Antenna Analyzers

What are they and what are they good for?

E. LeBlanc

W7EFL

Parts of Analyzer

- RF signal generator with variable frequency
  - You need to be able to inject RF in the antenna to measure electrical characteristics
  - Low-power transmitter (yes, it does make some RFI)
- RF detector
  - Need to be able to detect the RF injected
  - Essentially a receiver
- Measurement circuit
  - Meter, graphic display, etc.
  - Some instruments have memory and other computation/display functions

Antenna measurement

- Antenna resonance
- Antenna impedance (some, but not all instruments give direct ±**j**X measurements)
- You can take the instrument to the antenna feed point to avoid transmission line loss interfering with measurement.
- Some instruments can cancel out the feedline to virtually place the instrument at the antenna feed point

SWR measurement

- Most analyzers give a direct measurement of SWR.
- You don't need to measure forward power, reflected power, and plug in the numbers.
- Line loss can mask SWR because the reflected power is dissipated in the line as well as the forward (incident) power.
- It is easier to read SWR off the analyzer meter than to calculate it.
- You don't need to use high-power and contribute to RFI.
- You can measure SWR outside of the ham band (helpful when trimming an antenna to length)
- Some instruments are capable of SWR measurement at other than 50Ω so be sure you are using the correct Z_0 impedance setting.

What is SWR?

- SWR is an abbreviation for standing wave ratio.
- You may also see VSWR or iSWR, indicating voltage or current respectively.
- Standing waves occur when a waveform hits a discontinuity in the transmission line and a portion of the power is reflected.
  - Discontinuity – a change in impedance.
  - A coaxial cable with a characteristic impedance (Z_0) of 50 Ω connected to an antenna with a resistance of 100 Ω will result in reflected power and SWR. In this case the SWR is 2:1.
- Maximum power transfer occurs when the source impedance is equal to the complex conjugate of the load impedance.

Reflection coefficient and SWR calculation

- The reflection coefficient is frequently represented by Γ (gamma), where **Γ** = $\mathbf{V}_R/\mathbf{V}_F$ or **Γ** = $(\mathbf{Z}_L - \mathbf{Z}_0) / (\mathbf{Z}_L + \mathbf{Z}_0)$. **Bold font** indicates phasor or complex value.
- **Γ** takes into account any complex components, however only the magnitude is required to calculate SWR. The magnitude of the reflection constant is represented by ρ (rho). $\rho = |\mathbf{\Gamma}|$
- If you have a directional wattmeter, you can determine ρ from the forward and reverse power measurement while transmitting.
- $\rho = \sqrt{(P_R/P_F)}$
- SWR = (1+ρ)/ (1-ρ)
- Since SWR = (1+ρ)/ (1-ρ), if ρ = 0, SWR = 1:1. 1:1 is perfect.
- As ρ approaches 1, the SWR approaches ∞.

Standing waves—an example.

- Take the example of a (lossless) coaxial cable with a characteristic impedance (Z_0) of 50 Ω connected to an antenna with a resistance of 100 Ω and push 50 watts into it. $P = V^2/Z_0$ so V = 50 V.
- For a 2:1 VSWR to exist, there must be a reflected voltage V_R that adds to and subtracts from 50 V to result in a ratio of 2:1.
- V_R turns out to be 16.66 V to create a maximum V of 66.66 V and a minimum of 33.33 V.
- Reflected power is $P_R = 16.66^2/50\ \Omega = 5.6$ watts.
- With SWR of 2:1, about 11% of the incident power is reflected.

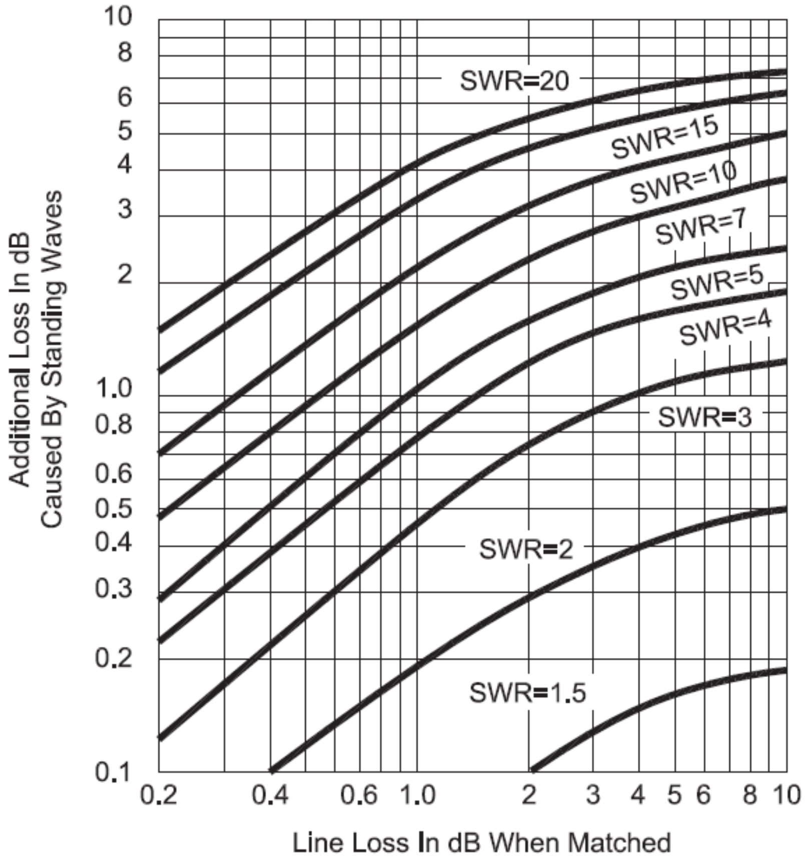
Summary of SWR example

- Transmitter sends 50 W incident power down a 50 Ω line terminated in a 100 Ω antenna.
- A reflected wave of 16.66 V RMS is sent back towards the transmitter.
- At points spaced λ/2 along the line, V_R adds to the forward 50 V resulting in 66.66 V maxima along the line.
- At points displaced λ/4 from the maxima along the line, V_R subtracts from the forward 50 V resulting in 33.33 V minima along the line.
- SWR is simply the ratio of maximum to minimum values in the standing wave.
- Power reflected is 5.6 W.
- Power delivered to the antenna is 44.4 W.

Why you should be (somewhat) concerned about high SWR

- High SWR results in reduced efficiency.
- High SWR results in increased loss in transmission line.
- Your transmitter or amplifier may not “like” operating into a high SWR.
  - An antenna tuner can make the transmitter happy.
  - An antenna tuner is actually an impedance matching circuit, it does not “tune” an antenna!
  - The most effective location for an impedance matching circuit is at the location of the discontinuity.
- High SWR increases voltage stress on feedline dielectric.

Additional feedline loss due to SWR



How high is "high" SWR?

