Get the Most from your Antenna Analyzer

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Agenda

Review of Impedance concepts

Scalar and Vector Analyzer – Descriptions

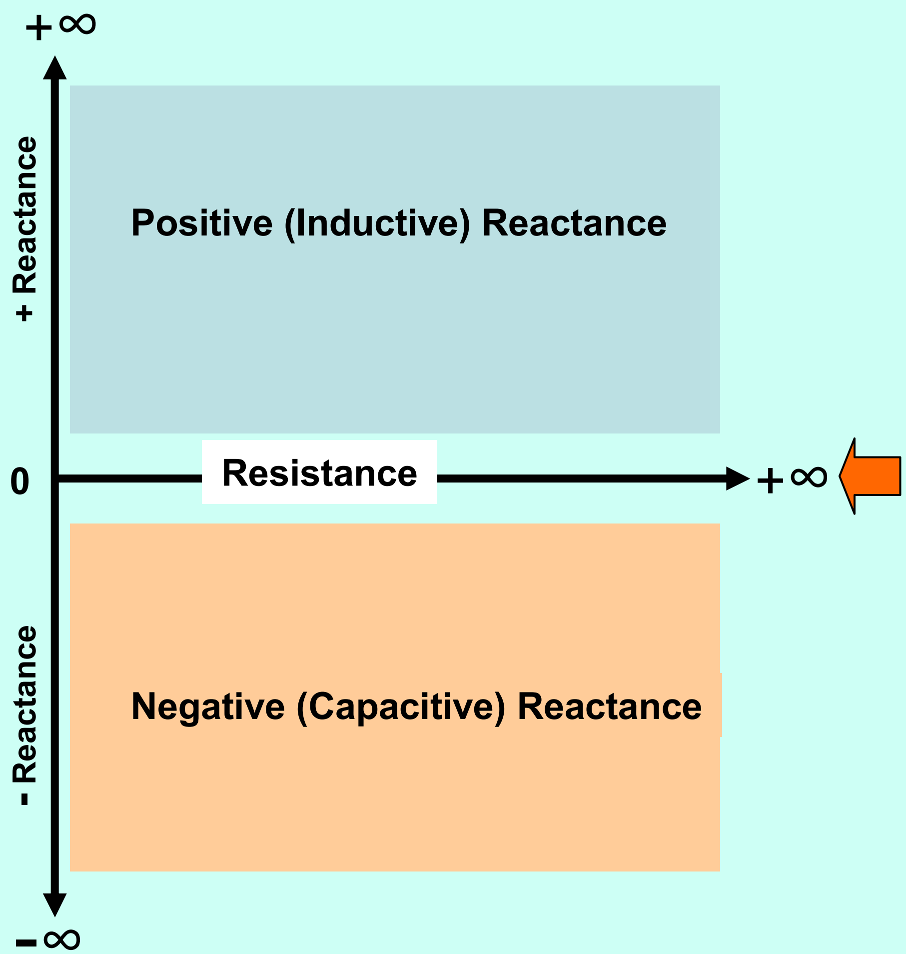
What you can do with a scalar analyzer

What you can do with a vector analyzer

Some applications

Verify your analyzer

Impedance = Resistance and Reactance



Resistance and reactance are independent

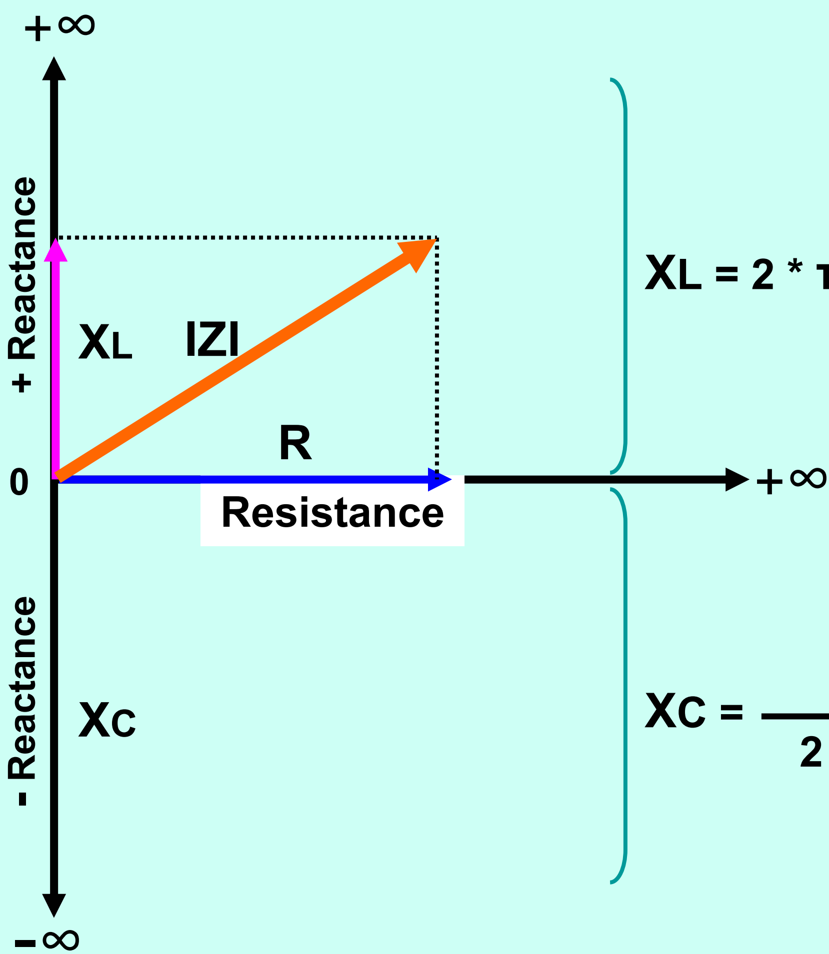
They combine at right angle like triangles

You can only dissipate power
in the resistance part

Reactances of opposite sign will subtract

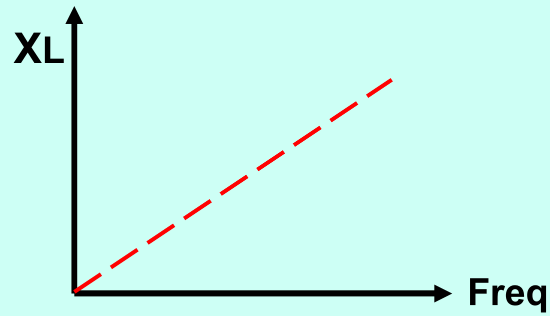
This property is used in tuners, filters,
resonators…

Resistance R, Reactance X and Impedance Magnitude IZI

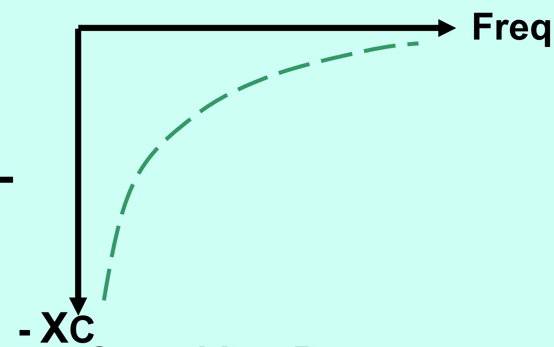


$$X_L = 2 * \pi * F * L$$

$$X_C = \frac{-1}{2 * \pi * F * C}$$



Inductive Reactance
Increases with Freq.



Capacitive Reactance
Decreases with Freq.

Impedance Z, Reflection Coefficient and SWR

Impedance = resistive (R) and reactive part (X)

$$Z = R + j \cdot X$$

$$|Z| = \sqrt{R^2 + X^2}$$

Impedance magnitude

$$\Gamma = \frac{Z - Zo}{Z + Zo}$$

Reflection coefficient Γ (magnitude + angle). Zo is the reference Z
Γ goes from -1.0 > 0 > +1.0

$$RL = -20 \cdot \log(|\Gamma|)$$

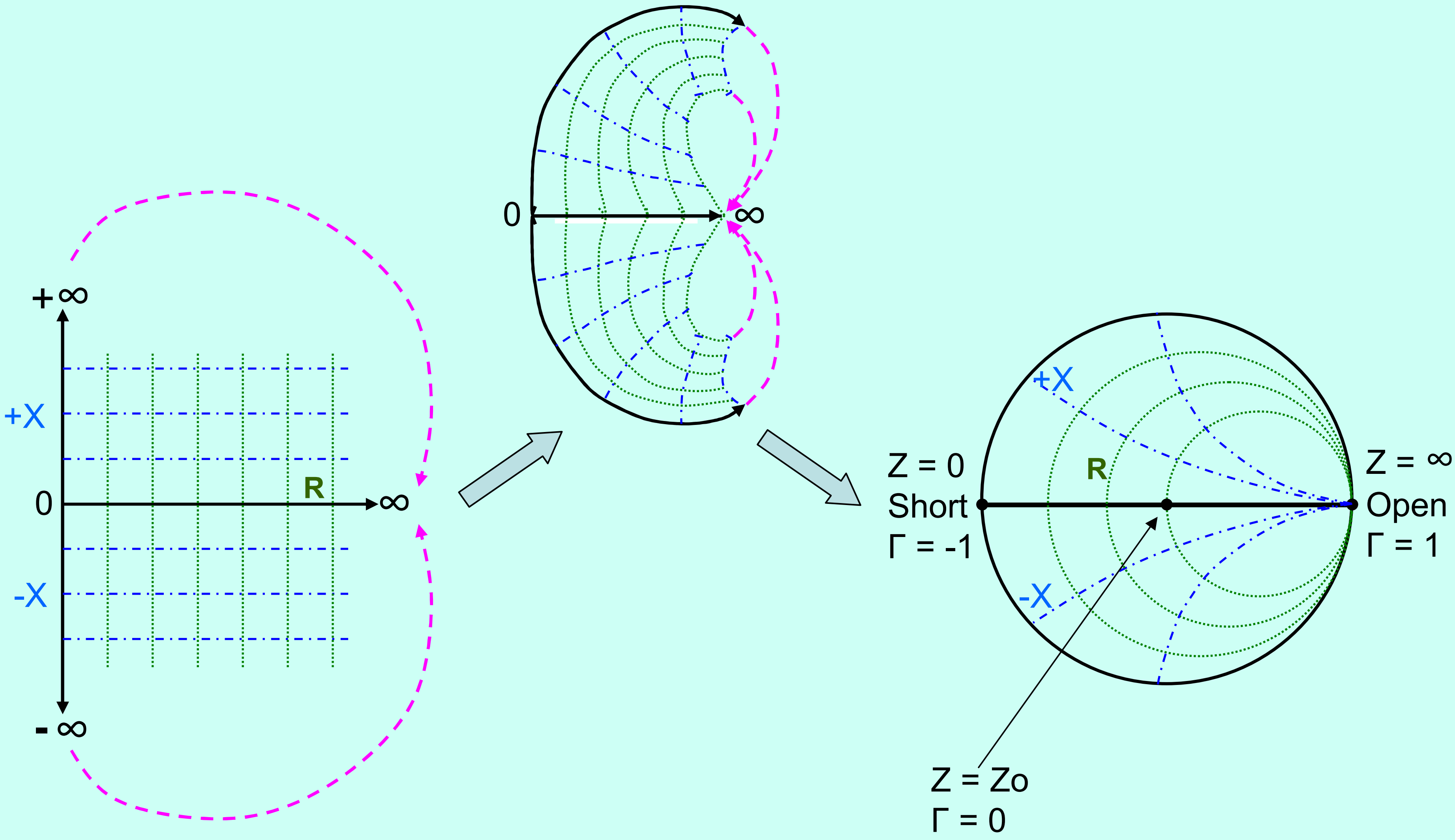
RL = Return Loss in dB $|\Gamma|$ **= magnitude of the reflection coefficient**

$$SWR = \frac{1 + |\Gamma|}{1 - |\Gamma|}$$

SWR (also called voltage standing wave ratio)
Goes from 1 to ∞

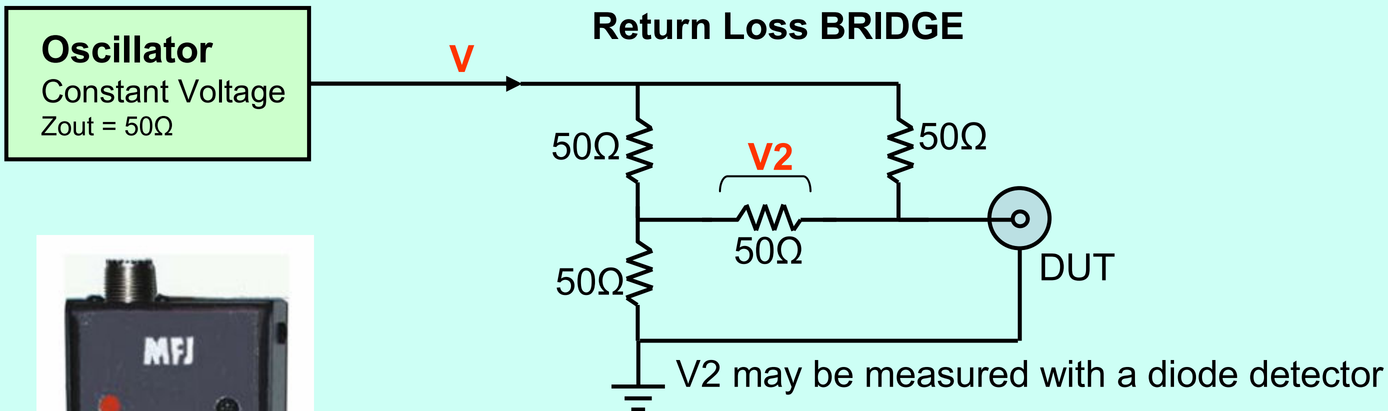
	SWR		Reflection Coeff.		Return Loss (dB)
Z = Zo	1:1	→	0	→	∞
Z = 0	∞	→	-1	→	0
Z = ∞	∞	→	+1	→	0

The Smith Chart



A Basic Scalar Analyzer

One VOLTAGE MEASUREMENT allows measuring the SWR



Example of a basic
SWR Analyzer: MFJ 207

V2 voltage magnitude is measured with V constant.

