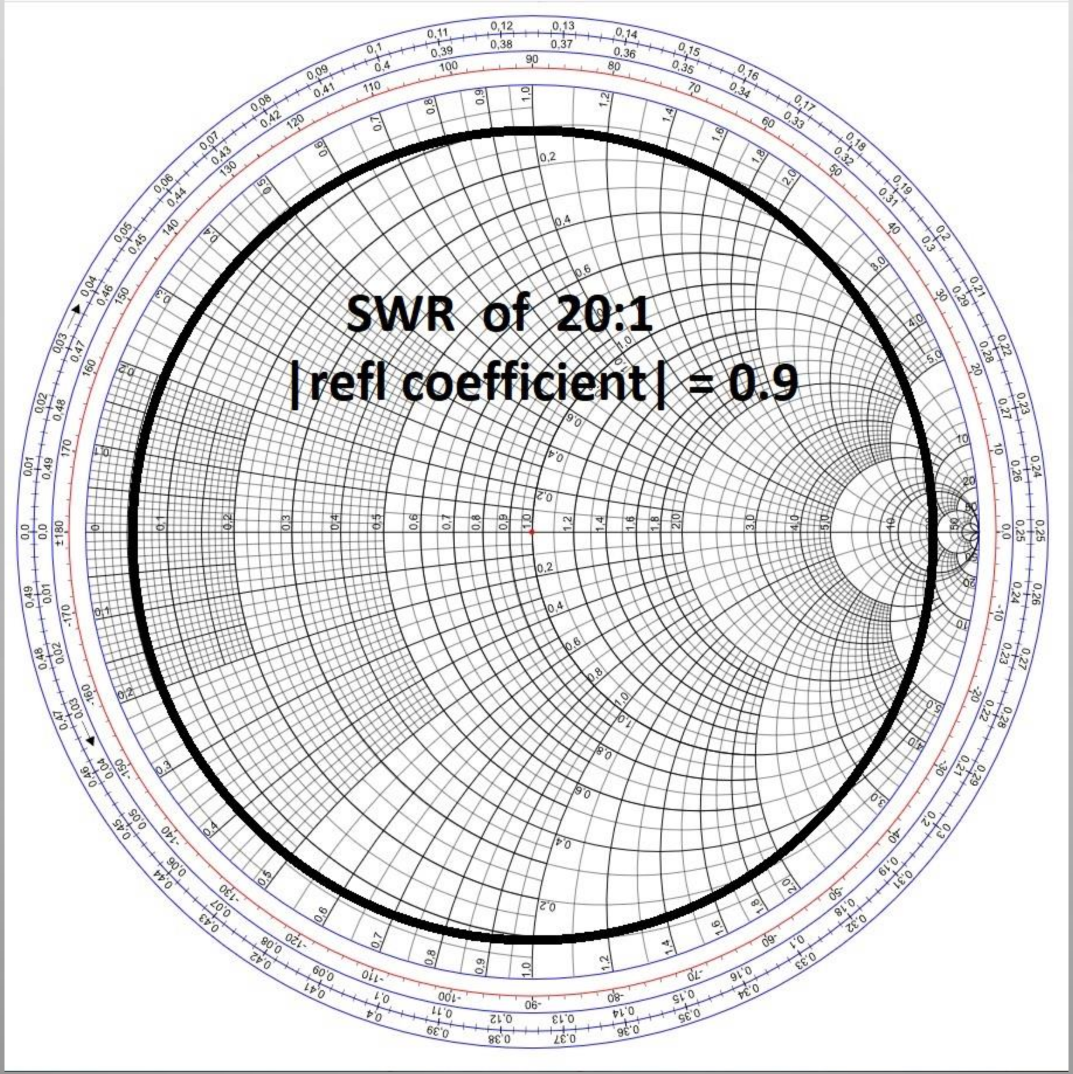
50% of incident voltage is reflected
All values of R+jX on perimeter: ρ = 0.5 and SWR 3:1
SWR of 3:1 ==> 25% reflected power



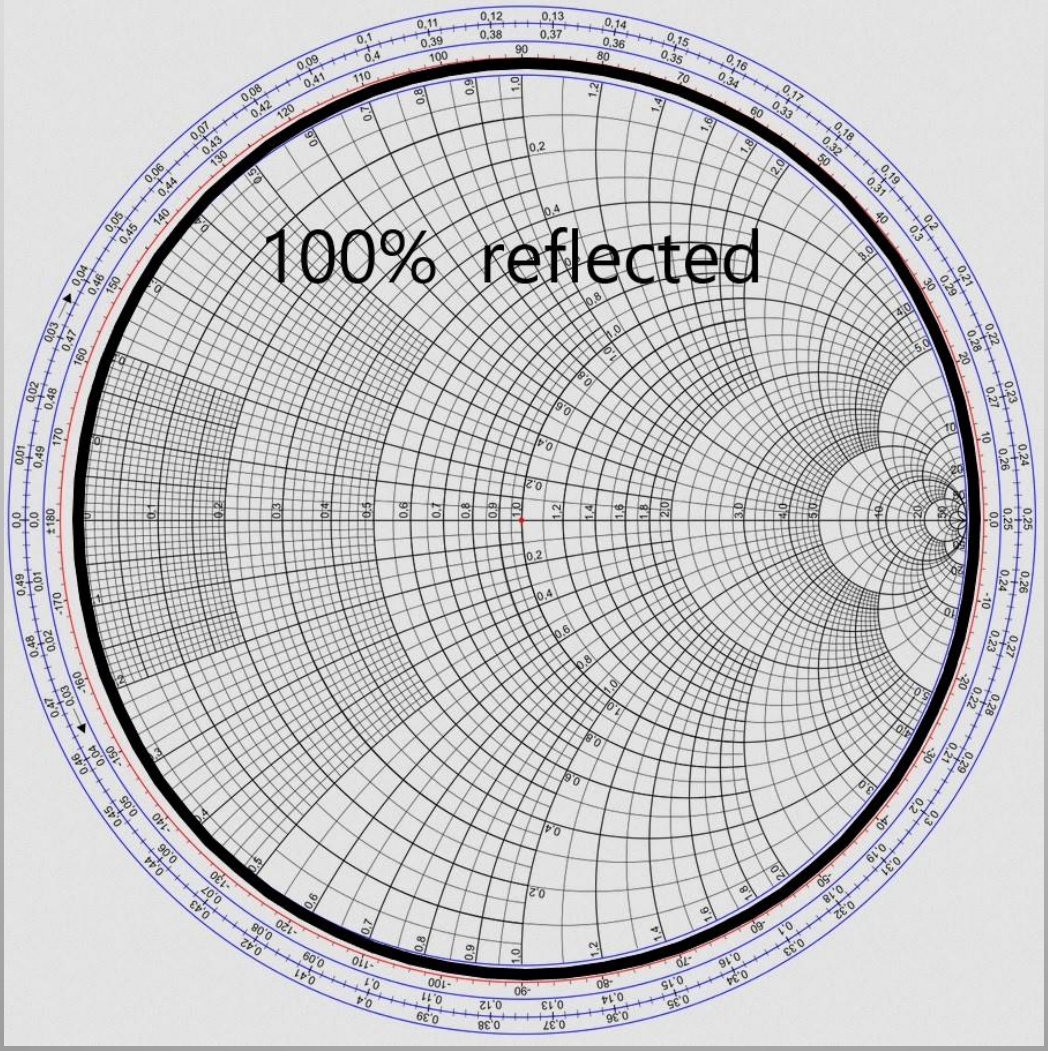
SWR of 4:1 with 60% reflected voltage



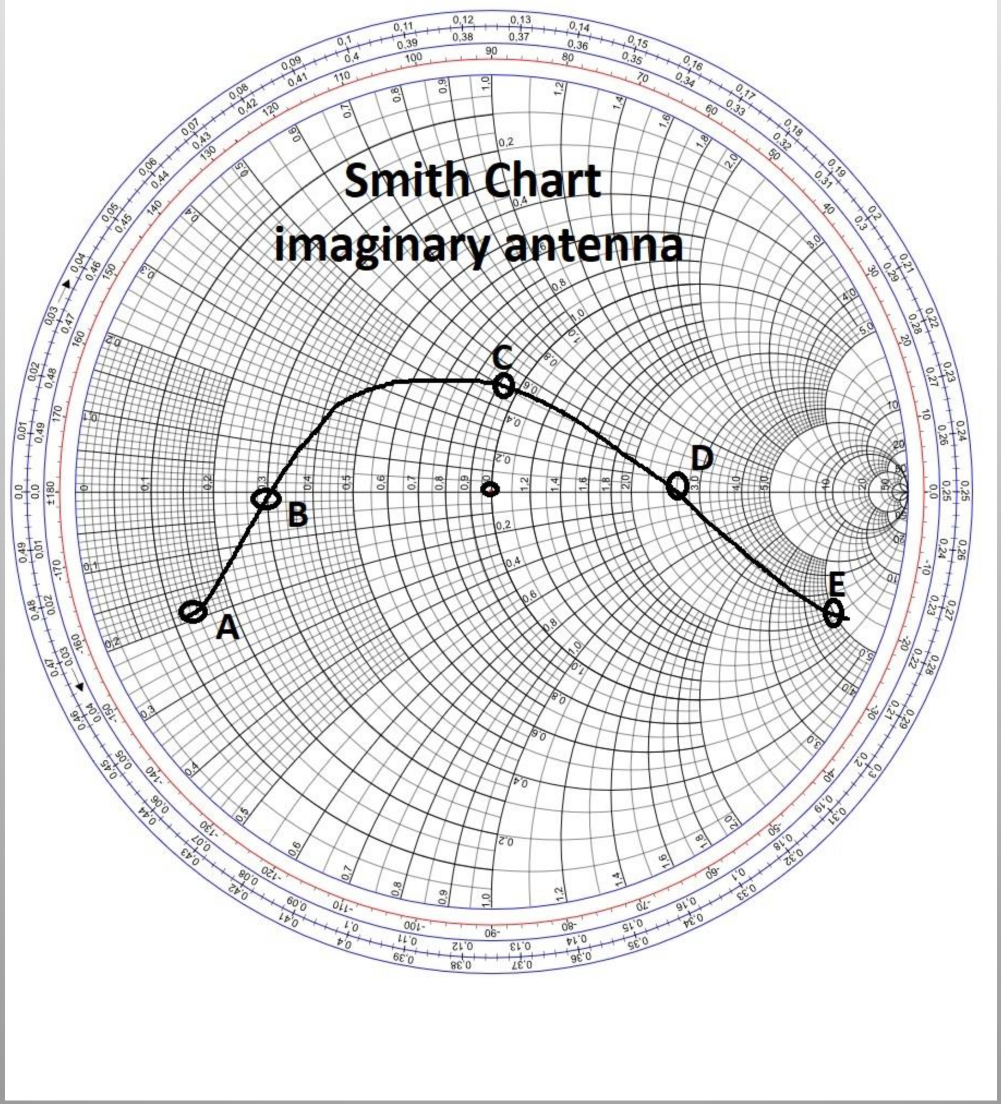
90% reflected voltage: ρ = 0.9 ==> SWR 20:1



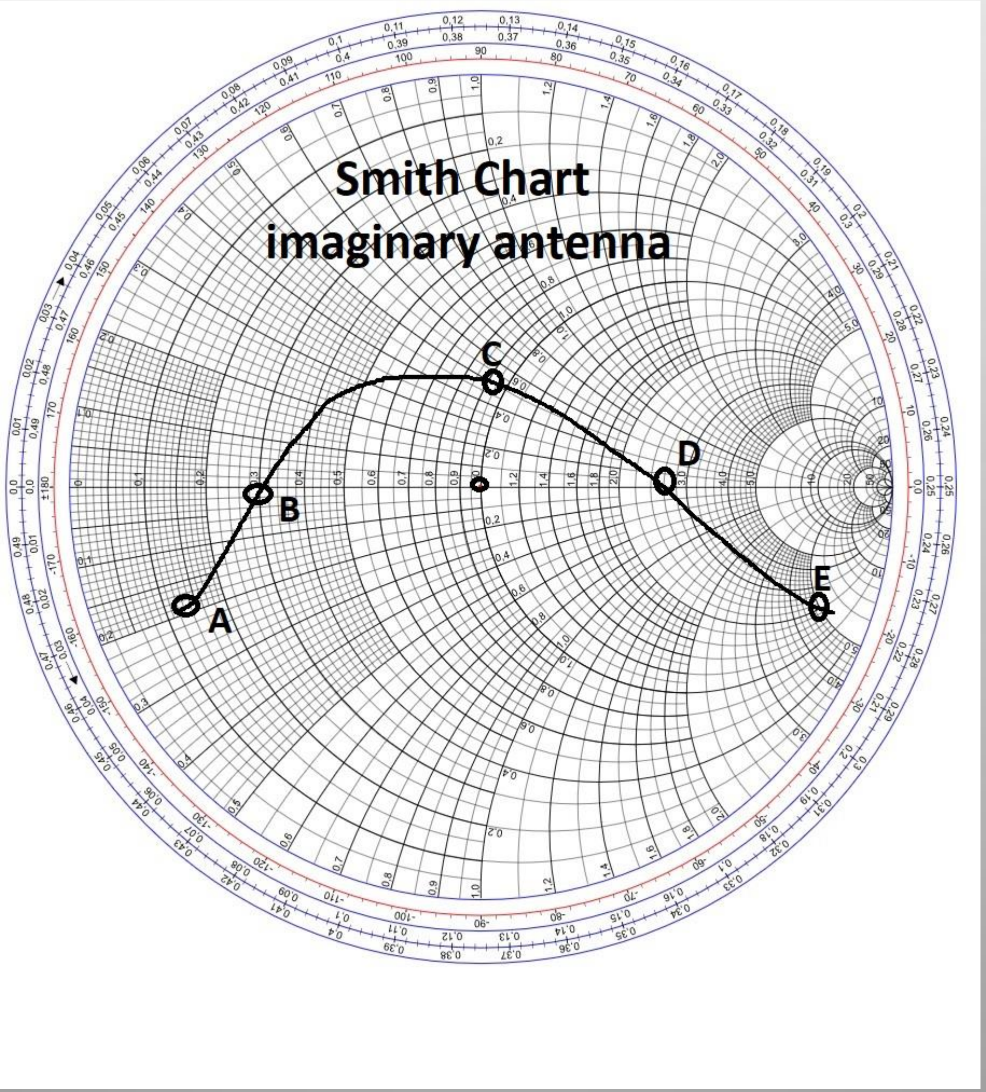
What is the SWR with 100% voltage reflected?



