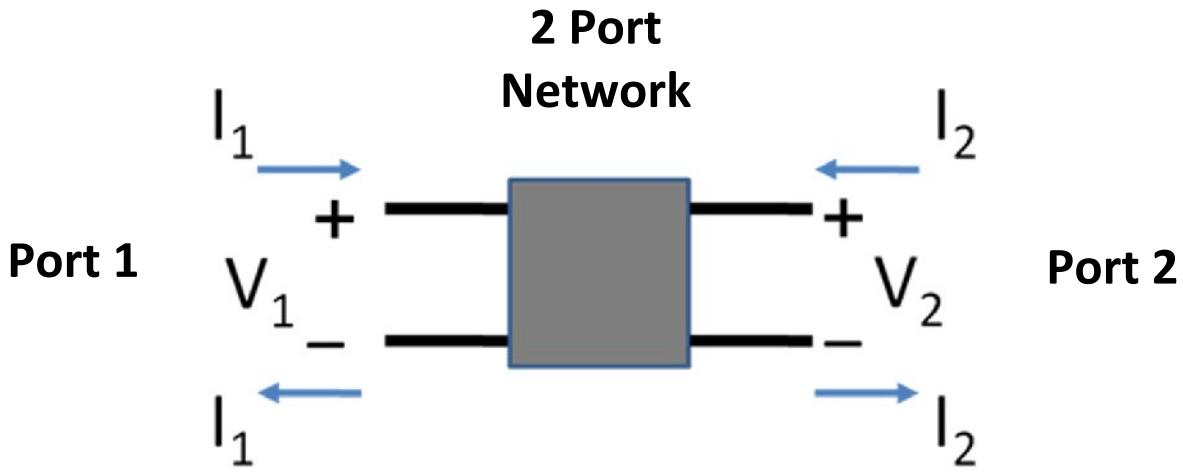
Measuring RF Parameters of Networks

Bill Leonard
NØCU

NAØTC - 285 TechConnect Radio Club
http://www.naøtc.org/

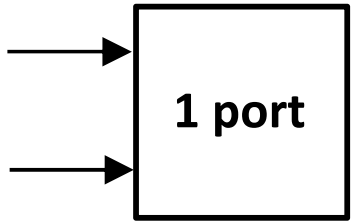
What is a Network?

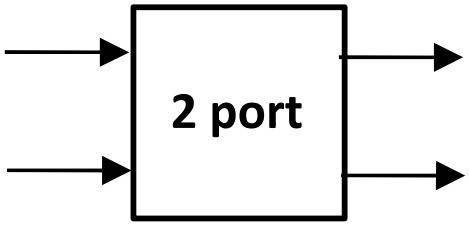
- A Network is a group of electrical components connected is a specific way in order to perform a desired electrical function
  - Any ***linear*** circuit with four terminals can be represented as a two-port network with a full set of ***parameters***
  - **Conditions:**
    - A network can**not** have any internal signal sources
    - **"Port Condition"** must be met: Current in = current out

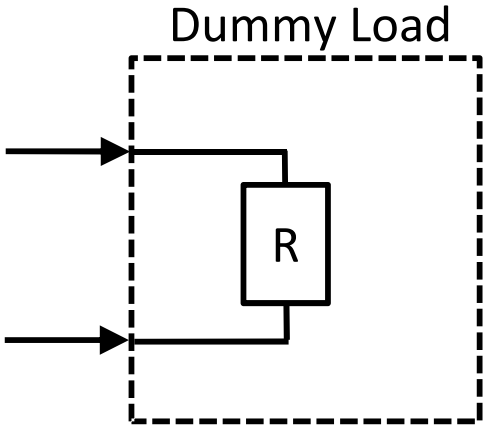


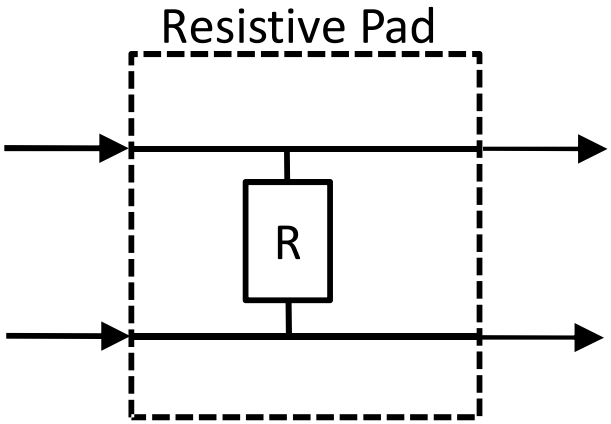
What is a Network?

- # Port: a term that describes the number of external interfaces to the Network
  - A Network can have any number of ports
  - 1 port and 2 port networks are the most common



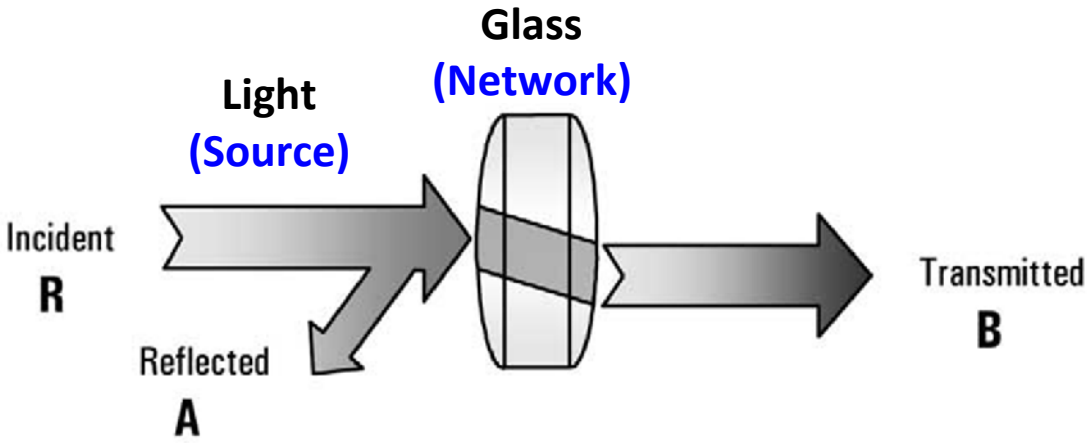


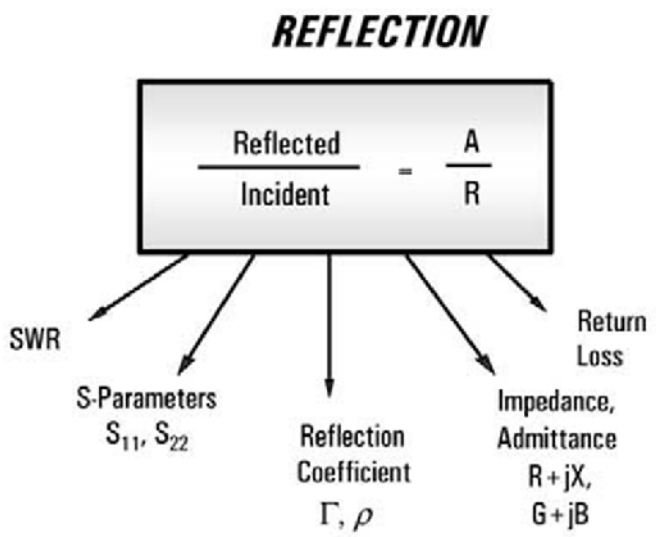


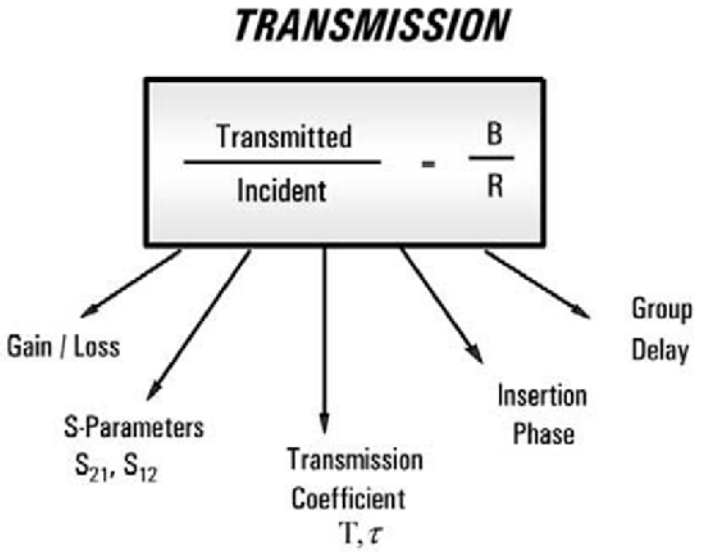


Types of Parameters

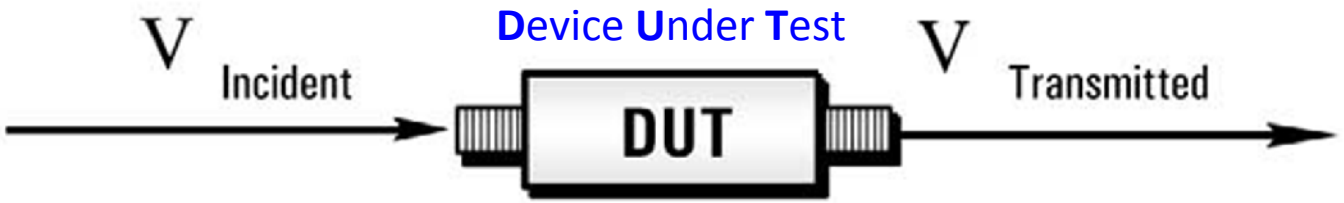
- Numerous parameters are available (Z, Y, H, G, ABCD, etc)
  - Each has advantages and disadvantages
- ***S (Scattering) parameters*** are based upon ***incident and reflected voltages***
  - **Use 50 Ω source and load impedances**
    - **More accurate at RF frequencies than shorts or opens**







Transmission Parameters



$$\text{Transmission Coefficient} = T = \frac{V_{\text{Transmitted}}}{V_{\text{Incident}}} = \tau \angle \phi$$

$$\text{Insertion Loss (dB)} = -20 \log \left| \frac{V_{\text{Trans}}}{V_{\text{Inc}}} \right| = -20 \log \tau$$

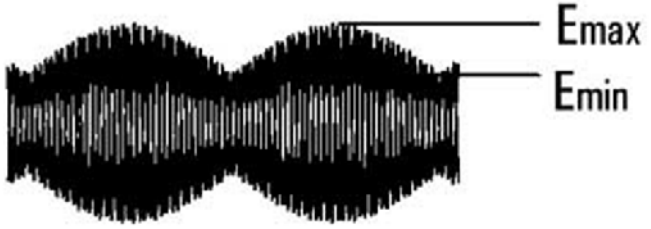
$$\text{Gain (dB)} = 20 \log \left| \frac{V_{\text{Trans}}}{V_{\text{Inc}}} \right| = 20 \log \tau$$

Reflection Parameters

Reflection Coefficient

$$\Gamma = \frac{V_{reflected}}{V_{incident}} = \rho \angle \Phi = \frac{Z_L - Z_0}{Z_L + Z_0}$$

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

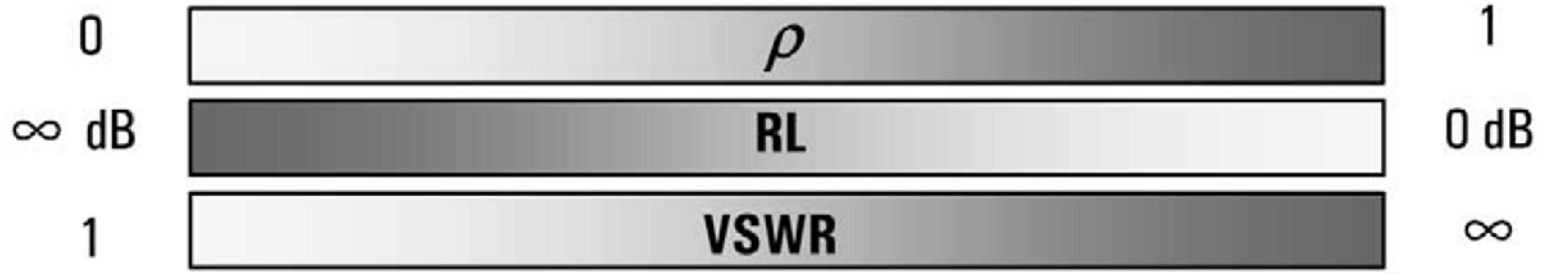


Voltage Standing Wave Ratio

$$\text{VSWR} = \frac{E_{max}}{E_{min}} = \frac{1 + \rho}{1 - \rho}$$

No reflection
($Z_L = Z_o$)

Full reflection
(Z_L = open, short)



Three different ways of saying the *same* thing!

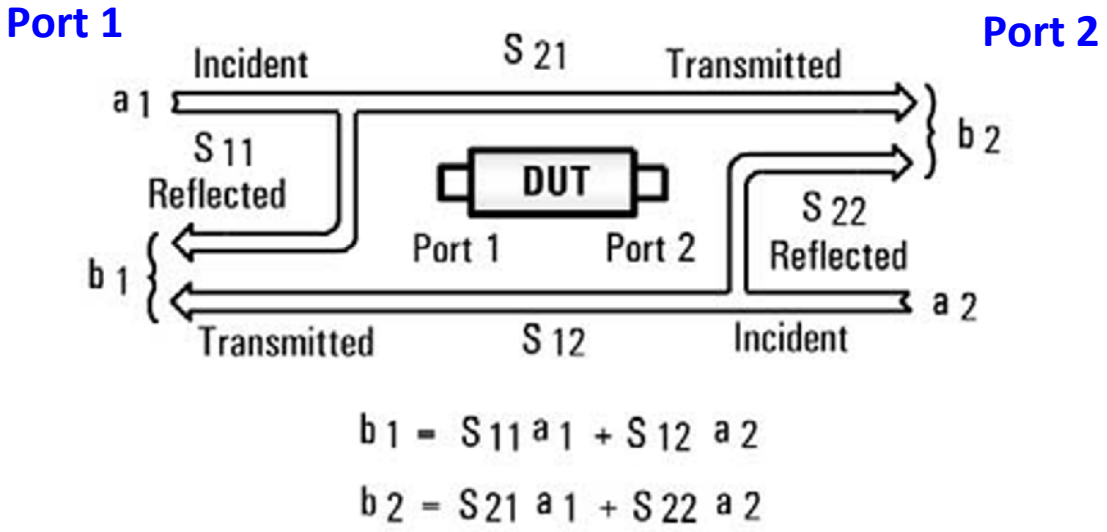
The Four S Parameters

- S_{11} = input reflection coefficient (***input match***)
- S_{22} = output reflection coefficient (***output match***)
- S_{21} = forward transmission coefficient (***gain or loss***)
- S_{12} = forward transmission coefficient (***reverse isolation***)

Signal input port (Incident)

Signal measurement port (Transmitted or Reflected)

All S parameters are *complex* quantities (have magnitude & phase)



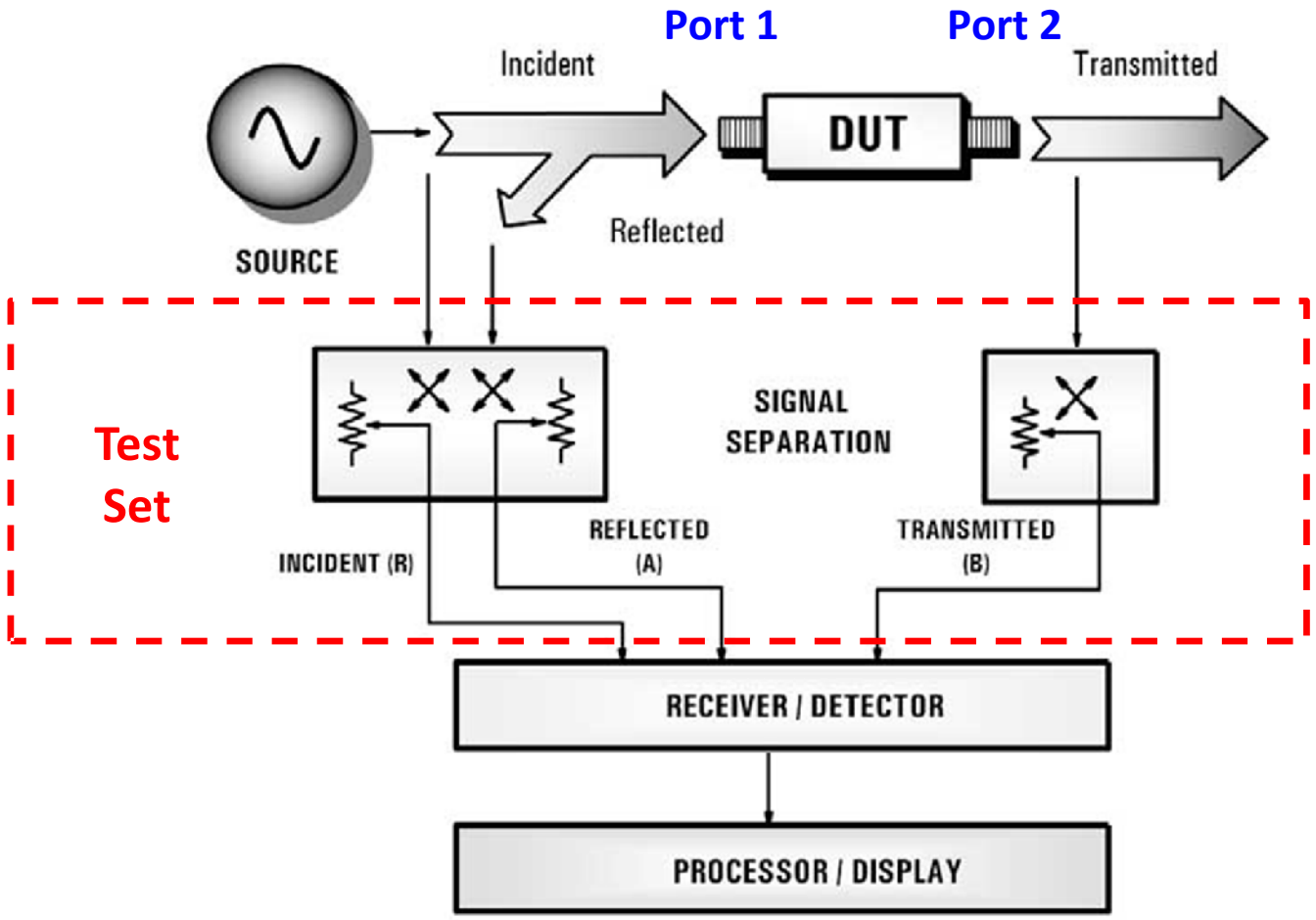
$$b_1 = S_{11} a_1 + S_{12} a_2$$

$$b_2 = S_{21} a_1 + S_{22} a_2$$

RF Engineers love S Parameters, Hams don't!