V2 corresponds to the magnitude of Γ → SWR

Measures SWR directly – but not so accurate

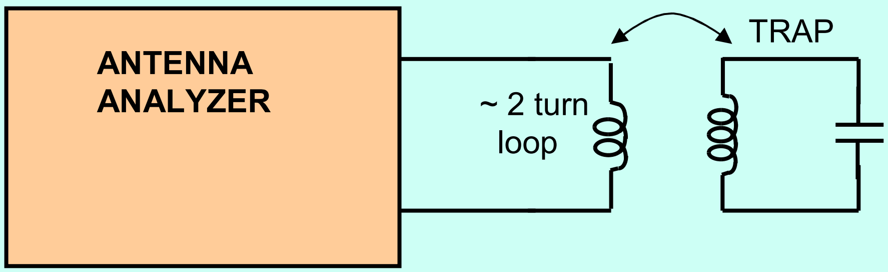
Cannot measure high SWR

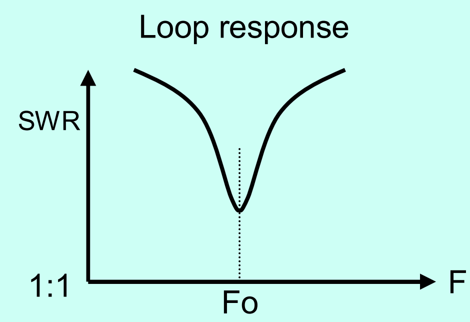
Measures Trap Resonant Frequency and Q factor

Coax Impedance up to 100Ω

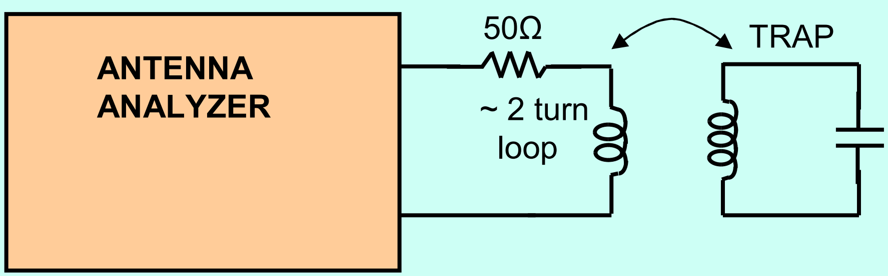
Ferrite Impedance magnitude. And more…

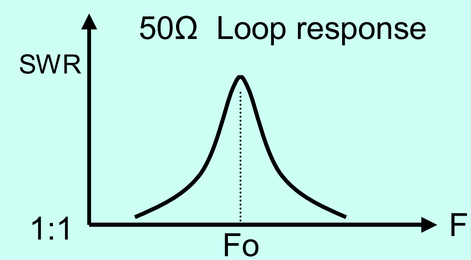
Trap Resonant Frequency





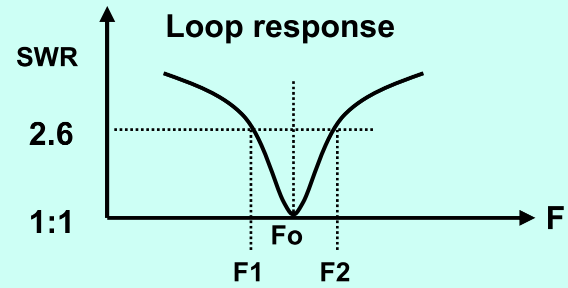
In both cases:
the coupling loop is lightly
coupled to the trap to measure
the resonant frequency Fo.





Q factor Measurement

Ref: http://ve2azx.net/technical/Q-FactorMeas_on_LC_Circuits.pdf



As before use a coupling loop (<u>without the 50 Ω resistor</u>)

Adjust the coupling to get 1:1 SWR at the resonant frequency Fo

Change the frequency to get an SWR of 2.6:1.

Record the TWO frequencies F1 and F2 that give an SWR of 2.6:1

Compute $Q = \frac{Fo}{F2 - F1}$

Example: **Fo = 7.100 MHz, F2 = 7.135 MHz, F1 = 7.064 MHz**

$$Q = \frac{7.1}{7.135 - 7.064} = 100$$

Ref: http://ve2azx.net/technical/MesureZcable_en.pdf

Mesuring the Impedance of a Coax Using an SWR Analyser (up to 100Ω)

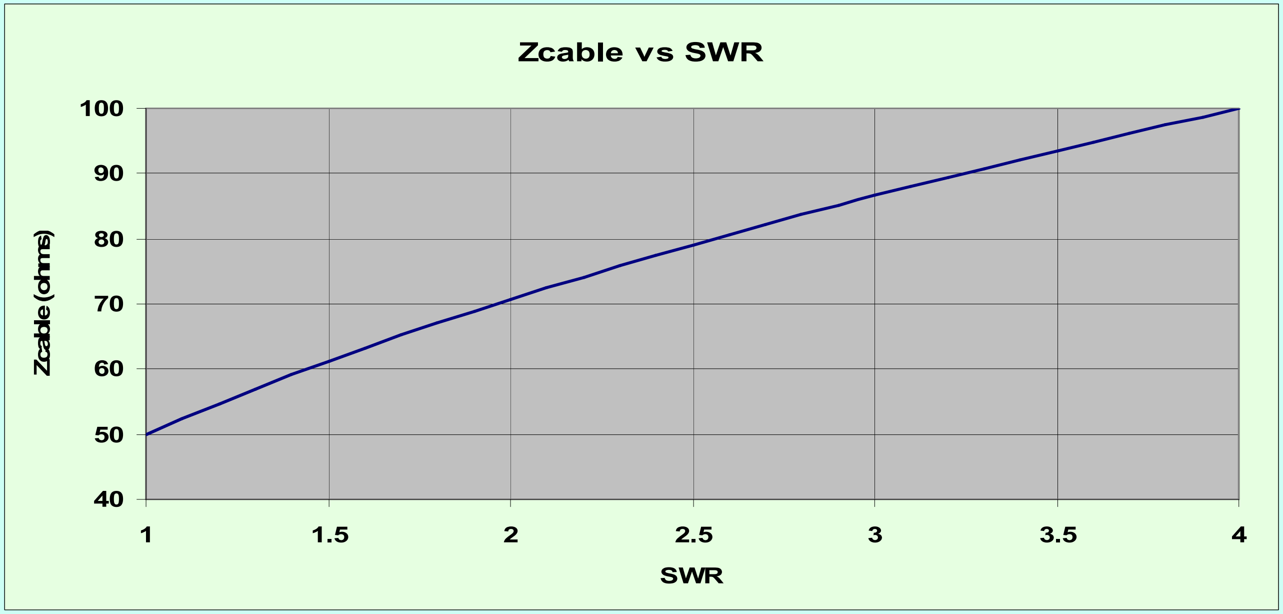
Connect the cable to the SWR analyzer and **terminate the other end with a 50 ohms load**.
Measure the SWR. If you get 1:1, then the cable impedance is 50 ohms.
If the SWR is above 1:1, change the frequency to **maximize** the SWR reading.

Calculate the required frequency (F in MHz), which is related to the cable length L in feet :
F = 185 / L (This is approximately the quarter wavelength frequency)

Calculate Zcable at the **frequency where the SWR is maximum**, or use the graph below:
Exemple: SWR = 2.25 gives Zcable = 75 ohms

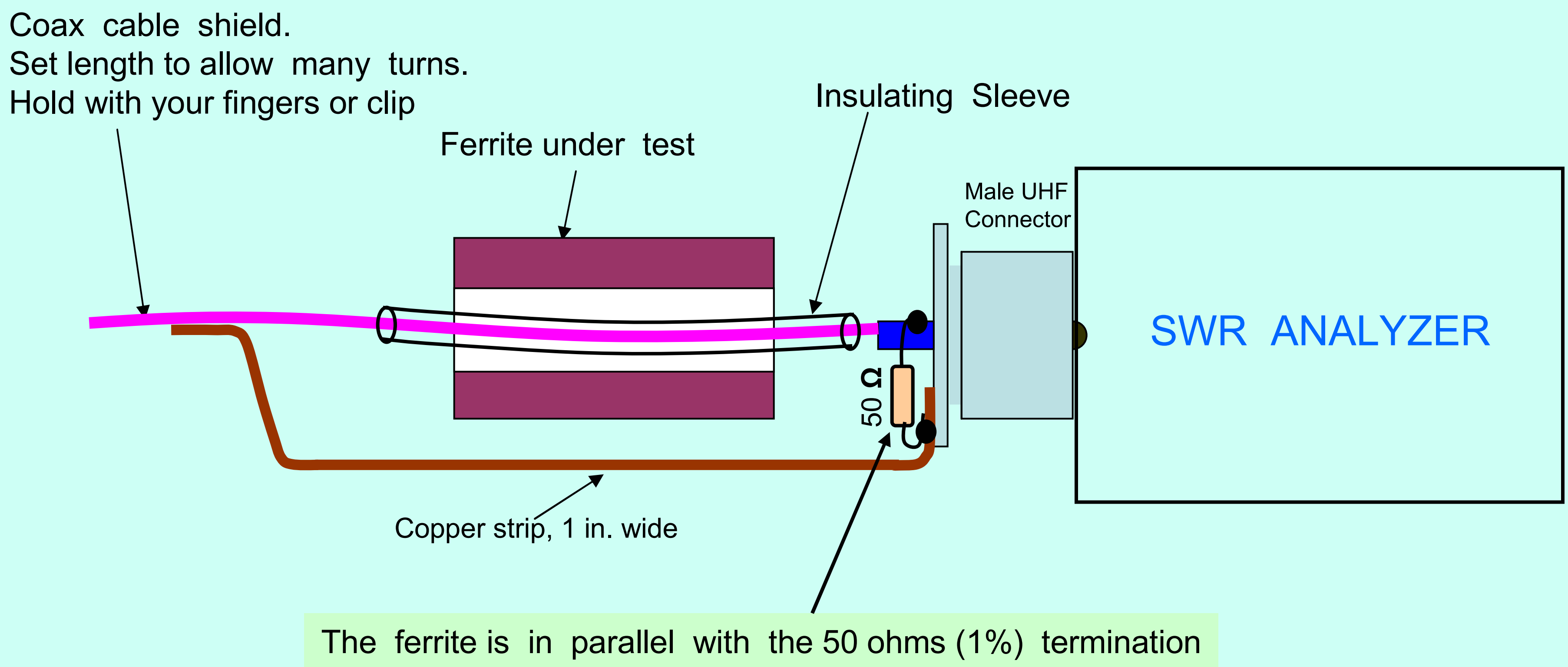
$$Zcable = 50 * \sqrt{SWR}$$

NOTE: This technique is valid for Zcable from 50 ohms to 100 ohms.