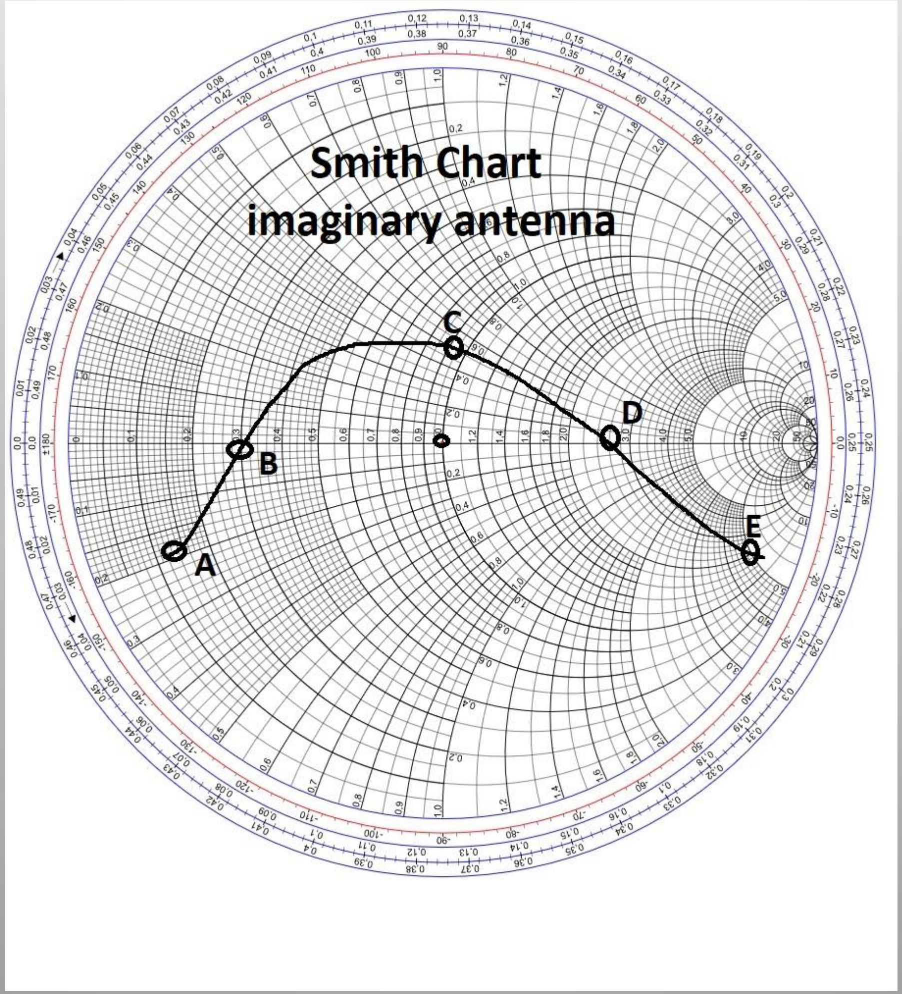
QUIZ: Where is this antenna <u>resonant</u> ?



QUIZ: Where is the SWR lowest?



Where is the Resistance lowest?
Where is the Resistance highest?
Where is the Impedance highest? (extra credit)