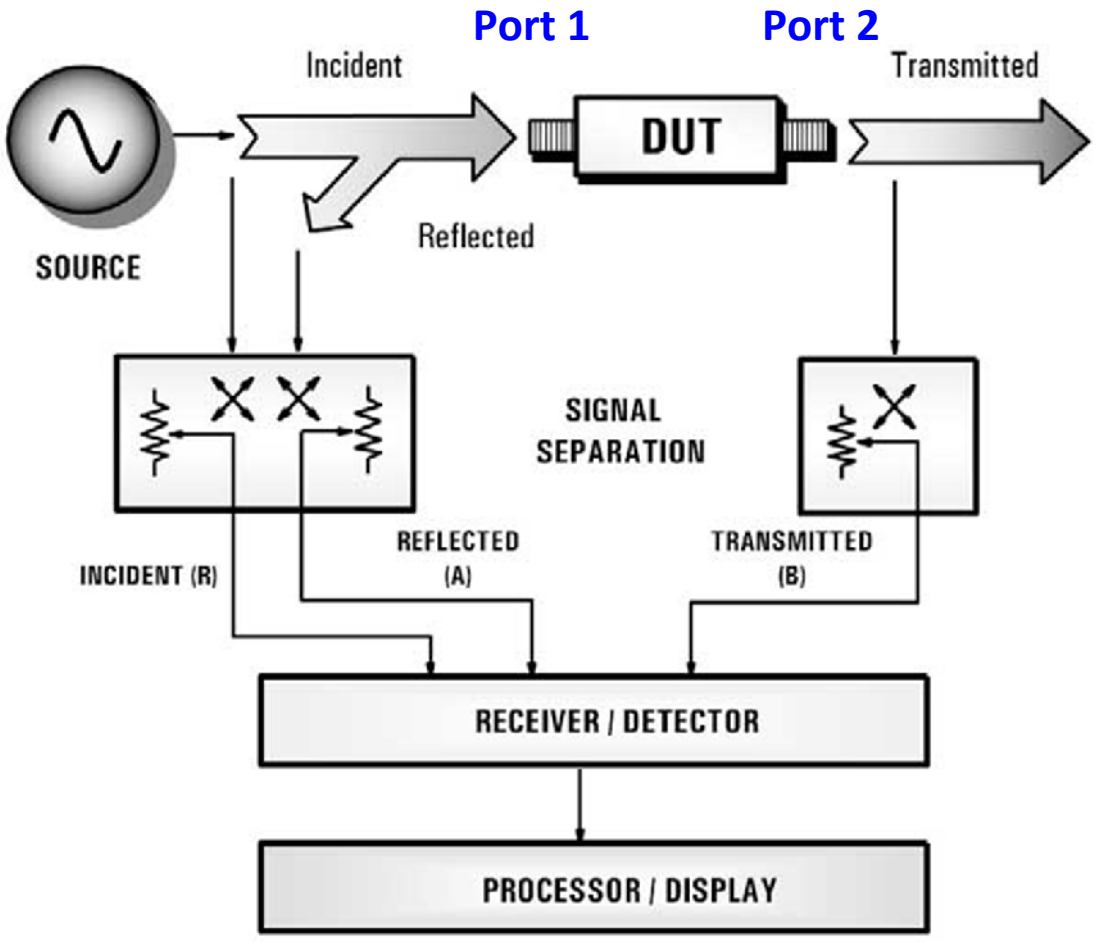
Network Analyzer Architecture

- The basic architecture of a **2 Port Network Analyzer** :
  - Signal generator
  - Test set
  - One or more receivers
  - Computer (to acquire, process and display the data)



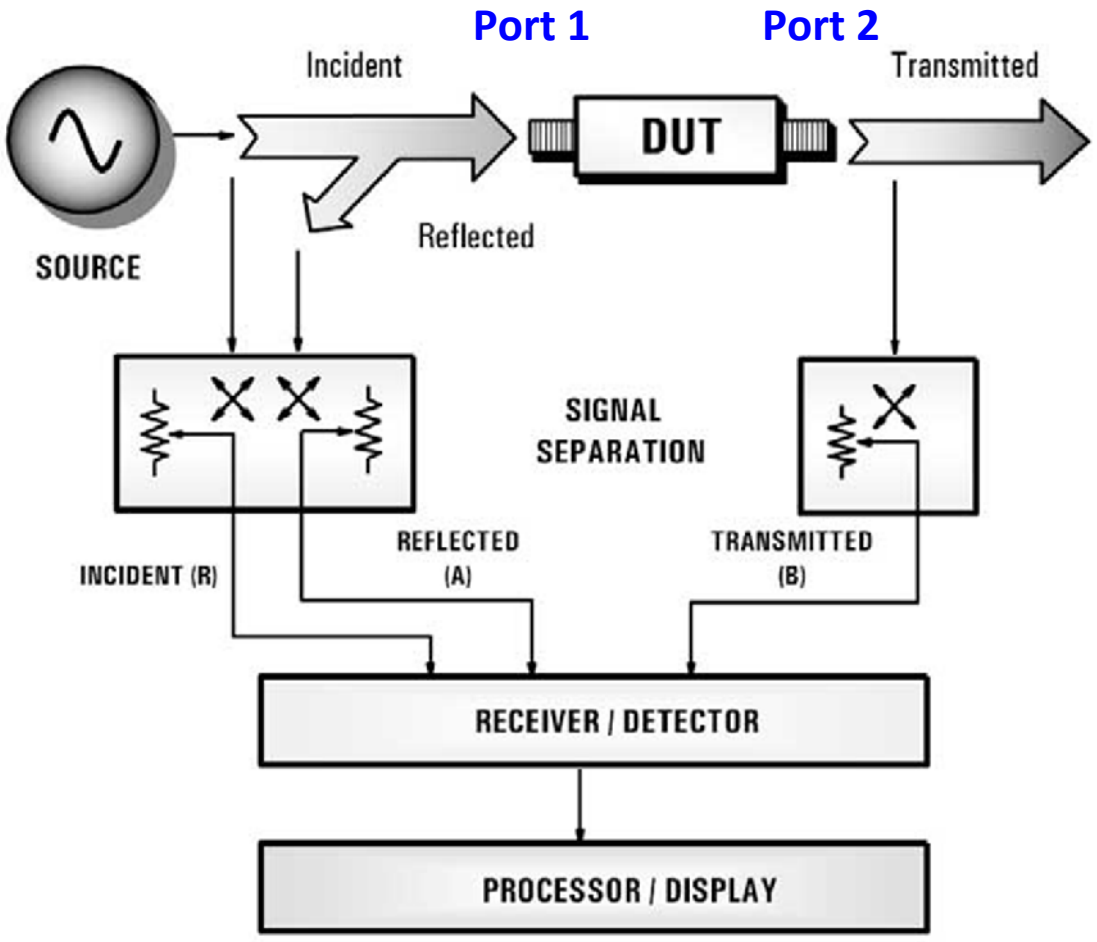
Network Analyzer Architecture

What is missing?



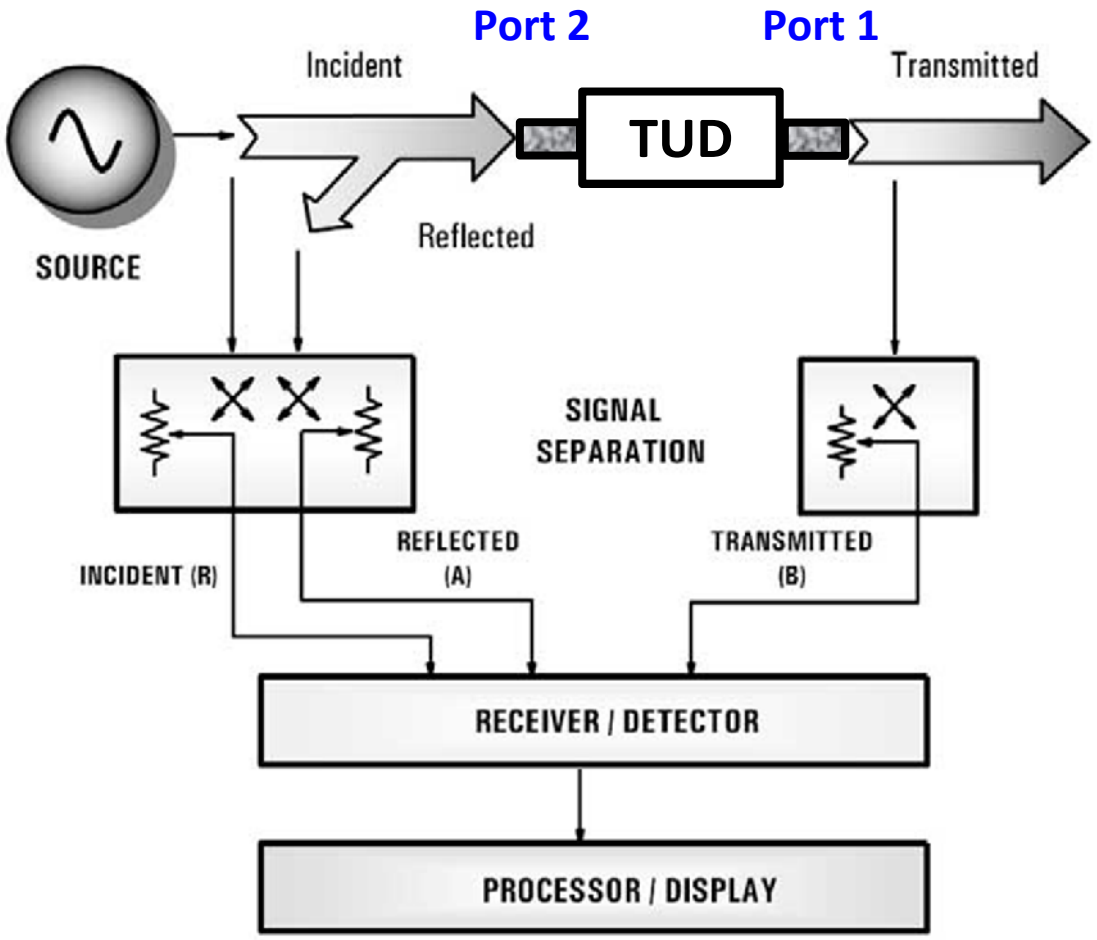
Network Analyzer Architecture

Can't measure S_{12} or S_{22}



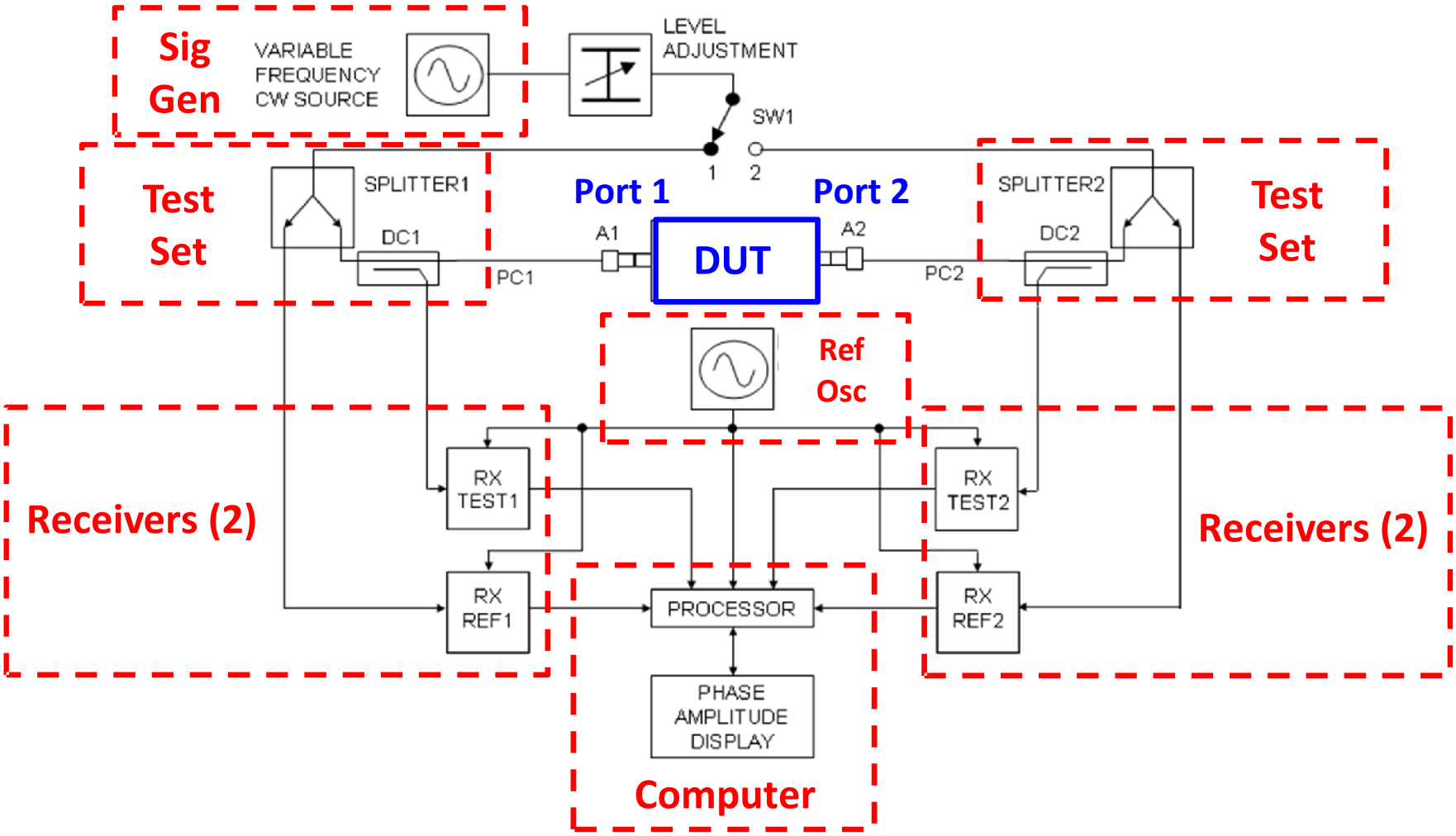
Network Analyzer Architecture

Solution 1: reverse the DUT



Network Analyzer Architecture

Solution 2: use RF switches, splitters + ...



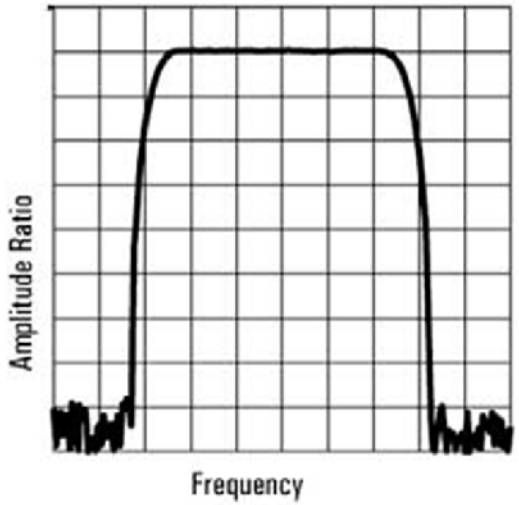
Note: there are 4 independent receivers!