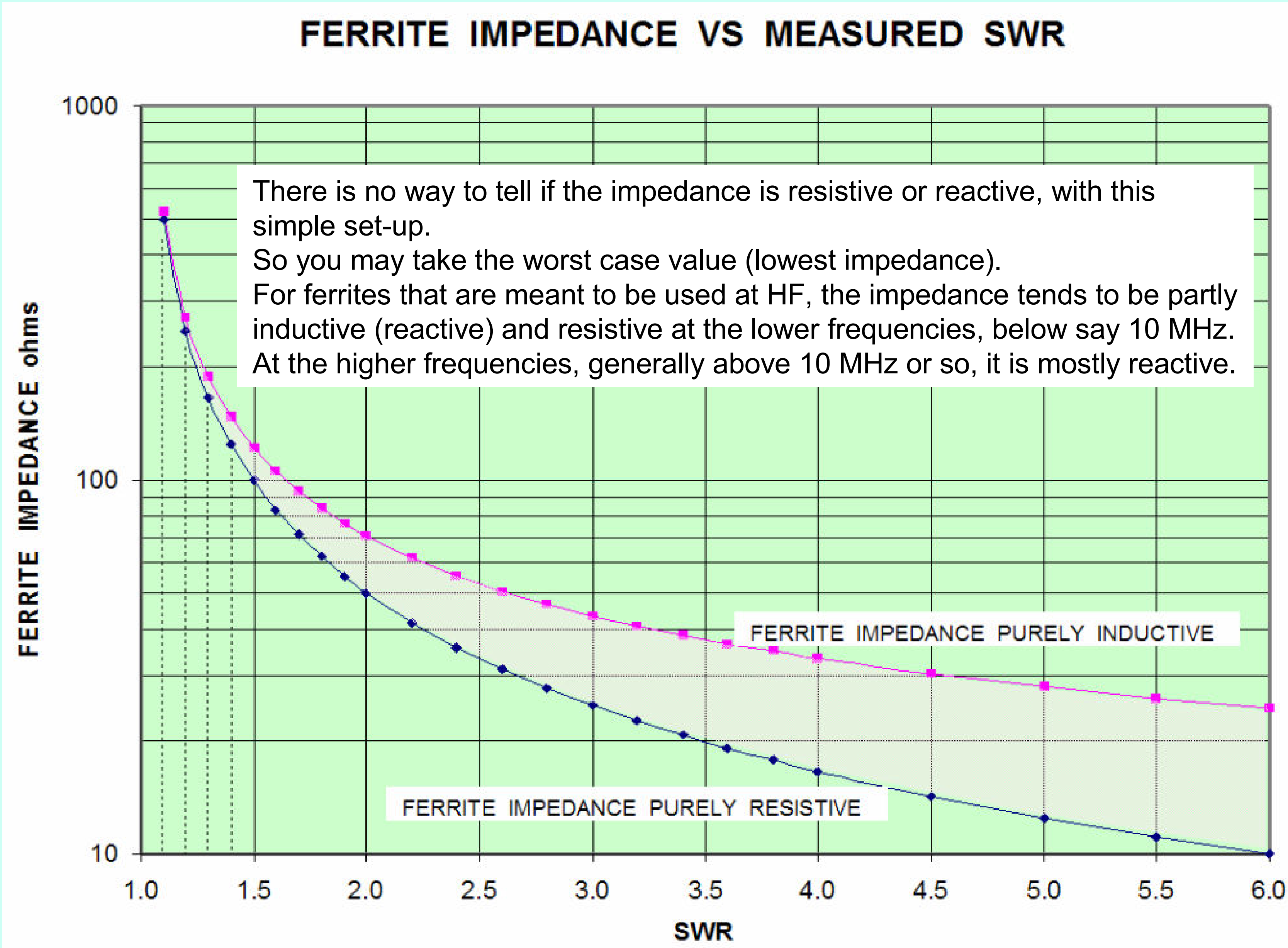


Ref: http://ve2azx.net/technical/Check_your_Ferrites.pdf

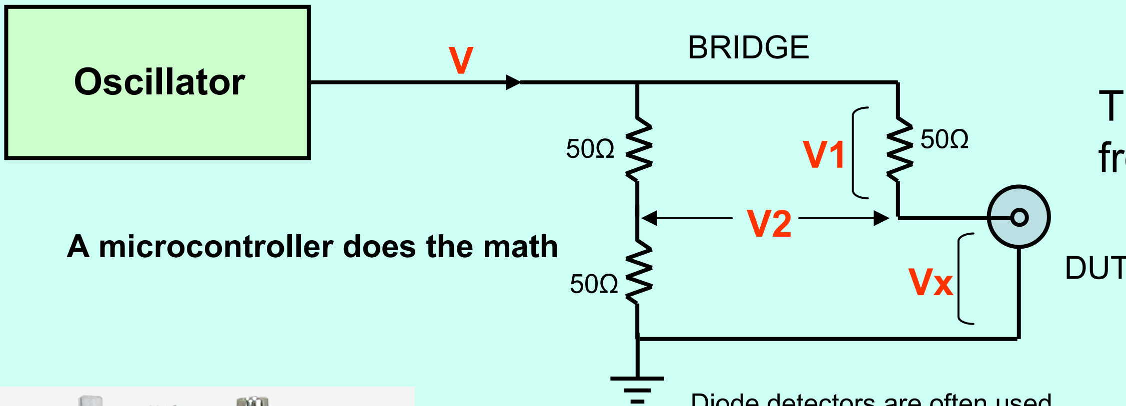
CHECK YOUR FERRITES WITH YOUR SWR ANALYZER



NOTE: This technique may be used to check the impedance of an antenna, or any other device, by using a coaxial Tee and a 50Ω termination.


FERRITE IMPEDANCE VS MEASURED SWR
There is no way to tell if the impedance is resistive or reactive, with this simple set-up.
So you may take the worst case value (lowest impedance).
For ferrites that are meant to be used at HF, the impedance tends to be partly inductive (reactive) and resistive at the lower frequencies, below say 10 MHz.
At the higher frequencies, generally above 10 MHz or so, it is mostly reactive.
FERRITE IMPEDANCE PURELY INDUCTIVE
FERRITE IMPEDANCE PURELY RESISTIVE
FERRITE IMPEDANCE ohms
1000
100
10
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
SWR

Three VOLTAGE MEASUREMENTS allow Measuring Resistance and Reactance, but NOT the sign



A microcontroller does the math

The impedance is computed from Vx, V1 and V2

Diode detectors are often used.
Non linearities limit dynamic range and must be calibrated out.

The classical MFJ259

More accurate than the MFJ 207

Measures Impedance Magnitude, RL, RefCo (Γ)

Measures capacitance and inductance

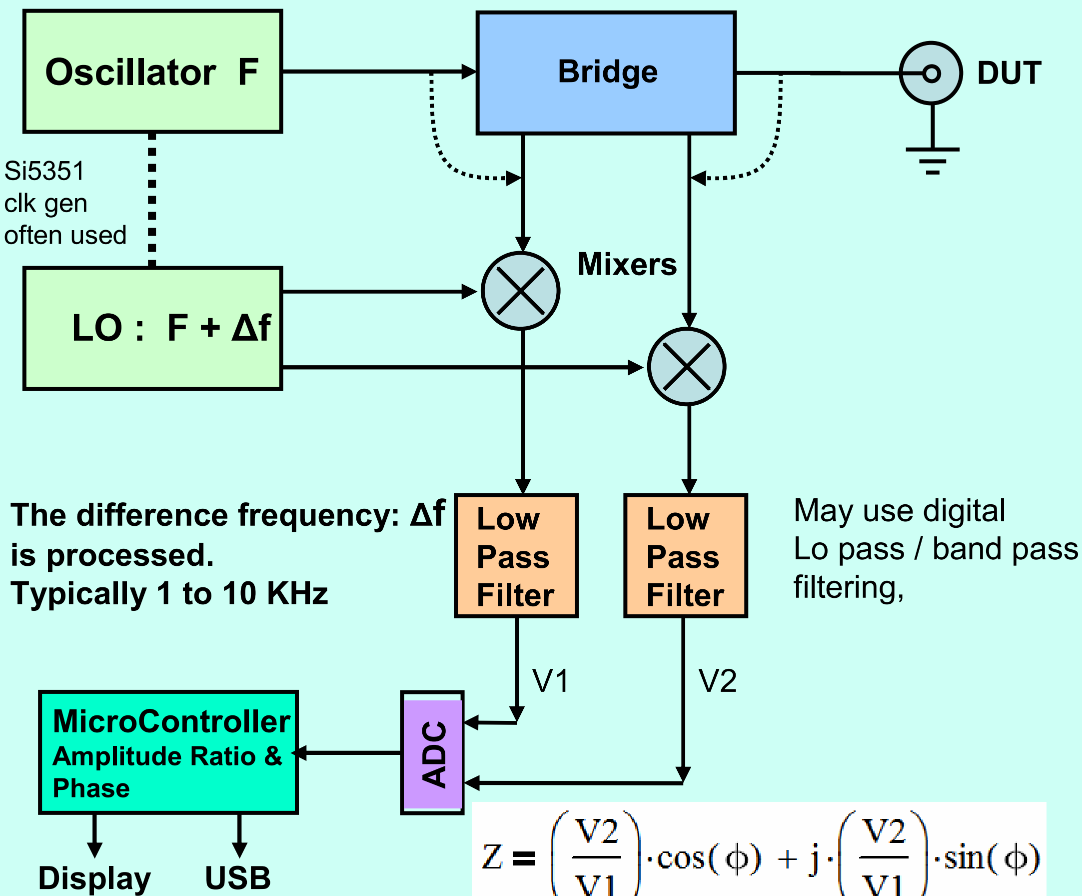
Measures Coax losses

Broadband detectors make it susceptible to interferences.

The Vector Analyzer

Measure Resistance and Reactance, including the sign

Typical system based on super-heterodyne receiver



$$Z = \left(\frac{V2}{V1}\right)\cdot\cos(\phi) + j\cdot\left(\frac{V2}{V1}\right)\cdot\sin(\phi)$$

Potentially larger dynamic range
Since it has selective receivers

More accurate: OSL calibration
(Open, Short, Load) **(No adj'nt inside)**

Smith Chart Display

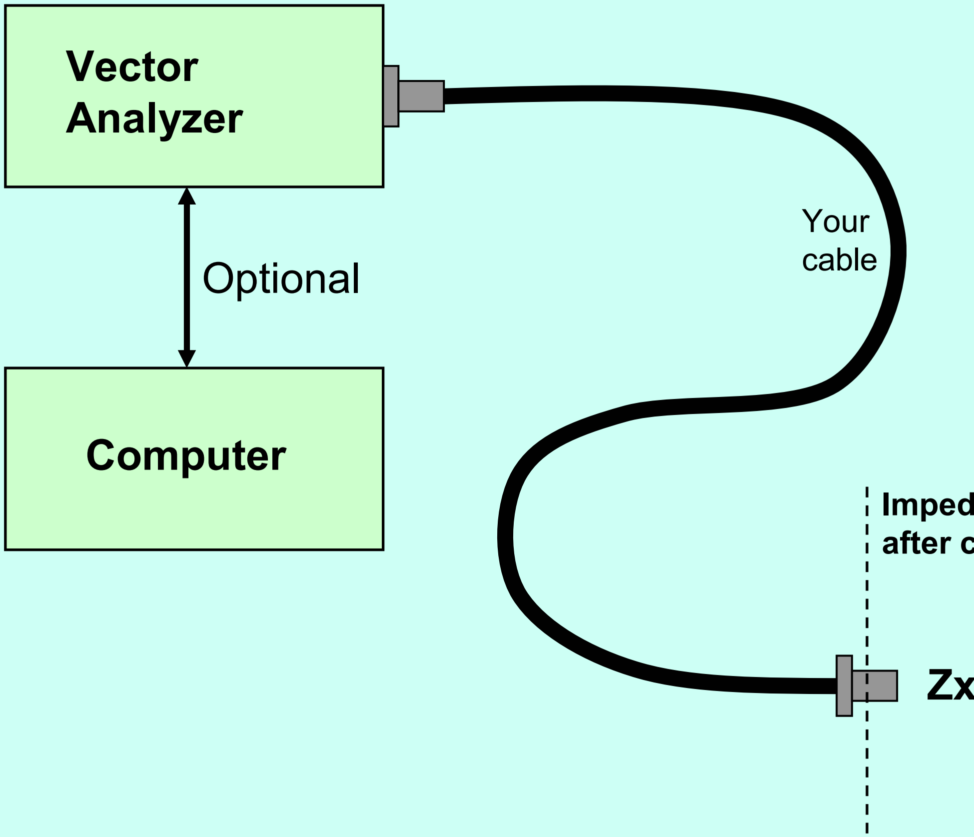
Q Factor of Components

USB link to power and control unit from the computer. Easier !

Allows more complex measurements. Ex: TDR, crystals.

Vector Analyzer Calibration

The analyzer accuracy <u>critically</u> depends on three standards

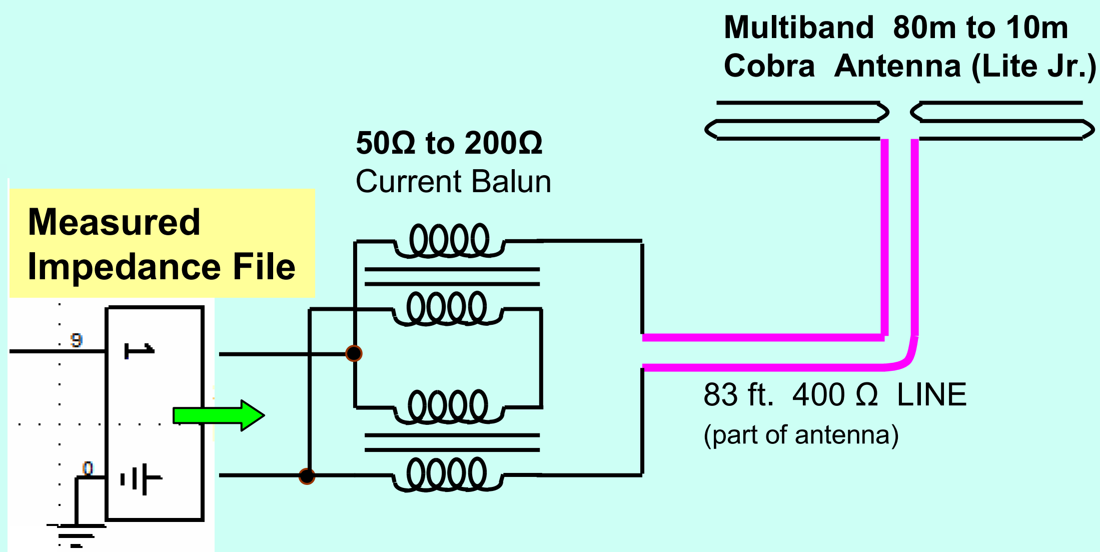


The imperfections of the standards are described in a CAL KIT definition file.

They are taken into account when calculating the value of Zx

Impedance Zx is measured at the cable end after calibration with short, open and load.