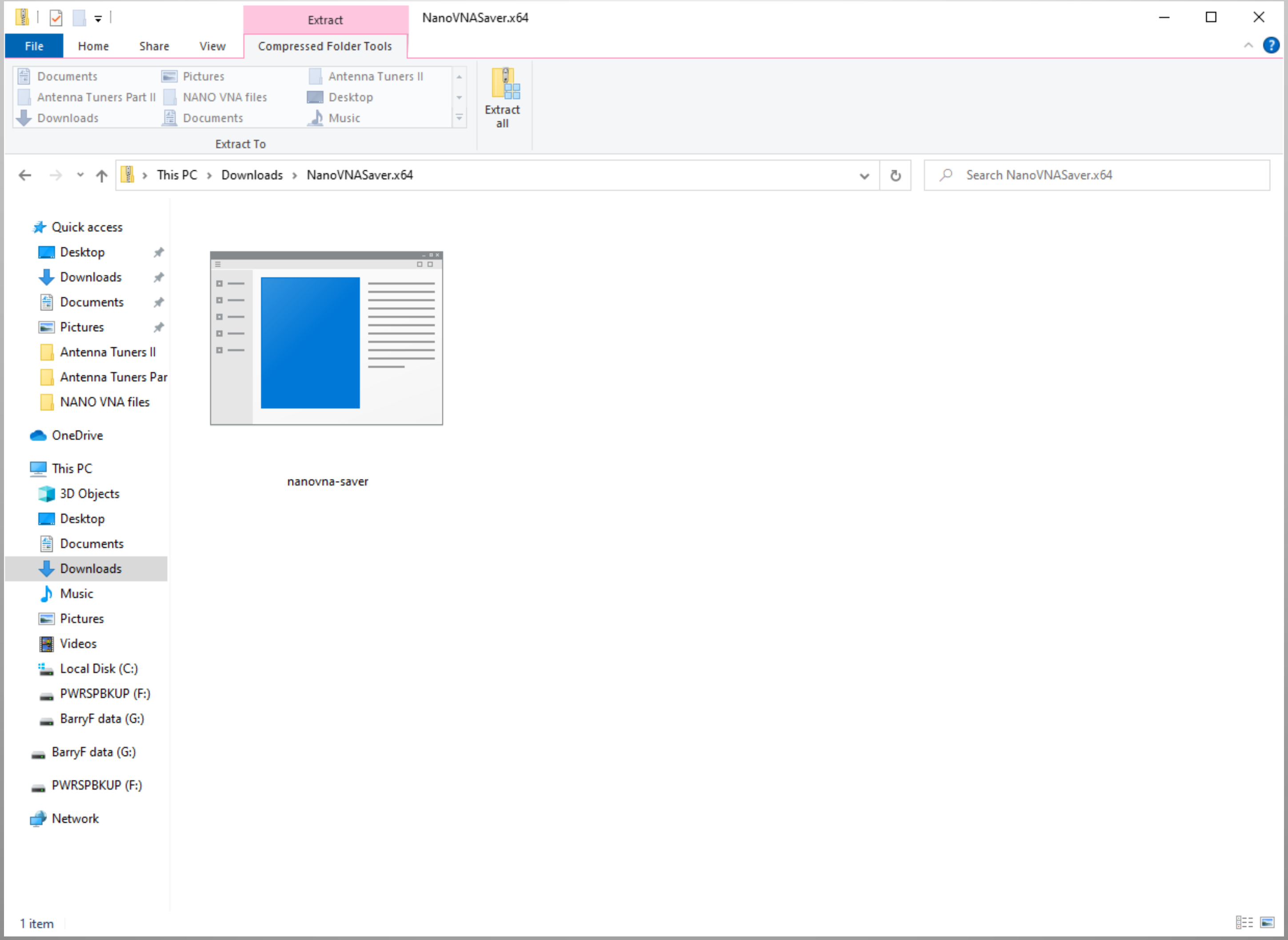


USB connections to computer and battery charger

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

Nano VNA Saver software

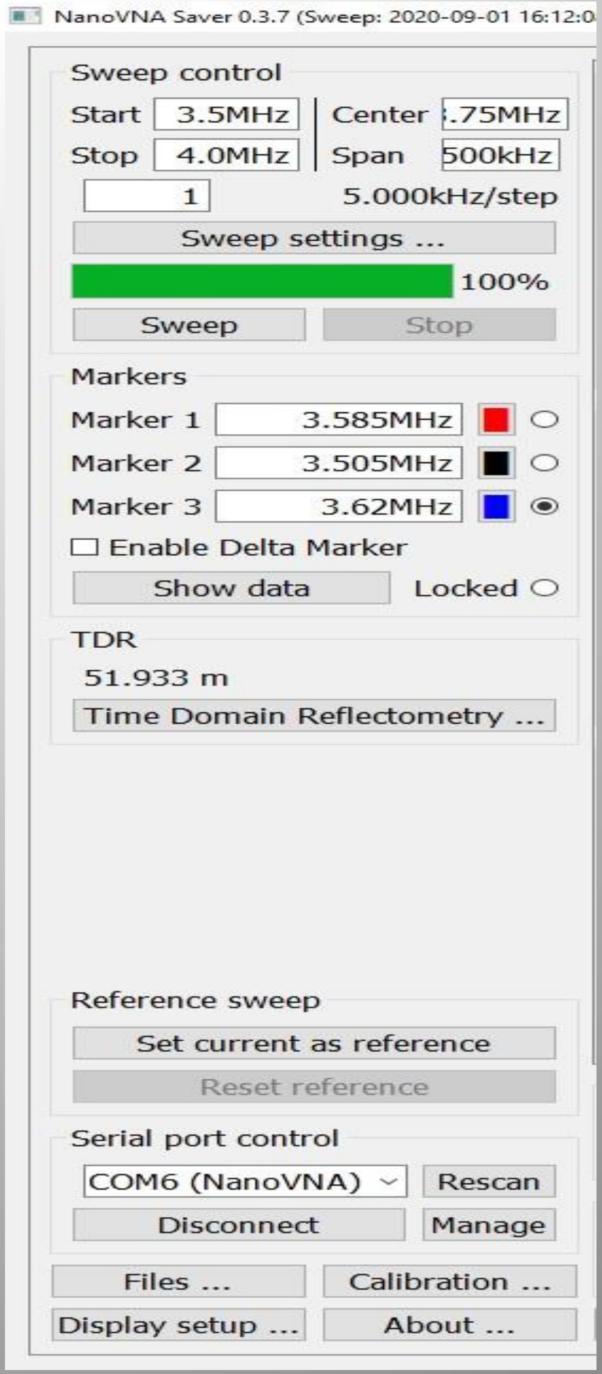
much easier to use by computer control



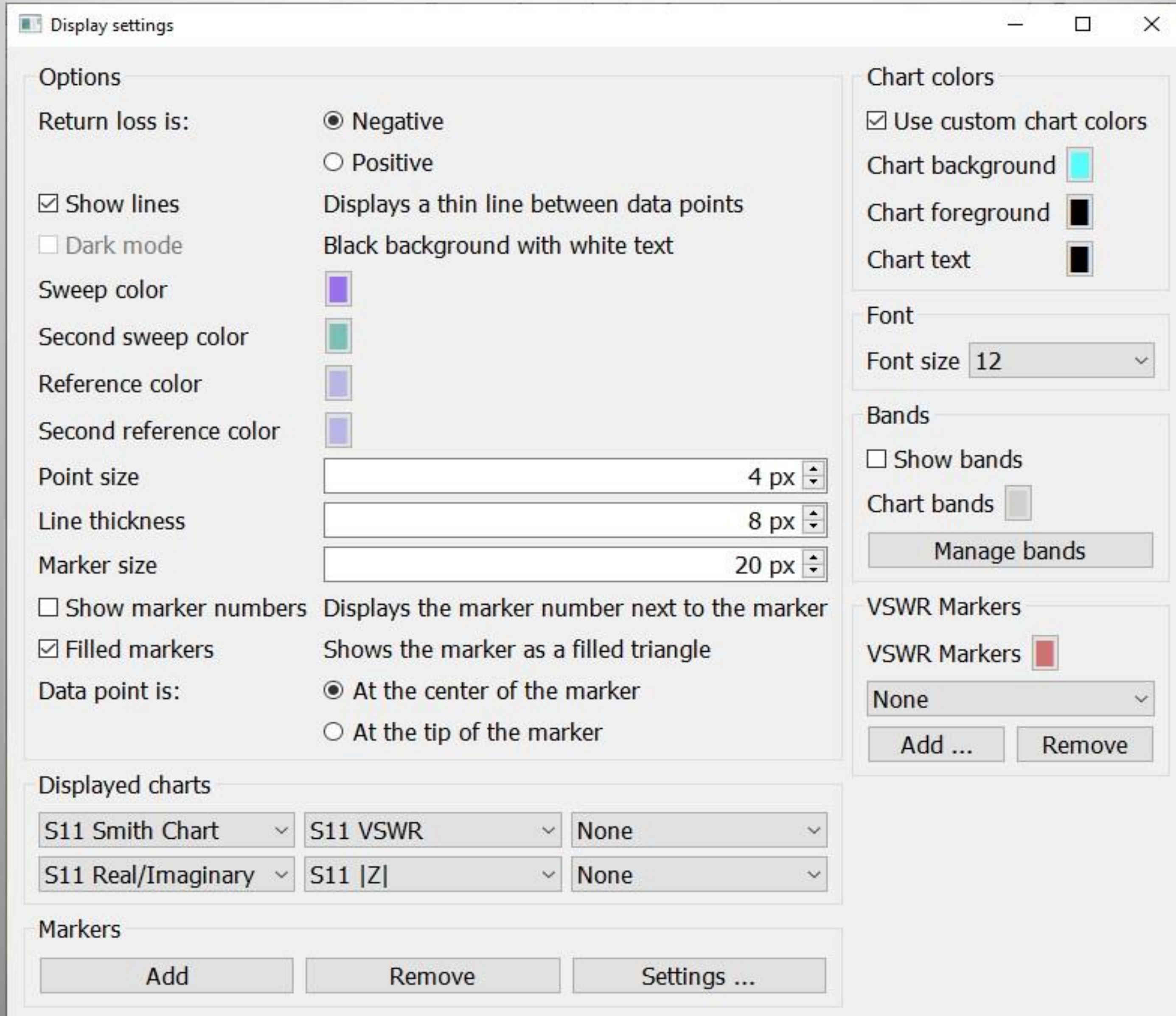
Computer Control Settings

Com Port select
Frequency Range
Select Markers

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



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



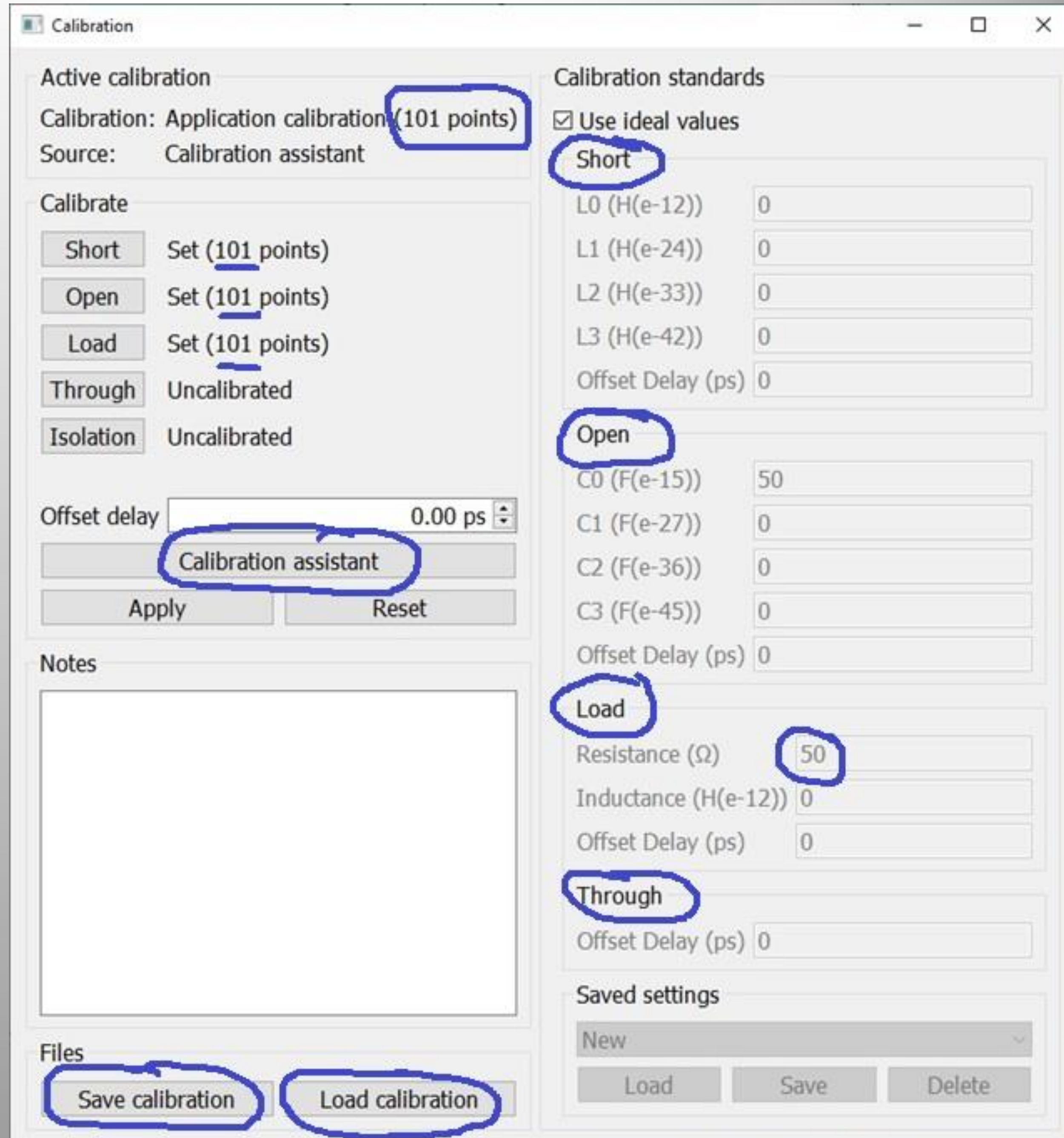
Do a calibration first
Calibration "assistant"

take min of 101 readings

SHORT
OPEN
LOAD
THROUGH two ports
ISOLATION two ports

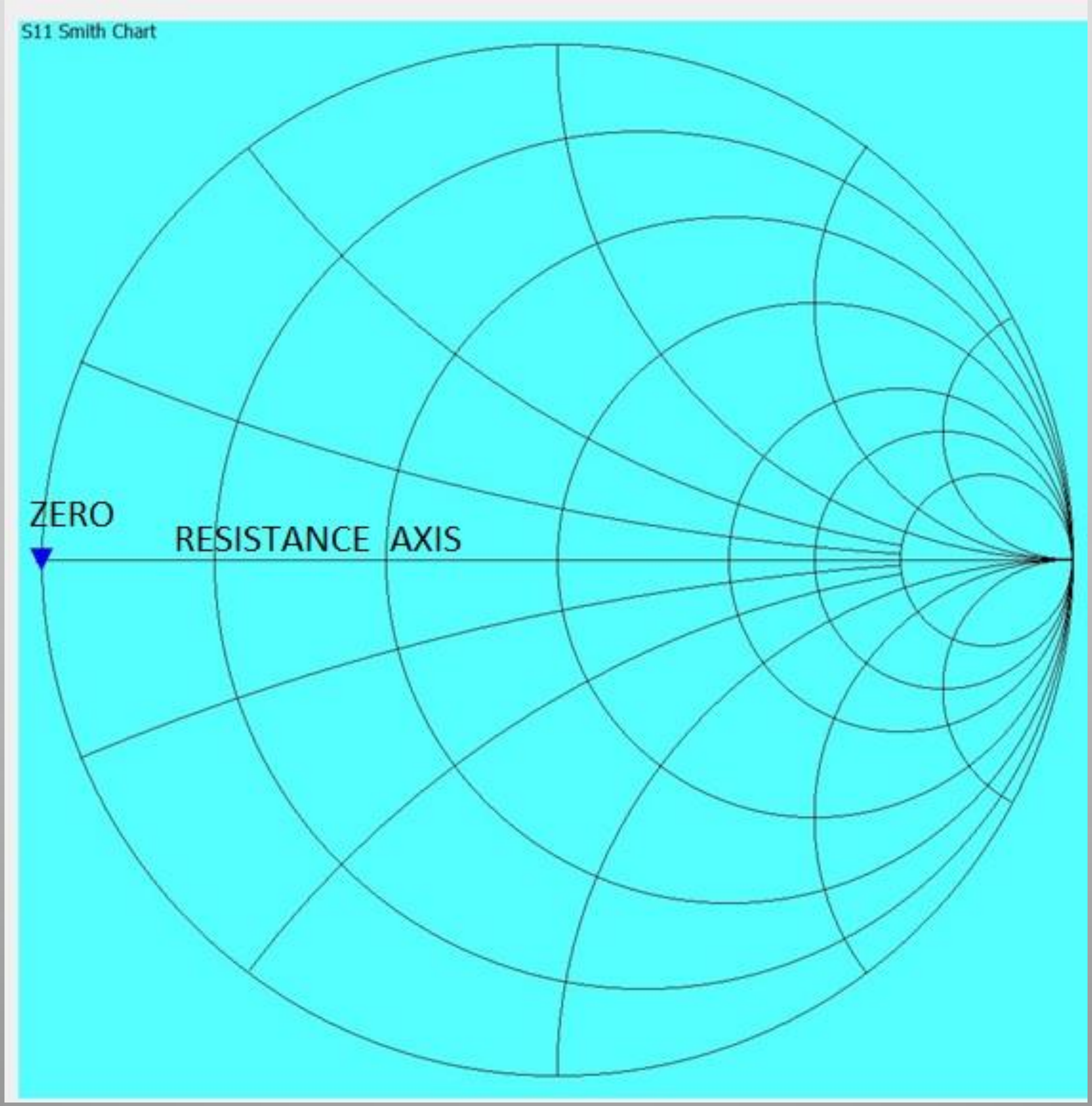
SAVE CAL files

You can use up to 5000 data points to plot

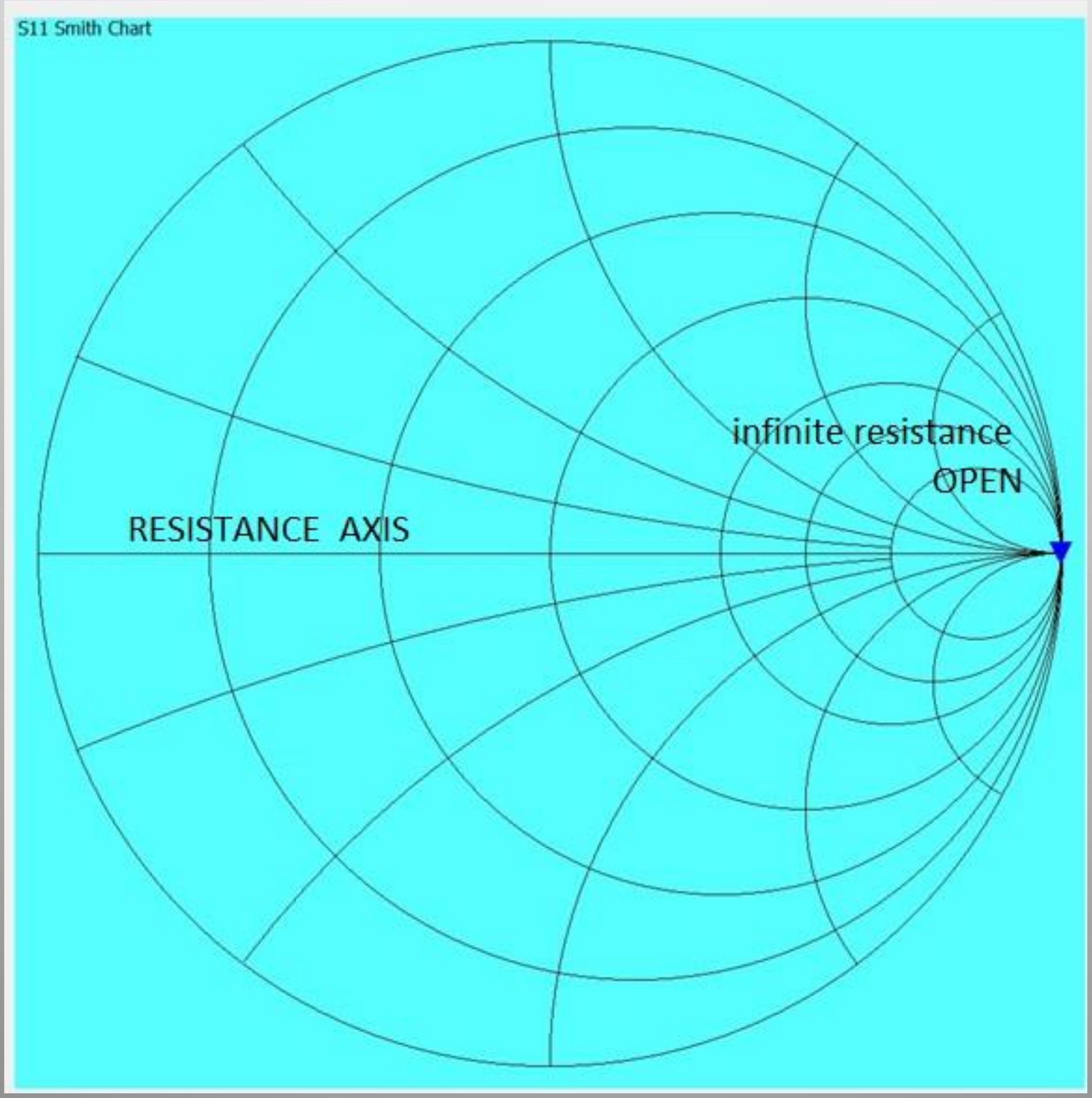


First Step: **CALIBRATE** VNA over a frequency range (MHz)
Calibration standards included as **SMA connectors**
Short, Open, Load (50-ohm), and Through

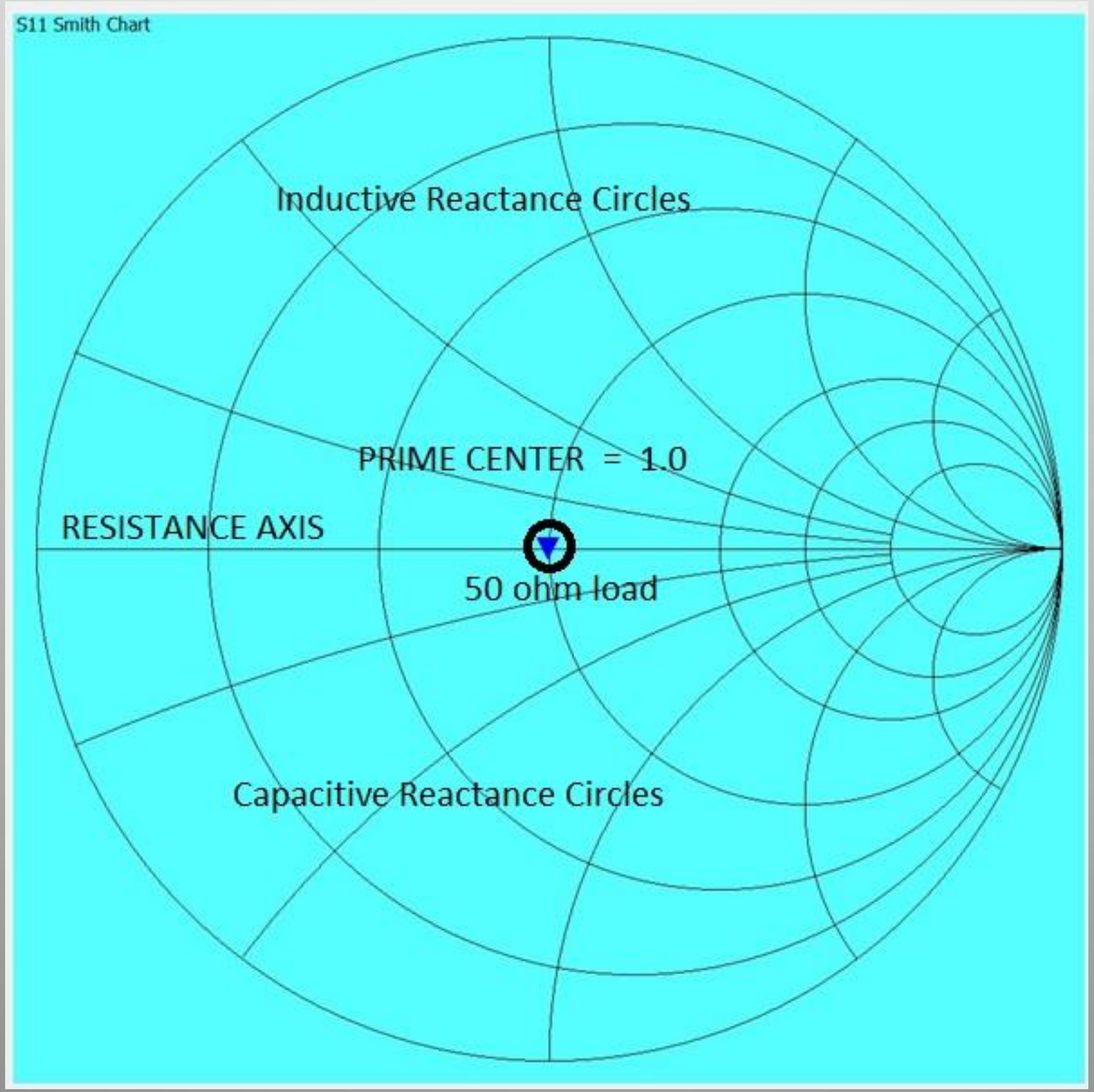
Calibration: **SHORT** circuit (ZERO R) on far left of the Smith Chart RESISTANCE axis