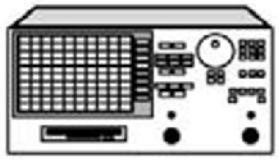
Types of Network Analyzers

- ***RF Network Analyzers*** measure the magntude and phase of incident, reflected, and transmitted power
  - **Three** basic types of RF Network Analyzers:
    - Scalar Network Analyzer (**SNA**):
      - Only measures amplitudes (no phase)
      - Faster and cheaper than a VNA
    - One Port Vector Network Analyzer (**1 Port VNA**)
      - Measures both amplitude and phase
      - Only measures reflection parameters (no transmission or isolation)
    - Two Port Vector Network Analyzer (**2 Port VNA**)
      - Measures both amplitude and phase
      - Measures all transmission & reflection parameters
- **Other types of Network Analyzers:**
  - **Microwave Transition Analyzer** (MTA)
  - **Large Signal Network Analyzer** (LSNA)
  - **Packet Network Analyzer** is used to evaluate computer data networks

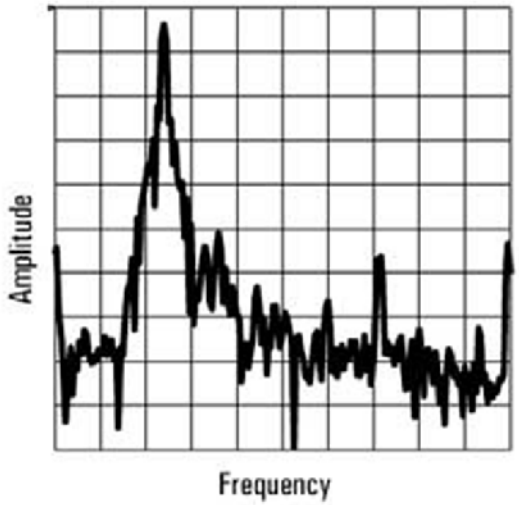
Spectrum vs Network Analyzers

Network and ***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)

Note: Spectrum Analyzer + Tracking Generator = *Scalar* Network Analyzer

Types of Measurements Made by VNAs

- SWR referenced to any impedance
- Resistance and reactance at the cable input
- Resistance and reactance at the antenna terminals
- Resistance and reactance of discrete components
- Return loss
- Transmission loss
- Isolation/coupling
- Reflection coefficient
- Cable length
- Cable impedance
- Cable loss
- Distance to fault (open or short)
- S parameters
- Time Domain reflections along a transmission line (some models)

Network Analyzers Used by Hams

- **SWR bridges**
  - Minimal info
  - Used to tune a network (ie, an antenna) for low SWR
- **Noise bridges**
  - Display resistance and reactance
  - Indicate if reactance is inductive or capacitive
  - Used to tune a network (ie, an antenna) for a 50 Ω match
- **Antenna analyzers (MFJ-259, Autek VA1, etc)**
  - Good accuracy but limited range
- **Vector Network Analyzers designed for Ham applications**
  - Kits to fully built & tested units
  - Both one and two port VNAs
  - Both Analog and DSP types
  - Good to excellent accuracy and dynamic range
- **Commercial grade Vector Network Analyzers**

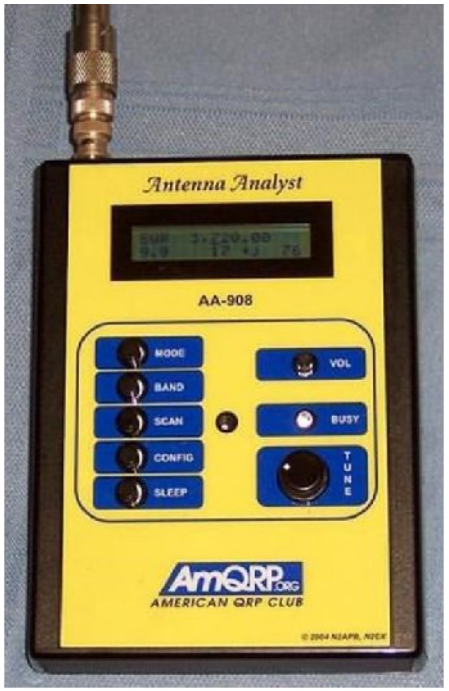
Various **Antenna** Analyzers (1 Port VNAs)

MFJ-259B

VK5JST Aerial Analyser

RigExpert AA-54

Autek VA1



Antenna Analyst

Antenna Analyzer Displays

Single-Frequency (peep-hole) type:

MFJ-259B

Autek VA1

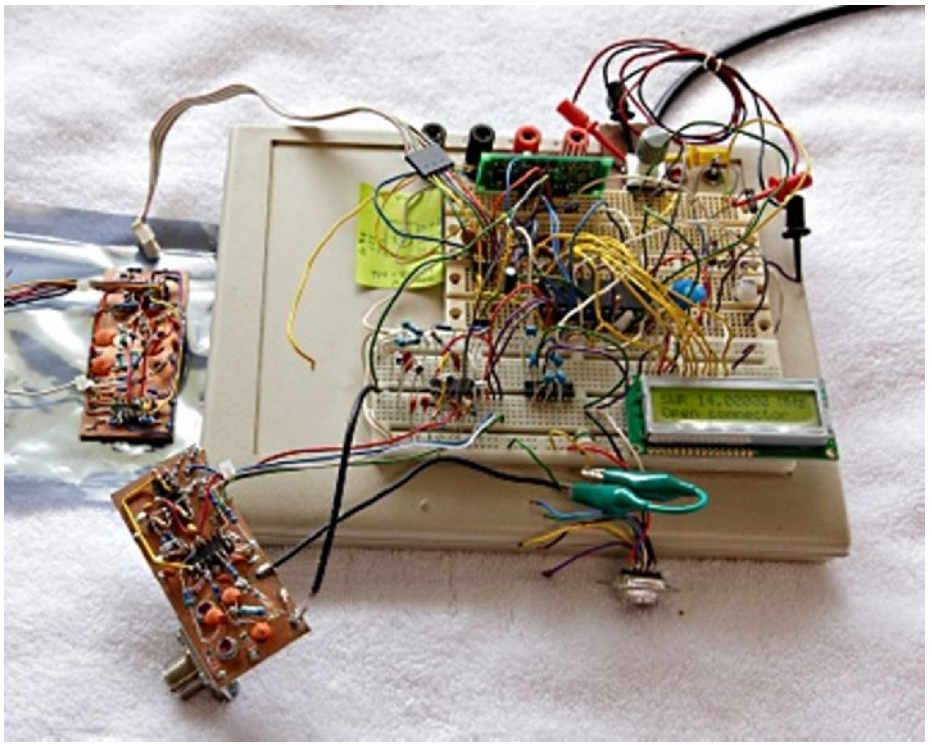
VK5JST Aerial Analyser

Antenna Analyst

Various **Network** Analyzers

Ten-Tec VNA ($650)

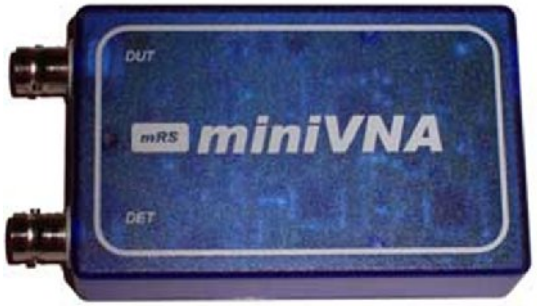
ACØST Development

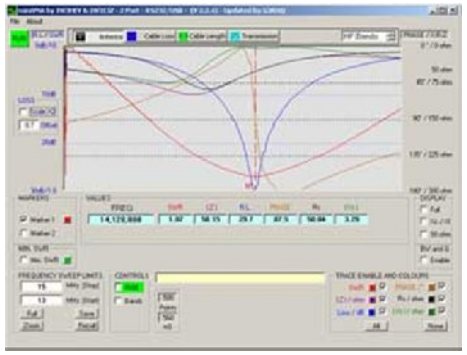


Array Solutions VNA 2180 ($1500)

Various **Network** Analyzers

Mini VNA ($400)





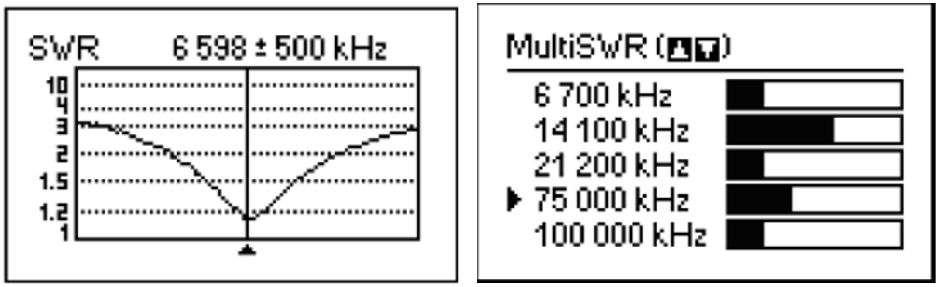
Agilent N5245A ($30K to >$60K)

N2PK VNA Kit ($?)

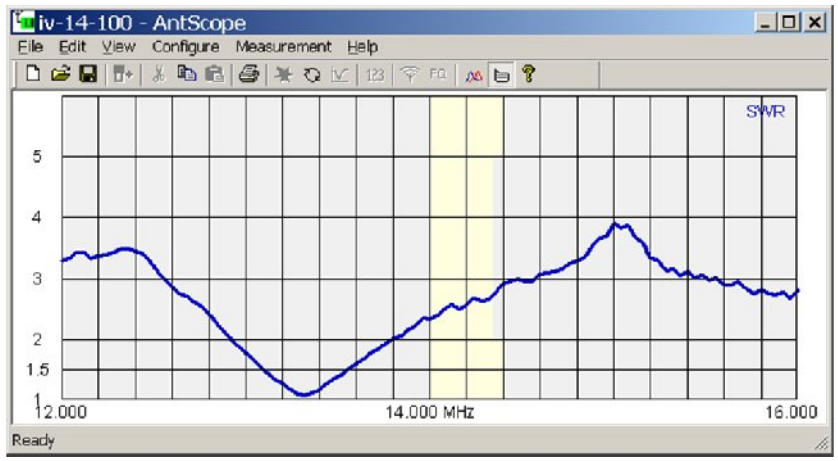
Network Analyzer Displays

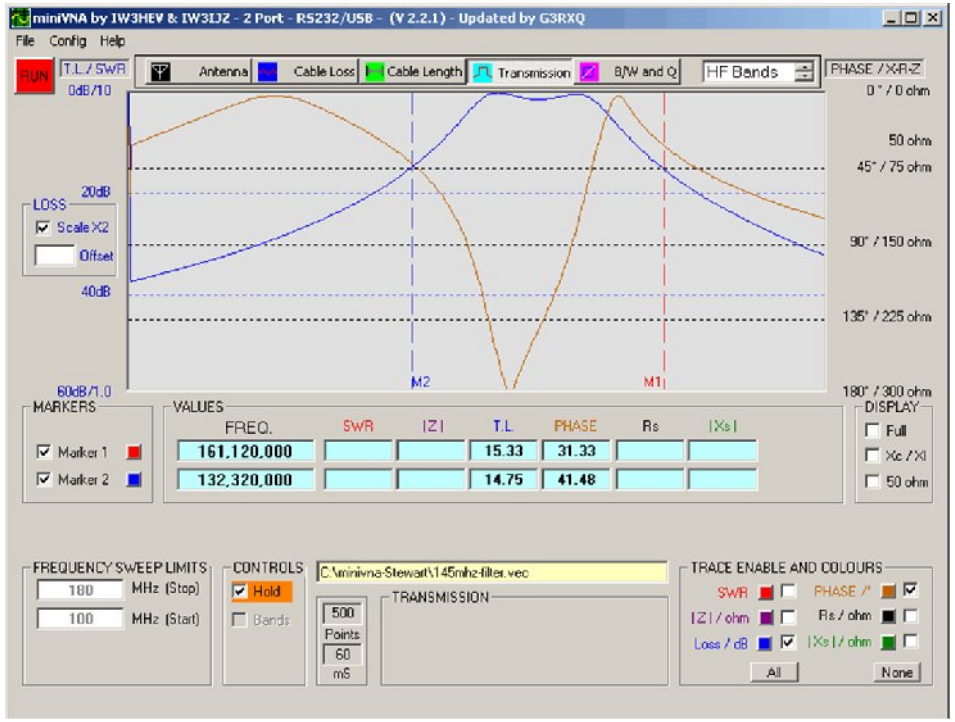
Multi-Frequency (spectrum) type:

RigExpert AA-54



miniVNA

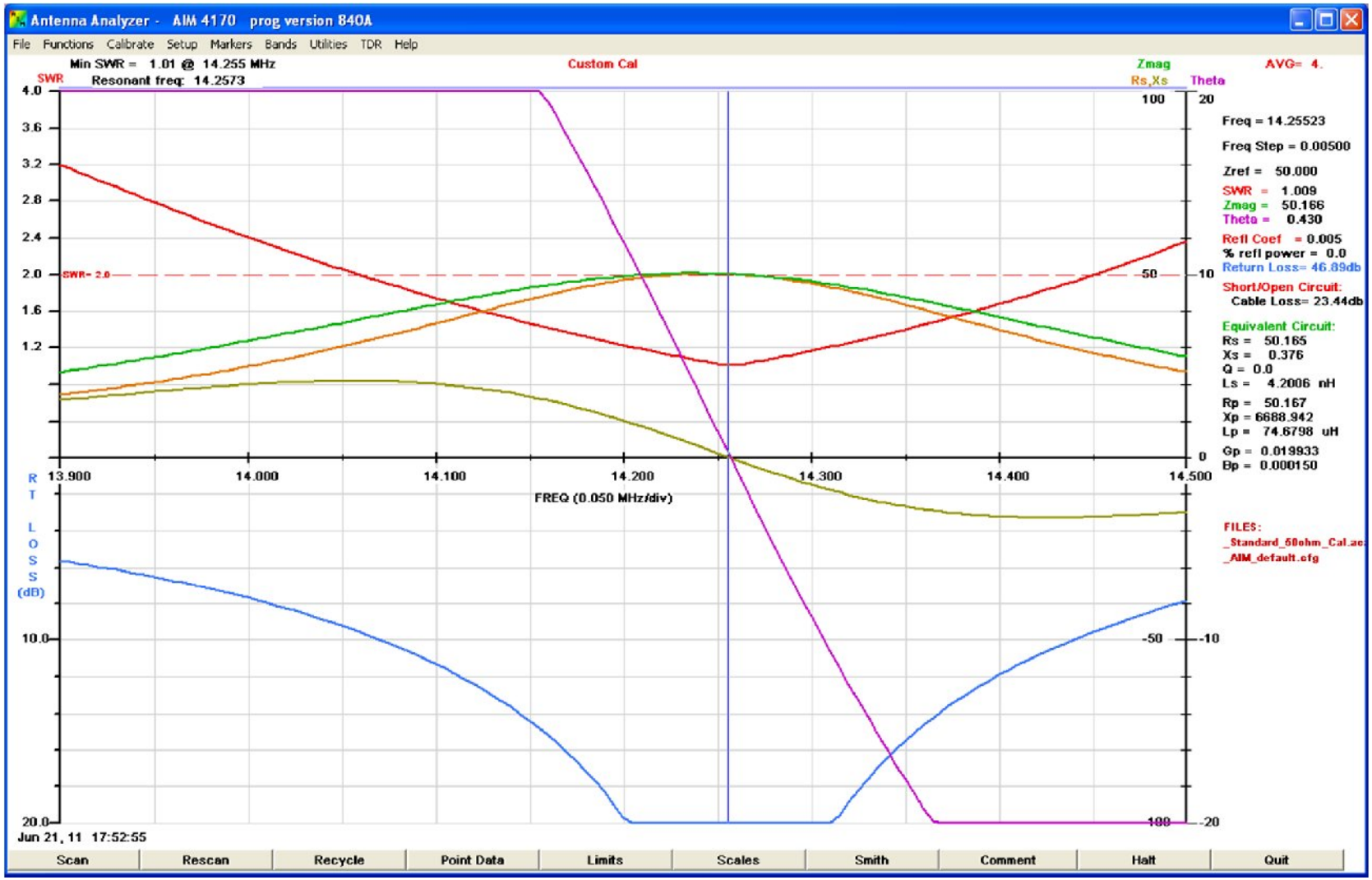




Network Analyzer Displays

Multi-Frequency (spectrum) type:

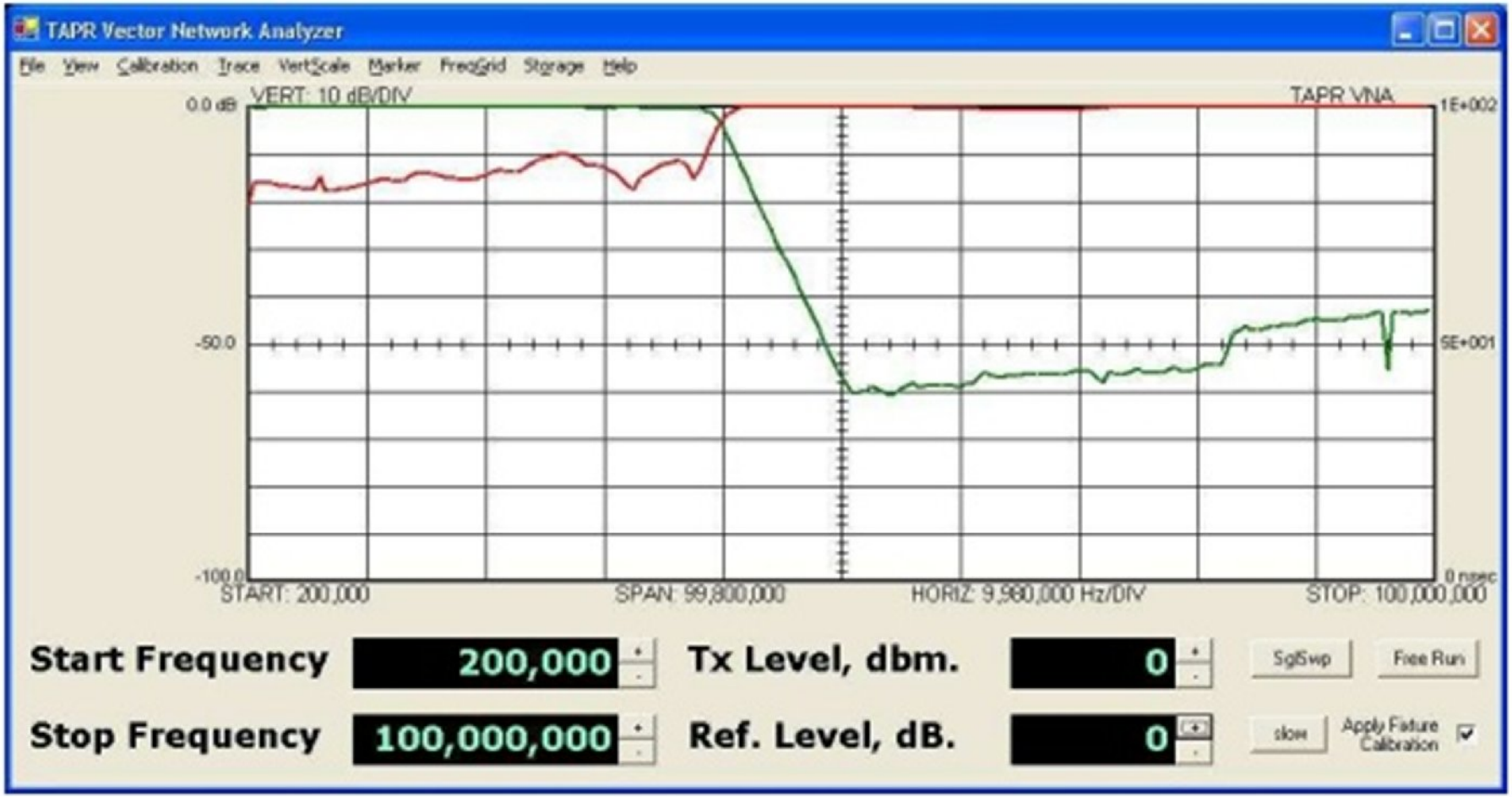
AIM-4170C



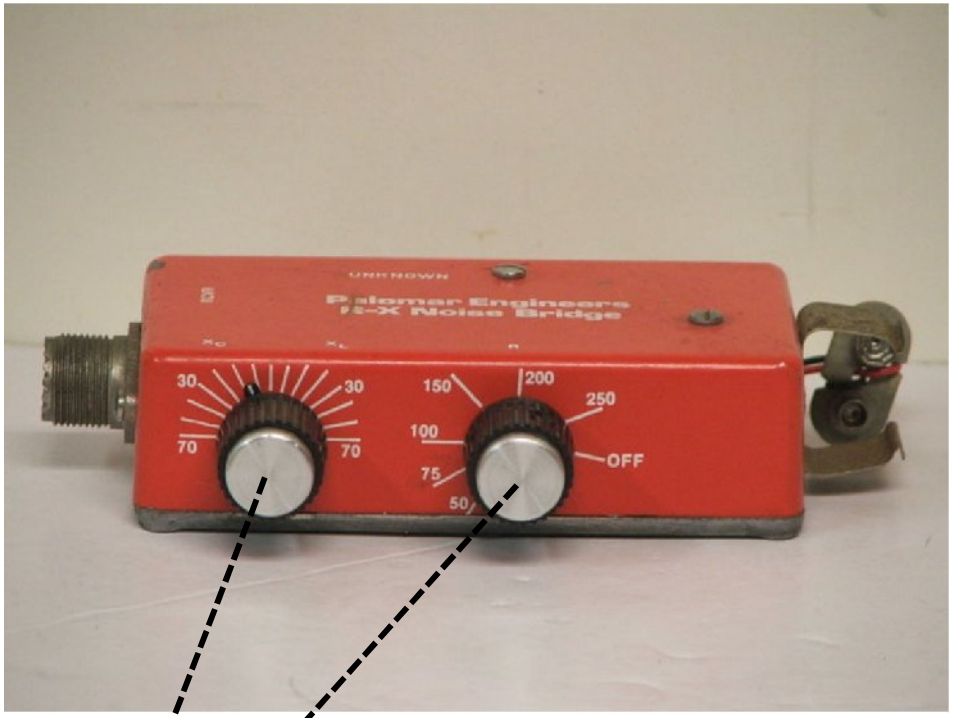
Network Analyzer Displays

Multi-Frequency (spectrum) type:

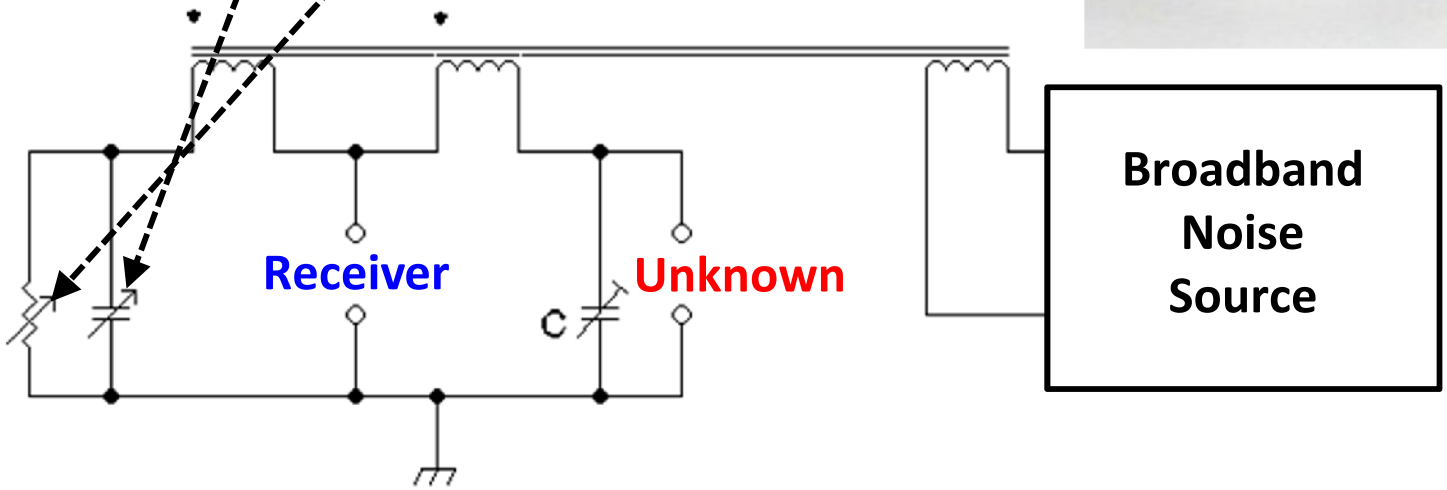
Ten-Tec (TAPR) VNA



Noise Bridge



- **A good and inexpensive (~$20 used) way to start out**



Broadband Noise Source

MFJ-259B **SWR** Analyzer (1 Port VNA)

- Measurements available:
  1. Cable length (ft)
  2. Cable loss (dB)
  3. Capacitance (pF)
  4. Impedance magnitude (ohms)
  5. Impedance phase (degrees)
  6. Inductance (uH)
  7. Reactance (ohms)
  8. Resistance (ohms)
  9. Resonance (MHz)
  10. Return loss (dB)
  11. Signal frequency (MHz)
  12. SWR

- This device is a **general purpose instrument**:
  - Designed to aid in tuning/measuring 50 Ω systems with low (<3:1) SWR
  - Impedance range is limited (7 to 650 ohms)
  - Accuracy is not specified for any measurement
  - Can***not*** distinguish inductance from capacitance
  - Very susceptable to interference from external signals

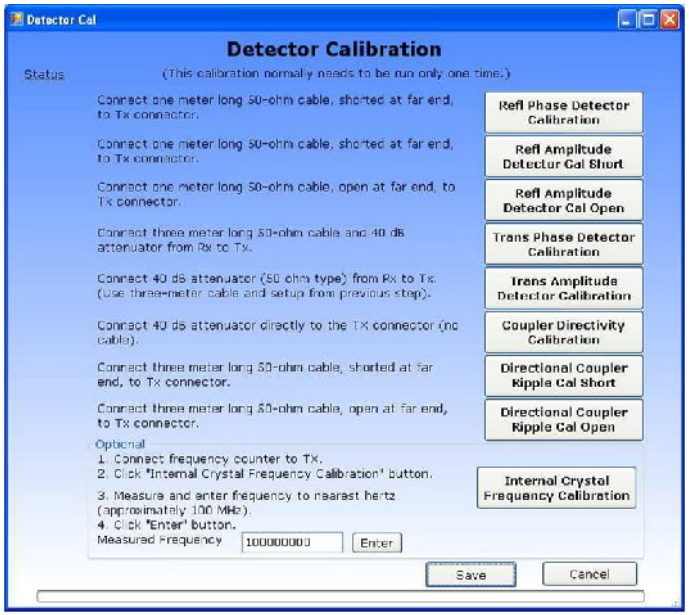
TenTec 6000 (2 Port VNA)

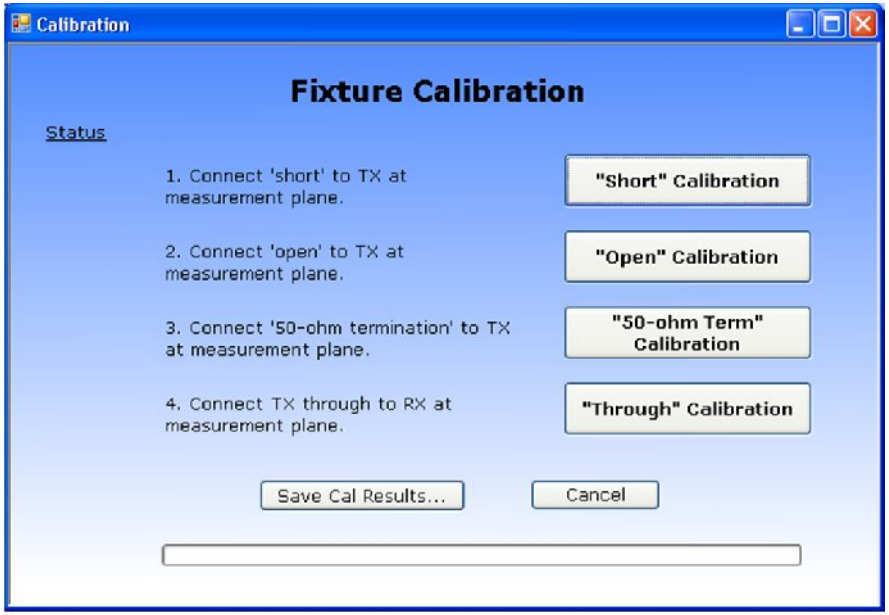
- Designed and developed by Tucson Amateur Packet Radio (TAPR)
  - **TAPR** developed both the hardware and software
  - Measures **all four S parameters** with **moderate accuracy and dynamic range**
  - **Ten Tec** builds, sells, and services this unit under license from TAPR

- TAPR
  - Non-profit R&D group based in Tucson, AZ
  - The goals of TAPR are to:
    1) support R&D efforts in the area of amateur digital communications,
    2) disseminate information on packet and digital communications,
    3) provide affordable and useful kits for experimenters and hobbyists,
    4) pursue and help advance the amateur art of communications, and
    5) support publications, meetings, and standards in the area of amateur digital communications

TenTec 6000 VNA

- Calibration:
  - **Very important to achieve specified accuracy**
  - Two types:
    - Detector Cal
      - Only needs to be done once
    - Fixture Cal
      - Needs to be done for each test fixture used
      - **Allows for measurements to be referenced to a remote antenna**

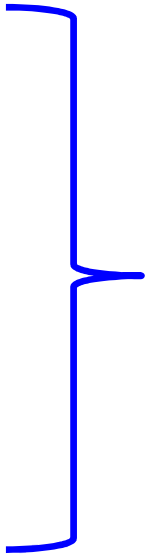




TenTec 6000 VNA Display Options

S Parameters:

- **S_{11} Magnitude (rectangular)**
- **S_{11} Phase (rectangular)**
- **S_{21} Magnitude (rectangular)**
- **S_{21} Phase (rectangular)**
- **S_{21} Group Delay (rectangular)**
- **S_{11} Magnitude as SWR (rectangular)**
- **S_{11} as R ohms**
- **S_{11} as jX ohms**



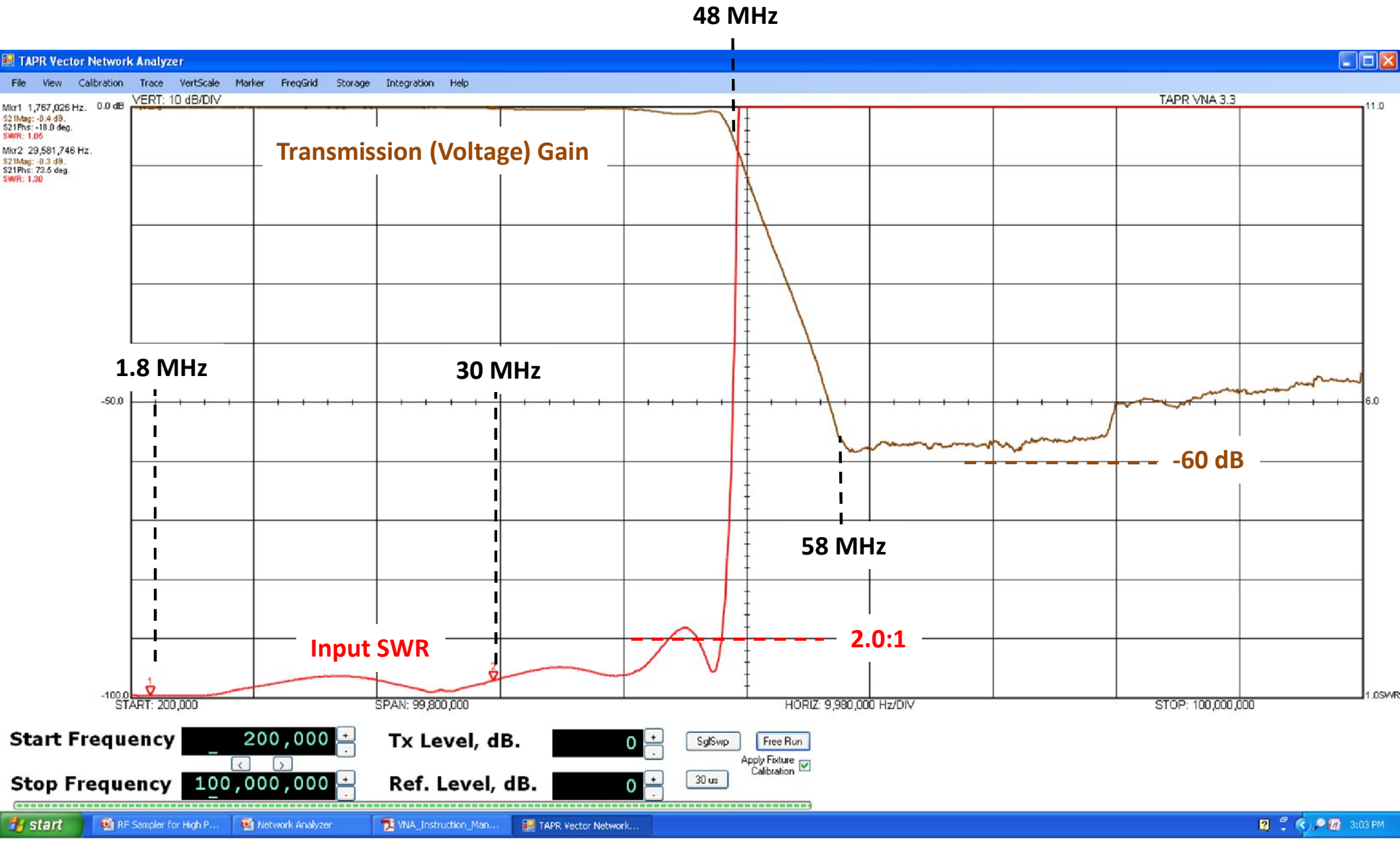
Any/all can be displayed at the same time