Using a Vector Analyzer to design a Matching Network to correct Bad SWR across the 80m Band



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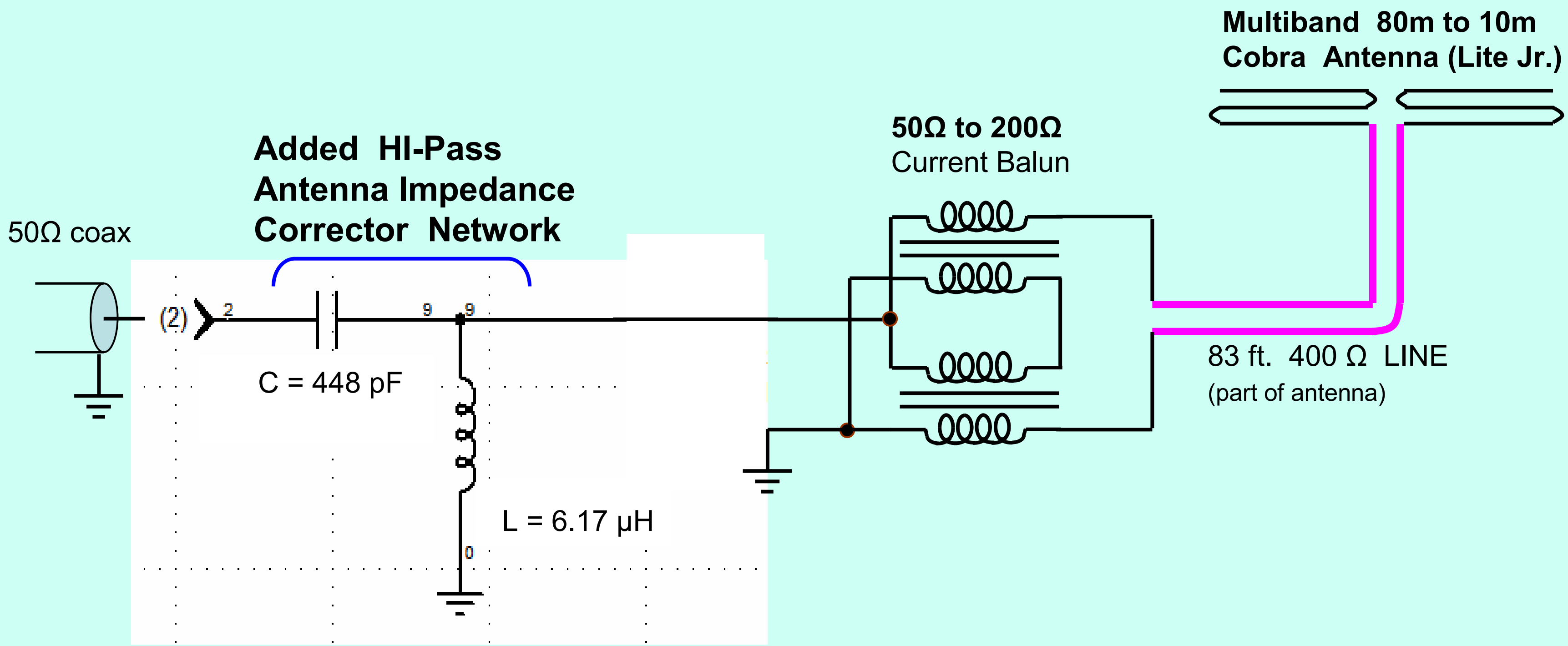
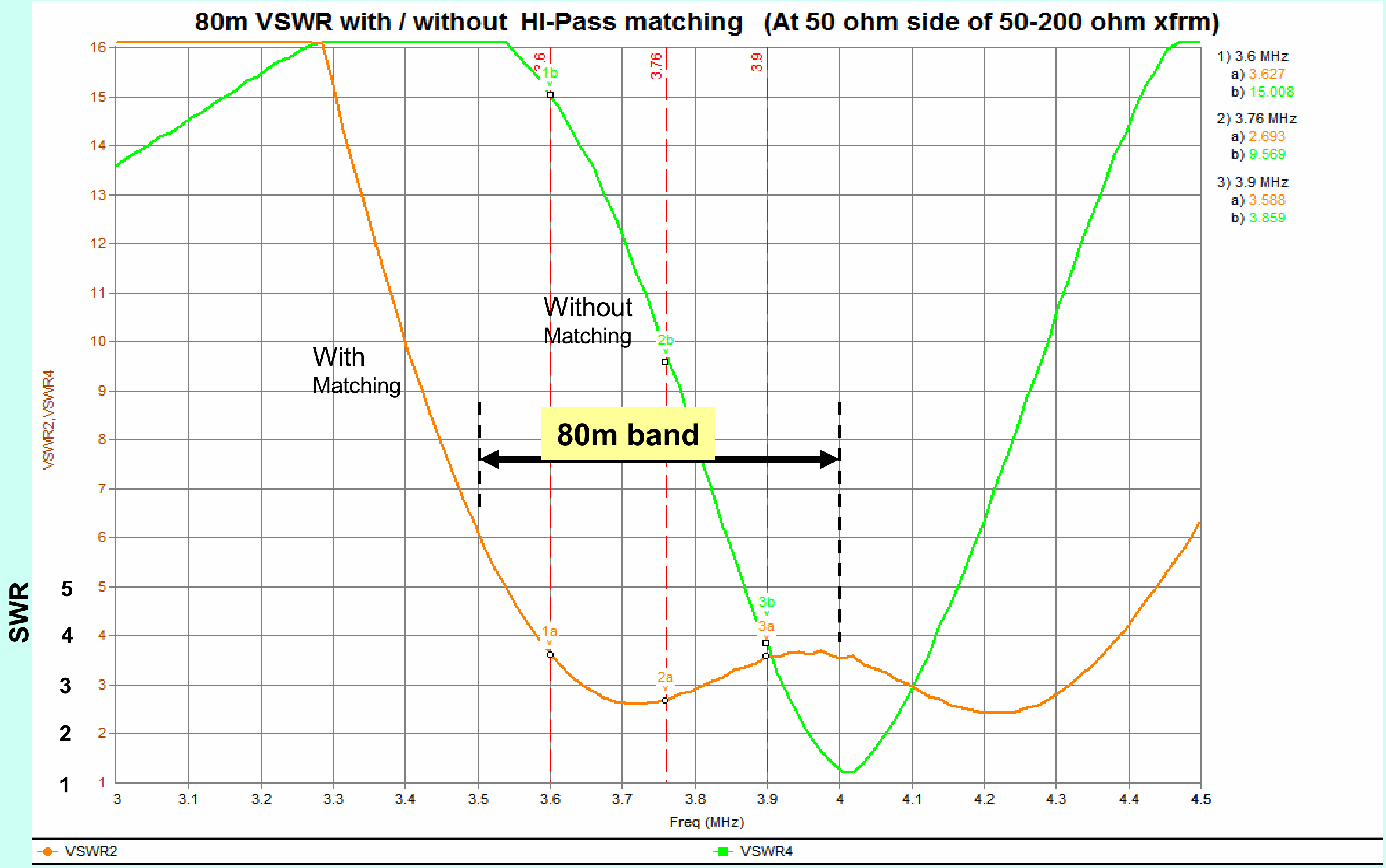


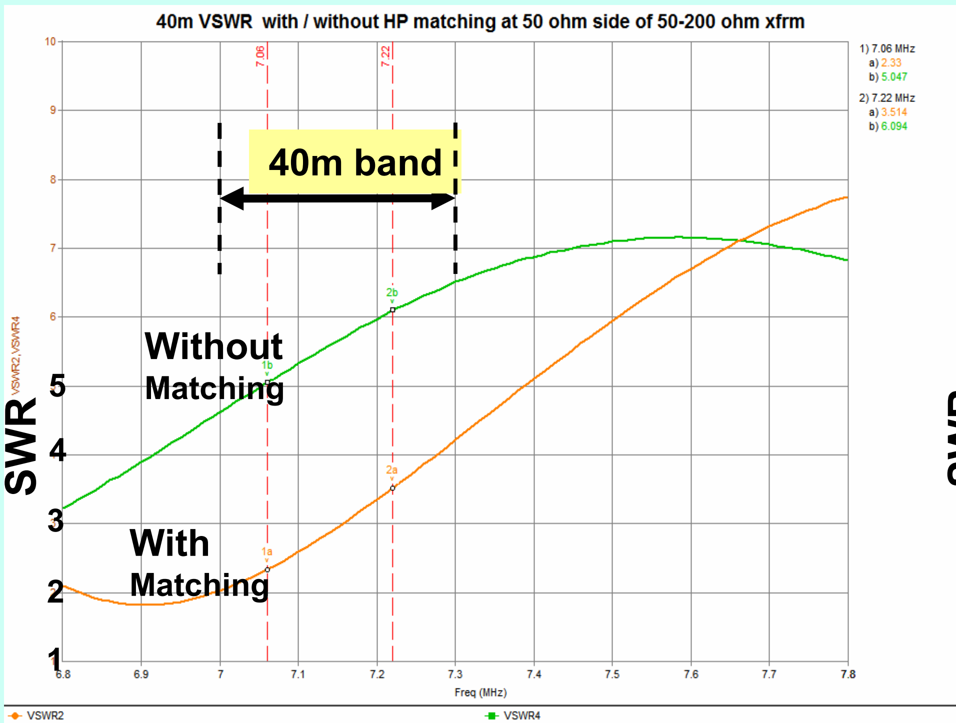
C and L components were manually optimized in my RF simulator.

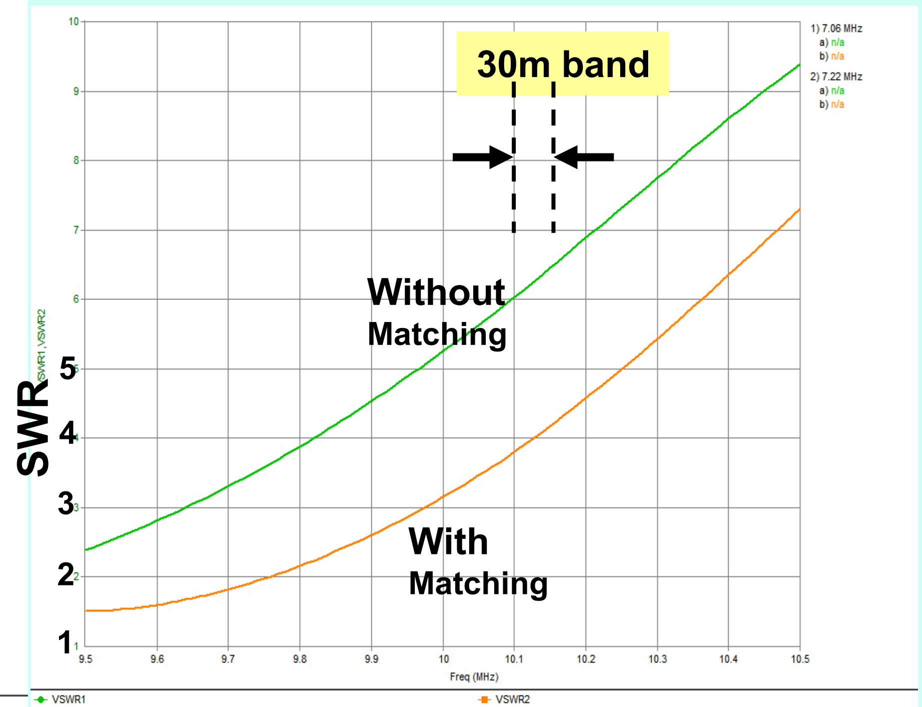
Antenna Impedance Corrector for 80m band



Antenna Impedance Corrector

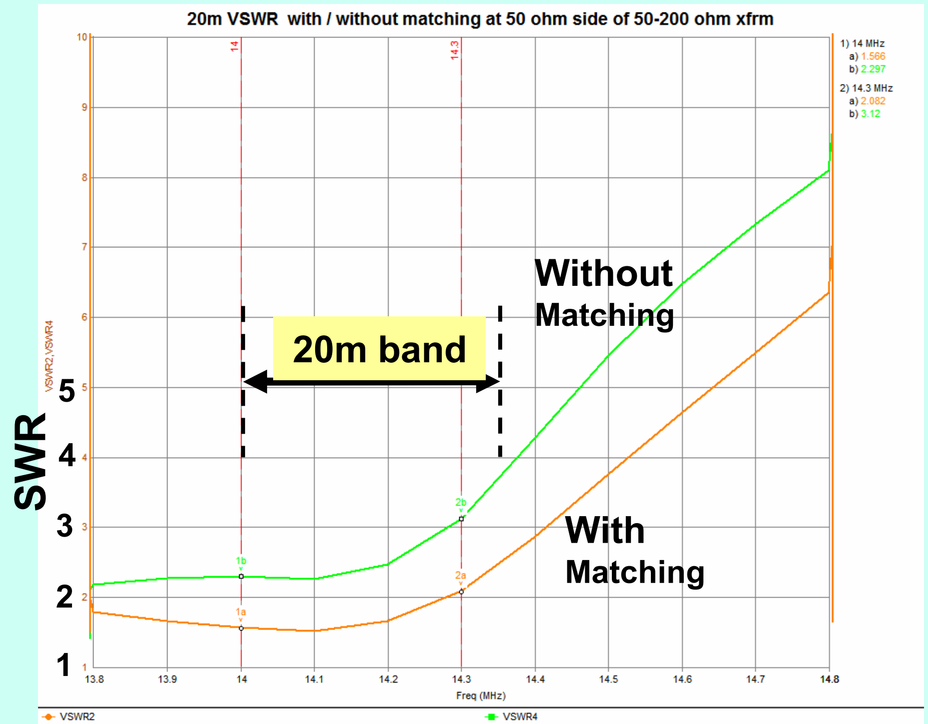
SWR with / without Matching 40m and 30m Bands





Antenna Impedance Corrector

SWR with / without Matching 20m band



The effect of the impedance corrector decreases as frequency increases.