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



Calibration: <u>**50-ohm**</u> **LOAD (prime center)**
middle of the RESISTANCE scale: normalized to **1.0**

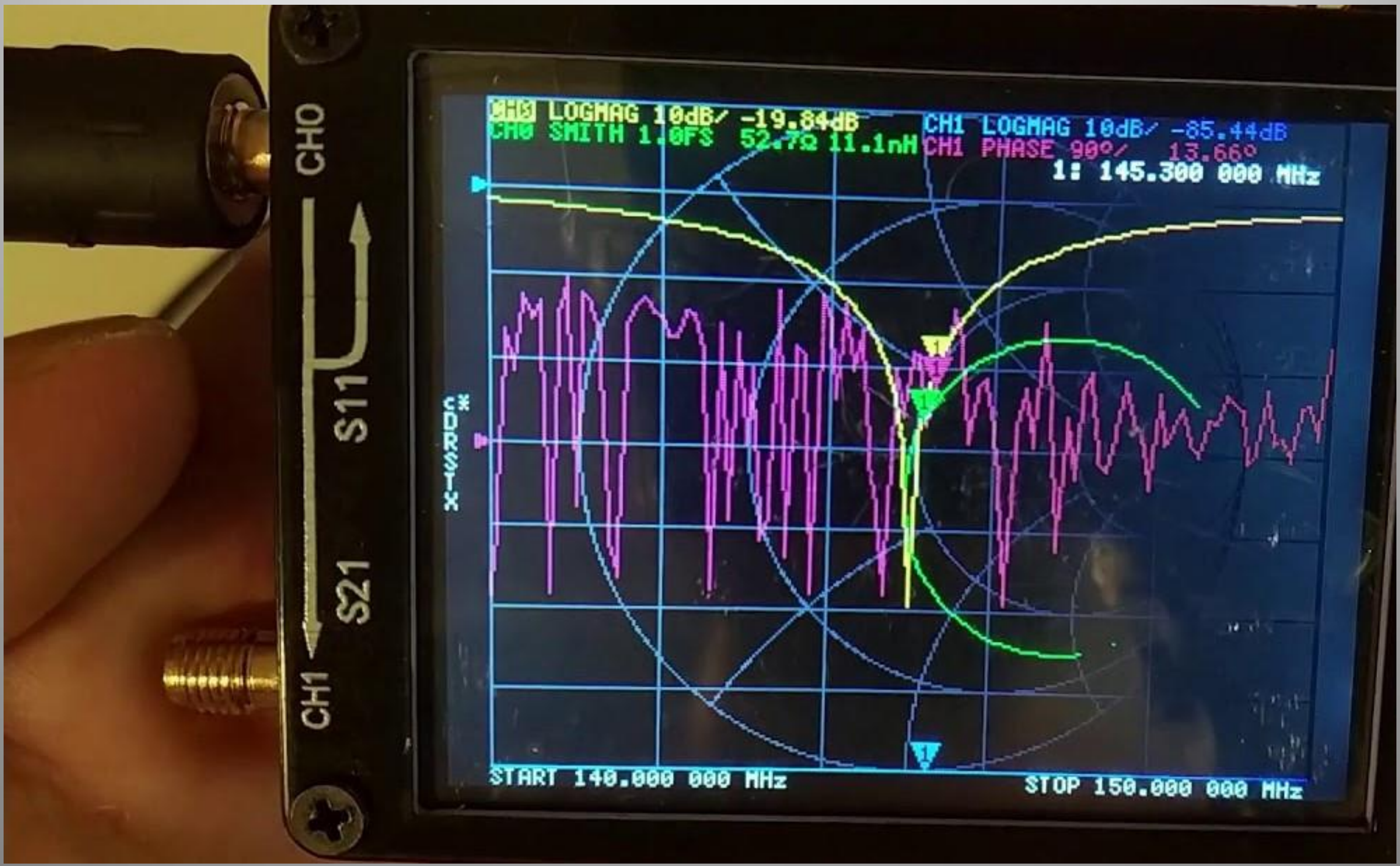


You can also CALIBRATE the device

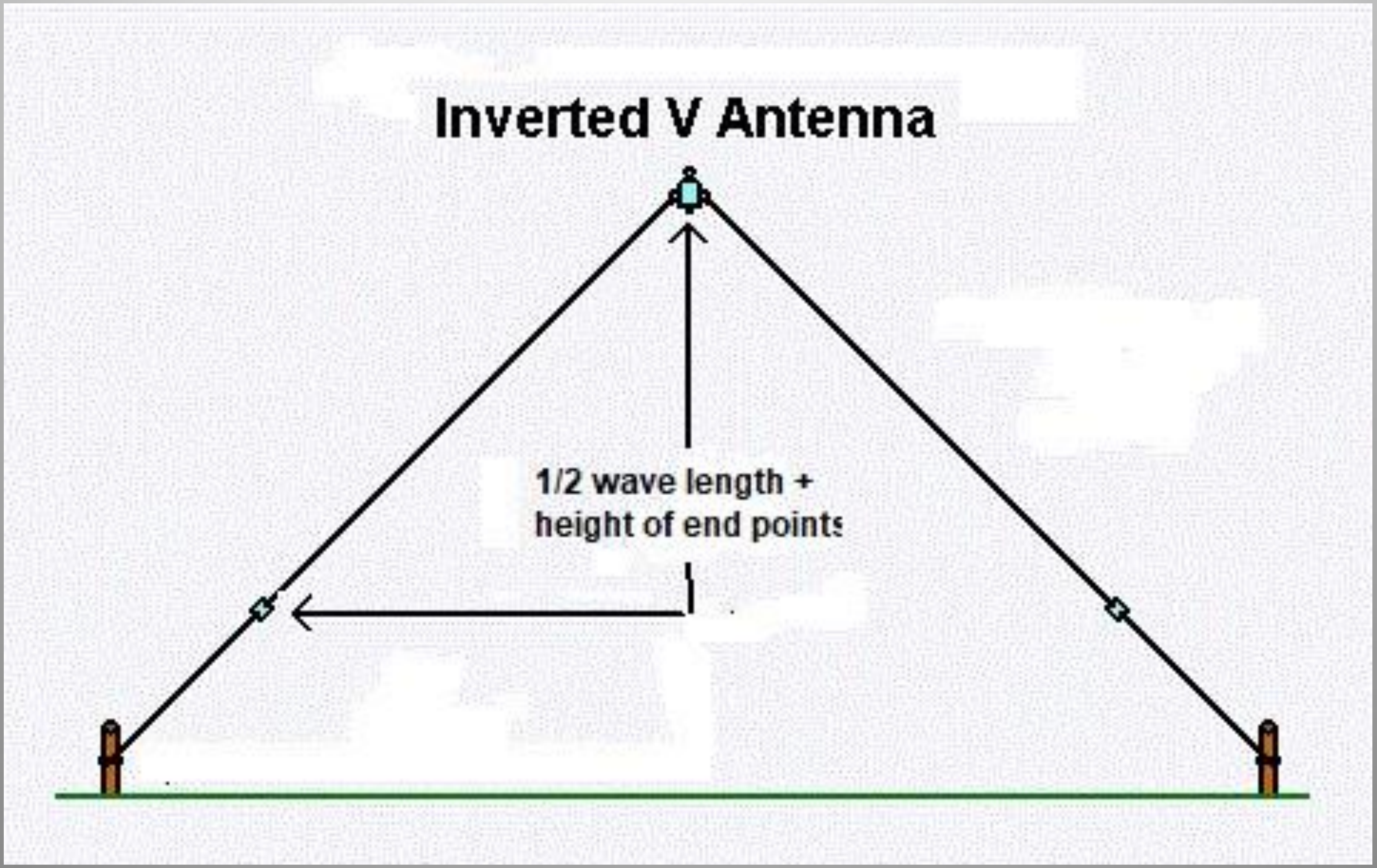
on its own (small) screen: limit of <u>101 data points</u>

Let's put the Nano VNA to work testing real antennas

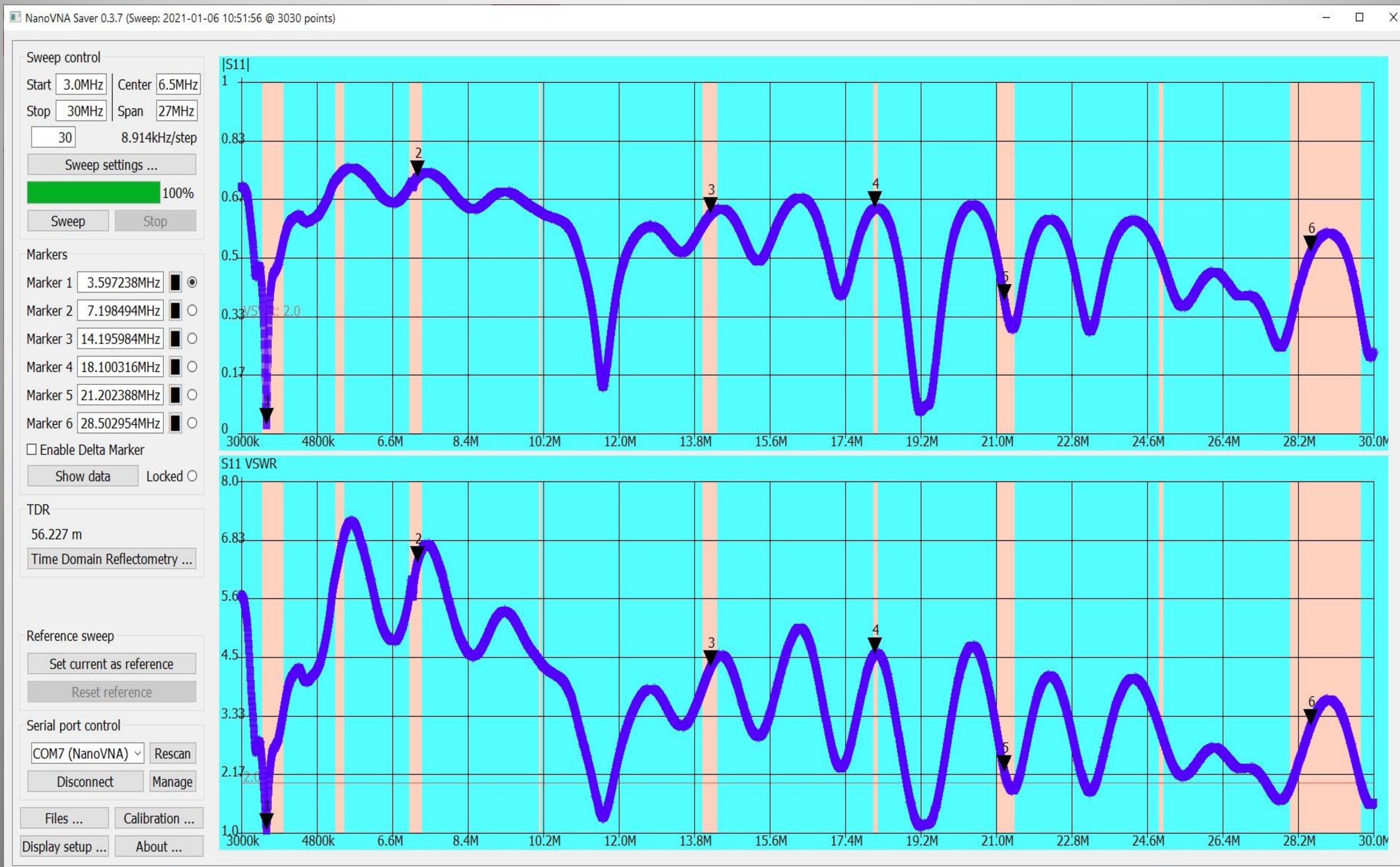
S11 = Signal goes out Ch0 and returns to same port



