# Antenna Analyzers Vector Network Analyzers Barry2 k3eui



# Flow Chart: Vector Network Analyzer



# 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)

# **Measure antenna characteristics**

resistance, reactance, impedance resonance, SWR, Smith Chart cable impedance and attenuation

## 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





#### **Rig Expert** has many models with various graphical displays CCAR has one in W3EOC







# 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?



# Enter the Nano VNA instrument: \$50



# Two "ports": Ch 0 and Ch 1 4 traces in 4 colors



Measurement: limit of 100 data points resistance, reactance, impedance, SWR, return loss, phase Smith Chart plots cable length and attenuation



FORWARD - REFLECTED - THROUGH signals DUT = "device under test" typical reference impedance = 50 ohms



# **Important Parameter Definitions**

# Reflection coefficient = V (reflected) / V (incident) reflection coefficient = $\rho$ (rho) $0 < \rho < 1$

**REFLECTION LOSS** (dB) =  $-20 \log (\rho)$ 

**SWR** =  $(1 + \rho) / (1 - \rho) = V(max) / V(min)$ 

# How these relate to each other

# **Reflection Parameters**

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



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



# Useful Cables: SMA to SO239 coax



# USB connections to computer and battery charger



# Nano VNA Saver software

#### much easier to use by computer control



Computer Control Settings

Com Port select Frequency Range Markers

Sweep resolution SAVE and RETRIEVE files Display setup of GRAPHS Calibration

Sweep control			
Start 3.5MHz	Center .75MH		
Stop 4.0MHz	Span 500kH		
1	5.000kHz/ste		
Sweep s	settings		
	100%		
Sweep	Stop		
Markers			
Marker 1	3.585MHz		
Marker 2	3.505MHz		
Marker 3 3.62MHz			
🗆 Enable Delta	Marker		
Show data	a Locked		
51.933 m			
JI.955 III	Deflectere des		
Reference swee	p as reference		
Reference swee Set current Reset i	ep as reference reference		
Reference swee Set current Reset i Serial port cont	p as reference reference		
Reference swee Set current Reset i Serial port cont COM6 (Nanov	ep as reference reference rol (NA) ~ Rescan		
Reference swee Set current Reset i Serial port cont COM6 (Nanov Disconne	ep as reference reference rol (NA) ~ Rescan ct Manage		
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NanoVNA Saver 0.3.7 (Sweep: 2020-09-01 16:12:0)

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

Display settings		e tel sub en lla sub	– 🗆 X
Options			Chart colors
Return loss is:	<ul> <li>Negative</li> <li>Positive</li> </ul>		✓ Use custom chart colors Chart background
<ul> <li>☑ Show lines</li> <li>□ Dark mode</li> <li>Sweep color</li> </ul>	Displays a thin line bet Black background with	ween data points white text	Chart foreground Chart text
Second sweep color			Font Font size 12 ~
Second reference color			Bands □ Show bands
Point size Line thickness		4 px 👻 8 px 🕏	Chart bands
Marker size Show marker numbers Filled markers	Displays the marker nu	20 px ਦ mber next to the marker filled triangle	VSWR Markers
Data point is:	<ul> <li>At the center of the</li> <li>At the tip of the mar</li> </ul>	marker ker	None ~
Displayed charts			Add
S11 Smith Chart ~	S11 VSWR ~	None ~	
S11 Real/Imaginary ~	S11  Z  ~	None ~	
Markers			
Add	Remove	Settings	

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

Active calibration	Calibration standards
Calibration: Application calibration (101	
Source: Calibration assistant	Short
Calibrate	L0 (H(e-12)) 0
Short Set (101 points)	L1 (H(e-24)) 0
Open Set (101 points)	L2 (H(e-33)) 0
Load Set (101 points)	L3 (H(e-42)) 0
Through Uncalibrated	Offset Delay (ps) 0
Isolation Uncalibrated	Open
termination of the second s	C0 (F(e-15)) 50
Offset delay 0.0	0 ps 🗧 C1 (F(e-27)) 0
Calibration assistant	C2 (F(e-36)) 0
Apply Reset	C3 (F(e-45)) 0
Notes	Offset Delay (ps) 0
	Load
	Resistance (Ω) 50
	Inductance (H(e-12)) 0
	Offset Delay (ps) 0
	Through
	Offset Delay (ps) 0
	Saved settings
	New
Files	incom