Using a Vector Analyzer to check if your tuner is operating within its matching range

MFJ 929 Tuner Spec's

- Impedance matching range : 6 to 1600 ohms
- SWR matching range : Up to 8:1 for < 50 ohms and up to 32:1 for > 50 ohms

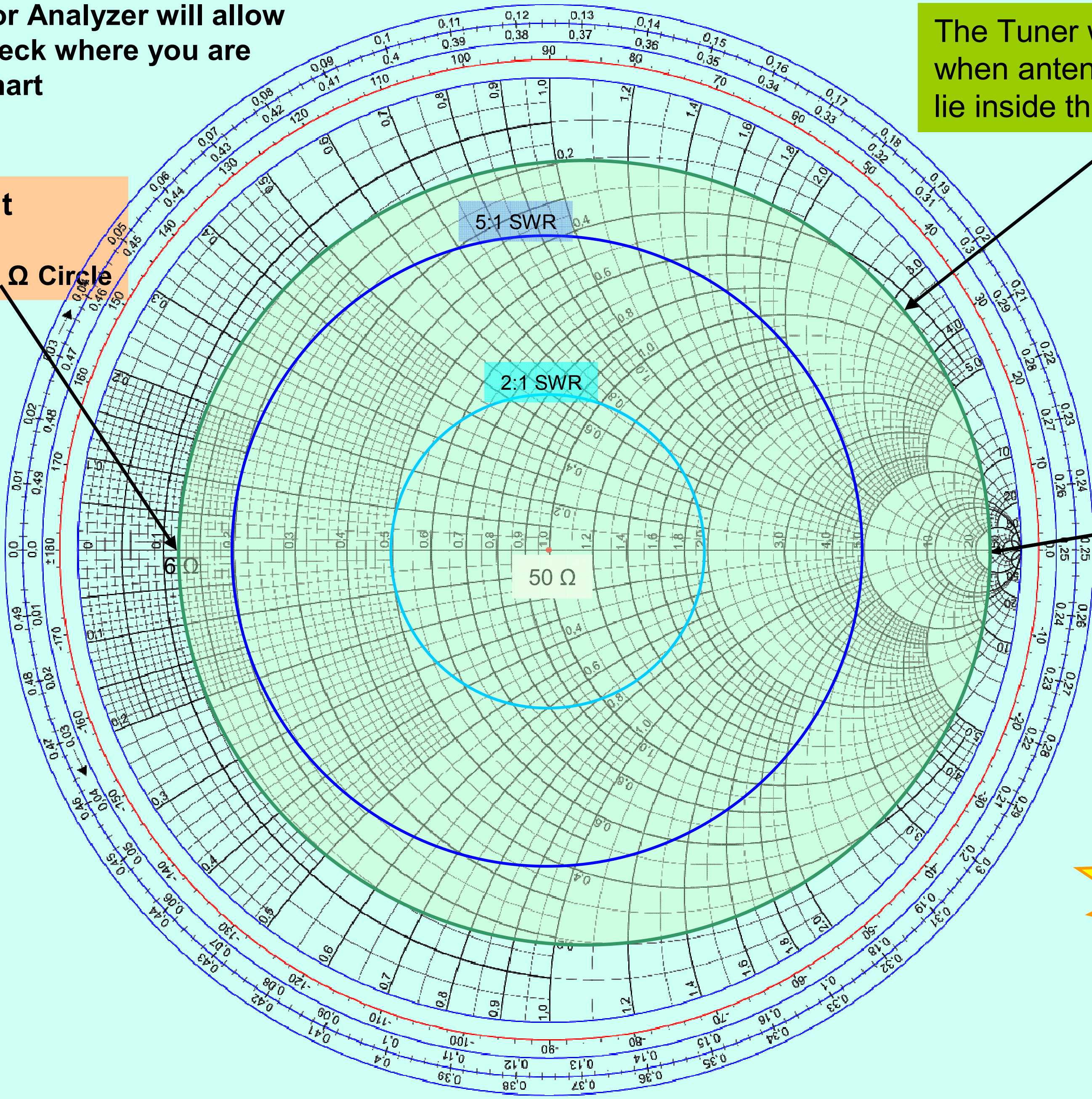
MFJ 929 Tuner

Tuner losses increase as you get closer to its impedance/SWR limits.

The Vector Analyzer will allow you to check where you are on this chart

The Tuner will work properly when antenna impedances lie inside the green area

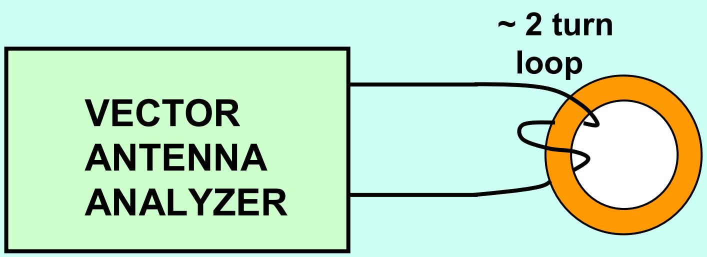
Tuner Limit
8:1 SWR
= 50Ω / 8 = 6 Ω Circle



Tuner Limit
32:1 SWR
= 50Ω * 32 = 1600 Ω

Plot the Chart for every band.

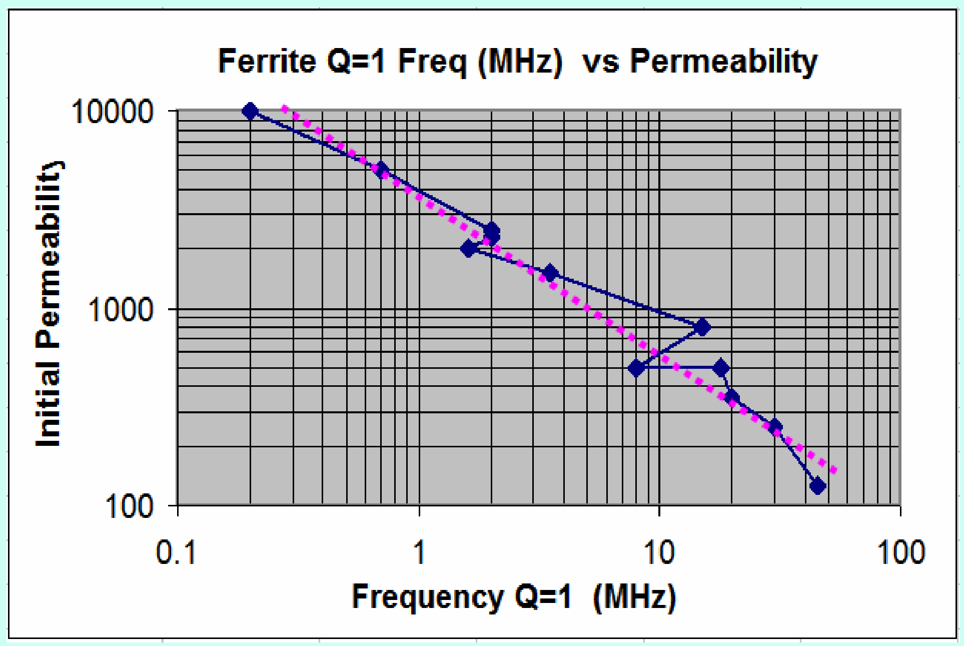
Using a Vector Analyzer to Identify Ferrite type (Not for powdered Iron)



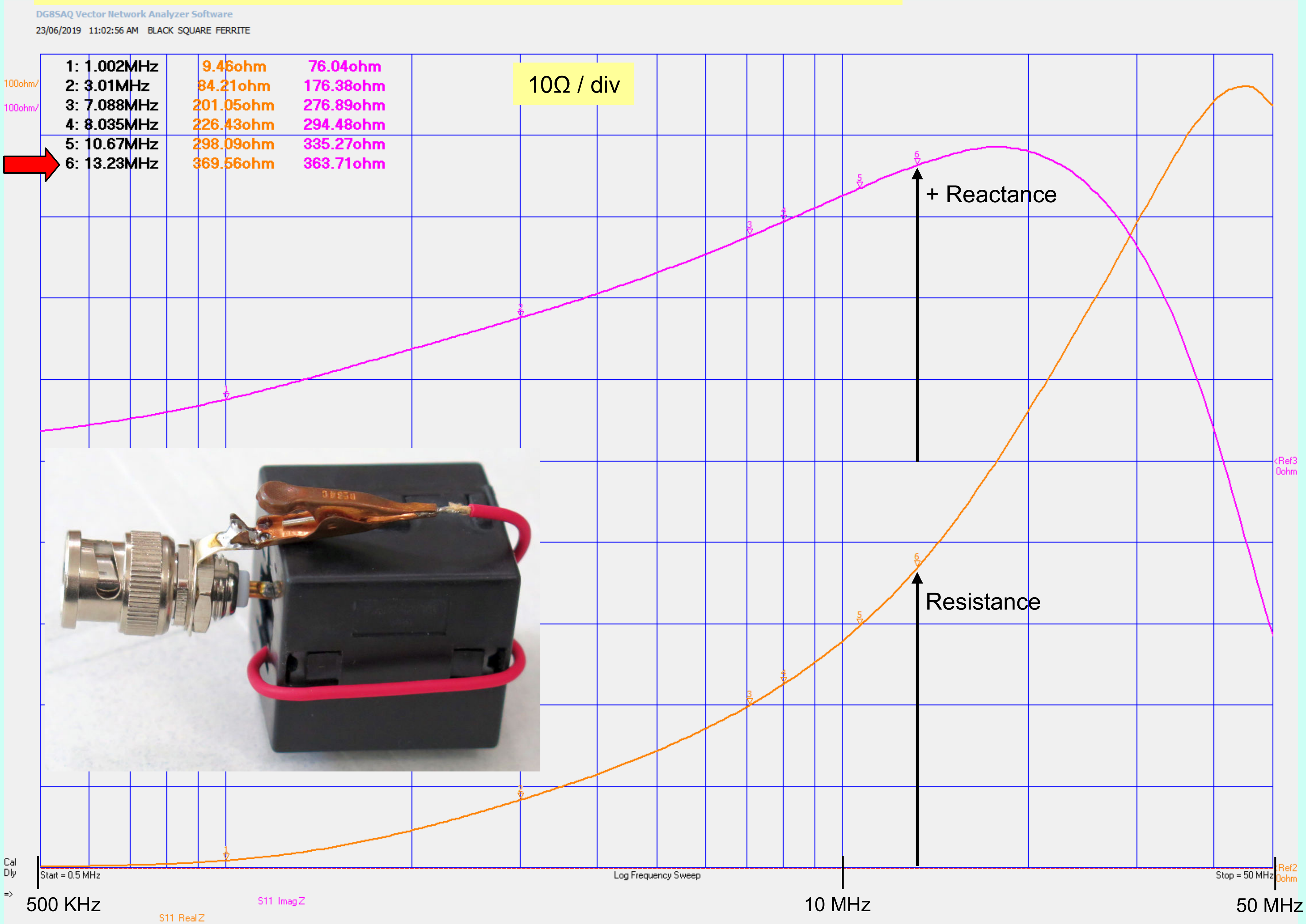
Adjust the frequency until **Resistance = Reactance**

The obtained frequency tells us:
Ferrite useable frequency range
The LOW frequency permeability → The material type