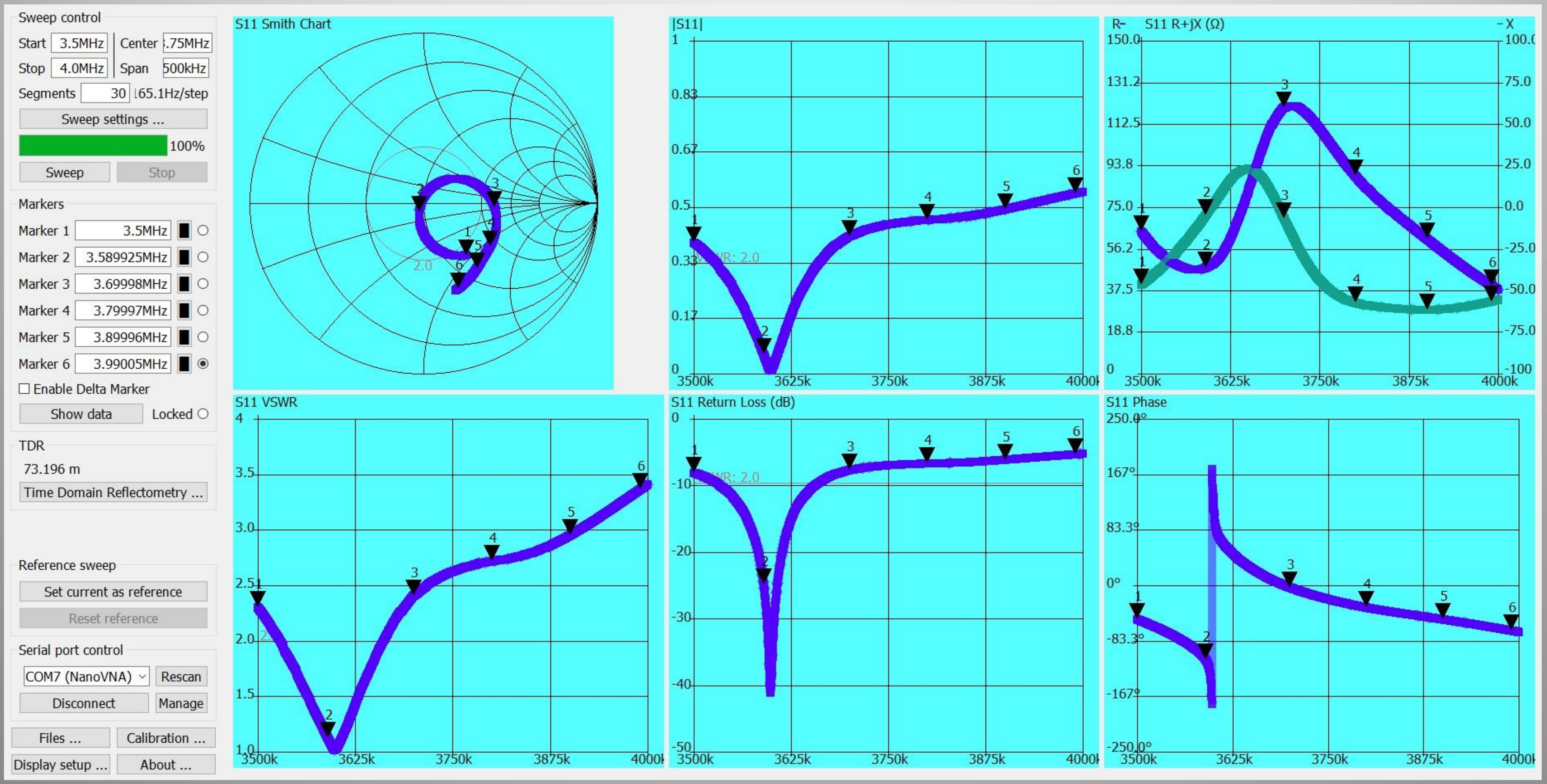
135 feet long 80 meter Inverted V antenna
center fed with 150 ft RG213 (50 ohm) and W2DU current balun
What are the resonant frequencies of this antenna?



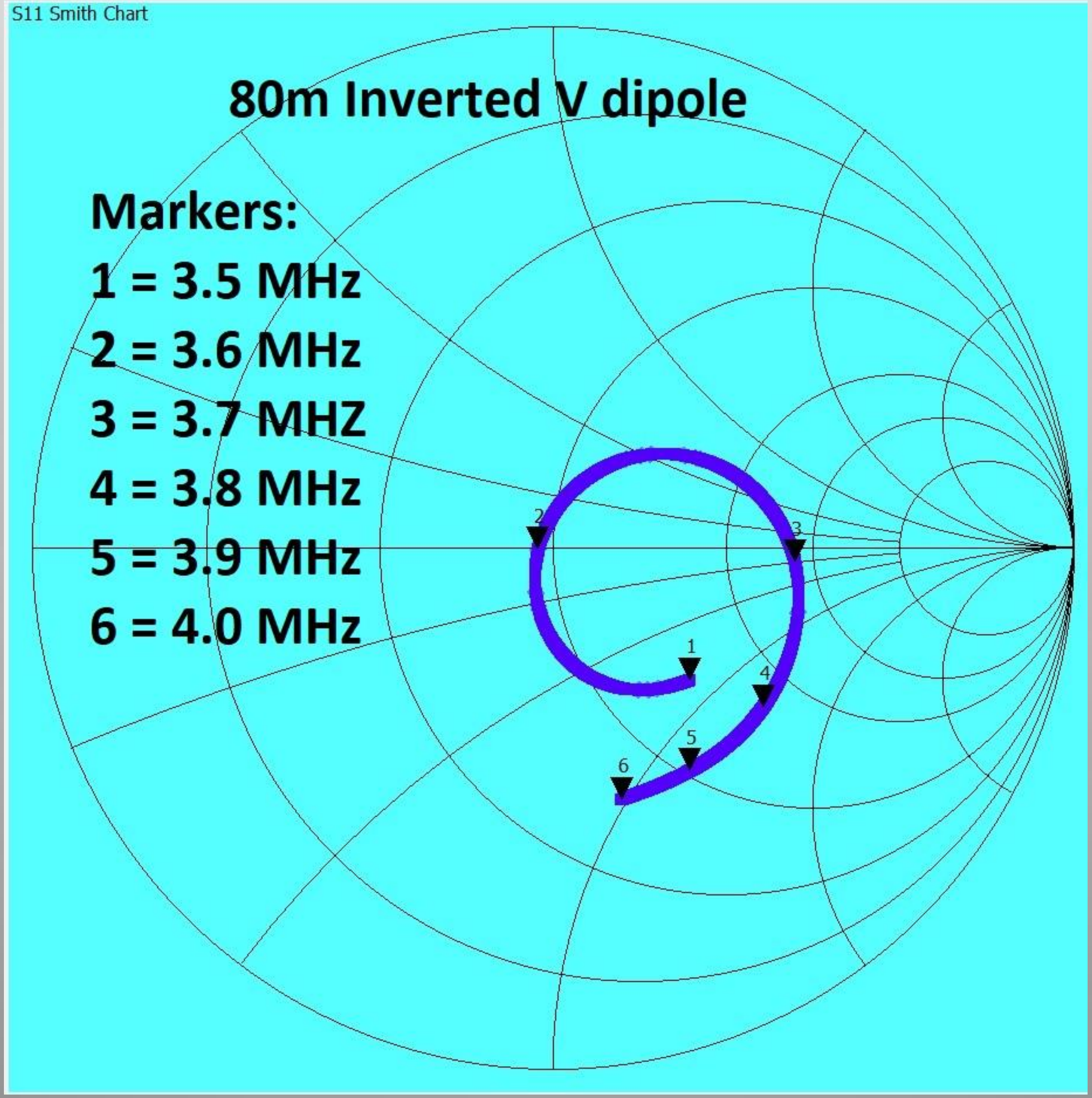
Reflection coefficient S11 and SWR plot
VERY low SWR at 3.6 MHz
Note resonant odd “harmonics” are not in ham bands



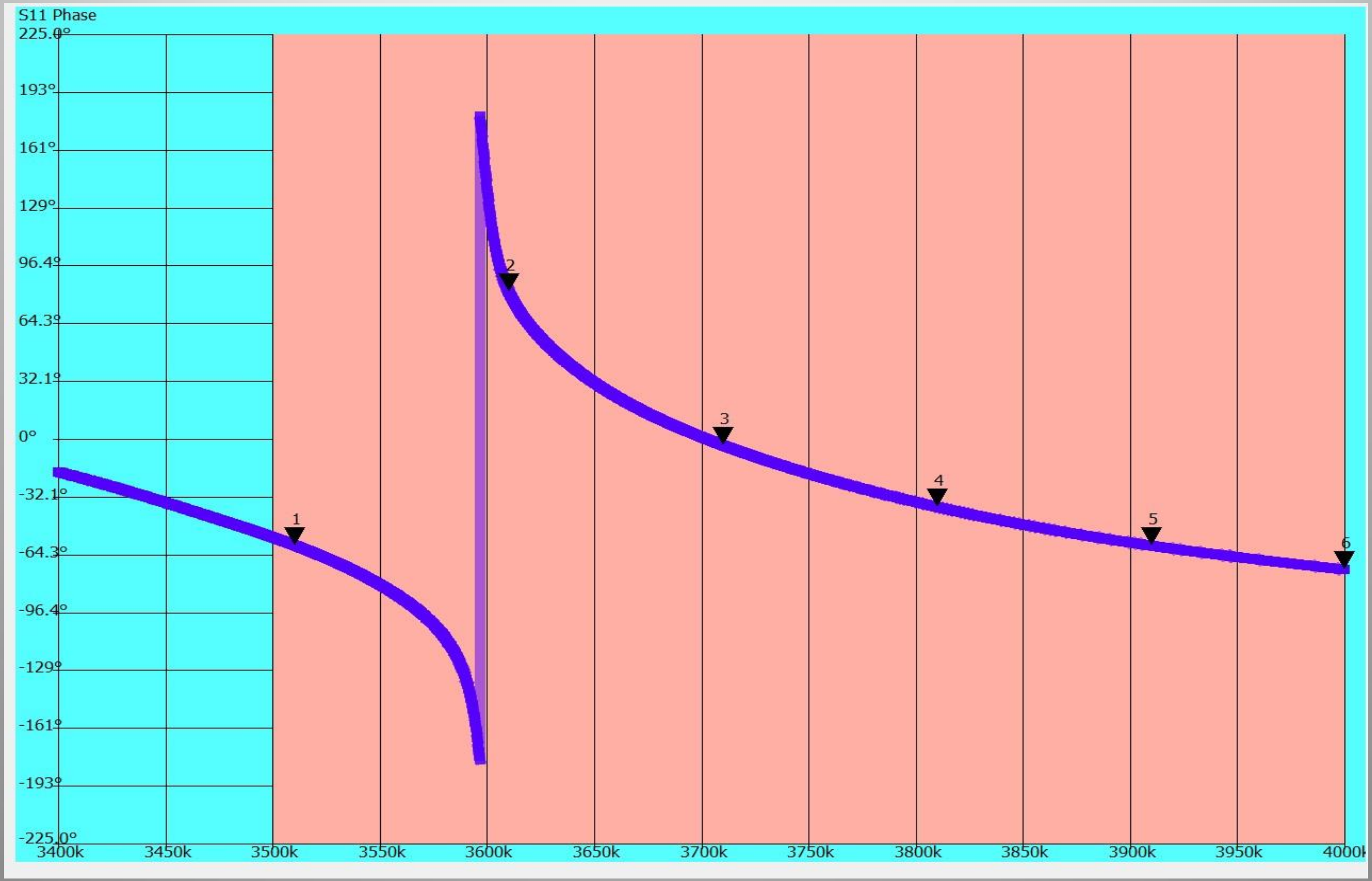
80m Dipole measured from my SHACK: 3.5 to 4.0 MHz
note where the SWR of 2.0 is on Smith Chart
What is the PHASE graph revealing?



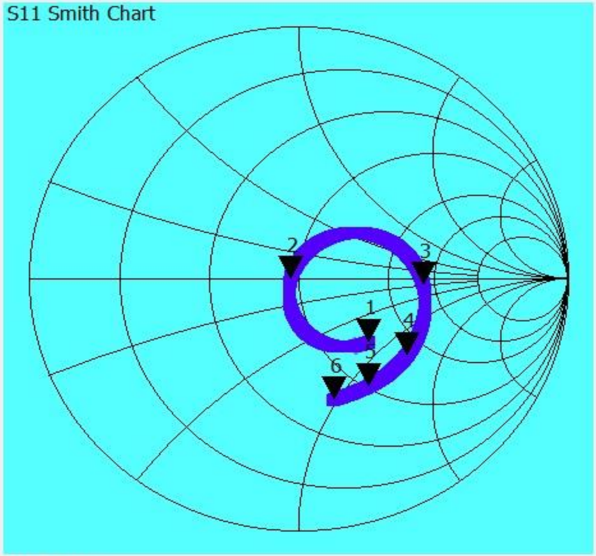
Smith Chart tells you everything you want to know
What TWO frequencies show zero reactance (resonance)?
Where is the lowest SWR on the band?