- While 1:1 is definitely low SWR, defining high SWR is more difficult and it depends. . . .
  - What can your transmitter or amplifier tolerate?
  - If you are using an antenna tuner, how much mismatch can it compensate for?
  - How much additional loss are you willing to tolerate in your feedline?
- Generalizations (always risky to make).
  - 2:1 is pretty good.
  - Most tuners can match 3:1.
  - Frequently SWR of 6:1 is not a real problem.

Transmission line measurements

- Electrical length
  - Since open-ended transmission lines have zero reactance (X) at lengths that are odd multiples of $\lambda/4$, it is a simple matter to determine the frequency that corresponds to $\lambda/4$.
- Velocity factor
  - Velocity factor (VF) is easily determined once you can determine electrical length.
  - VF is needed if you are going to make phasing harnesses or impedance matching stubs.
- Physical length
  - A tape measure is usually easier.
- Fault (short or open) location

Features

- The things that were important to me were:
- Must have
  - Coverage through 440 MHz
  - Good graphic display
  - Automatic frequency sweep
- Good to have
  - Computer interface
  - Smith chart

Three popular analyzers

- MFJ 269c
- Comet CAA-500 MkII
- RigExpert AA-600

MFJ-269c

- Pro
  - Popular—many users
  - Good basic function
  - Analog meters
  - External power
  - $400 price point
- Con
  - Very touchy frequency adjustment
  - No automatic sweep
  - No memory/computer interface


POWER
ON
UHF
OFF
MFJ
14.260 MHz 1.0
Rs=50 Xs=0
MFJ HF/VHF/220MHz/UHF SWR ANALYZER
530 KHz - 230 MHZ + UHF
MODEL MFJ-269C
GATE
MODE
SWR
IMPEDANCE
FREQUENCY MHz
67-113
28-67
113-155
11-28
155-230
UHF
LOWER
RANGE
1.0-2.1
4.7-11.0
0.53-1.0
TUNE

Comet CAA-500 MkII

- Pros
  - Large analog meter
  - Digital readout
  - Bar graph
  - Auto sweep function
  - External power
  - $400 price point
- Cons
  - No computer interface
  - Separate N-connector for UHF (I am sure to have the antenna on the wrong connector)


SWR
OHMS
STANDING WAVE ANALYZER
21240
CAA-500
Mark II
1.8-500MHz
Sweep
Center
Graph
ON/OFF
BAND
FREQ.
COMET
ANTENNA

RigExpert AA-600

- Pros
  - Good computer interface
  - Supports Smith Chart (extra cost in US)
  - Only one RF input (N-type)
- Cons
  - No analog meter
  - Price point $600
  - Need to remove batteries to charge them
  - Battery charger