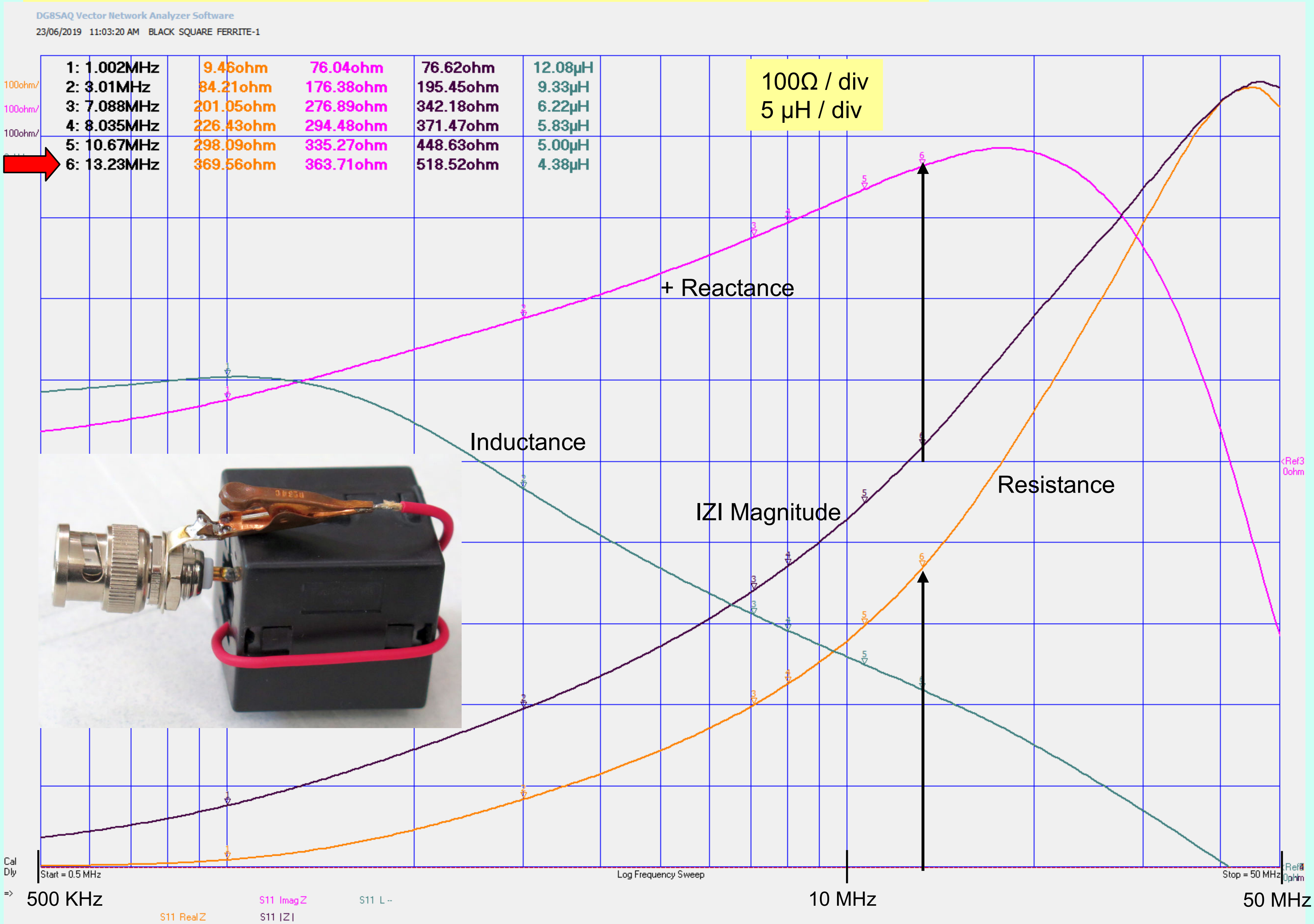
	Init Perm.	F(X=R)	F(X=R) MAX
Material	**µi**	**MHz**	**MHz**
61	125	45	
52	250	30	
51	350	20	
44	500	18	
46	500	8	
43	800	15	30
31	1500	3.5	10
77 (72)	2000	1.6	
78	2300	2	
73	2500	2	
75 (J)	5000	0.7	
76 (W)	10000	0.2	



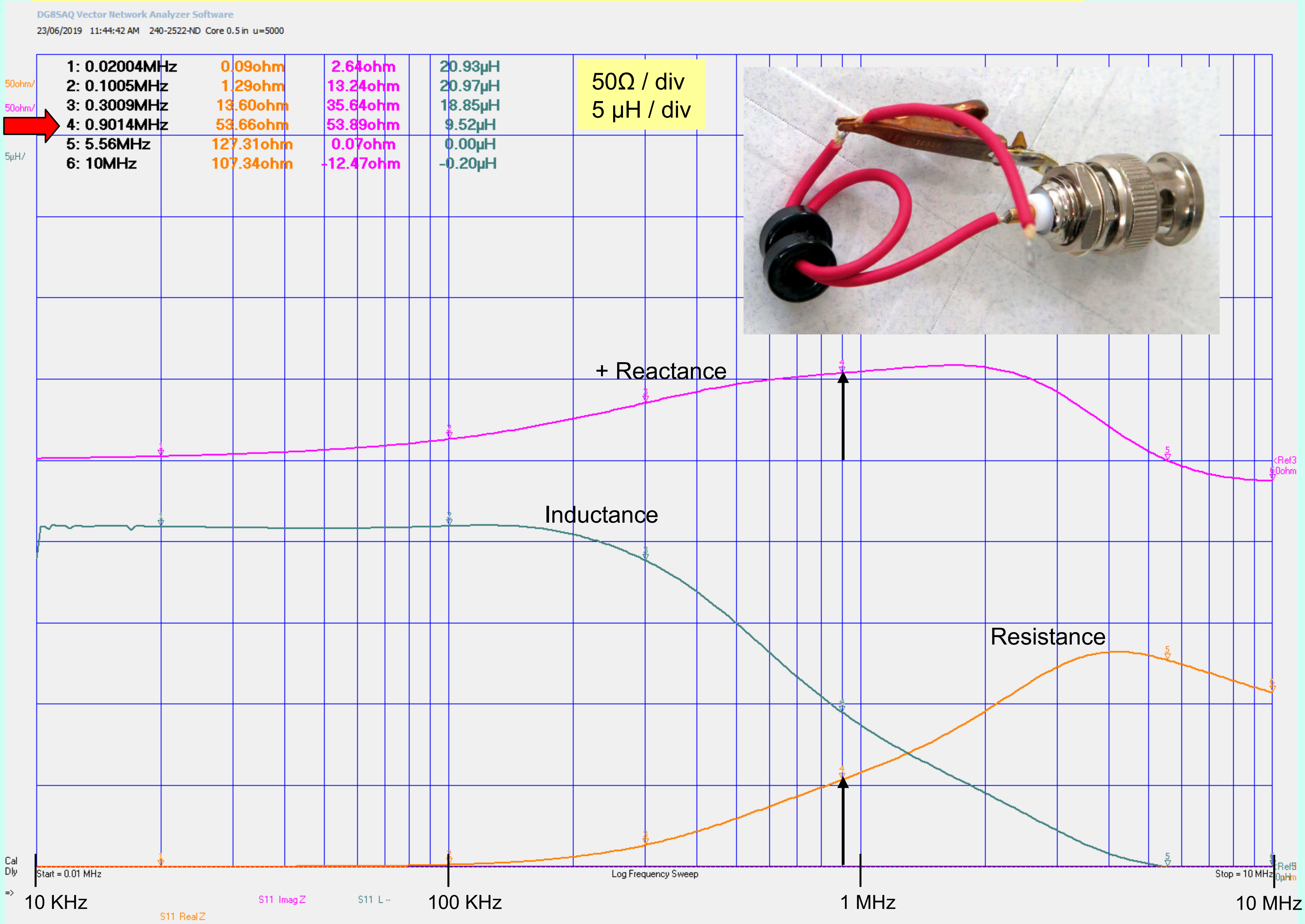
Measurement Examples Clamp-on Ferrite μ ~ 800



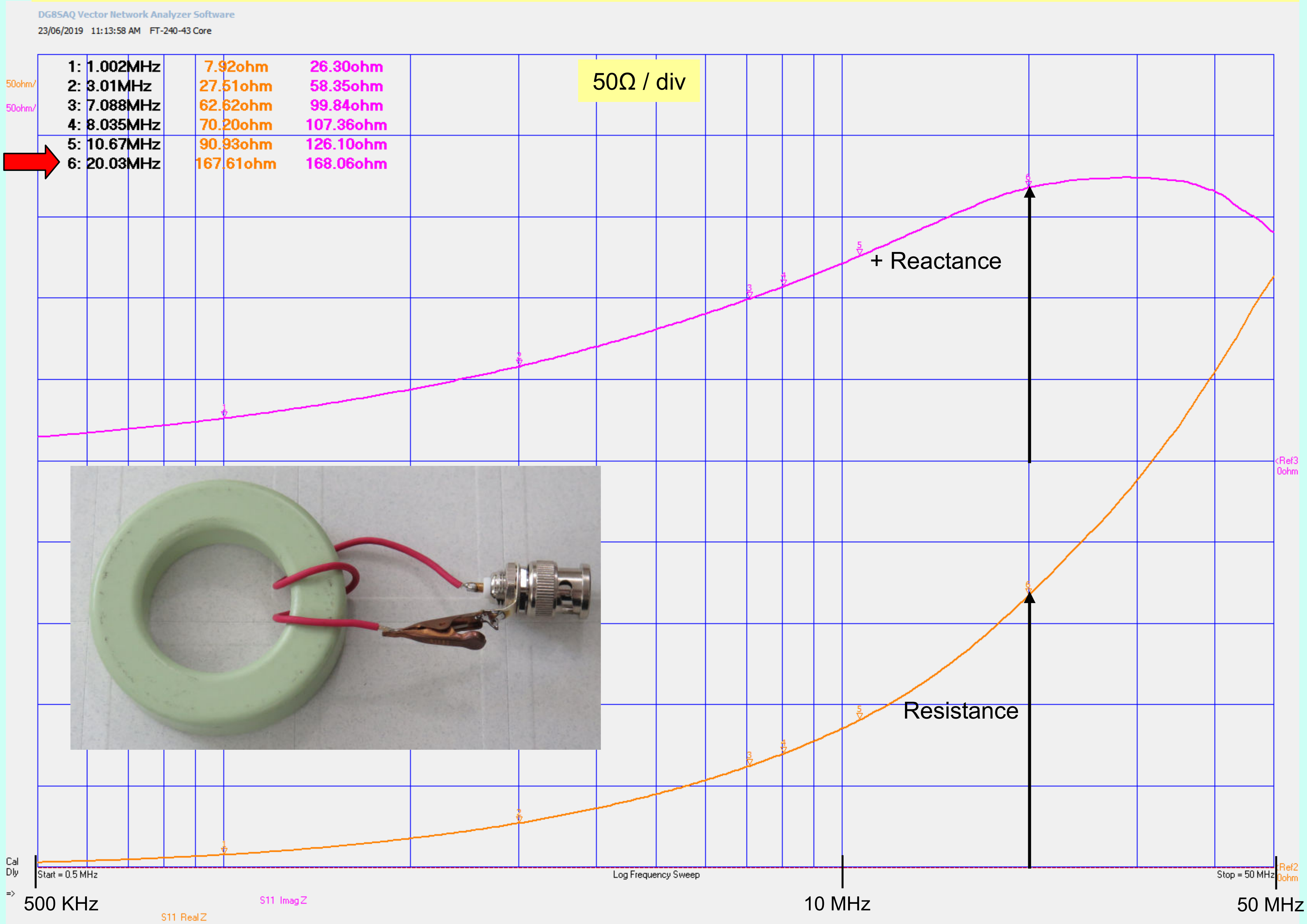
Measurement Examples Clamp-on Ferrite µ ~ 500
Inductance and Z magnitude added



Measurement Examples   0.5 in Ferrite μ = 5000 from specs



Measurement Examples 2.4 in Ferrite μ = 800 from specs, #43 material



Time Domain Reflectometry (TDR)

Impedance vs Frequency Data → Impulse DFT or Step DFT Calculations → Impedance vs Time / Distance Data

(DFT = Discrete Fourier Transform)

- Measure impedance values vs ***frequency*** and
- Transform them towards equivalent values along ***time***.
- Distance is related to time via the Velocity Factor (varies from 0.66 to 0.95)

Need to use the whole frequency span to resolve small discontinuities.
Frequency sweep 10 KHz to 600 MHz, 2000 points

Allows testing coax cable discontinuities: shorts, opens, impedance (bumps), kinks…

$$\text{Time Resolution (sec)} \sim = \frac{1}{10^{*}\text{Freq span (Hz)}}$$

$$\text{Max Time Span (sec)} \sim = \frac{\text{\# of freq points}}{2 * \text{Freq span (Hz)}}$$