Smith Chart (Normal and zoom)

Time Domain Reflections

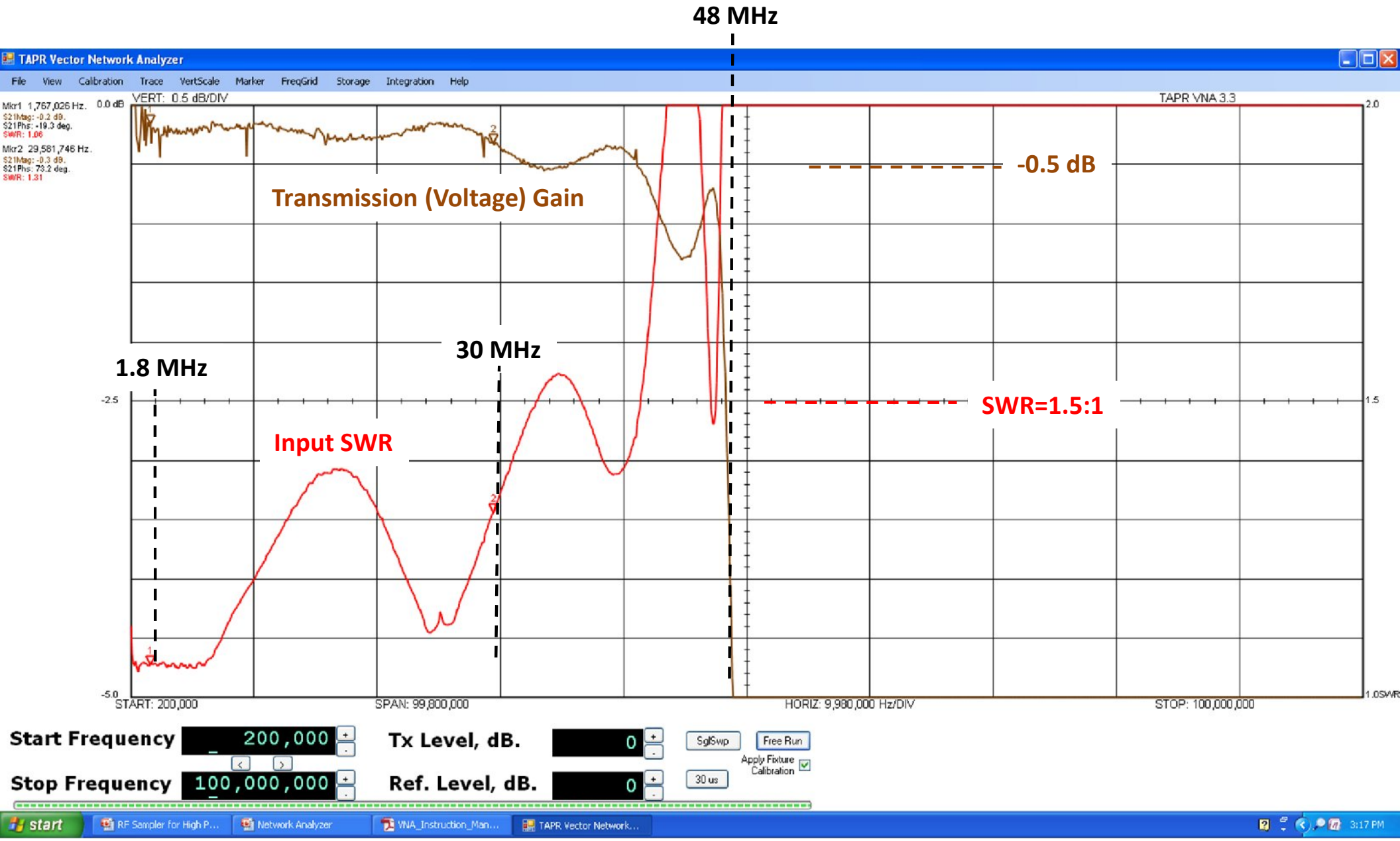
TenTec 6000 VNA

- Rectangular Display of **50 MHz Lowpass Filter**



TenTec 6000 VNA

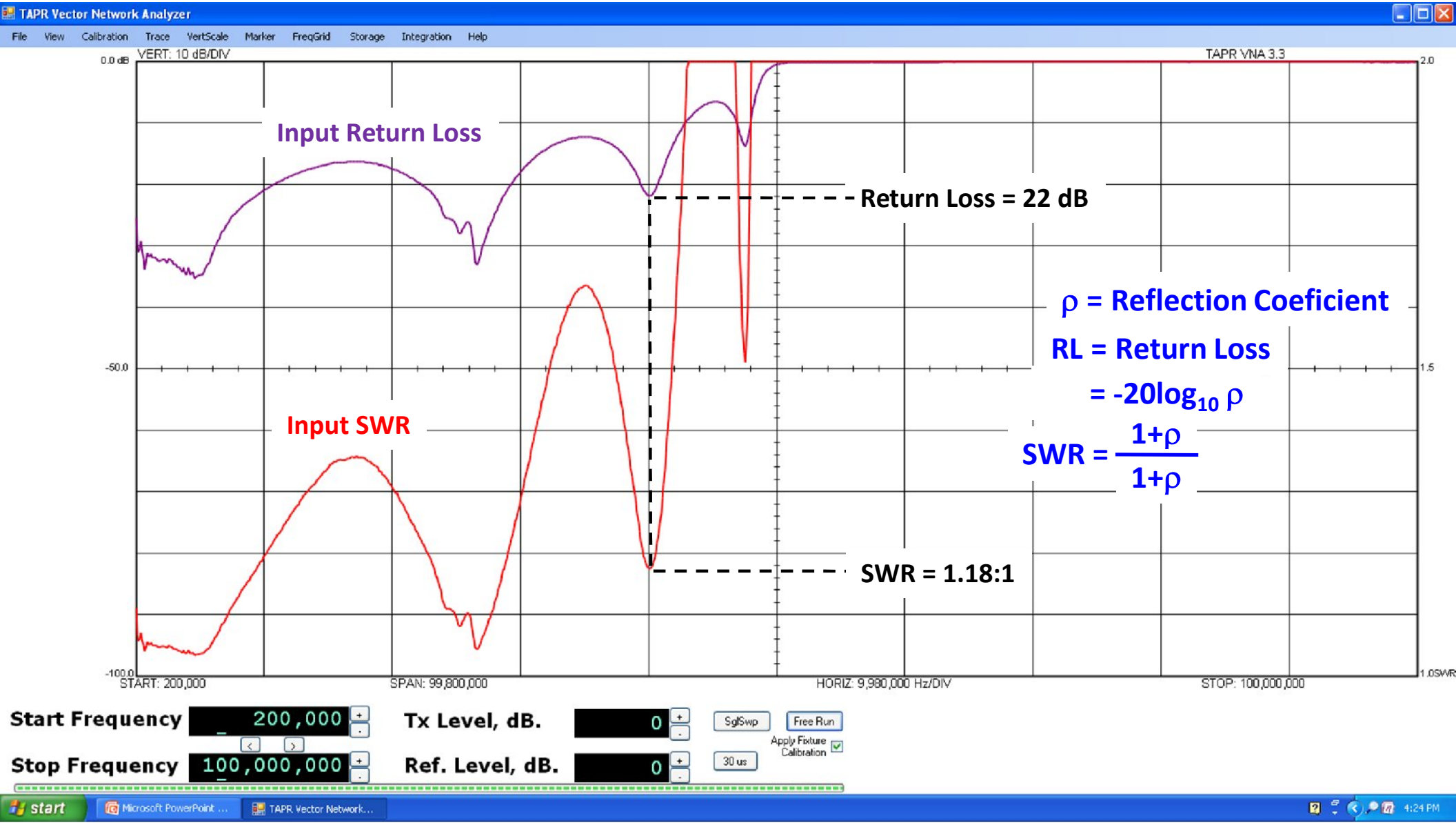
- Rectangular Display of **50 MHz Lowpass Filter**



TenTec 6000 VNA

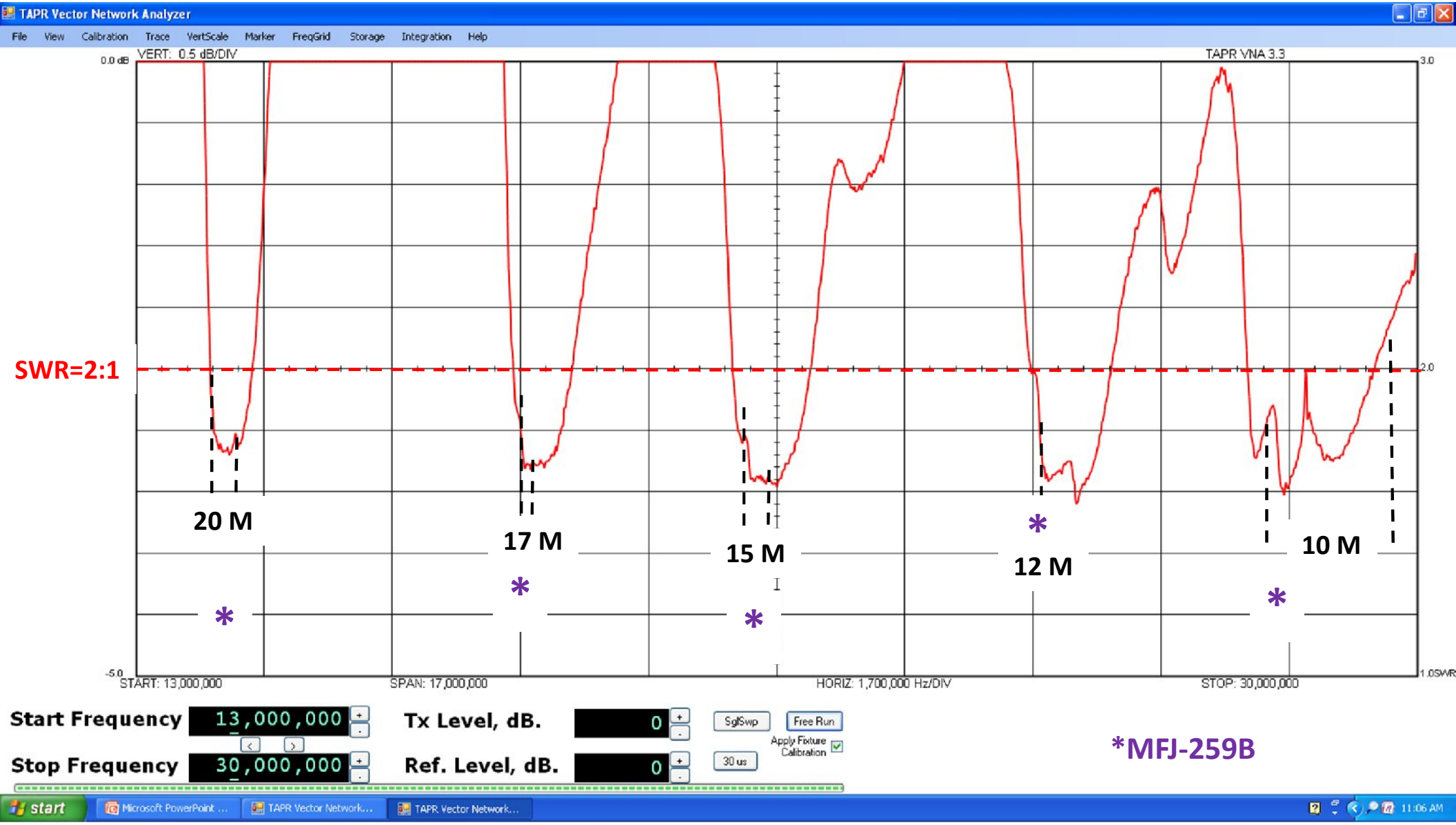
- Rectangular Display of **50 MHz Lowpass Filter**