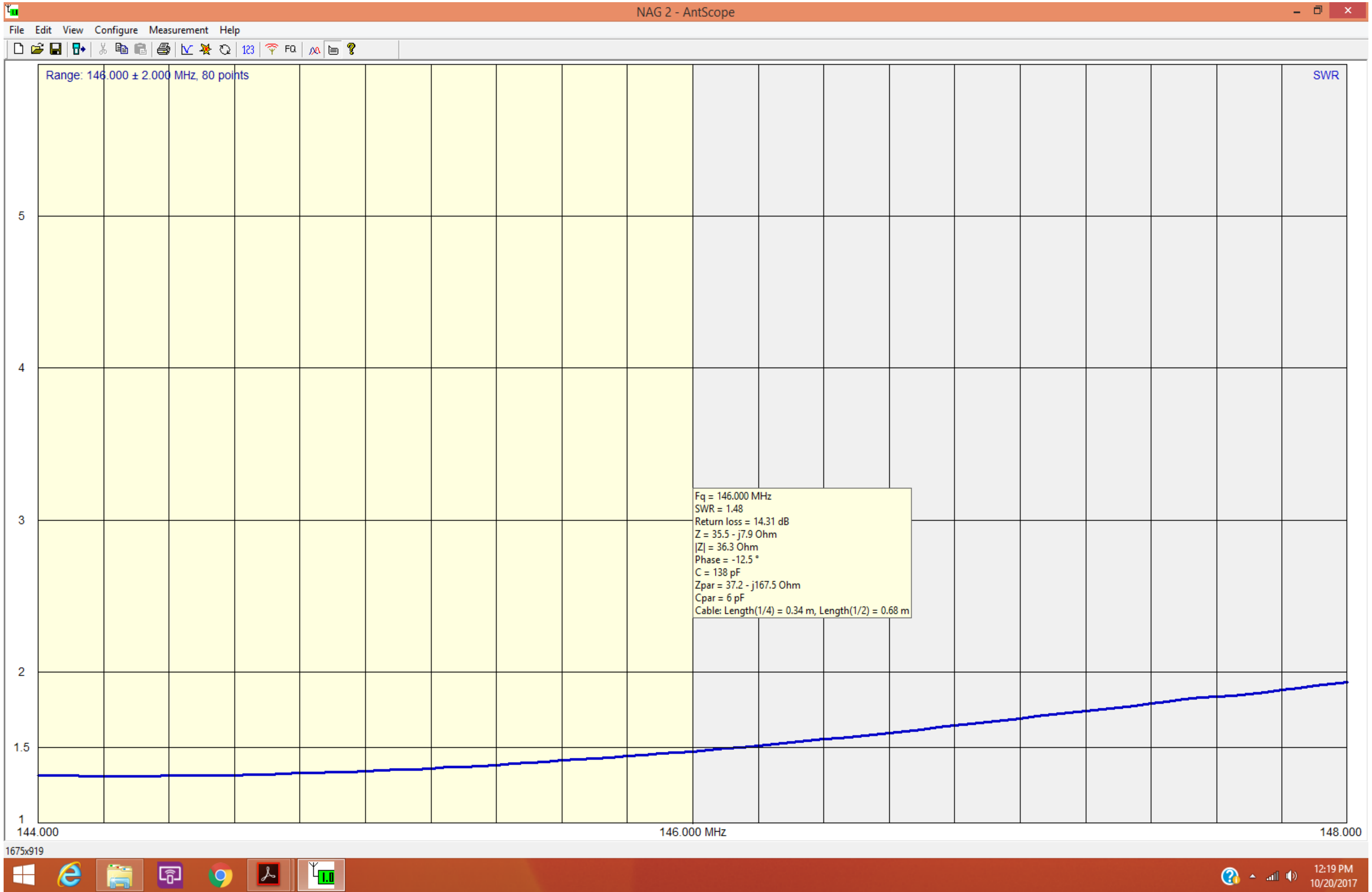

RigExpert
AA-600

A good selection of adapters is a must

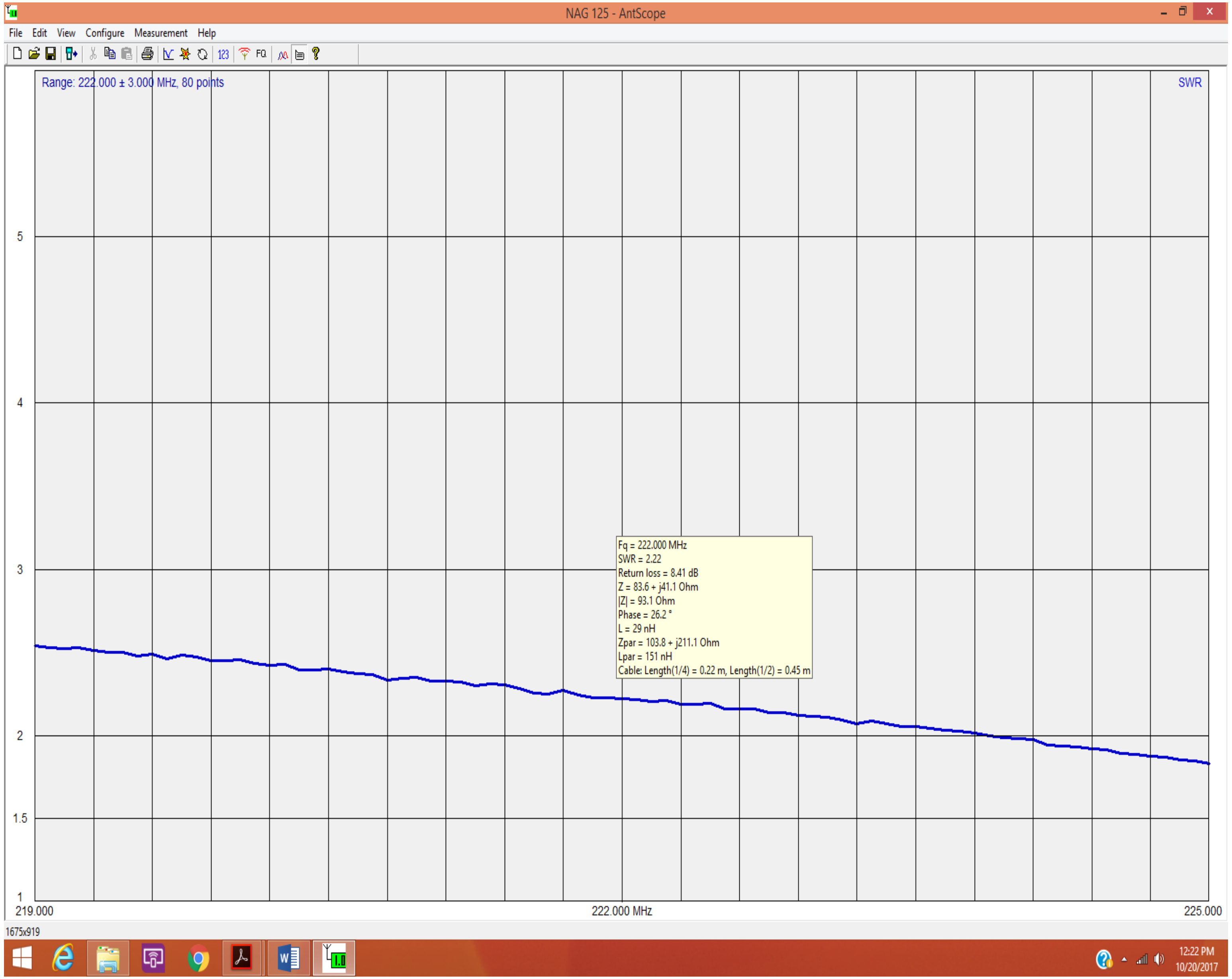
Example of SWR measurement

- Sweeping the band shows the SWR of an antenna over the frequency range.
- You can determine if a manufacturer is “stretching the truth” with their SWR claims or if a particular example does not measure up.
- The example that follows is a tri-band mobile (2m, 1.25m, and 0.7m) Nagoya antenna.