340 m

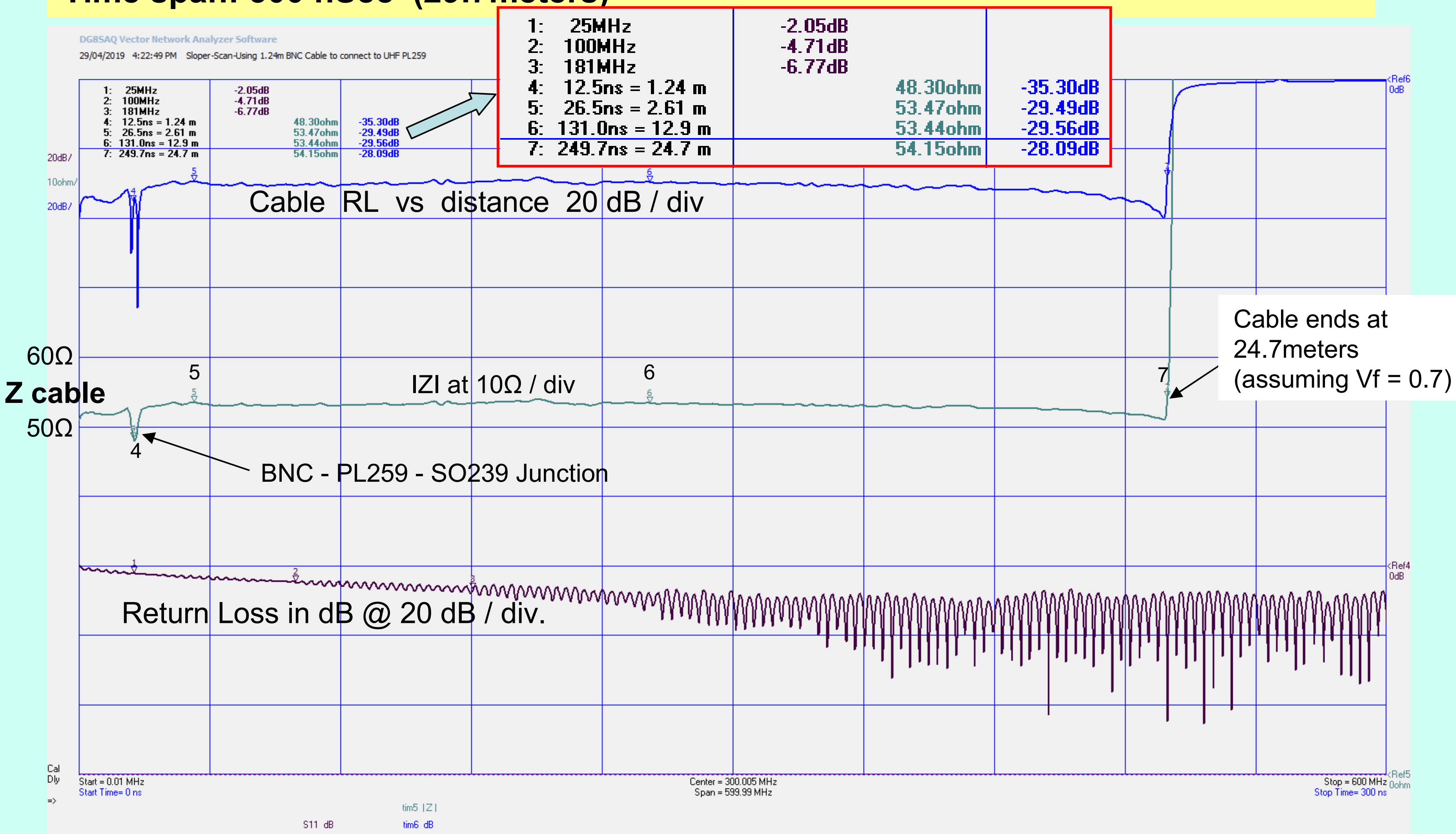
$$\text{Distance Resolution (cm)} \sim = \frac{3 * V_f}{\text{Freq span (GHz)}}$$

→ 1.7 cm at 600 MHz span

Using a Vector Analyzer to Measure the IMPEDANCE PROFILE of 50Ω feed line of my sloper antenna

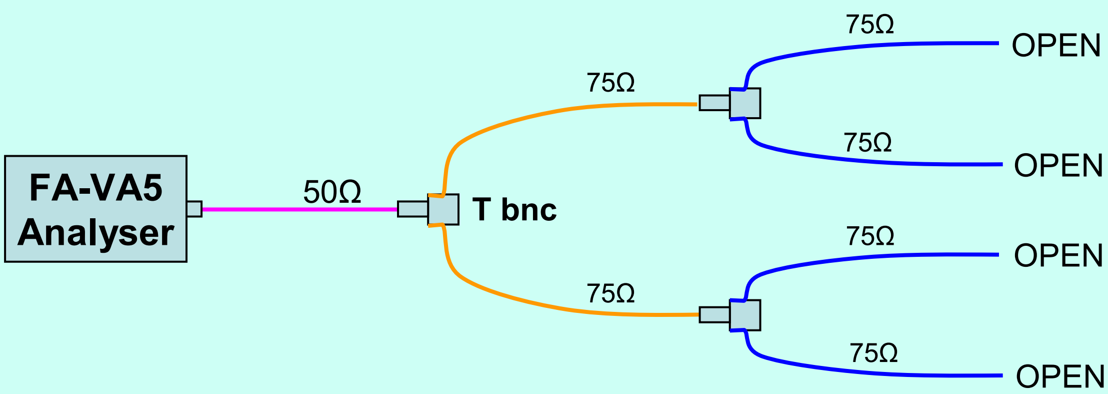
Frequency sweep 10 KHz to 600 MHz, 2000 points

Time span: 300 nSec (29.7meters)



Verify IZI vs cable length to identify line shorts/opens.

IMPEDANCE PROFILE Measurement on a Phasing Harness of a Four Loop VHF Antenna.
No loop present Frequency sweep 10 KHz to 600 MHz, 2000 points



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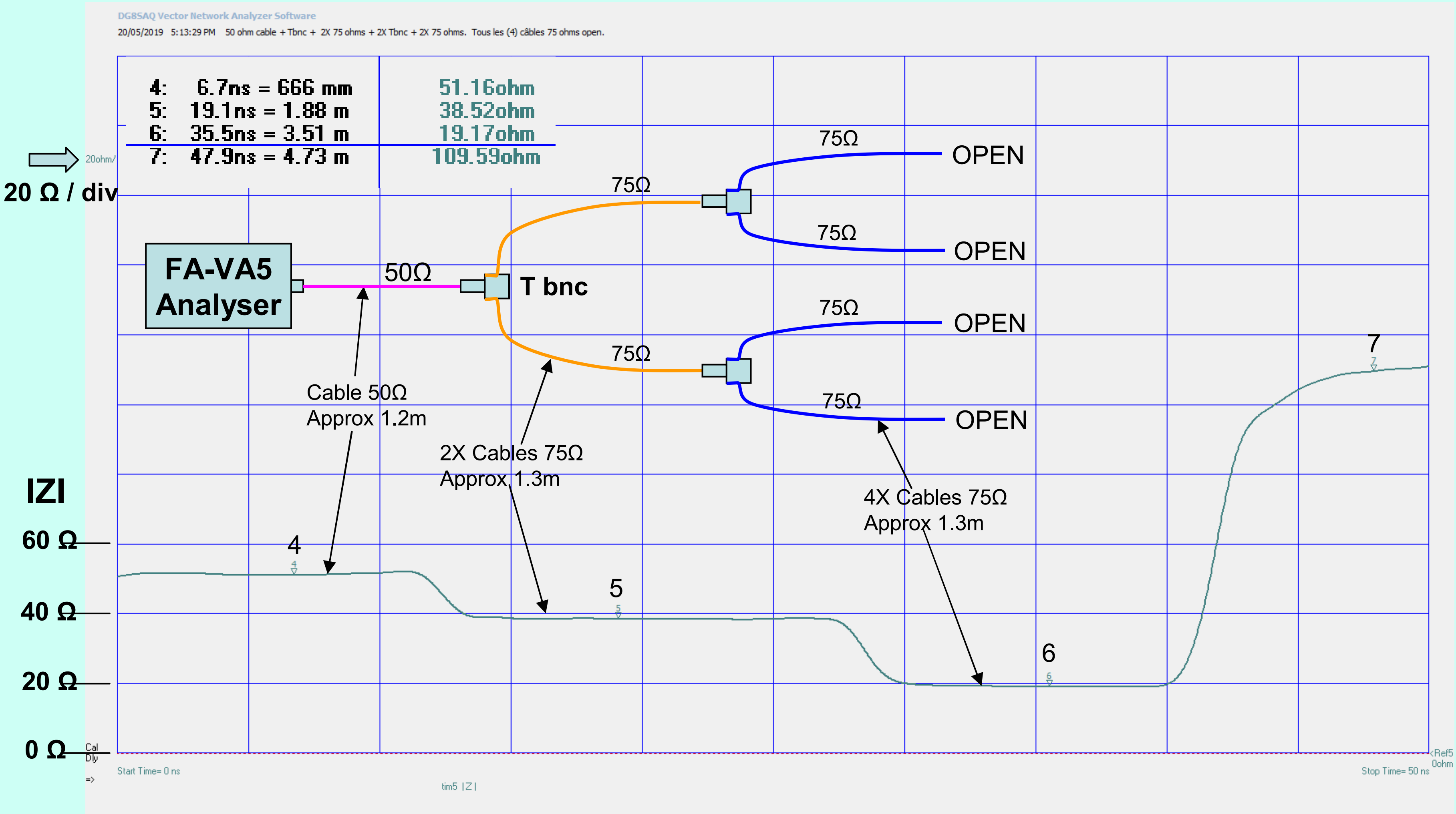


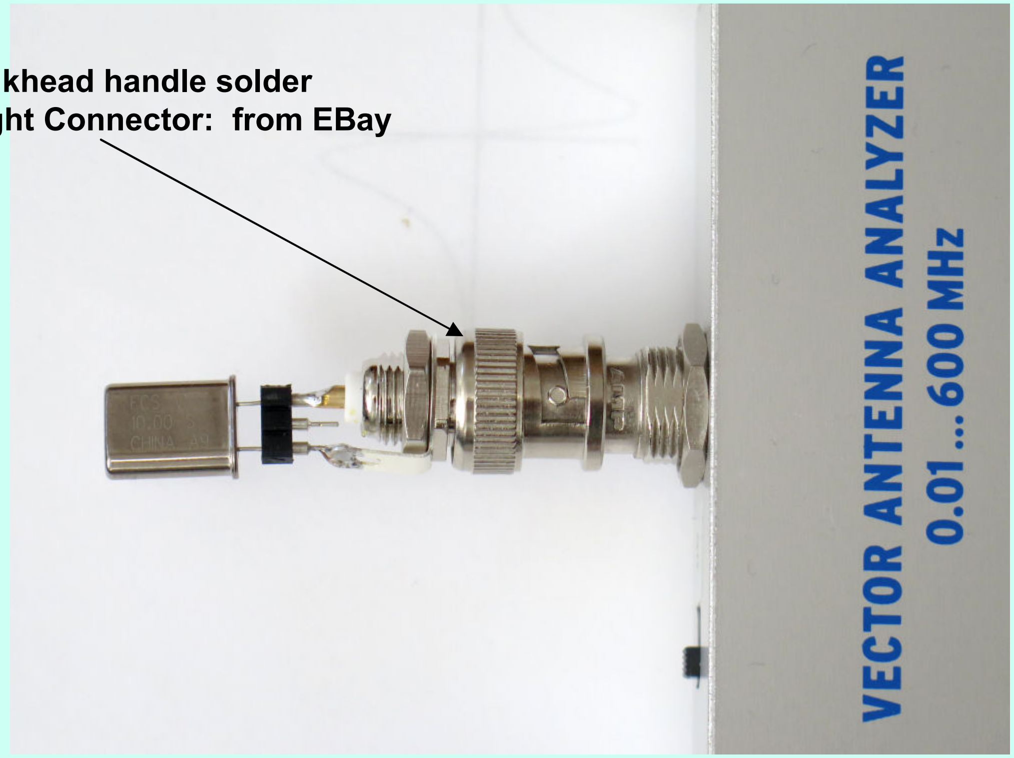
Quartz Crystal Testing

Access the TOOLS Menu of VNWA Software. Sweep was 101 points +/- 1% of frequency, Precise Mode.

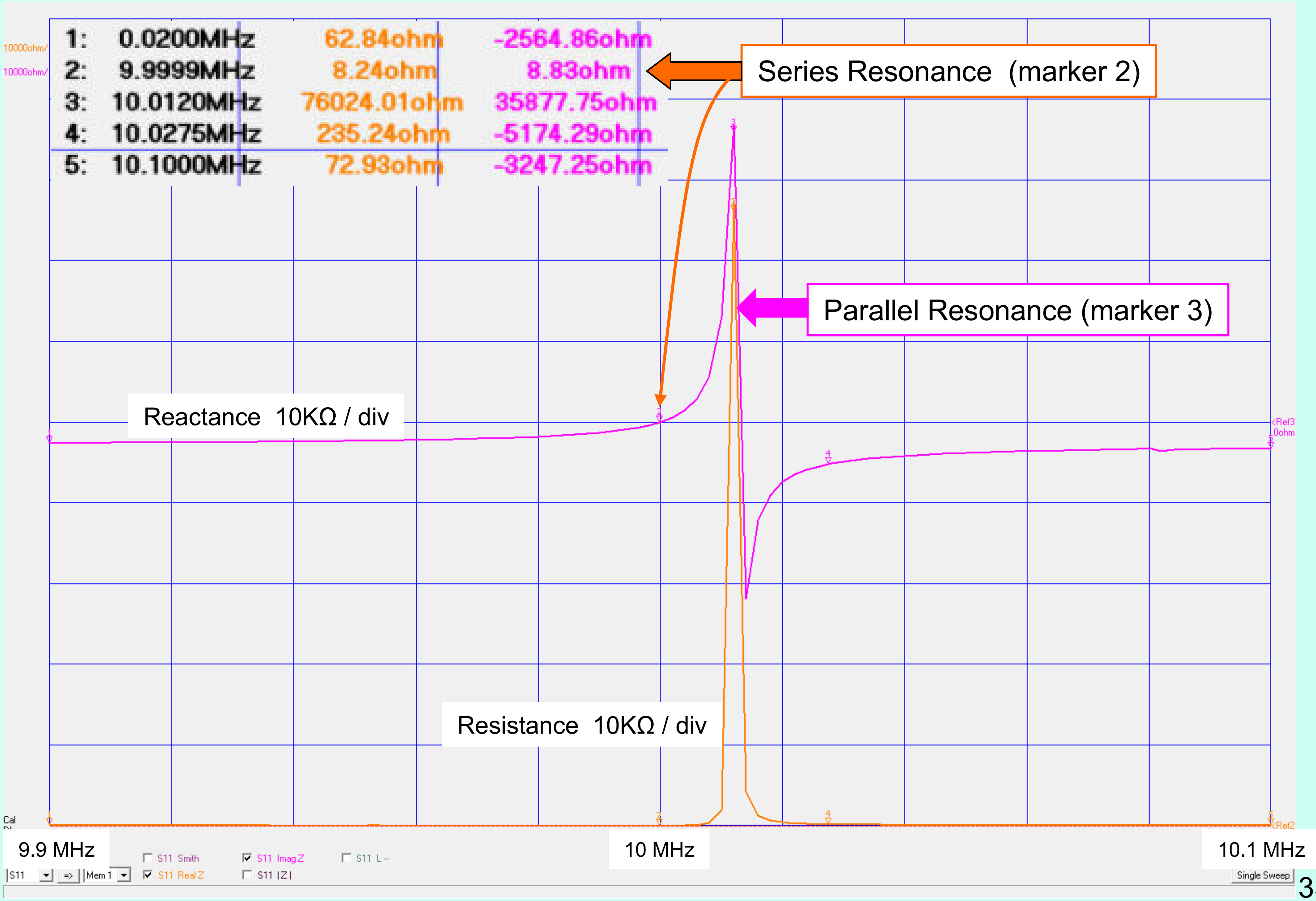
Measures the crystal impedance over a narrow range of frequencies. <u>Need to have 1 Hz resolution here.</u>