## Calibration: <u>SHORT</u> circuit (ZERO R) on far left of the Smith Chart RESISTANCE axis



# Calibration: <u>OPEN</u> 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



We WILL return to Smith Charts later

# You can also CALIBRATE the device on its own (small) screen: limit of 101 data points



Signal goes out and returns via same CHO port (Ch1 empty)

You have FOUR colors and FOUR graphs (if you want)



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

80 and 40 meter TRAP DIPOLE Trap is high-impedance LC tuned to 7 MHz Overall length about 110 feet



#### 80/40 meter trap dipole: 80m traces 25 feet above ground Tuned to the "low" end of 80m band

In NanoVNA Saver 0.3.7 (Sweep: 2020-10-01 12:01:06 @ 2020 points)					
<ul> <li>NanoVNA Saver 0.3.7 (Sweep: 2020-10-01 12:01</li> <li>Sweep control</li> <li>Start 3.5MHz</li> <li>Center 75MHz</li> <li>Stop 4.0MHz</li> <li>Span 500kHz</li> <li>Segments 20 247.6Hz/step</li> <li>Sweep settings</li> <li>100%</li> <li>Sweep Stop</li> <li>Markers</li> <li>Marker 1 3.502506MHz</li> <li>Marker 2 3.582214MHz</li> <li>O</li> </ul>	Marker 1         Return loss: -11.288 dB           Impedance: 32.9+j15.4 Ω         S11  S11 : 0.273           VSWR:         1.750           Marker 2         Frequency: 3.58234 MHz           Frequency:         3.58234 MHz           Impedance: 47.9+j502m Ω         S11  S11 : 0.022	S11 Smith Chart	×		
Marker 3 3.996201MHz Enable Delta Marker Show data Locked O TDR 121.747 m	VSWR: 1.046 S11  Z : 47.874 Ω	S11 VSWR	30.0 20 3500k 3625k 3750k 3876k 4001k R- S11 R+jX (Ω) -X		
Reference sweep	Frequency:         3.99625 MHz         Return loss:         -4.608 dB           Impedance:         35.3+j59.3 Ω          S11 :         0.588           VSWR:         3.858         S11  Z :         68.968 Ω	4.0	49.0     61.0       45.6     52.3       42.2     43.6       38.9     34.9		
Set current as reference		2.5	35.5		
Reset reference	S11		32 1 17 4		
Serial port control COM6 (NanoVNA) ~ Rescan Disconnect Manage Files Calibration	Min VSWR: 1.046 @ 3.58209MHz Return loss: -33.031 dB S21 Min gain: -118.070 dB @ 3.51166MHz Max gain: -118.070 dB @ 3.51166MHz	2.0 1.5 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0 1.0	25.4 25.4 22 3500k 3625k 3750k 3876k 4001k 7		
Display setup About	Analysis	3000K 3023K 3730K 3070K 4001	5500K 5025K 5750K 5070K 4001K		

#### **80/40 meter** Trap Dipole: **Smith Chart** Markers: RED 3500 kHz , BLACK 3600 kHz, GREEN 4000 kHz



#### 80/40m trap dipole: **RETURN LOSS** (dB) RL = -20 log (Voltage reflected / Voltage incident) If SWR = 1:1 then RL is infinite



#### **SWR** 80/40m trap dipole 3.5 to 4.0 MHz Markers: Red 3500 kHz, Black 3580 kHz, Green 3990 kHz


### 80/40 meter Trap Dipole Resistance R (left scale) BLUE and Reactance X (right scale) Note <u>TWO</u> locations where X = 0 (resonance)