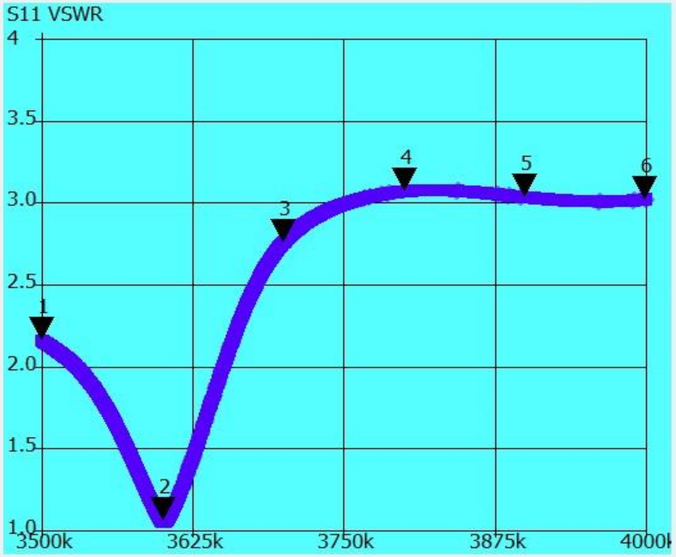


Resonance (3600 kHz) is easy to spot on this PHASE PLOT

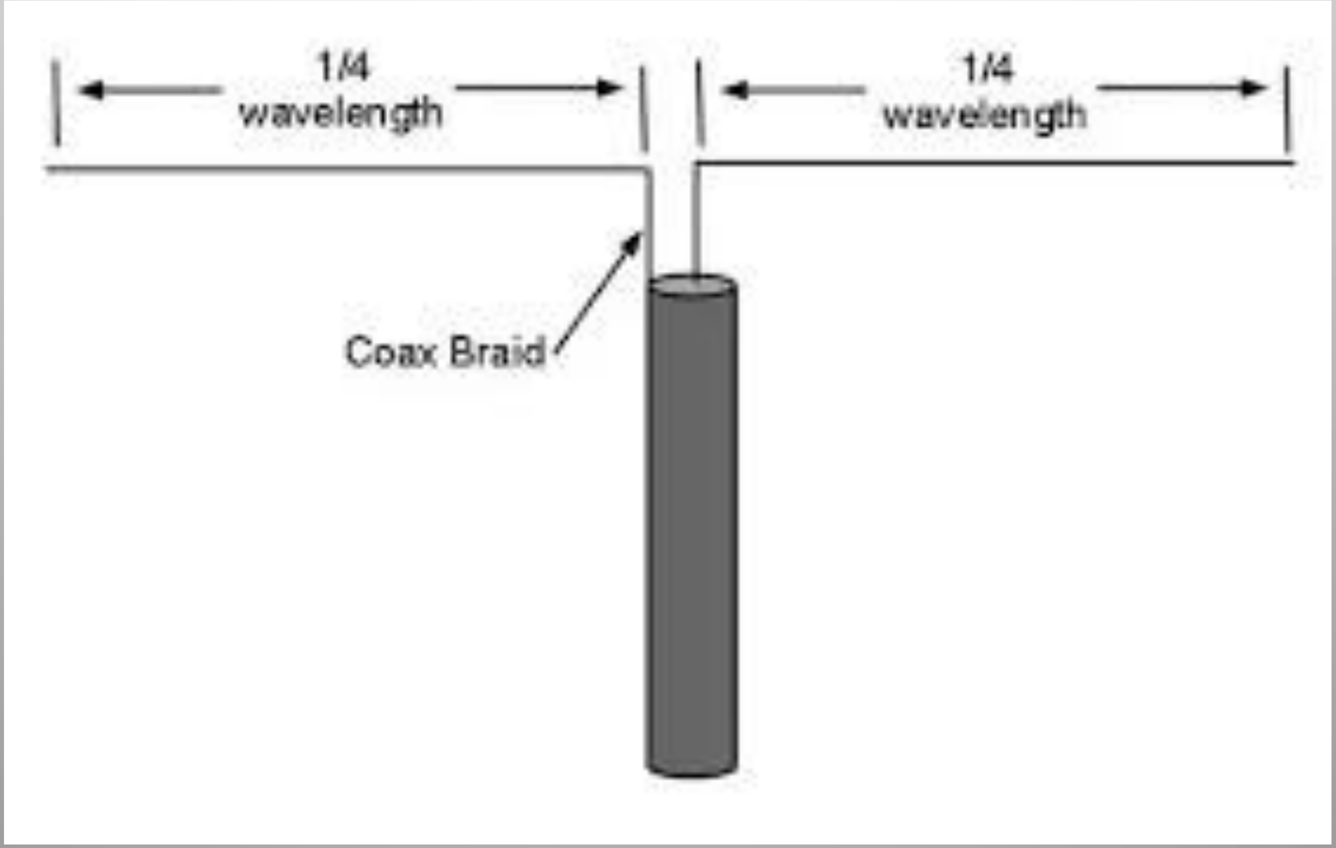


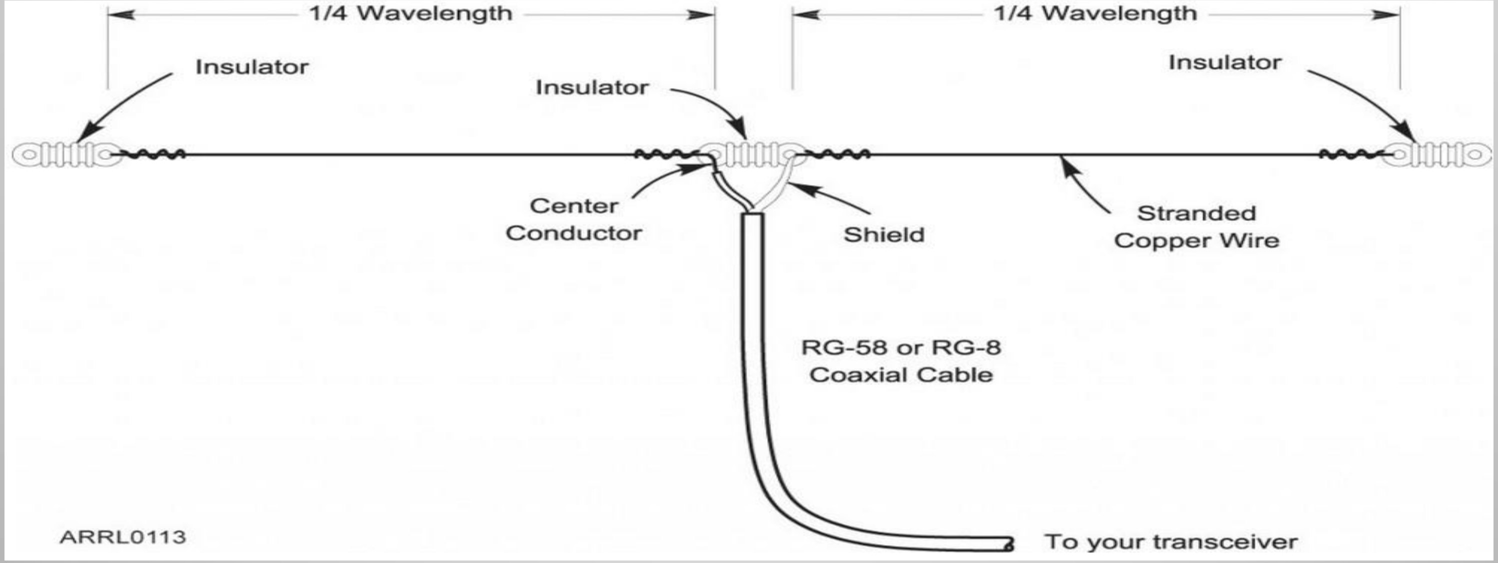
Can I QSY to the PHONE portion of band Marker # 5?
Ooops…. I see the SWR = 3:1 at 3900 kHz





I want to operate this dipole on the ENTIRE 80 m band
But the SWR is way too high at the low/high end of band





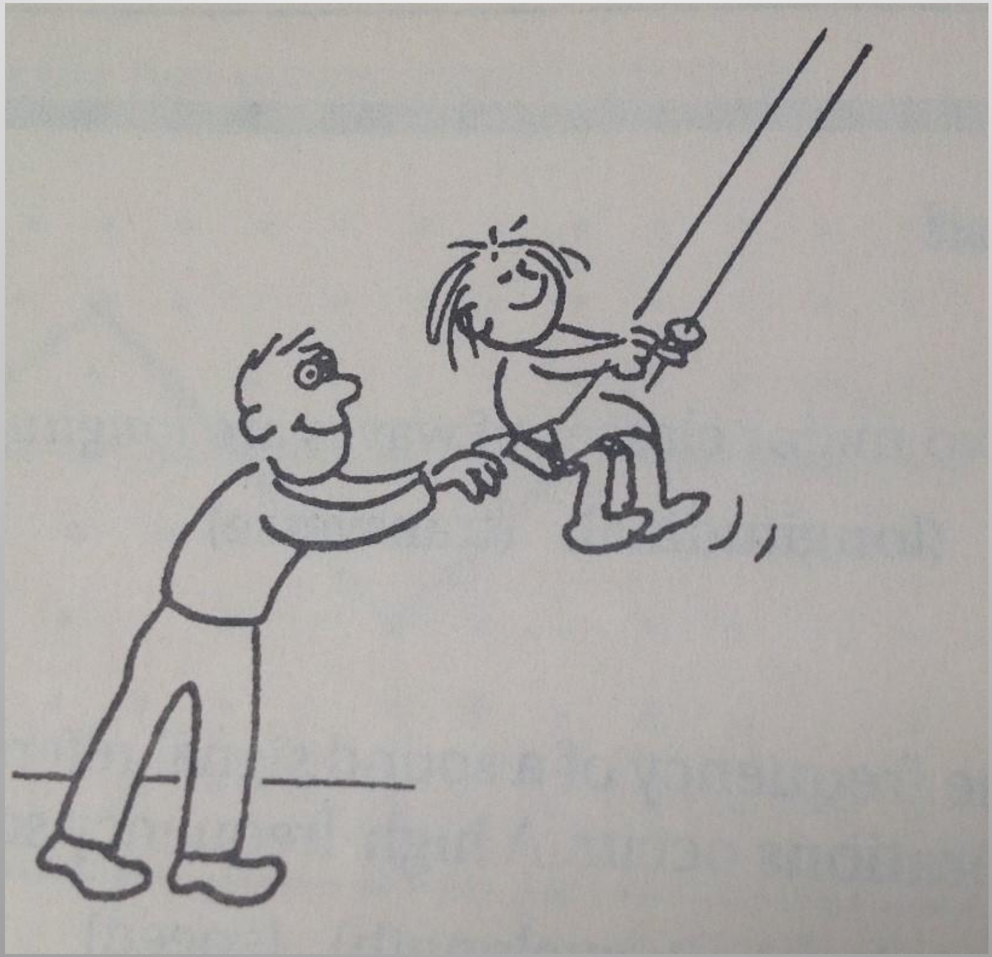
- Below resonance: the dipole is too short and the current leads the driving voltage (capacitive reactance)

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

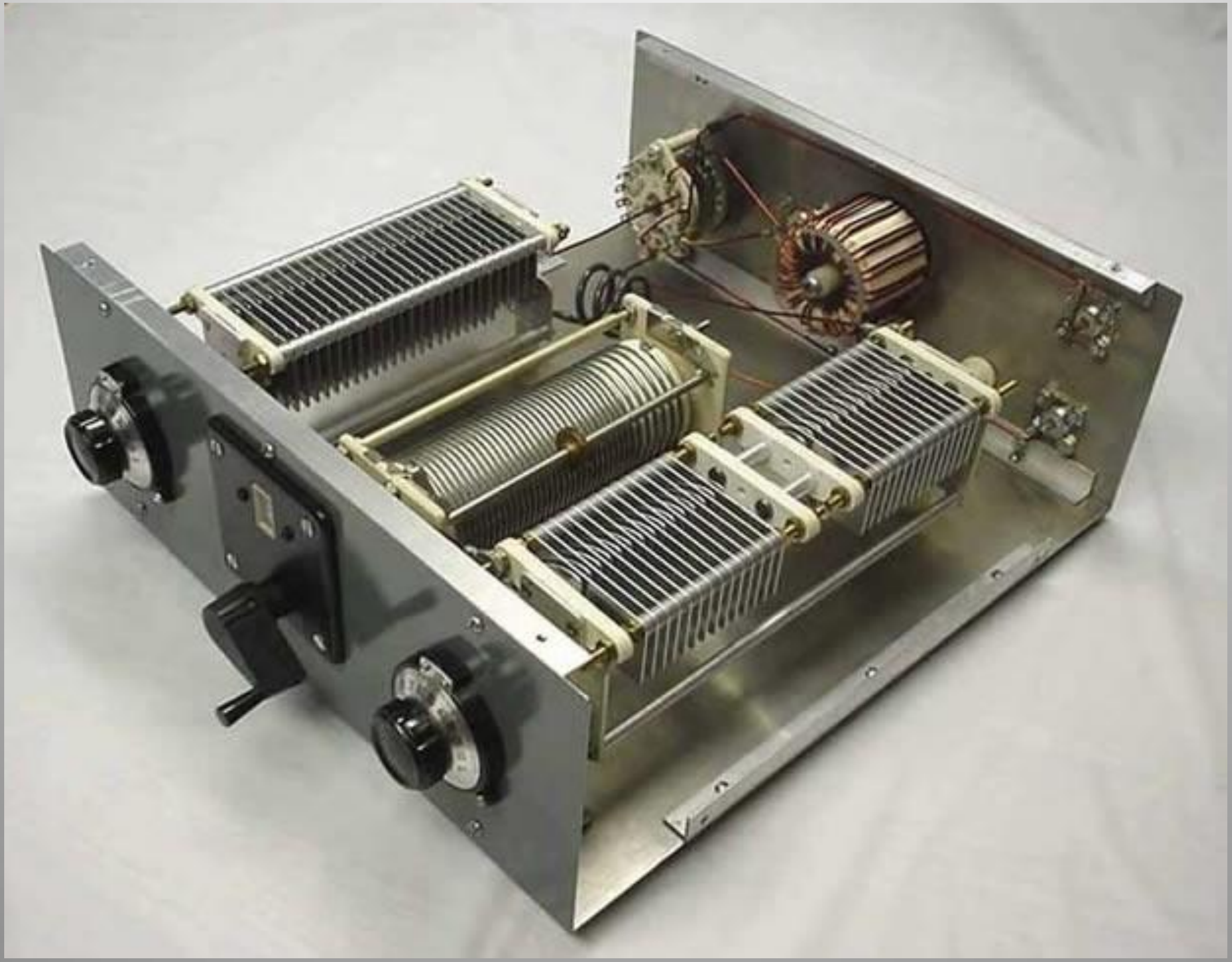
Do I have to shorten the antenna to operate at 3900 kHz?