From this data, the VNWA software derives the crystal equivalent circuit

BNC male plug bulkhead handle solder panel mount straight Connector: from EBay



Measured Resistance and Reactance of 10 MHz Crystal

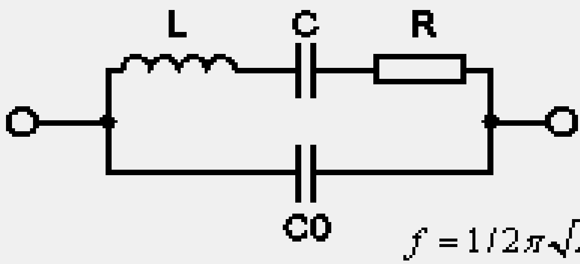


Measurement Results on a 10 MHz crystal Repeated 5 times.

The VNWA software fits the element values to the measured data

Crystal Analyzer - Analysis will be performed into 3-port data spaces s_11 and s_21 !!!

Equivalent Circuit



L = 13.23296 mH

C = 19.14262 fF

R = 8.29704388705115 Ohm

C0 = 4.82705204417940 pF

$f = 1/2\pi\sqrt{L \cdot C}$ = 9.99978880721022 MHz

$R \cdot Q = \sqrt{L/C}$ = 831.434208927011 x1000

Q = 100208

auto-optimize

source = S11

Transmission Test Jig Impedances = 50 Ohms

Batch Crystal Analyzer single sweep cont. sweep save list clear list

#	f / Hz	Q	L / H	C / F	R / Ohm
1	9999786.039	106713	0.01381190026	1.834025688E-14	8.13
2	9999789.986	100701	0.01337477724	1.893964992E-14	8.34
3	9999796.192	103122	0.01367100922	1.852923074E-14	8.33
4	9999796.295	102048	0.01364758271	1.856103637E-14	8.4
5	9999788.807	100208	0.01323296589	1.914262159E-14	8.3

10 Hz max Freq. delta

Verify the Accuracy of your Analyzer

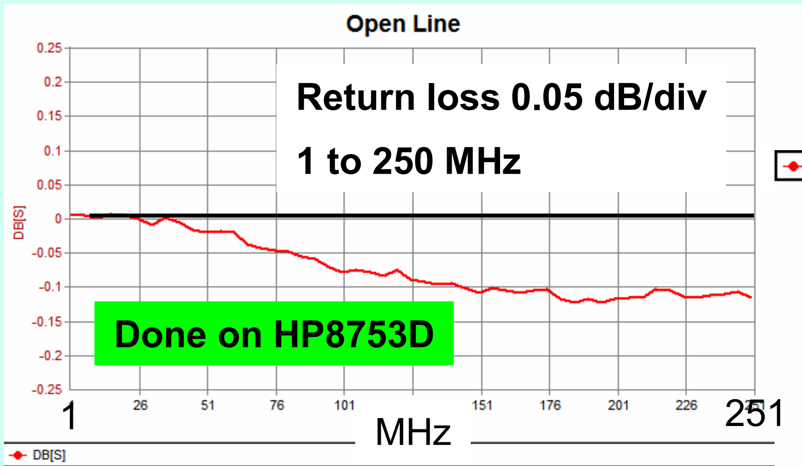
These tests apply to the full frequency range of the analyzer.

Connect a 50Ω termination at the analyzer input. Check SWR. Should be < 1.1:1

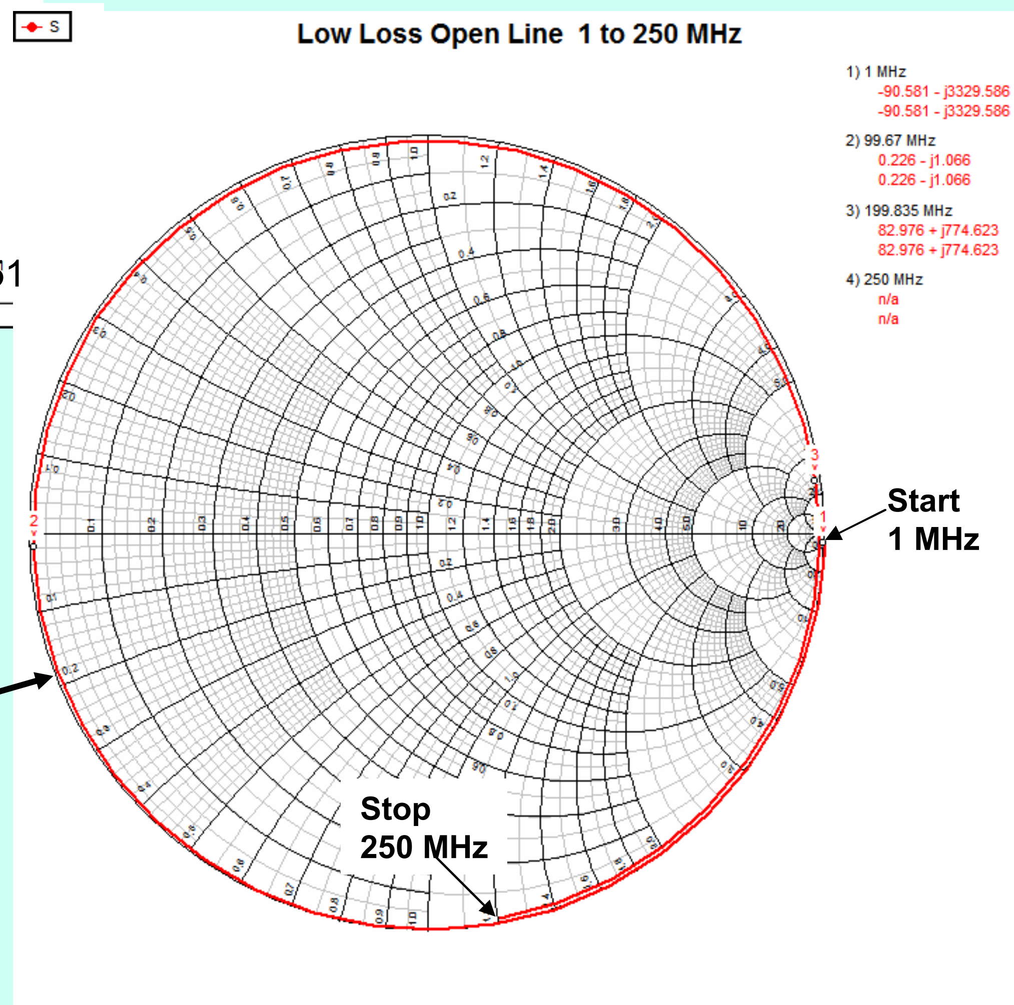
Connect two 50 Ω terminations at the analyzer input, using a Tee.
Check SWR. Should be 2:1

Connect a 100 Ω termination at the analyzer input. Check SWR. Should be 2:1

VNA acid test : Measurements at / close to infinite SWR using an Open Line

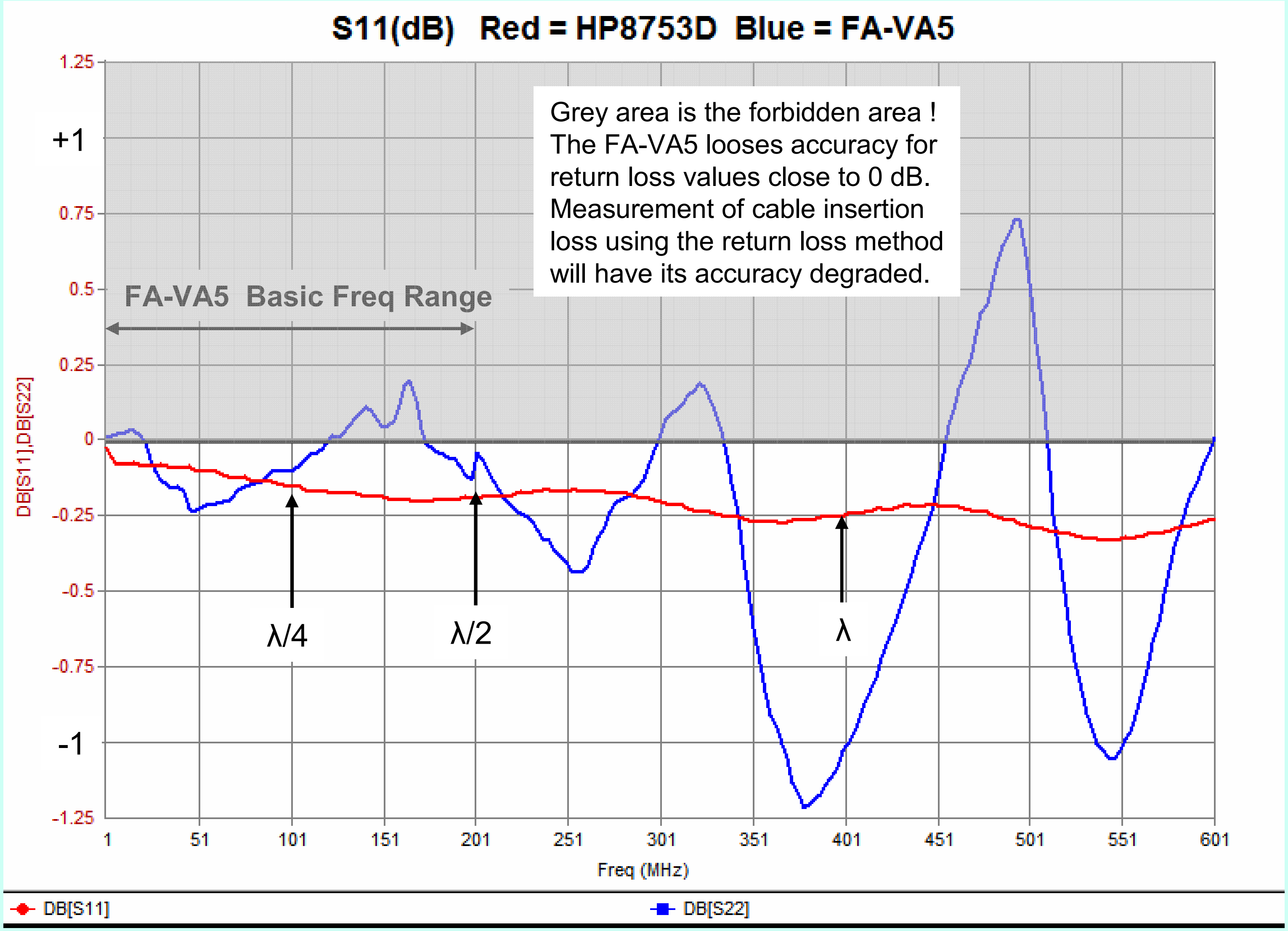


Return loss sweep on an OPEN low loss line @ 0.05 dB / div.
Must always stay at / below 0 dB



Smith chart shows a well behaved S11 curve circling progressively inside:
-> **Cal Kit Data OK**
-> **Analyzer is accurate**

VNA acid test : Measurements at / close to infinite SWR on an Open Line



About your Calibration Standards

Measurement accuracy never better than the standards used

CAL KIT definitions:

SHORT: ***delay*** in pS and frequency dependant ***inductance and resistance***

OPEN: ***delay*** in pS and frequency dependant ***capacitance***

LOAD: ***delay*** in pS and actual ***resistance*** plus ***series inductance*** and ***shunt cap.***

The VNA software must "know" these CAL KIT parameters via a CAL KIT file !

Most important above 30 MHz

References

FA-VA5 Presentation: https://www.youtube.com/watch?v=X8Z7veGV57o

Understanding the Fundamental Principles of Vector Network Analysis
https://literature.cdn.keysight.com/litweb/pdf/5965-7707E.pdf

A short review of antenna and network analyzers:
https://rigexpert.com/a-short-review-of-antenna-and-network-analyzers/

Q Factor Measurement on L – C Circuits:
http://ve2azx.net/technical/Q-FactorMeas_on_LC_Circuits.pdf

Check your ferrites with your SWR Analyzer:
http://ve2azx.net/technical/Check_your_Ferrites.pdf

Questions ?

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