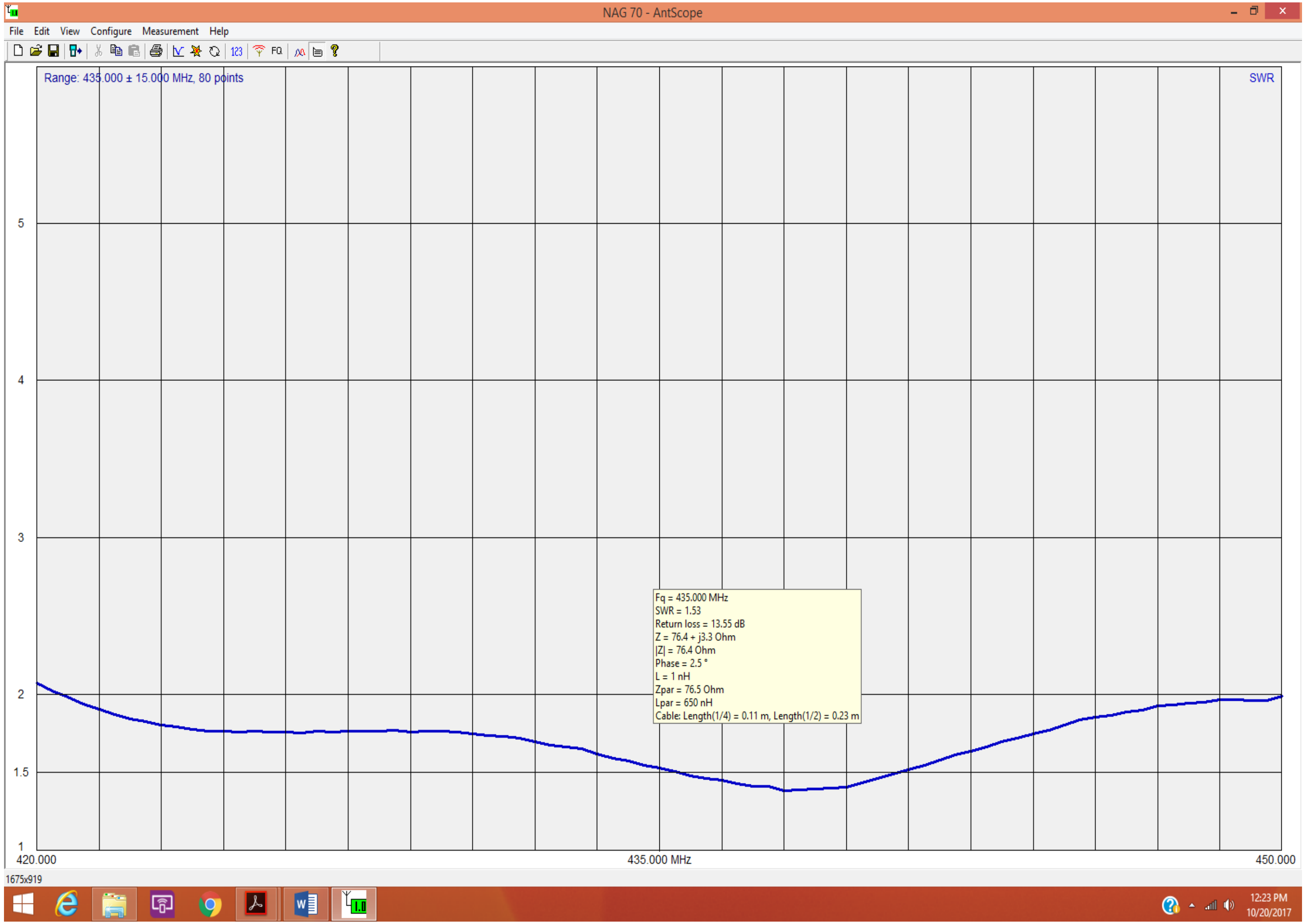
2 meter SWR <2 over entire band



1.25 meter SWR < 2 above 223.6 MHz

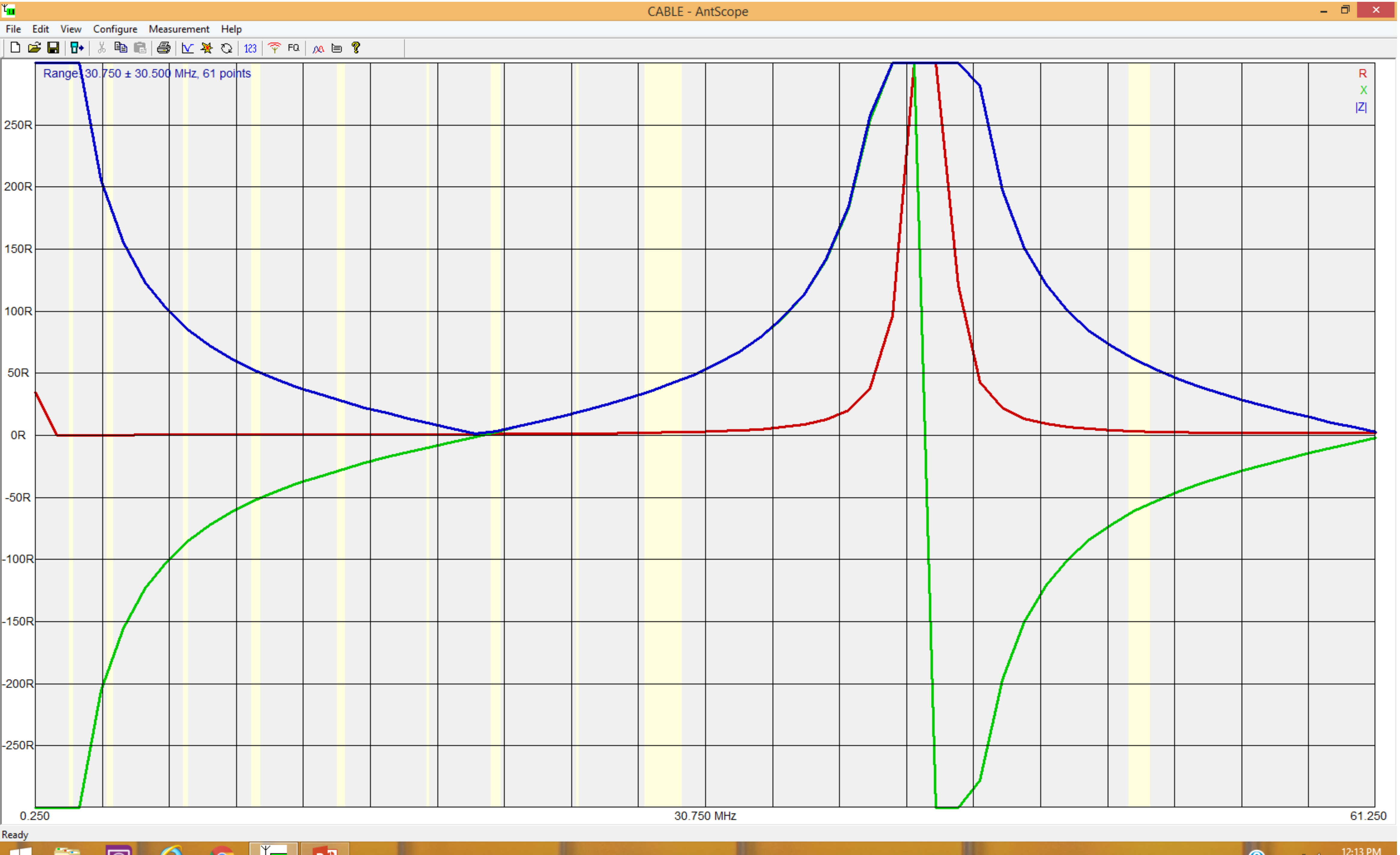


70 cm SWR <2 over most of band



Transmission line Velocity Factor (VF) measurement

- The following example is a 90” (2.29 meter) long piece of RG-58U.
- VF is not known—the dielectric may be foam or XLPE.
- Procedure:
  - Determine the frequency for one wavelength (λ) of the physical cable length.
  - Ensure that the lowest frequency odd multiple λ/4 is included in the sweep.
  - Look for zero values of X to find the λ/4, 3λ/4, 5λ/4, etc. frequencies.
  - This will give you the electrical length for λ/4.
  - Calculate the velocity in cable V = Fλ.
  - Ratio the velocity in cable to the free-space velocity to determine the VF.


CABLE - AntScope
File Edit View Configure Measurement Help
Range: 30.750 ± 30.500 MHz, 61 points
R
X
|Z|
250R
200R
150R
100R
50R
0R
-50R
-100R
-150R
-200R
-250R
0.250
30.750 MHz
61.250
Ready

VF Example

- (2.29 meters)(4) = 9.1 meters.
- 300E6 meters/sec ÷ 9.1 meters/cycle = 32.8E6 cycles/second
- We find the first crossing point frequency (F) of 21.25 MHz
- Calculate the velocity from the frequency and length: (21.25E6 cycles/second)(9.1 meters/cycle) = 193.3E6 meters/sec
- VF = 193.3E6 m/sec ÷ 300E6 m/sec = 0.645 ≈ 65%
- Yes, you could simply divide the measured frequency of 21.25 MHz by the free-space frequency of 32.8 MHz and come up with the answer. I did it the long way to show correlation with the definition of VF.