Think like GRAMPY

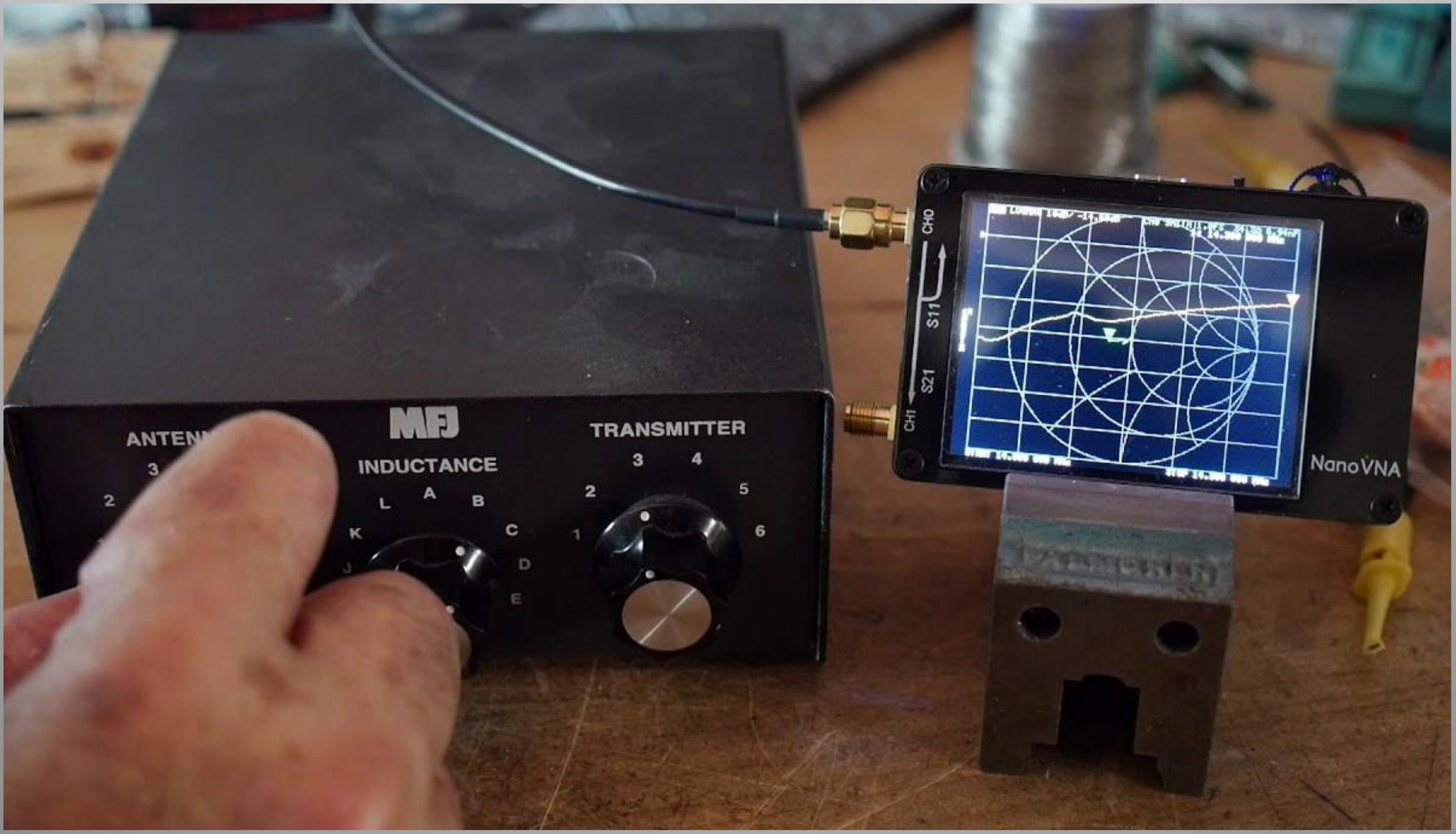
maybe there is a simple solution: how to cancel REACTANCE?



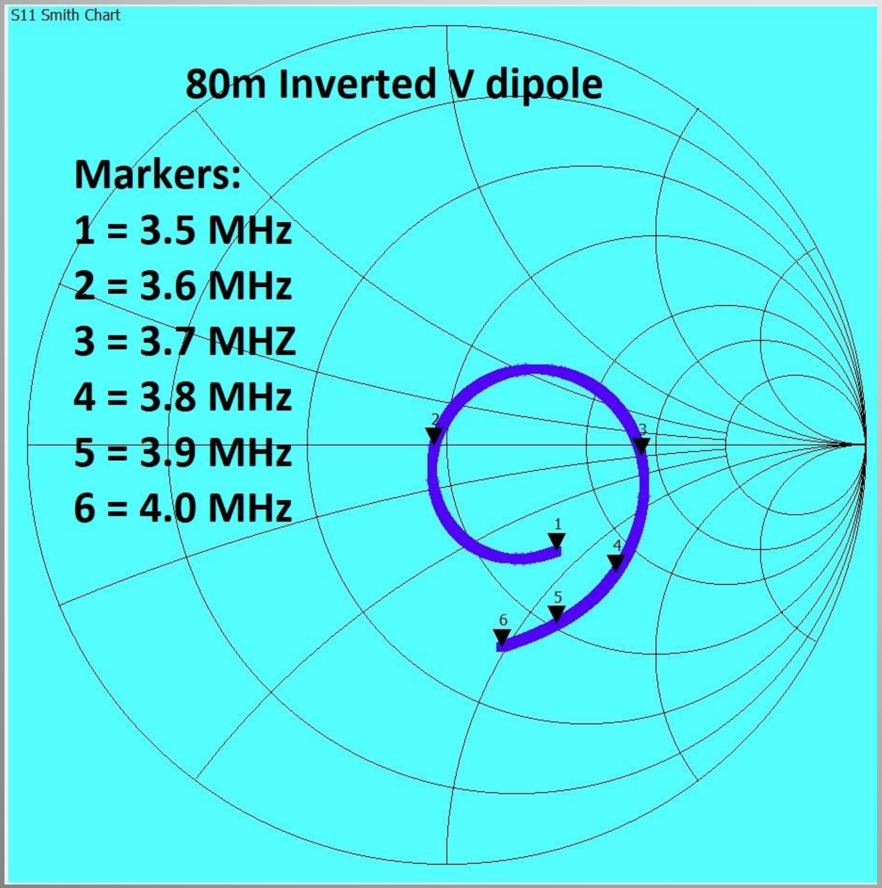
Tune out the REACTANCE in the shack by introducing a “**conjugate impedance**” in your antenna tuner

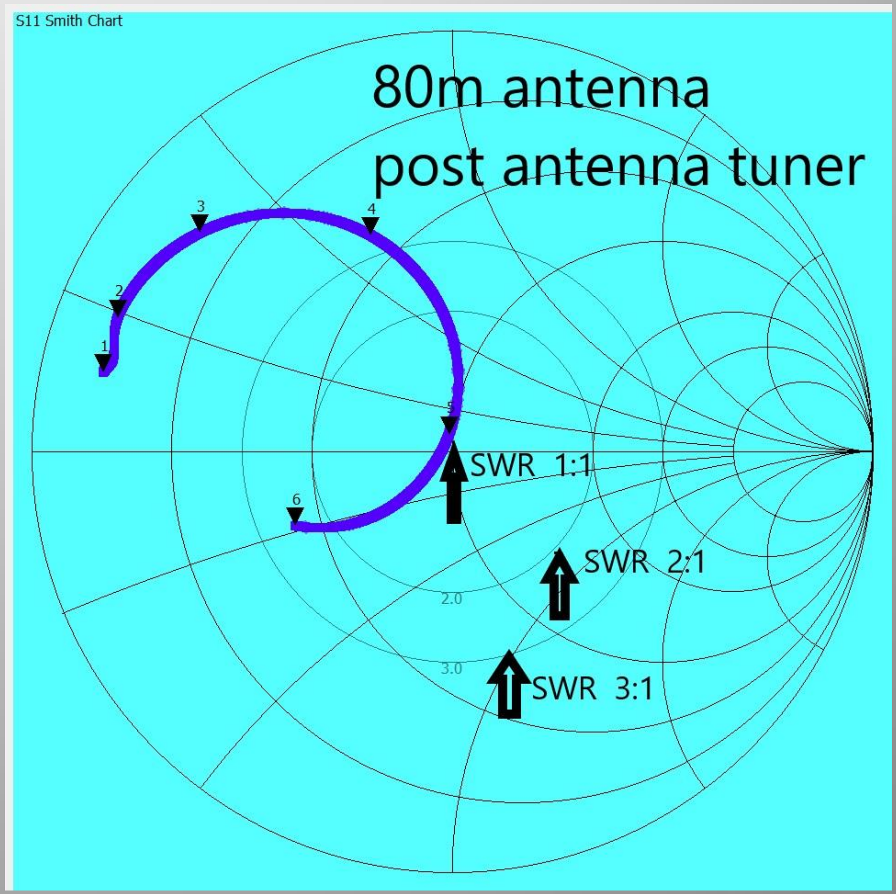


Use the VNA to adjust a manual ANTENNA TUNER
Where on the Smith Chart do you "want" the cursor?



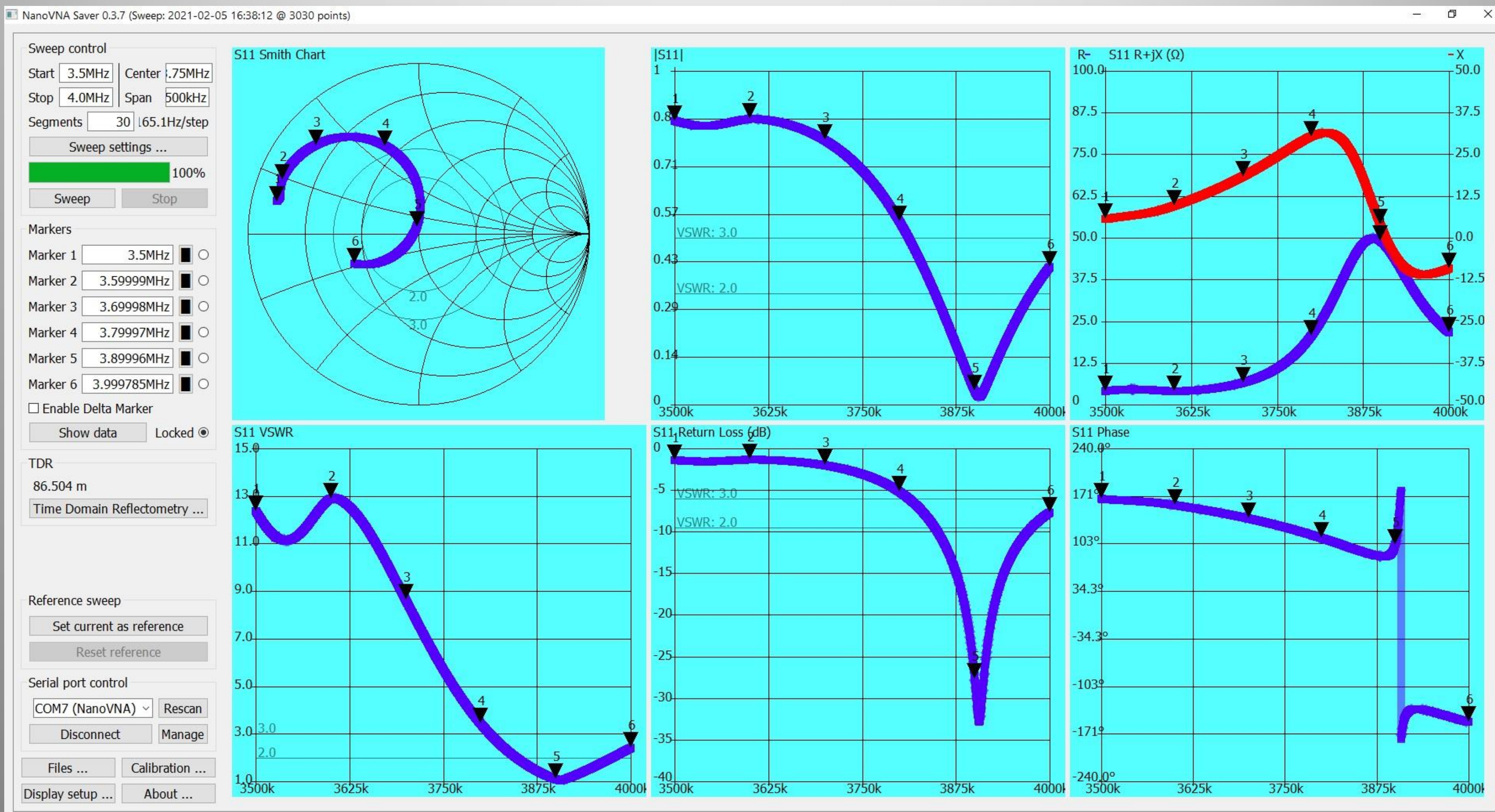
Before and After Antenna Tuner
Lowest SWR moved from 3600 to 3900 kHz