Input SWR versus Return Loss



TenTec 6000 VNA

- Rectangular Display of a **5 Band HEX BEAM**

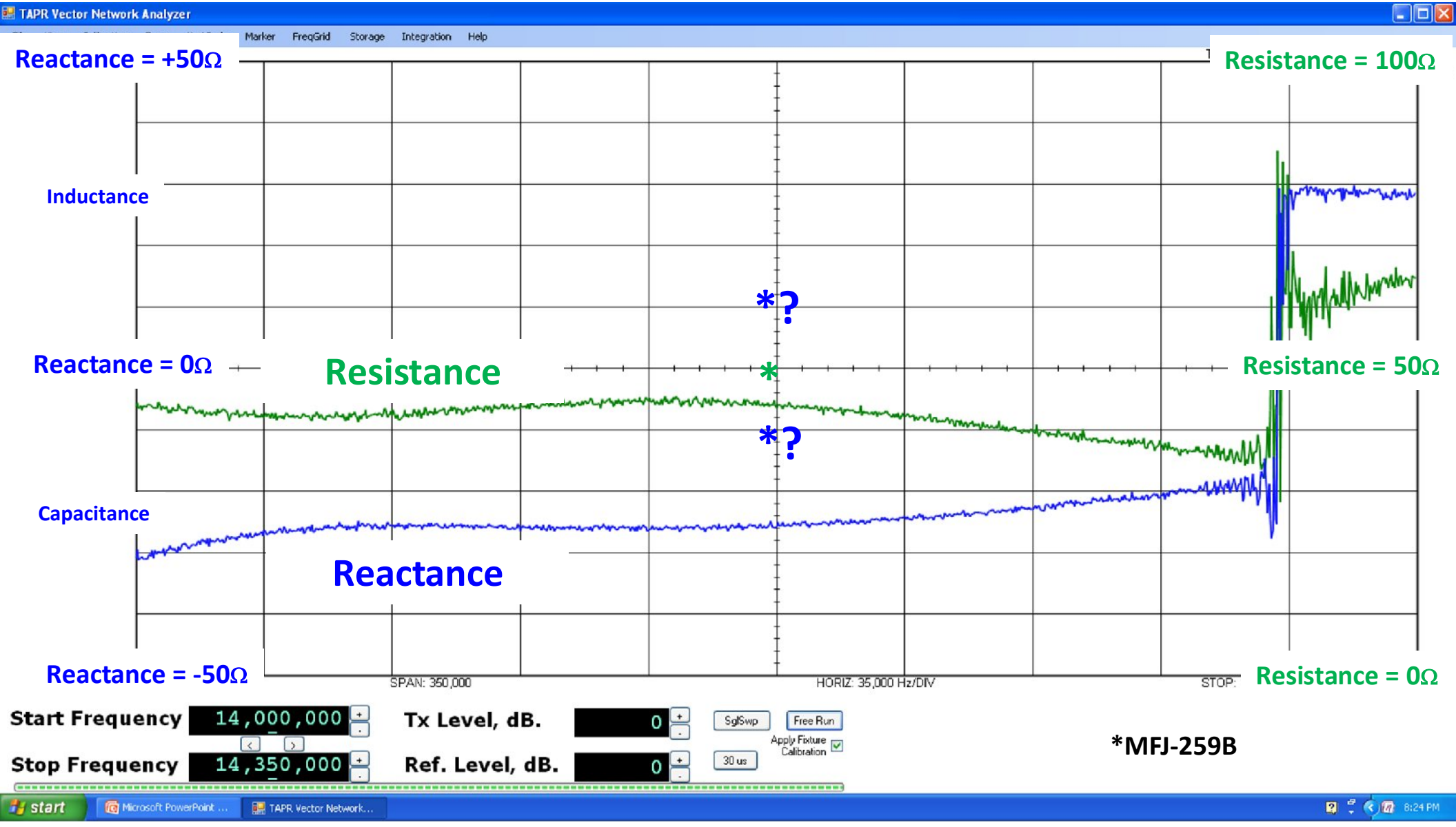


*MFJ-259B

TenTec 6000 VNA

- Rectangular Display of a **5 Band HEX BEAM**

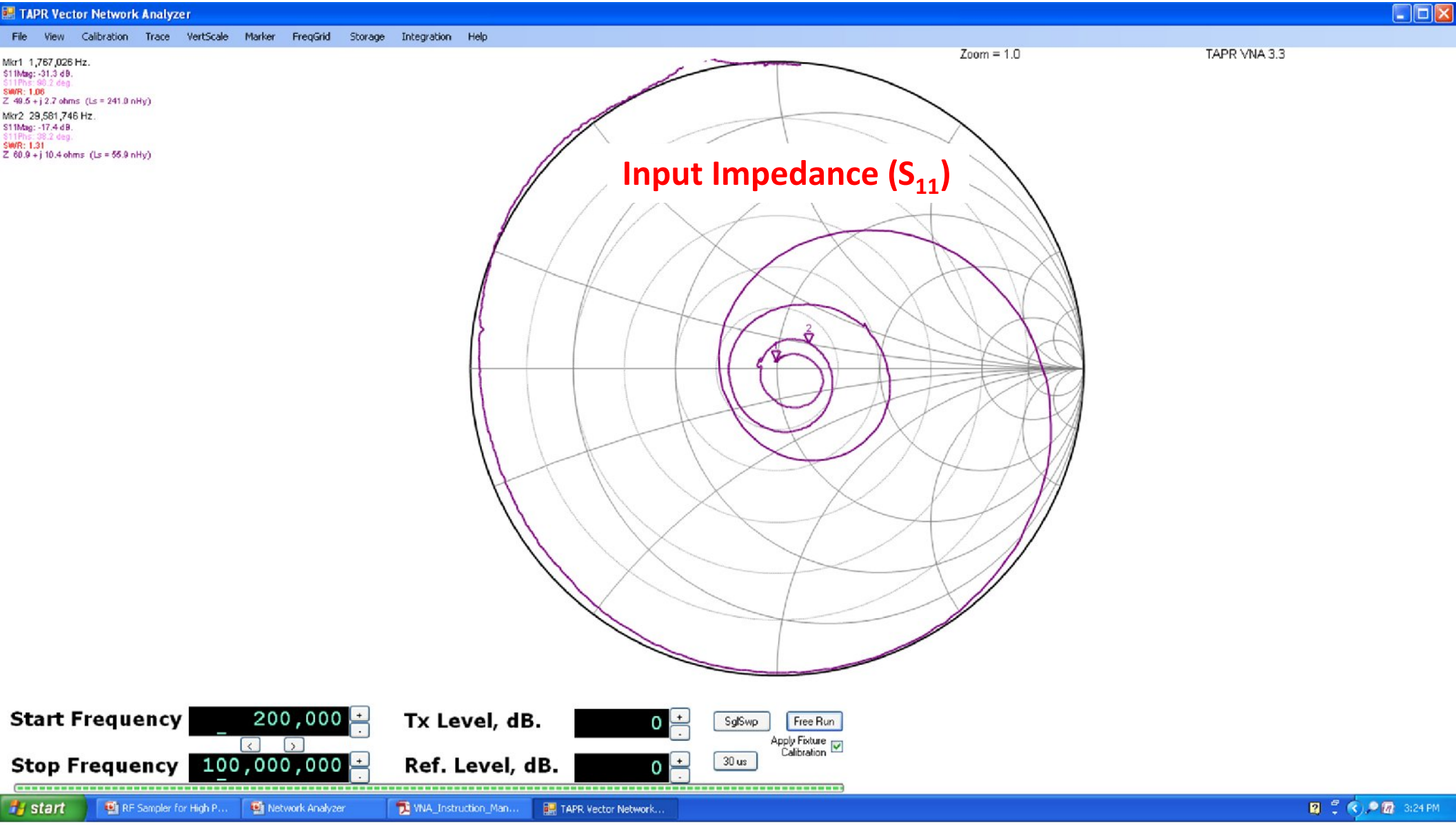
Input **Resistance** and **Reactance** across **20M band**



*MFJ-259B

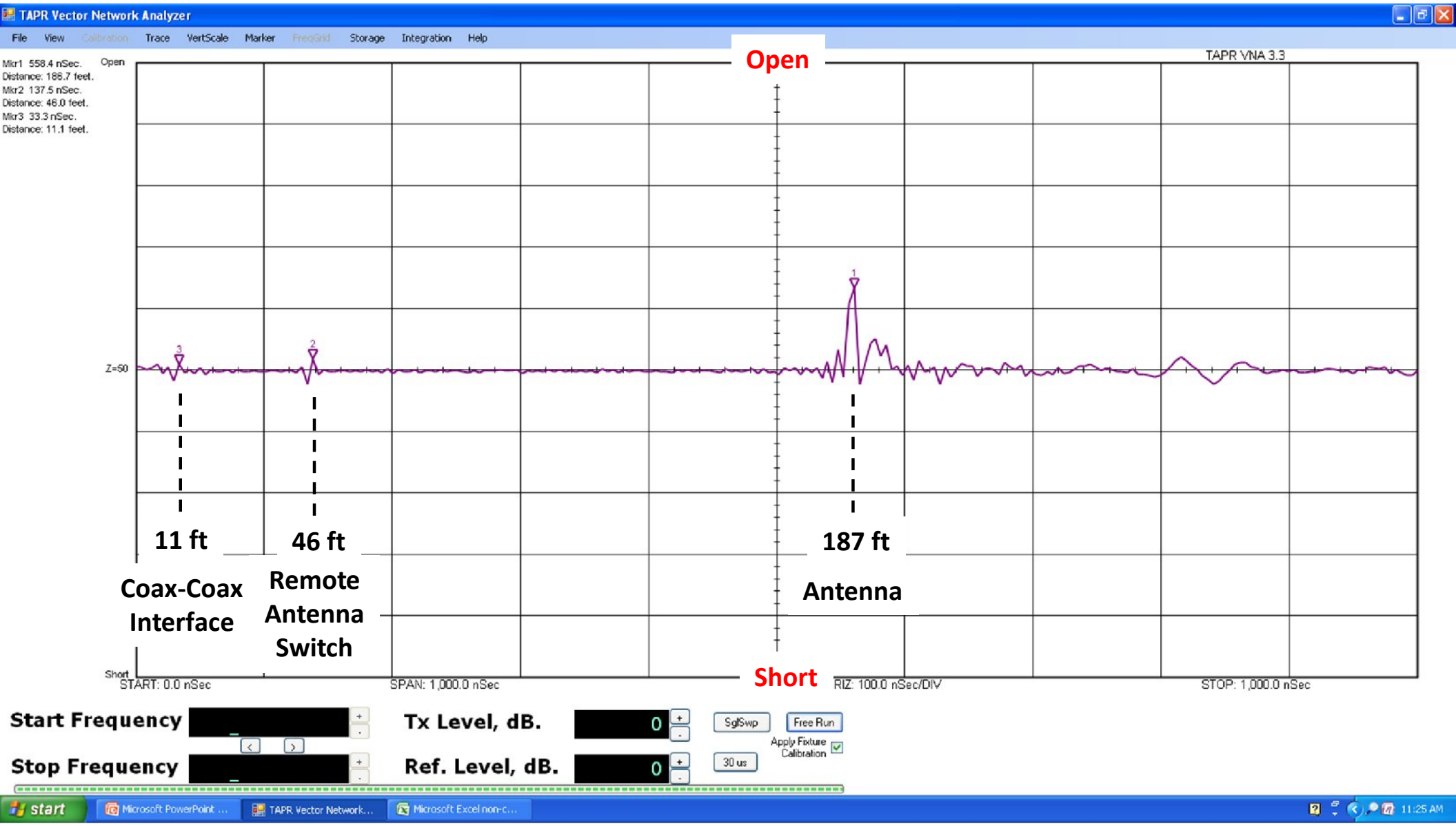
TenTec 6000 VNA

- Polar (Smith chart) Display of **50 MHz Lowpass Filter**



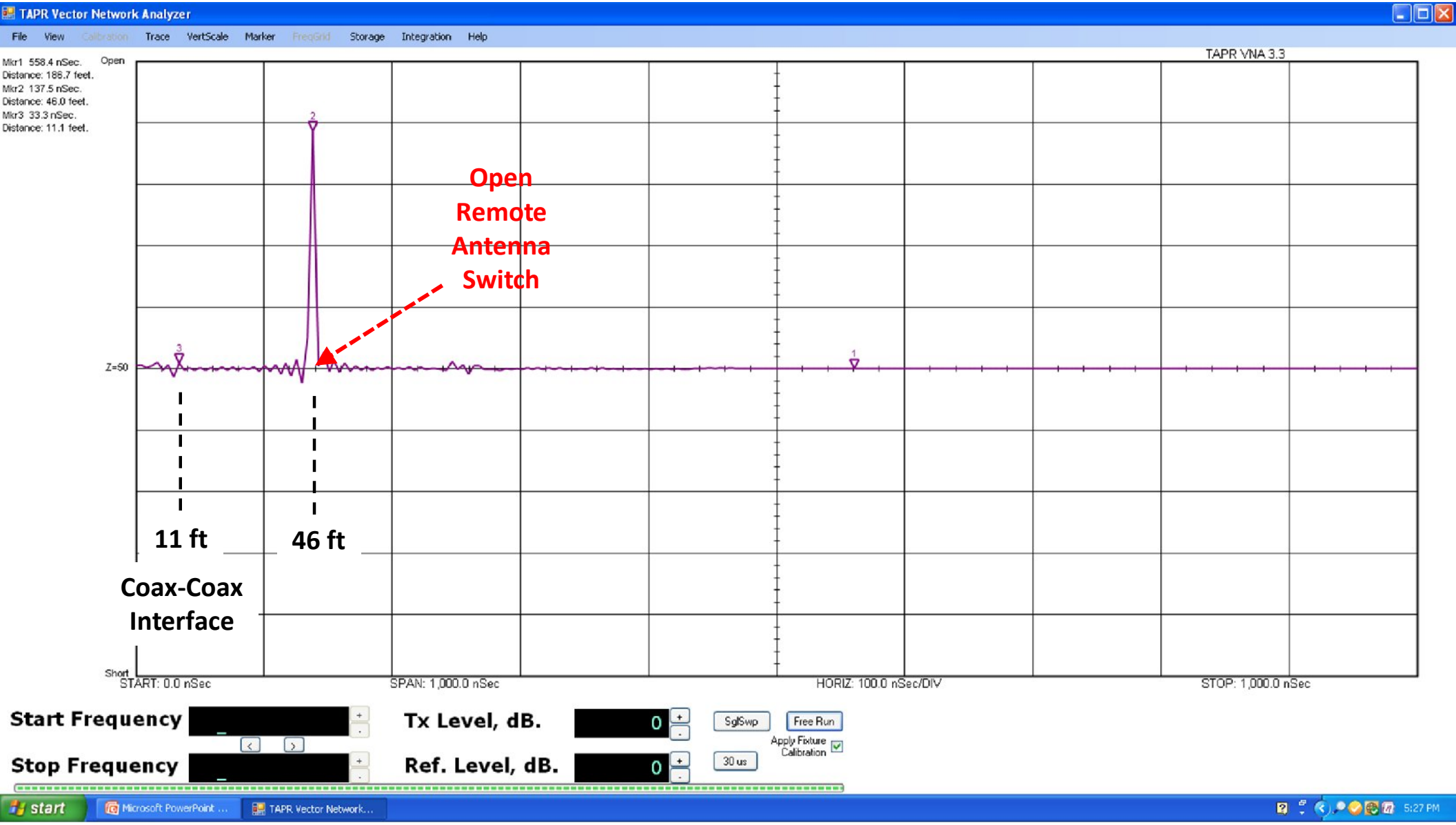
TenTec 6000 VNA

- Time Domain Reflectometer (TDR) Display of a **5 Band HEX BEAM**



TenTec 6000 VNA

- Time Domain Reflectometer (TDR) Display of a **Defective Antenna Switch**



Comparison of Specs

Function	6000	4170	Comments
S Parameters Measured	All 4	S_{11} only	
External Interference Rejection	Low	High	
Static Discharge Protection	No	Yes	Gas Discharge Tube
Max RF Input Signal Level	10 dBm (1 Vp)	16 dBm (2 Vp)	
Frequency Range	0.2-120 MHz	0.005-170 MHz	
Frequency Step Size	1 Hz up	1 Hz up	
Calibration	via S/W	via S/W	
SWR Range	1.0 to 11.0	1.0 to 20.0	
Resistance Range	0 to 10K	?	
Reactance Range	0 to +/-5K	?	
Impedance Range	N/A	0 to 5K	
Impedance Accuracy	?	+/-2%*	*% of reading (not full scale)
Phase Range	0 to +/-180^{o}	0 to +/-90^{o}	
Detector Type	Analog	Digital	
ADC Resolution	?	12 bits	
PC Interface	USB	RS-232	
Normal RF Signal Level	1 mw	10 uw	
-Adjustable	Yes	No	
Measurements can be ref to ant	Yes	Yes	
Can be used as a Sig Gen (Digital)	Yes	Yes	
-Amplitude Range	+0 to -50 dBm	-17dBm (30mV)	
-Amplitude Steps	1 dB	fixed	
-Frequency Range	0.2 to 144 MHz	0.005-170 MHz	
-Frequency Step	1 Hz	0.1 Hz	
TDR Resolution	4 nsec*	?	* (~1.5 ft in RG-8))
Cost	$650*	$545*	*Includes all Cal hardware

AIM-4170 Antenna Analyzer

(Network Analyzer)

Presentation for the 285-TechConnect Meeting

Dale Keller, ACØST

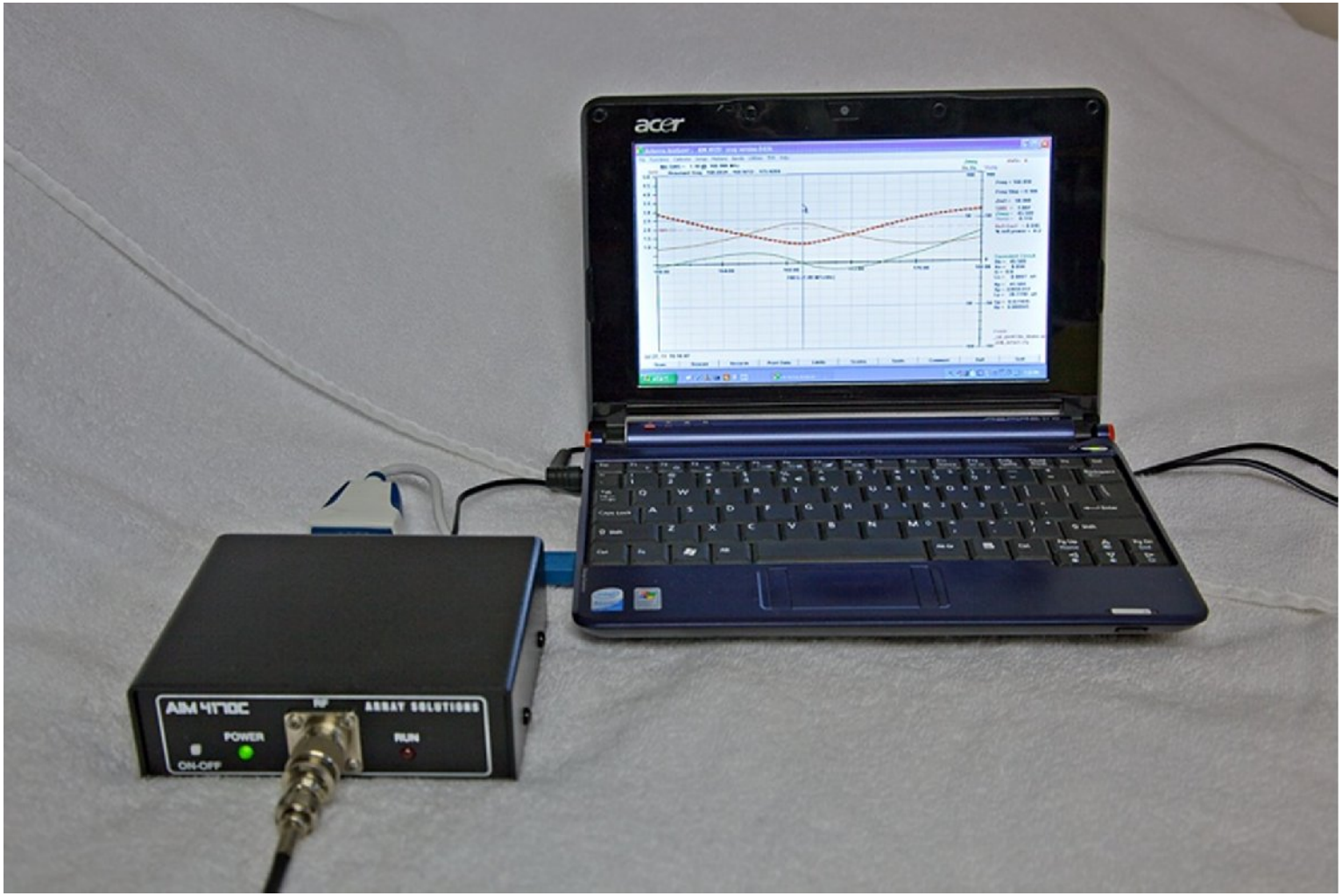
Introduction

It looks like this.

So where’s the screen?

User Interface

Use a desktop or laptop for the user interface.