Use of VF

- Now that we know the VF, we can use physical length to determine a given electrical length.
- Example: how long would a quarter-wave piece of this cable be at 146 MHz?
- $\lambda = 300/146 = 2.055$ m (free-space)
- $\lambda/4 = 2.055/4 = 0.514$ m (free-space)
- $\lambda/4 = (0.514 \text{ m})(0.645) = 0.332$ m (cable)
- (0.332 m)(3.28 ft/m)(12 inches/ft) = 13.07 inches
- Close enough to 13-1/16” on my tape measure

Cable length

- Even though the various manufacturers of analyzers tout the ability to "measure" physical cable length, I think it is easier to measure physically.
- Assuming that it cannot be measured physically for some reason proceed as follows:
  - Determine VF of cable
  - Find frequency (F) that corresponds to $\lambda/4$ for length of cable
  - Length in meters = (300E6 meters)(VF)/(4F)

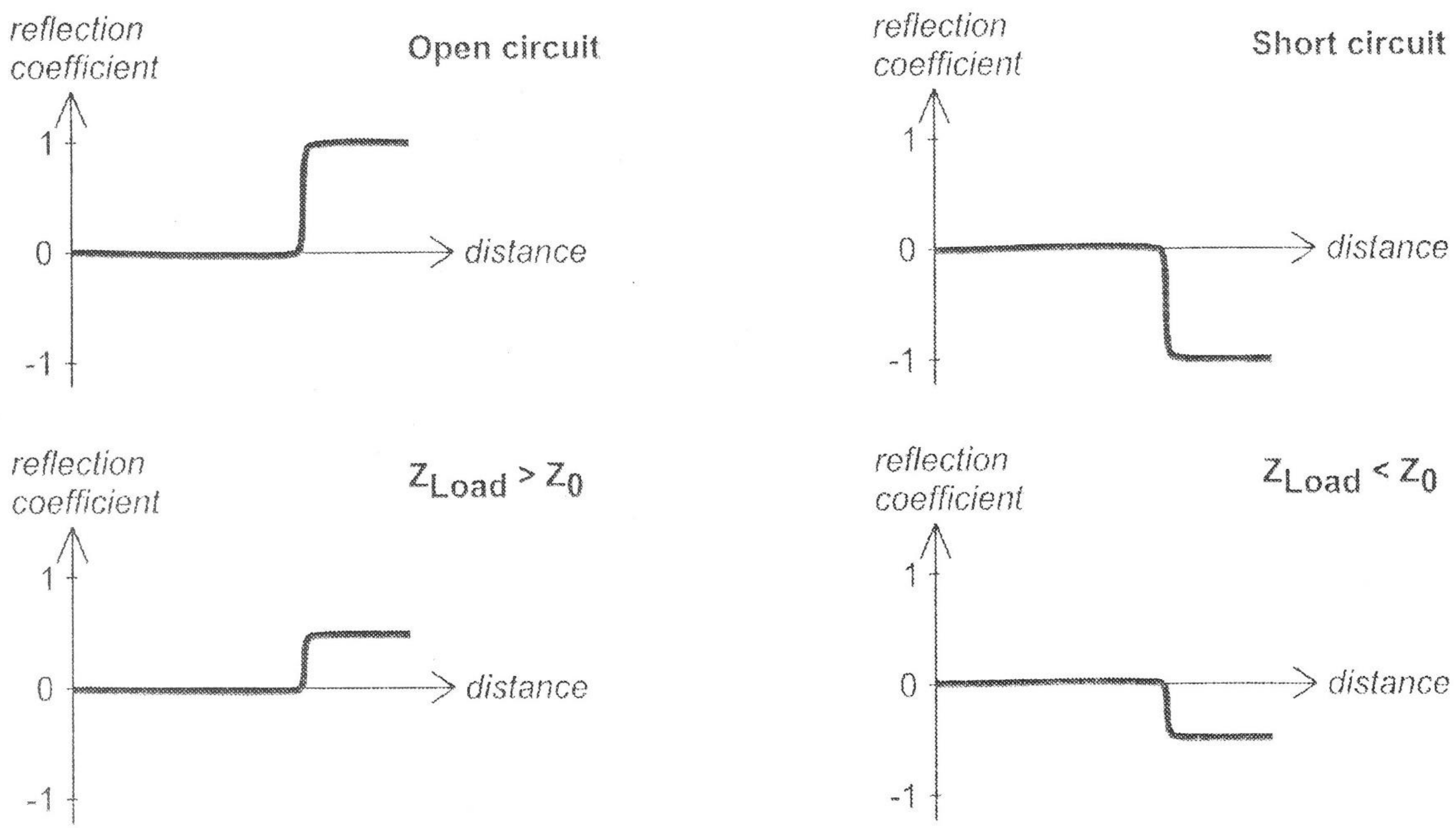
Length example

- Using the same measurements as in the previous example:
- F = 21.25 MHz
- Length = (300E6 m/sec)(0.645)/(4)(21.25E6 cycles/second) = 2.28 meters
- This is essentially the same answer that the tape measure gave without the benefit of fancy instruments and calculation.

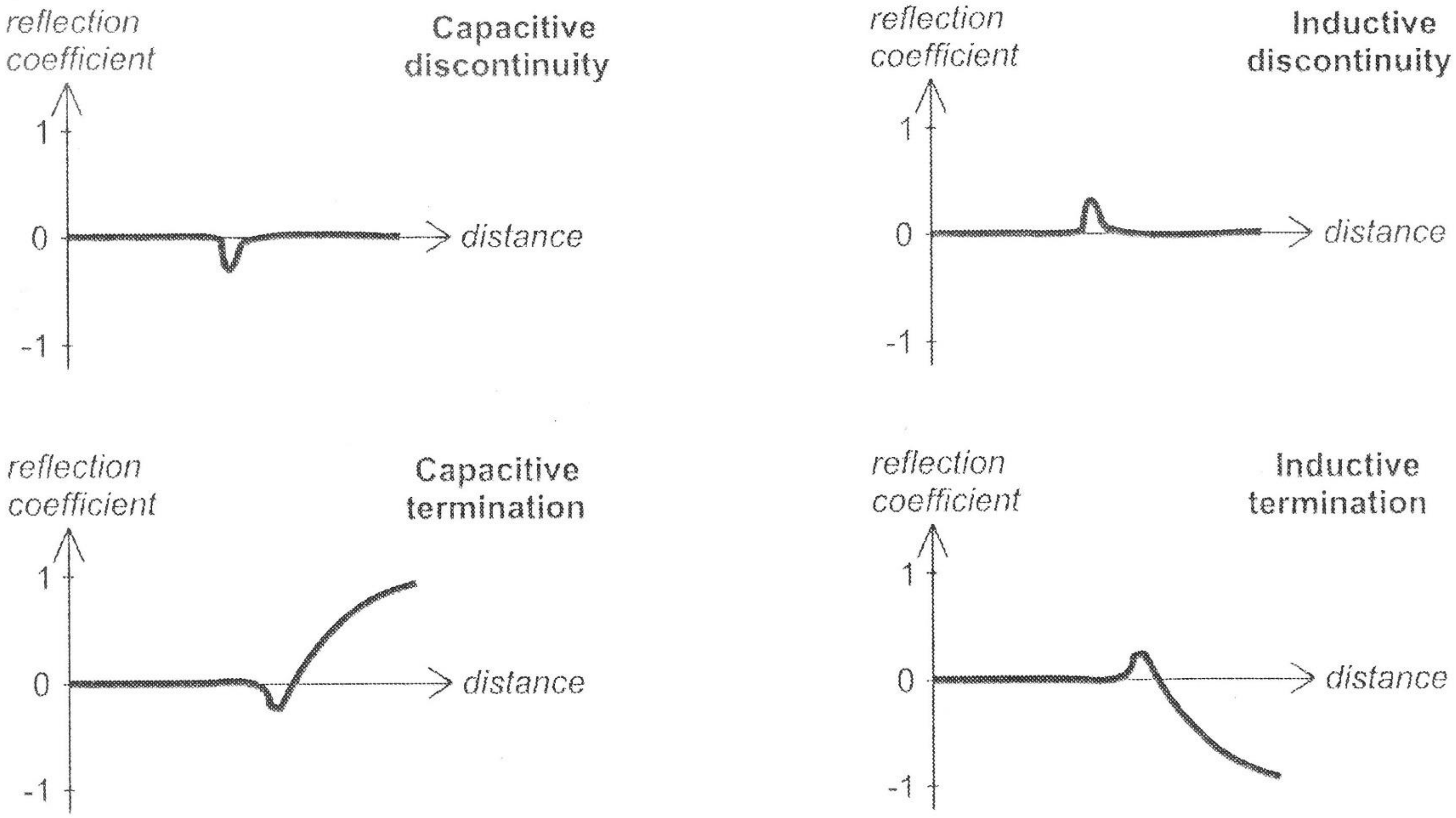
Time domain reflectometry (TDR)