### Trap Dipole 80/40 meter: **Impedance** (Z) Ideal = 50 ohms to match 50 ohm coax



### 80/40m trap dipole on 40 meters: 7.0 - 7.3 MHz



### 80 meter Inverted V fed with 100 ft RG213 and W2DU balun



### 80m Inverted V on porch cut for low end of band around 3580 kHz

NanoVNA Saver 0.3.7 (Sweep: 2020-10-01 18:1	7:11 @ 1010 points)		- 🗆 X
Sweep control       Start     3.5MHz       Stop     4MHz       Segments     10       Sweep settings       100%	Marker 1           Frequency:         3.57192 MHz           Impedance:         55.5-j2.76 Ω           VSWR:         1.124	S11 Smith Chart	S11  Z  130 117 103
Markers Marker 1 3.57198MHz Marker 2 3.506112MHz Marker 3 3.988241MHz C Enable Delta Marker Show data Locked TDR	Marker 2           Frequency: 3.50595 MHz         Return loss: -10.844 dB           Impedance: 67.3-j30.2 Ω         [S11]: 0.287           VSWR:         1.805         S11  Z : 73.702 Ω		90.0
73.048 m Time Domain Reflectometry	Marker 3           Frequency:         3.98806 MHz           Impedance:         42-j50.8 Ω           VSWR:         2.914	S11 VSWR 4.0 3.5 3.0	3500k     3600k     3700k     3800k     3900k     4000ł       R-     \$11 R+jX (Ω)     -X       125.0     34.8       114.4     23.2       103.8     11.6       93.1     0.0
Reference sweep Set current as reference	< >	2.5	- 82.5
Reset reference       Serial port control       COM6 (NanoVNA)        Disconnect       Manage       Files       Calibration       Dischau cature	S11 Min VSWR: 1.120 @ 3.57440MHz Return loss: -24.945 dB S21 Min gain: -120.334 dB @ 3.86010MHz Max gain: -120.334 dB @ 3.86010MHz	2.0 1.5 1.0 3500k 3600k 3700k 3800k 3900k 44	71.9 61.2 50.6 40 3500k 3625k 3750k 3875k 4000k

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



80 meter Vertical made from 40 ft of 2-inch surplus aluminum tubing tuned as ¼ wave (with loading coil) with two 65 ft radials



### 20 m Vertical with 17 ft radials



#### 20 meter <u>home brew</u> vertical: 17 ft high with two 17 ft radials this is obviously **mis-tuned** to 13.8 MHz

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



#### OR, just hook up my antenna tuner in the shack and lower the SWR on 20m



### Jetstream 10m vertical: 5/8 wave



## 10 meter vertical: 5/8 wave (about 20 ft tall) badly mistuned below the 10m band to 26.8 MHz



#### Same 10m antenna post antenna tuner



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





### Cushcraft R5 Vertical Impedance (10/12/15/17/20 meters)



### Cushcraft R5 SWR 20,17,15,12,10 meters 15 meter trap poorly adjusted SWR = 2.5 : 1 at 21 MHz



### Houston: we have a problem

### What can we do to improve 15m SWR On this Cushcraft R5 multi-band vertical?

### Enter: our Antenna Tuner (in the shack)



#### Cushcraft R5 SWR on 15 meters: before and after Antenna TUNER

20



### Cushcraft 10 element 2m beam



# The "Gamma Match" is an <u>UN-BALANCED</u> 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



### 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 **<u>50 ohm</u>** in the SO239 socket?





#### Attenuation (dB per 100 feet)

#### Coax Cable Signal Loss (Attenuation) in dB per 100ft\*

Loss*	<u>RG-174</u>	<u>RG-58</u>	RG-8X	RG-213	<u>RG-6</u>	<u>RG-11</u>	<u>RF-9914</u>	<u>RF-9913</u>
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?

TDR							<u> </u>	з х
RG-8X (Belden 9258) (0.82)								
Velocity factor	0.82							
Estimated cable lengt	h: 17.091m (56ft 0.	.9in)						
TDR 694,9	1	1		-	<u>i</u>		1	
				17.09m				
602.4				$-\Lambda$				
510.0								
417.5								
				$I \mid \Lambda$				
325.0								
			10					
232.6								
140.1								
47.47.0.0m 3.3m	5.94m 6.7m	10.0m	13.3m	16.7m	20.0m	23.3m	26.7m	30.0

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**



#### 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 but use TWO Channels



## A FM broadcast band-stop "filter"



## Measuring Toroid impedance



### Ready for a closer look at

# **Smith Charts**

### **Smith Chart for feed lines**

Where a feed line connects to your radio (or antenna tuner) the impedance has a unique value: Z = R +/-jX

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" - the "magic part" of tuners Resistance** is plotted on **horizontal** axis from 0 to infinity Often the PRIME **center** is set to 1.0 (for scale)



Plotting **REACTANCE**: circles tangent to RESISTANCE axis Inductors produce POSITIVE reactance Capacitors produce NEGATIVE reactance



# Every impedance (R + jX) value 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



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 <u>50 ohms</u> for convenience



For every antenna impedance (**R** + j**X**) there is a unique "conjugate match" location (**R** – j**X**) that will <u>CANCEL the X</u> and end up with 50 ohms R



## A Great Teaching Tool !



### This is via K5HAL Cullen