General Information

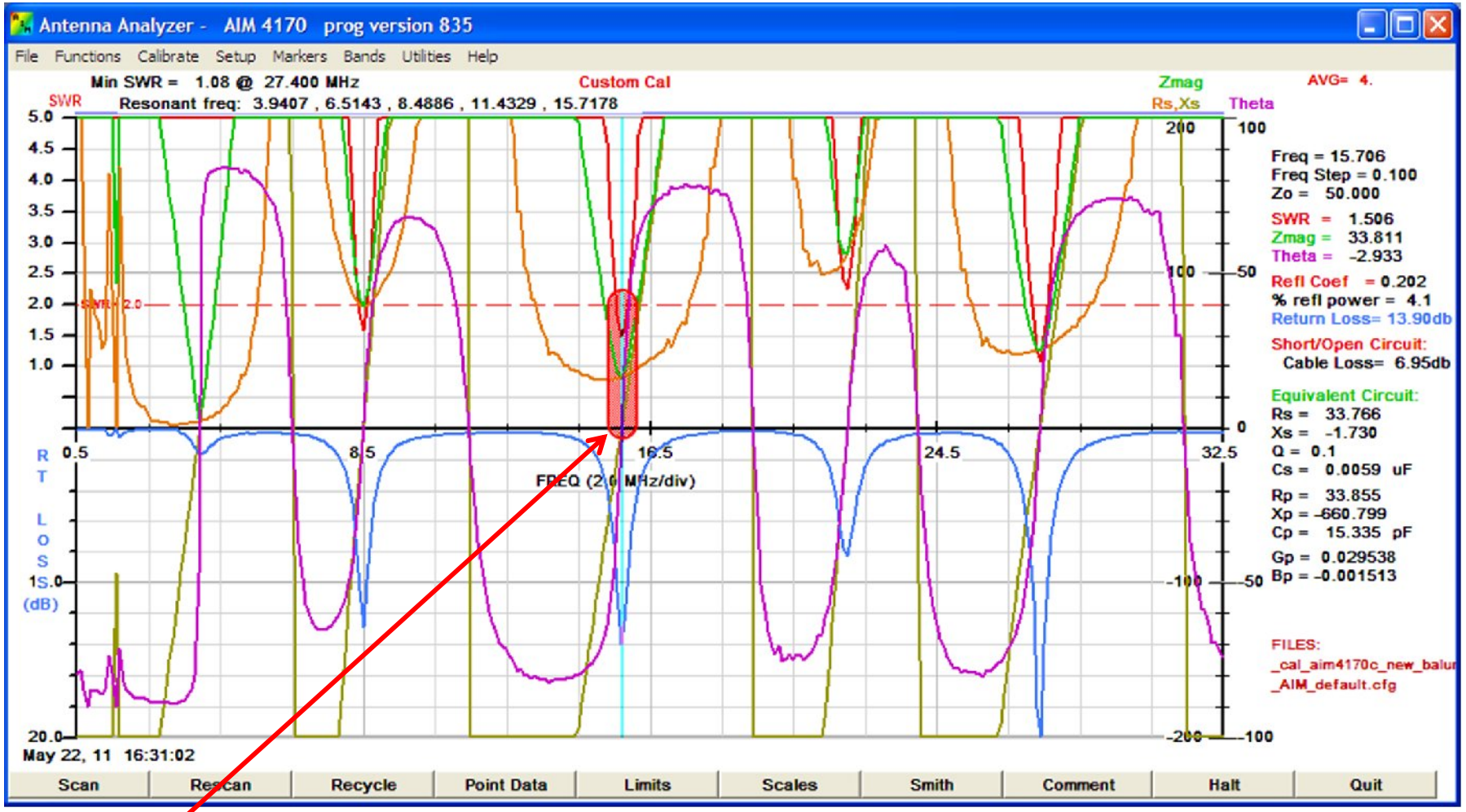
- This is more of a graphical network analyzer than an antenna analyzer.
- Instead of checking a single frequency controlled by your hand on a knob, it sweeps a frequency range and displays the data on a graph.
- Covers 0.1 to 170 MHz.
- $545.00

General Info (continued)

- This is probably the lowest priced network analyzer available, but compares very well with much more expensive lab equipment.
- Another model, AIM*uhf* ($$) goes up to 1 GHz.
- Array Solutions also makes a two-port VNA2180 Vector Network Analyzer ($$$).

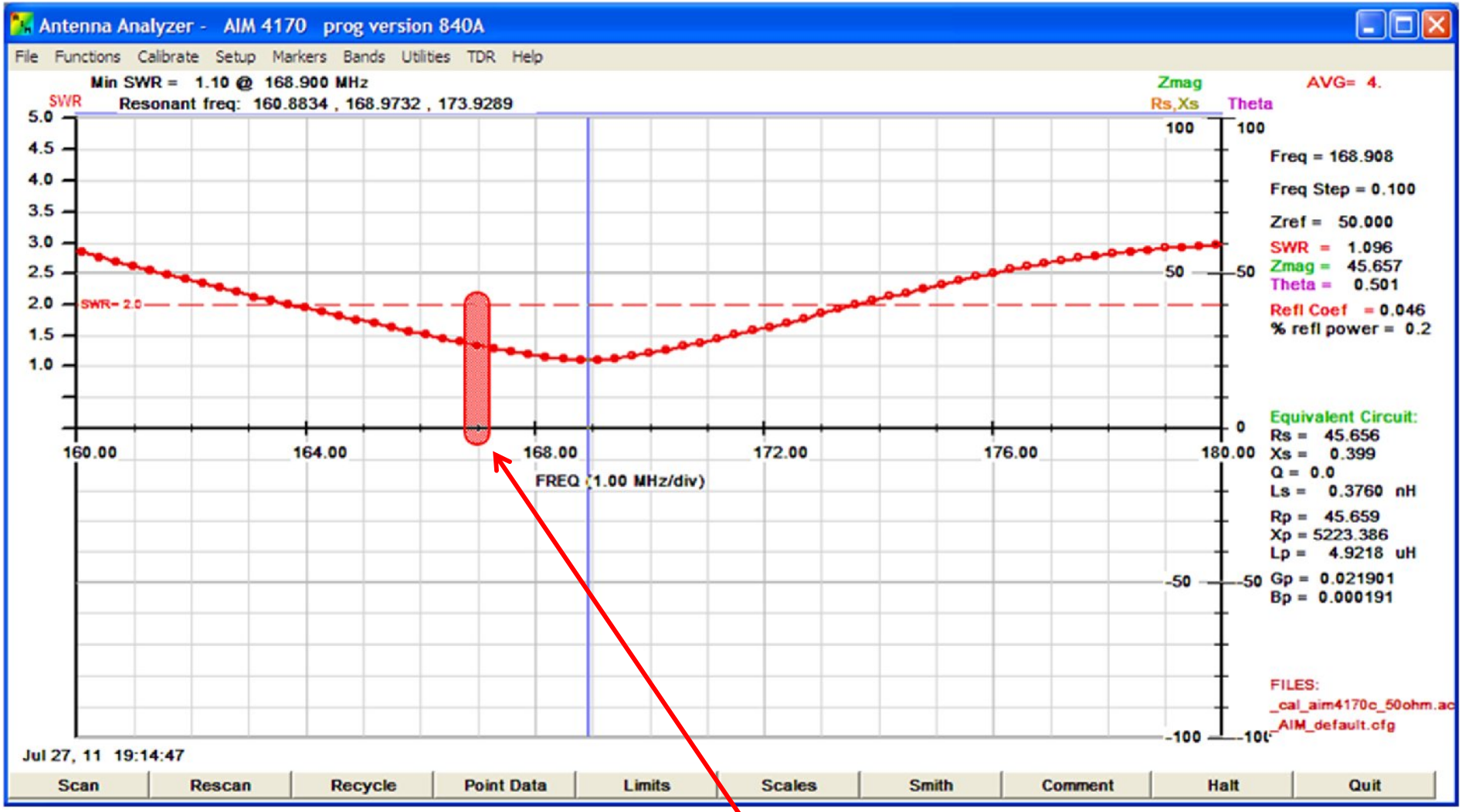
The Good

Provides ***much*** more information than a typical MFJ-259B.



The Good (continued)

You can turn off the info you don't need.



The Good (continued)

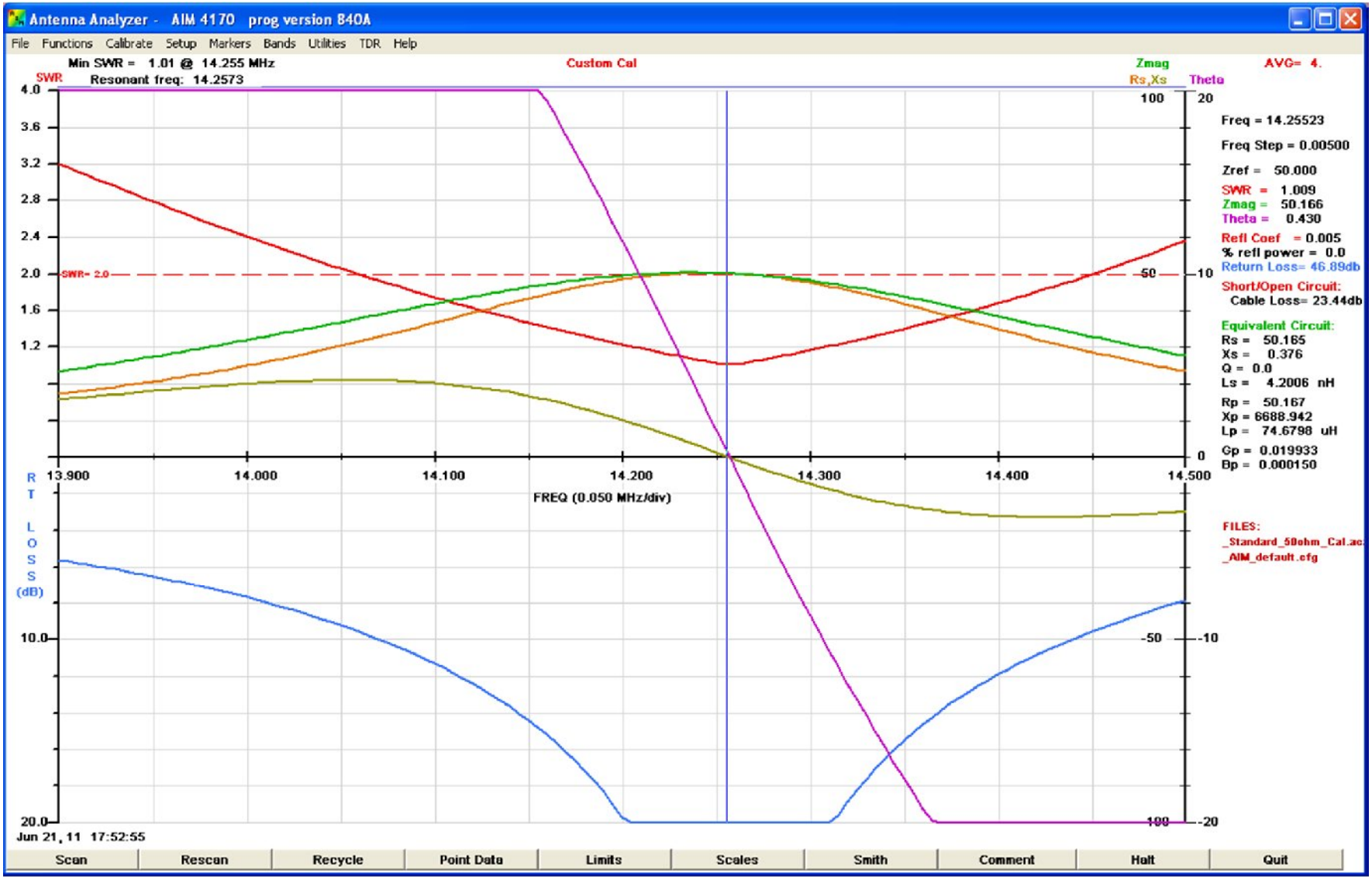
- High tolerance to external signals (AM broadcast interference, 60 Hz induced currents, etc).
- Can use a broadcast-band filter and calibrate around it.
- Calibrate to the "plane of measurement" - the point at which the actual measurement is made.
- Custom Calibration for cables, filters, baluns, etc. (plane of measurement, or measurement reference point).
- Accuracy: QST review said "the accuracy is exceptional and caused us to go back and check the calibration of our reference loads“. It compares very well to laboratory grade test instruments.

The Good (continued)

- Measure crystals, inductors, capacitors.
- Has a TDR function - find electrical length of coax, or a break point.
- Display a Smith Chart.
- "Live" mode (Point Data) like MFJ-259B.
- Free software updates.

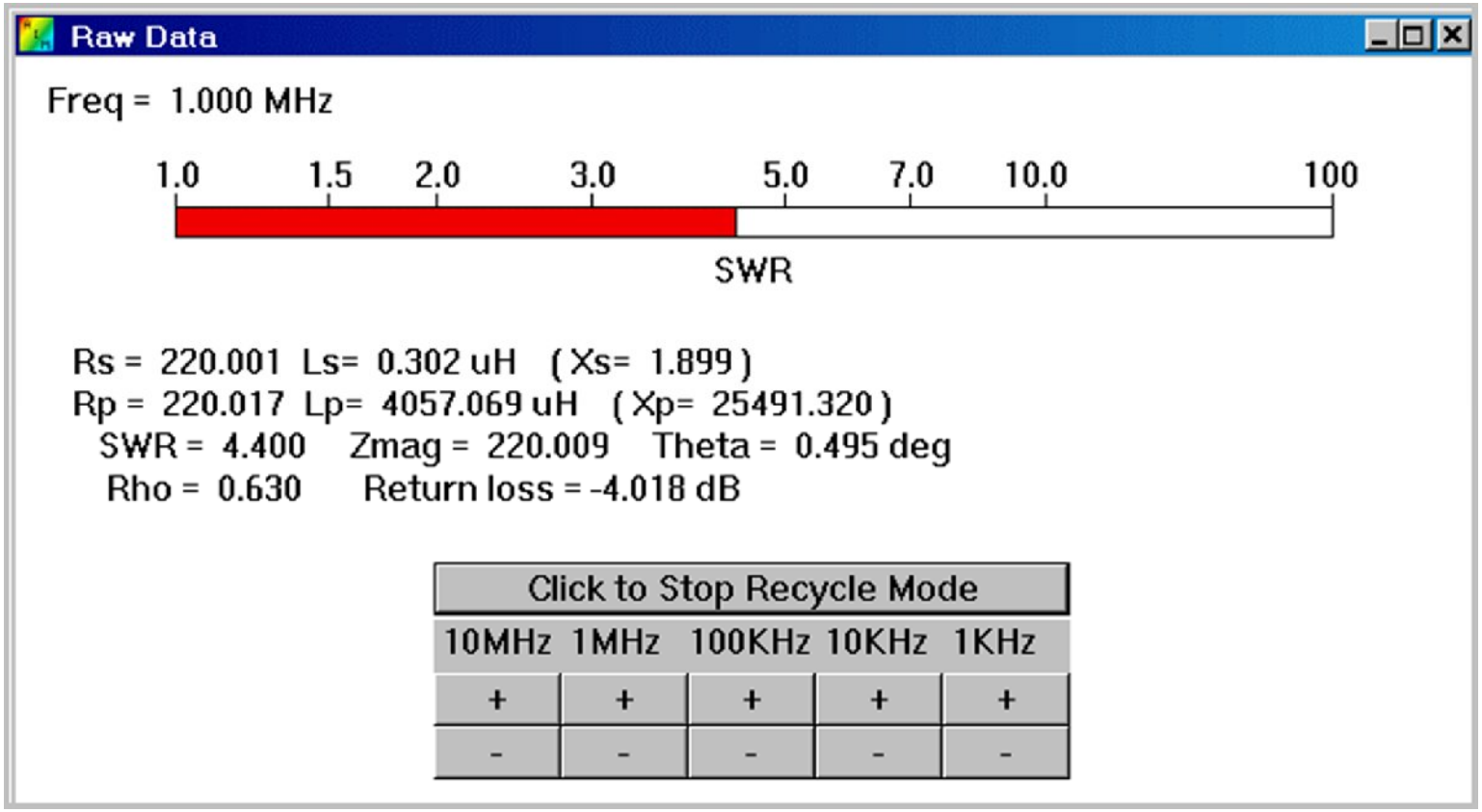
The Good (continued)