- TDR function can be used to locate cable faults by measuring the time it takes for a signal to be reflected back to the source from a discontinuity.
- The characteristic “signature” of the reflected signal indicates the type of fault.

TDR Fault Signatures

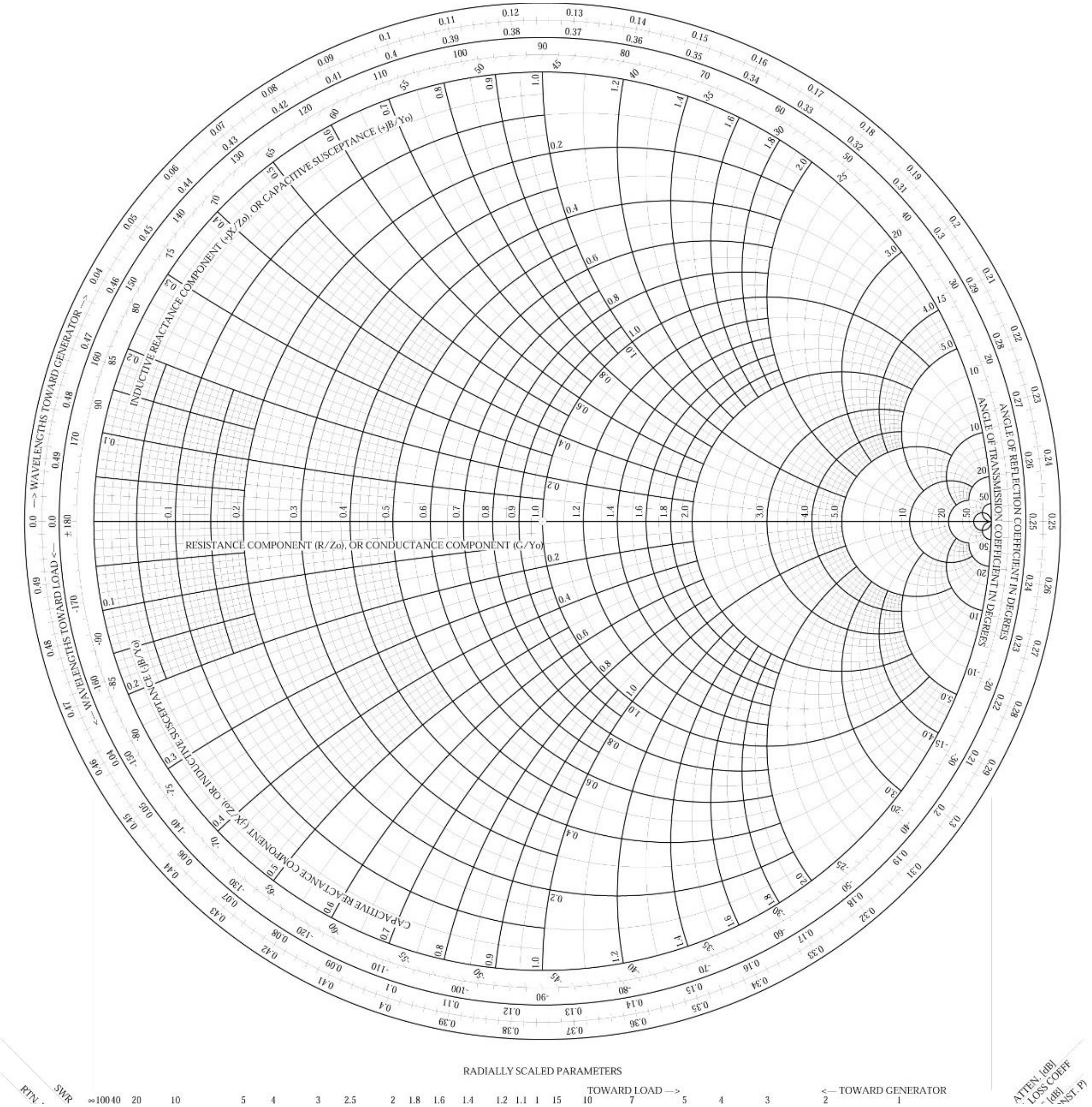


More TDR Fault Signatures



Smith chart

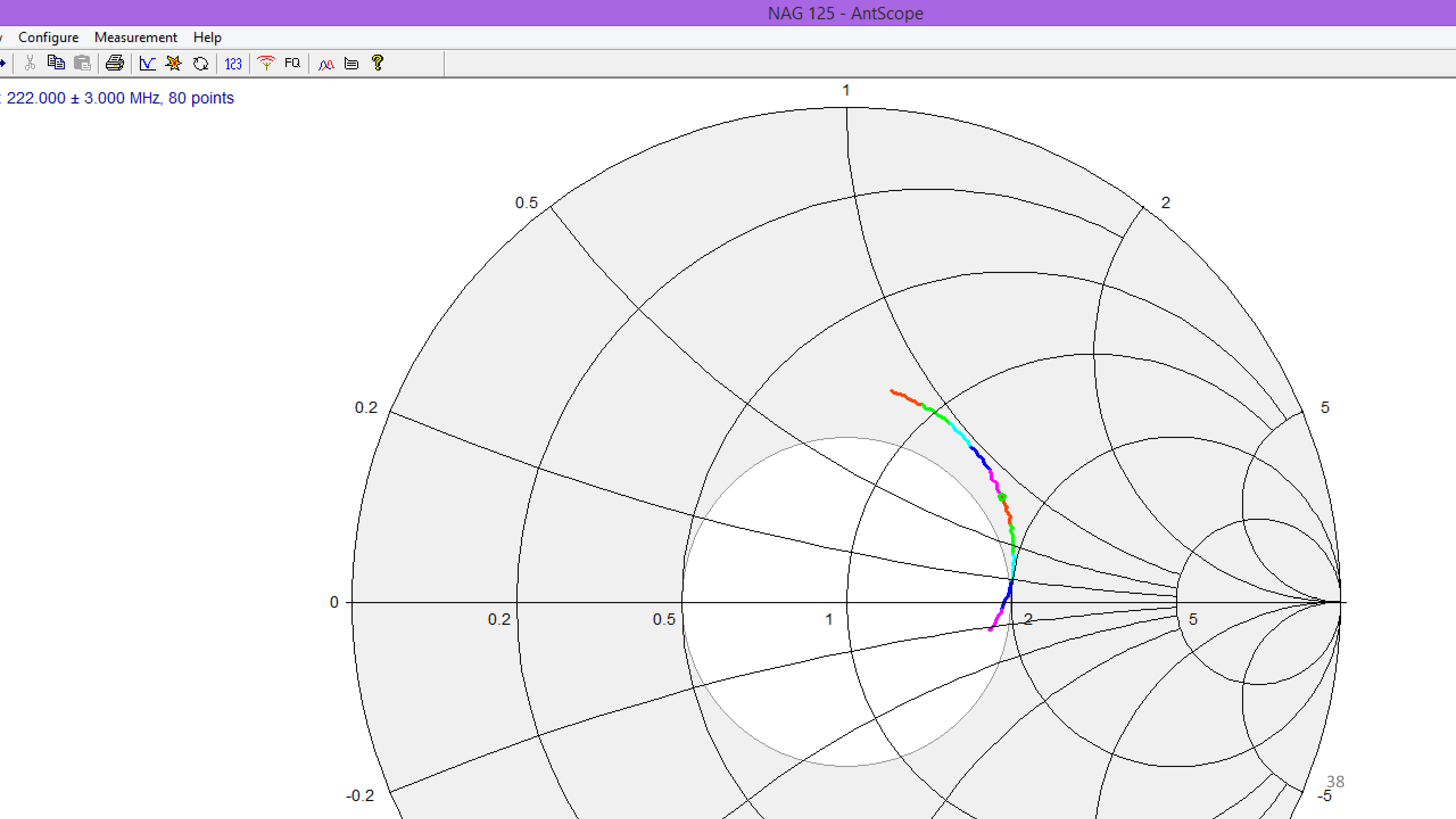
- The Smith chart is a specialized graph that can be used to aid in impedance matching and transmission line calculation.
- Invented by Phillip H. Smith (1905-1987).
- Resistance (or conductance) is plotted on the straight horizontal axis.
- Reactance (or susceptance) is plotted on the circular axes.