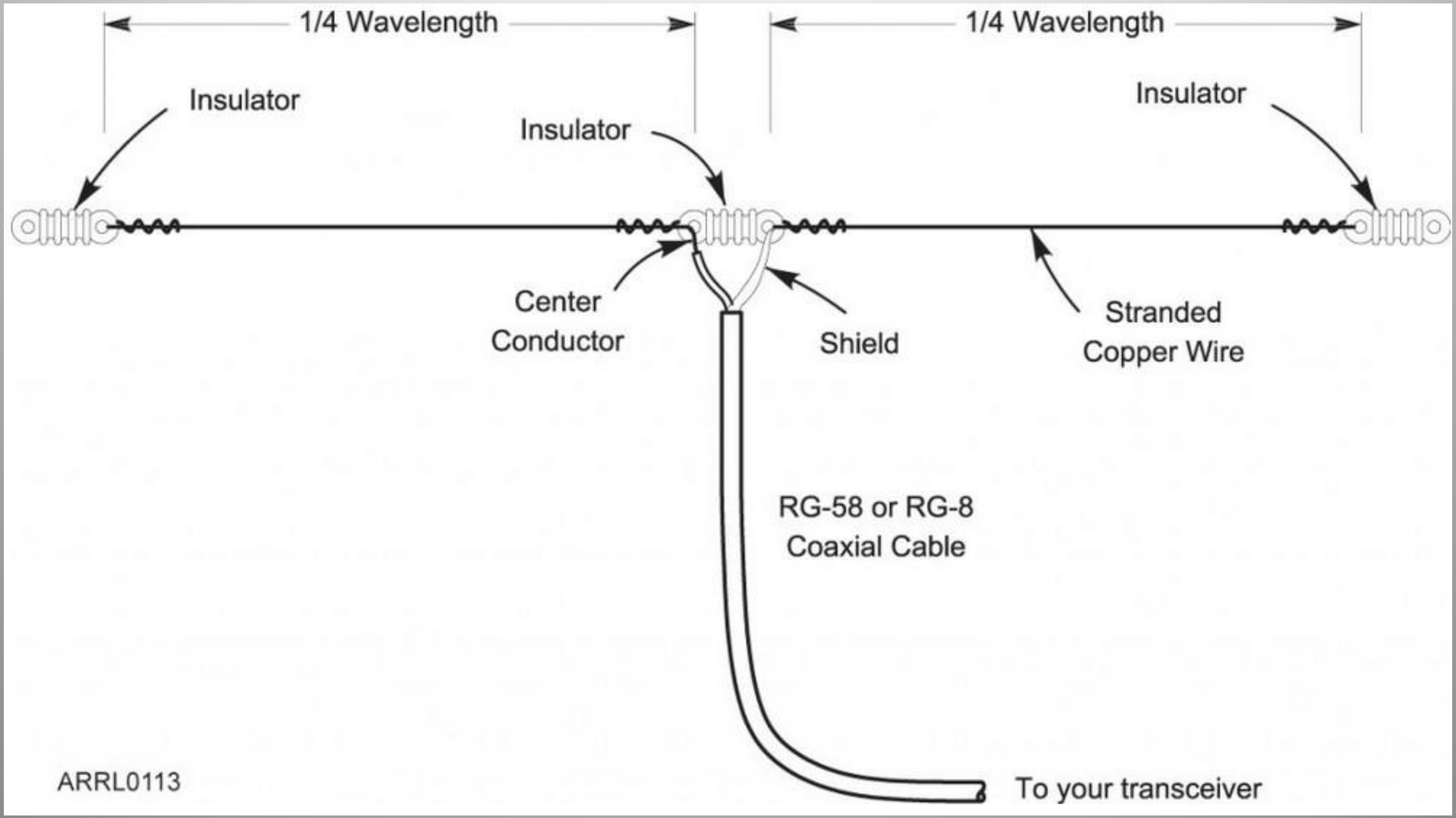


Same 80m antenna but now “tuned” to 3900 kHz (PHONE) by an antenna tuner <u>in the shack</u>

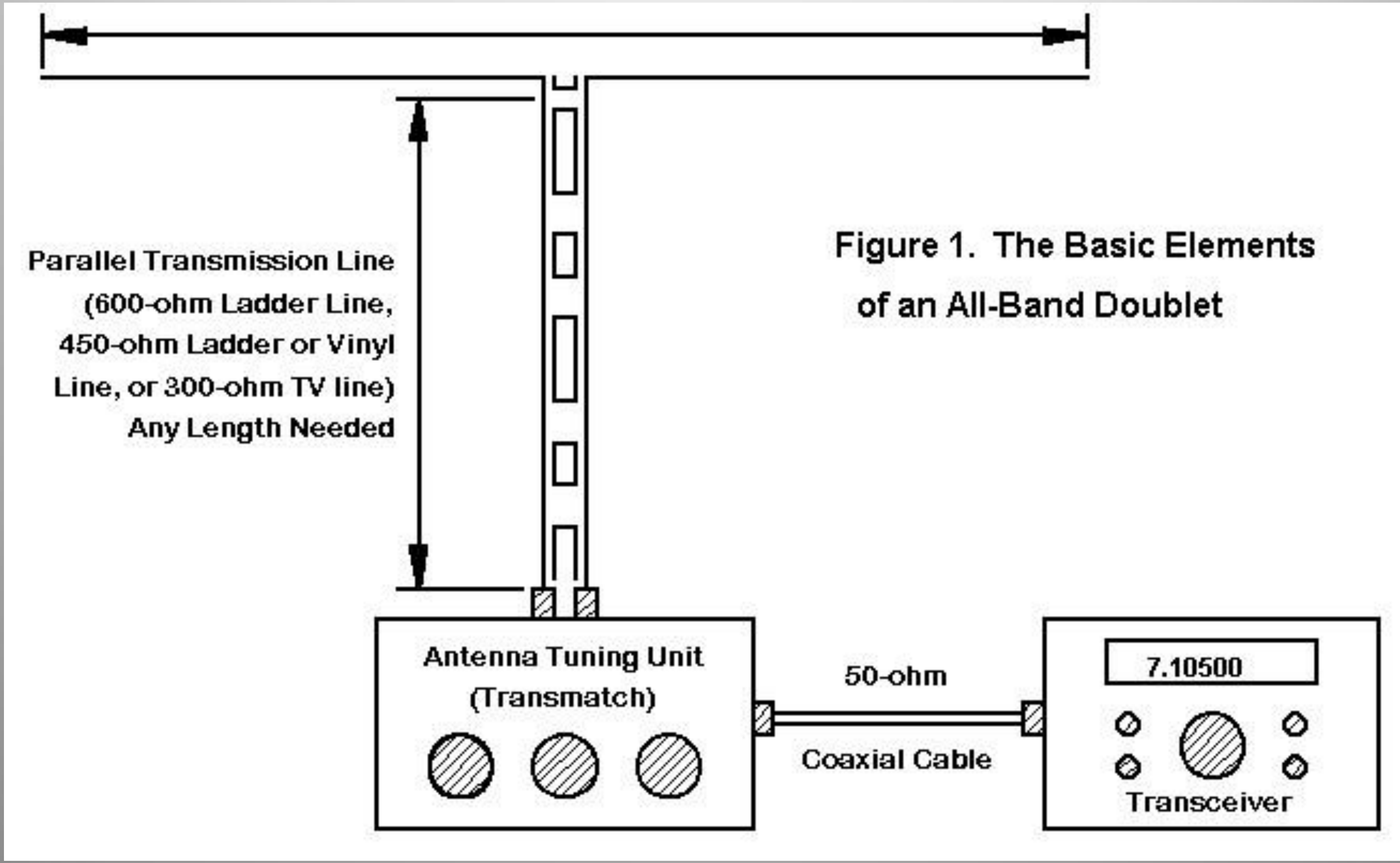
Note the rotated Smith Chart impedance graph and note the new lowest SWR frequency is 3900 kHz



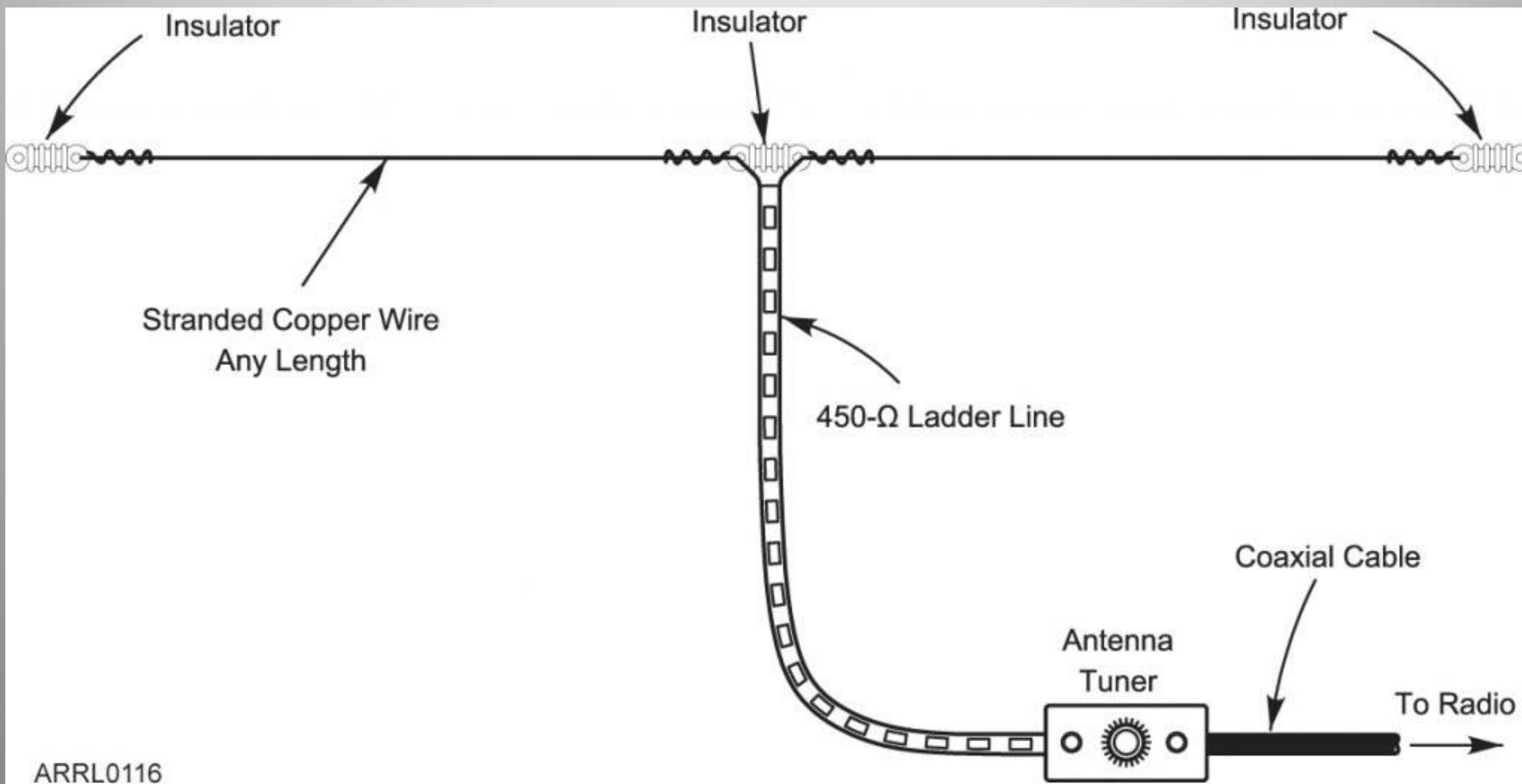
So does the **antenna itself** need to be **resonant** to work well on all bands?



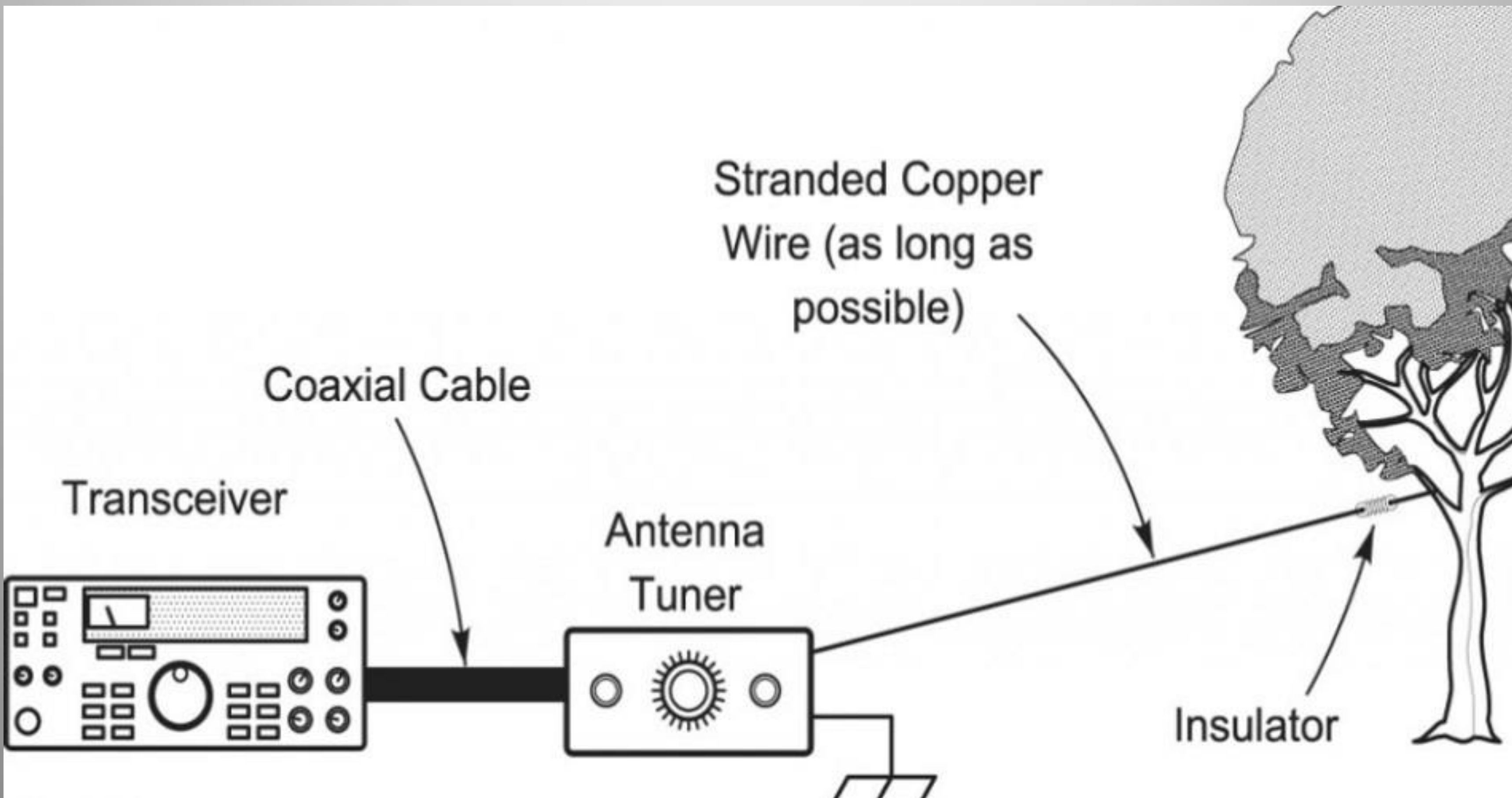
The “tuner” allows the rig to see 50 ohms Z
But has the SWR changed on the ladder line to the antenna?



130 ft Center Fed dipole with
Low-Loss BALANCED Ladder Line
can work on all HF bands with TUNER in the shack
WHERE is the SWR low in this image?



This “random” length <u>non-resonant</u> wire can work well on many HF frequencies with some help from an antenna <u>“tuner”</u>
What exactly is the antenna tuner “tuning”?



Now don’t you wish you owned one of these devices?