My 20-meter Inverted V



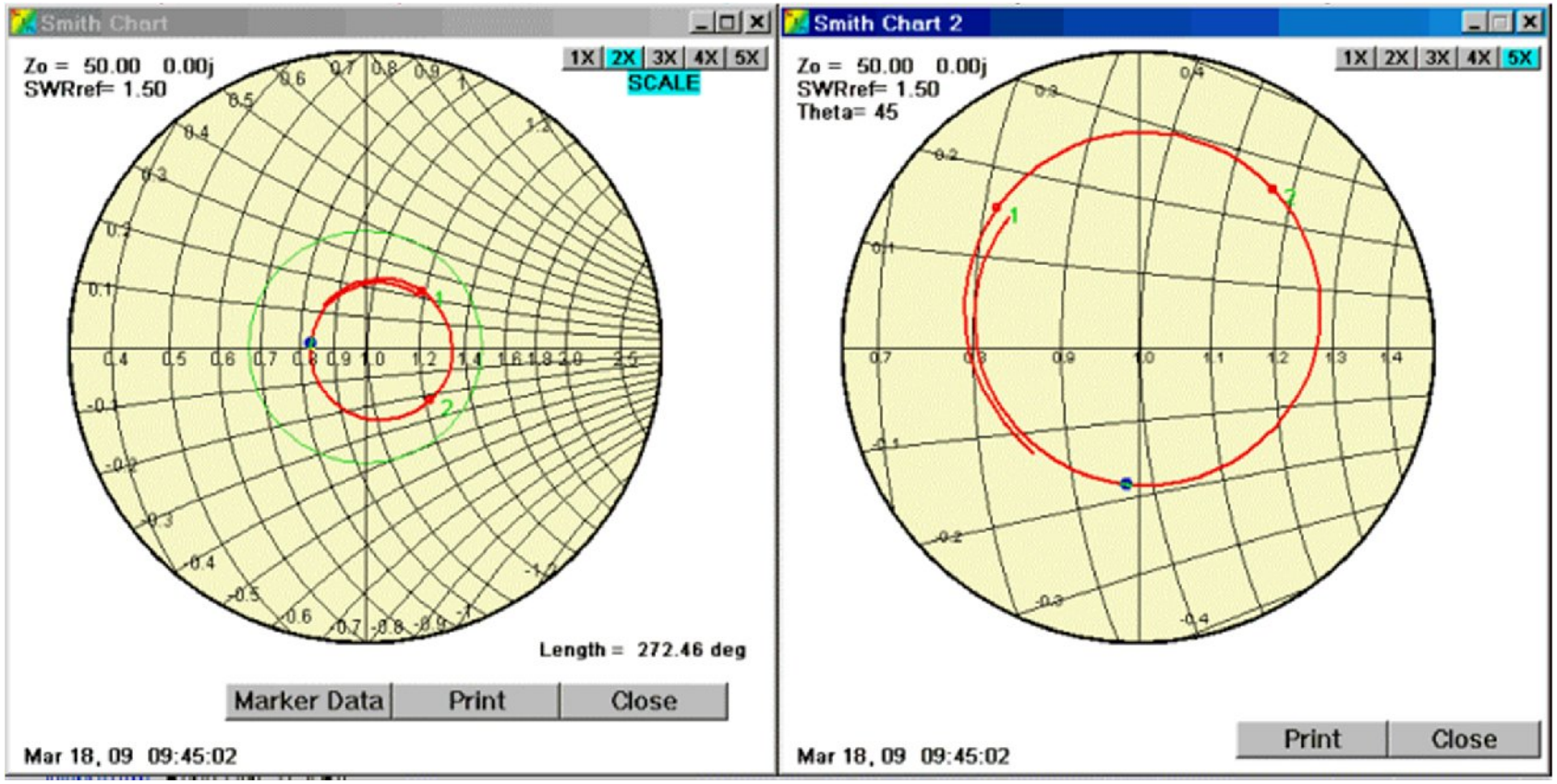
The Good (continued)

Point Data (Real-Time)



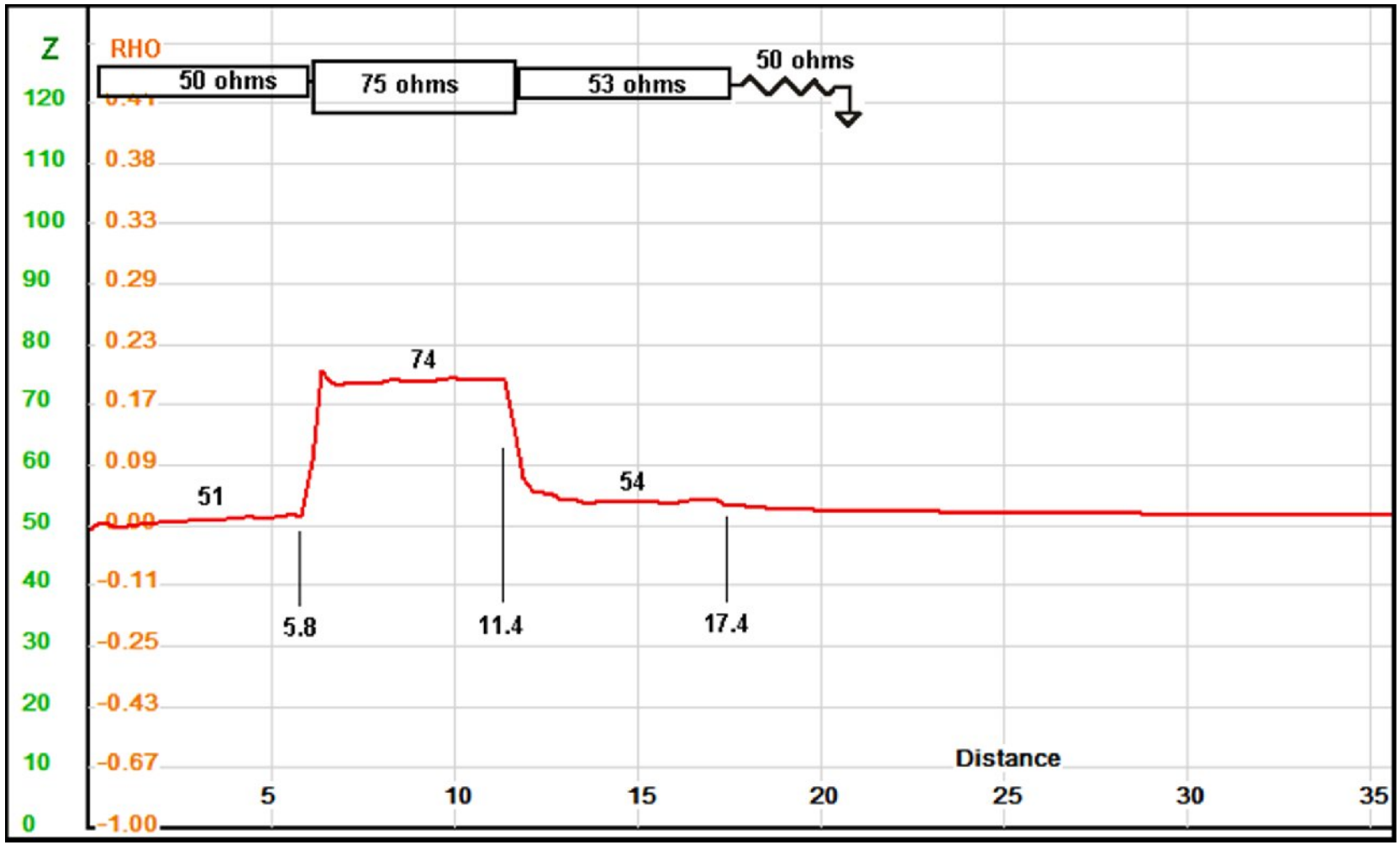
The Good (continued)

Smith Chart



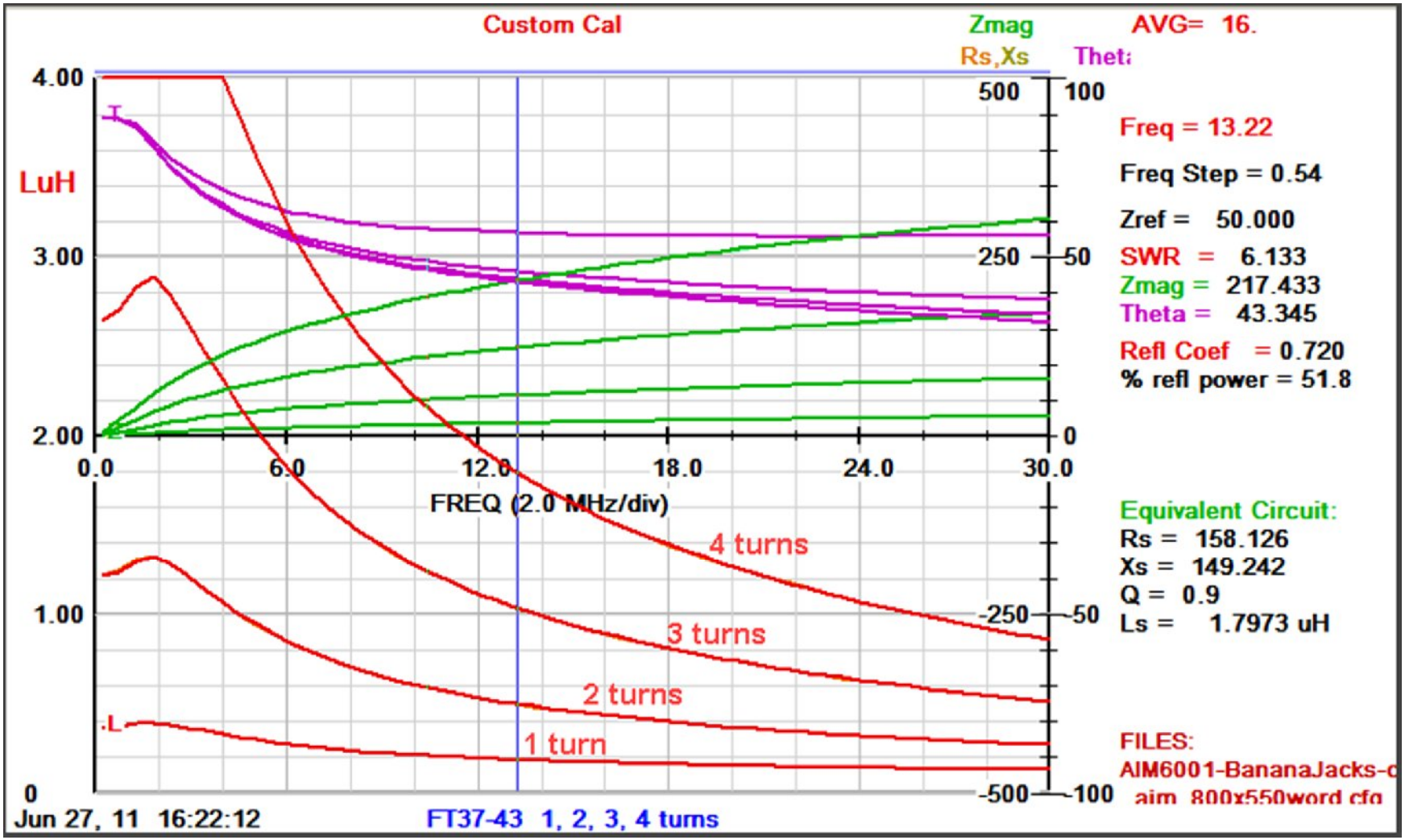
The Good (continued)

Time Domain Reflectometry



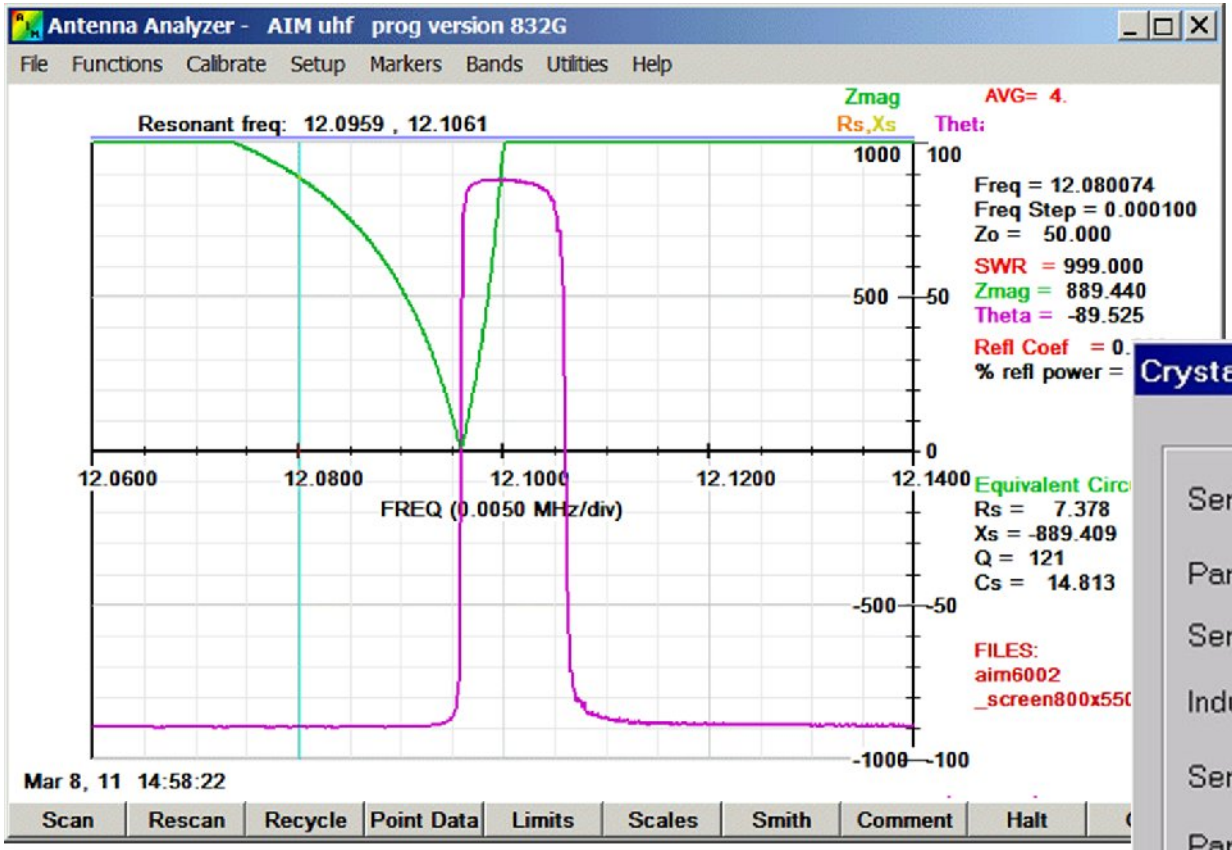
The Good (continued)

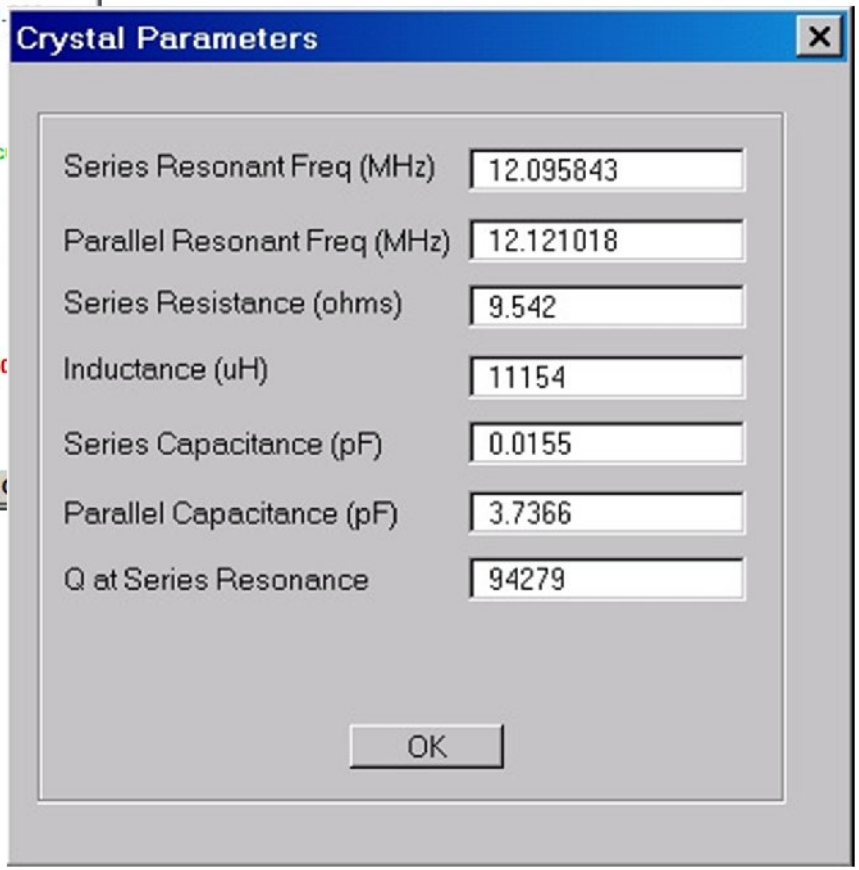
Inductance Measurement



The Good (continued)

Crystal Parameters Measurement





The Bad

- NOT much to complain about.
- The manual is good, but doesn't show everything, so you have to Google around for hints.
- Stray capacitance to ground is a problem when measuring high impedance circuits (like an end-fed half-wave antenna).

  Make short power and serial cables, run it on battery power, place it on a wooden table. It will still have more stray capacitance than a handheld instrument. My EFHWA should show >5K ohms, but gets flakey above about 2K ohms.

The Bad (continued)

Not as "handy" as MFJ-259B. It takes up more room and has more parts. It’s fine in the shop, but not as handy on the tower or in the field.

The Ugly

Conclusion

The best antenna analyzer is actually two analyzers -- one of each: a network analyzer like the AIM-4170, and a handheld unit like the MFJ-259B.

- W5BIG Bob Clunn website (designer, software developer, general information) http://www.w5big.com/
- Ordering website http://www.arraysolutions.com/Products/AIM4170.htm
- Ian Wade, G3NWR, has a PowerPoint presentation at http://homepage.ntlworld.com/wadei/aim4170.htm