- Values of constant SWR form circles concentric with the normalized value of R on the resistance axis (R=1.0).
- Normalization is when we divide measured R and X values by the characteristic transmission line impedance, e.g. 50 Ω.

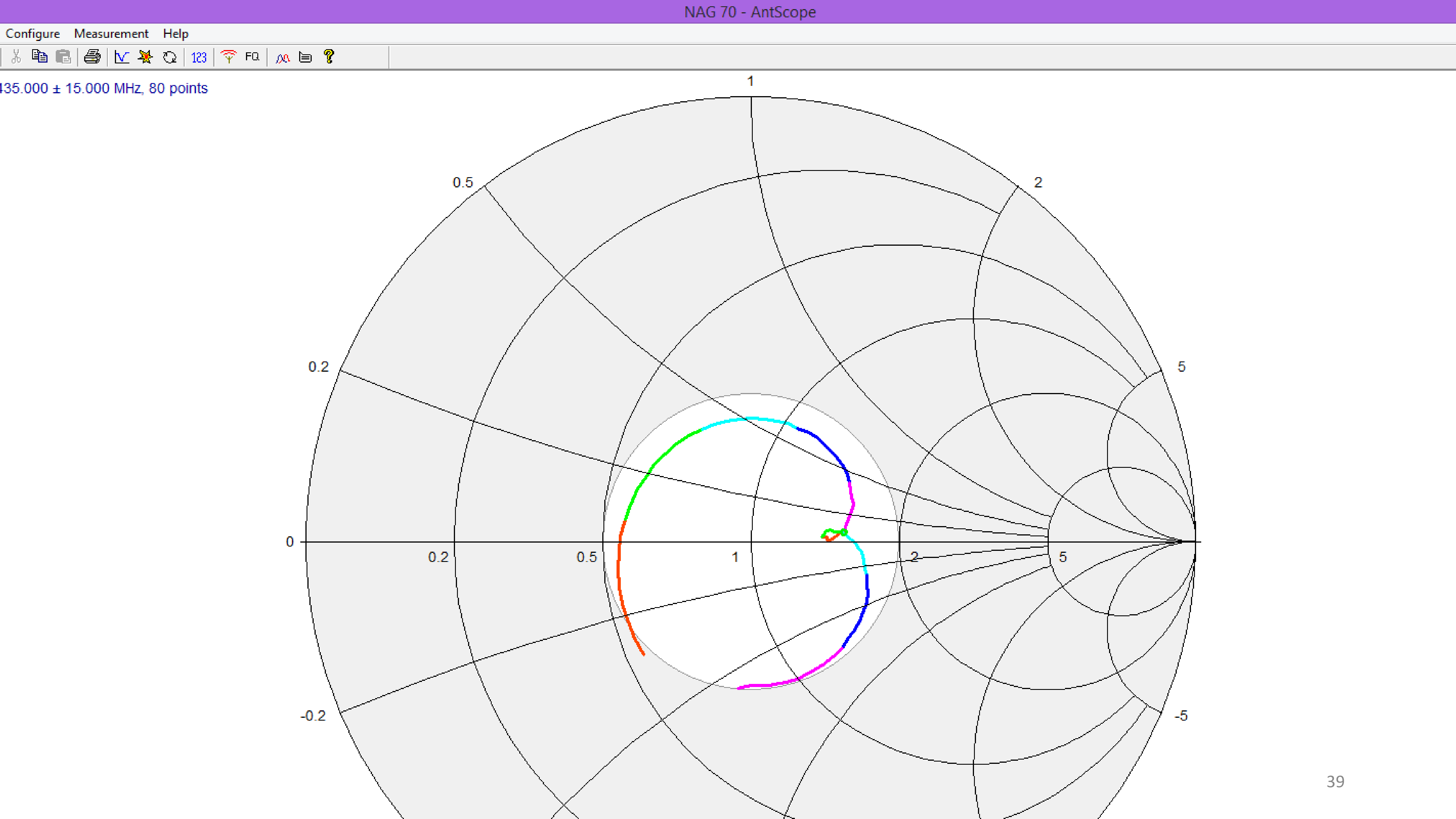


RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)
INDUCTIVE REACTANCE COMPONENT (+jX/Zo), OR CAPACITIVE SUSCEPTANCE (+jB/Yo)
CAPACITIVE REACTANCE COMPONENT (-jX/Zo), OR INDUCTIVE SUSCEPTANCE (-jB/Yo)
—> WAVELENGTHS TOWARD GENERATOR —>
<— WAVELENGTHS TOWARD LOAD <—
ANGLE OF REFLECTION COEFFICIENT IN DEGREES
ANGLE OF TRANSMISSION COEFFICIENT IN DEGREES
RADIALLY SCALED PARAMETERS
TOWARD LOAD —>
<— TOWARD GENERATOR

Properties of Smith chart

- Impedance repeats every λ/2—the circumference of the chart is one half wavelength.
- Impedance plotted on chart will have a corresponding admittance diametrically opposite.
- Corresponding impedance and admittance points are separated by a circumferential distance corresponding to λ/4.
- Constant values of SWR plot as a circle.
- Entire books have been written on the use of Smith charts.
  - P. H. Smith. *Electronic Applications of the Smith Chart.* McGraw-Hill 1969
  - W. N. Caron. *Antenna Impedance Matching.* ARRL 1989


NAG 125 - AntScope
Configure
Measurement
Help
FQ
: 222.000 ± 3.000 MHz, 80 points
1
0.5
2
0.2
5
0
0.2
0.5
1
2
5
-0.2
-5


NAG 70 - AntScope
Configure
Measurement
Help
435.000 ± 15.000 MHz, 80 points
1
0.5
2
0.2
5
0
0.2
0.5
1
2
5
-0.2
-5

What an Analyzer Can and Cannot Do

- Antenna analyzers tell you nothing about the radiation pattern of an antenna system.
- Antenna analyzers can help you troubleshoot antenna system problems.
- Antenna analyzers can help you trim an antenna to resonant length.
- Antenna analyzers can quickly determine the SWR of an antenna system over various frequencies which can be a tremendous help in designing and building impedance matching circuits.

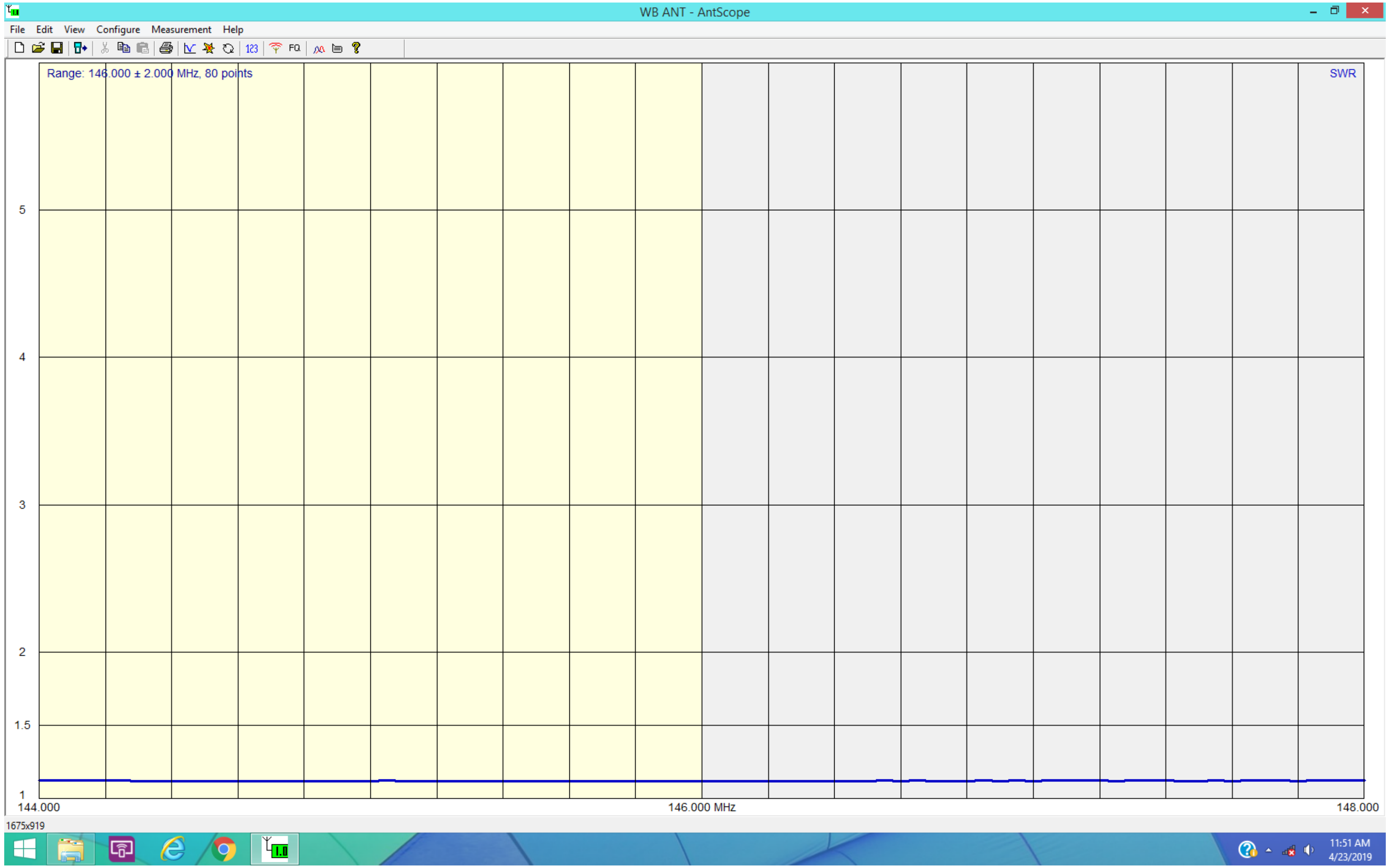
SWR Myths

- High SWR causes RFI. It does not.
- High SWR causes radiation from the shield of coax. Nope, but you might want to think about a balun.
- You can change SWR with different length feedline. You can improve impedance match with transmission line *segments* as matching devices, but simply varying the length of the line will not affect SWR (other than by increasing loss).
- If I have SWR of 1:1 (or close to it) my antenna will work great. It may, but low SWR itself is not a guarantee of that.

The quest for 1:1 SWR

- Low SWR is desirable for maximum power transfer between the antenna system and radio (Rx or Tx).
- Low SWR does not guarantee an effective antenna system. It is only one part of the picture.
- An antenna system that is a good radiator and has a relatively high SWR may work *better* than a system with low SWR that is a poor radiator.
- The following example illustrates an extreme case. . . .

Low SWR, Wide-band Antenna. Near 1:1 SWR over entire 2 meter band!



What this fantastic broadband antenna looks like.

- Obviously, this is not a very good antenna—it’s a dummy load.
  - Great SWR
  - Great bandwidth
  - Poor radiation pattern
- Remember SWR is only a part of the picture.