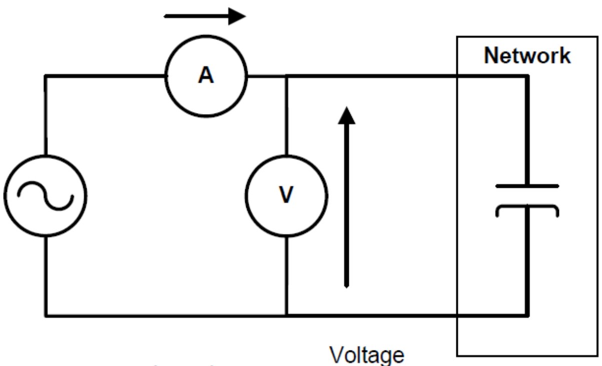
See end of document for links.

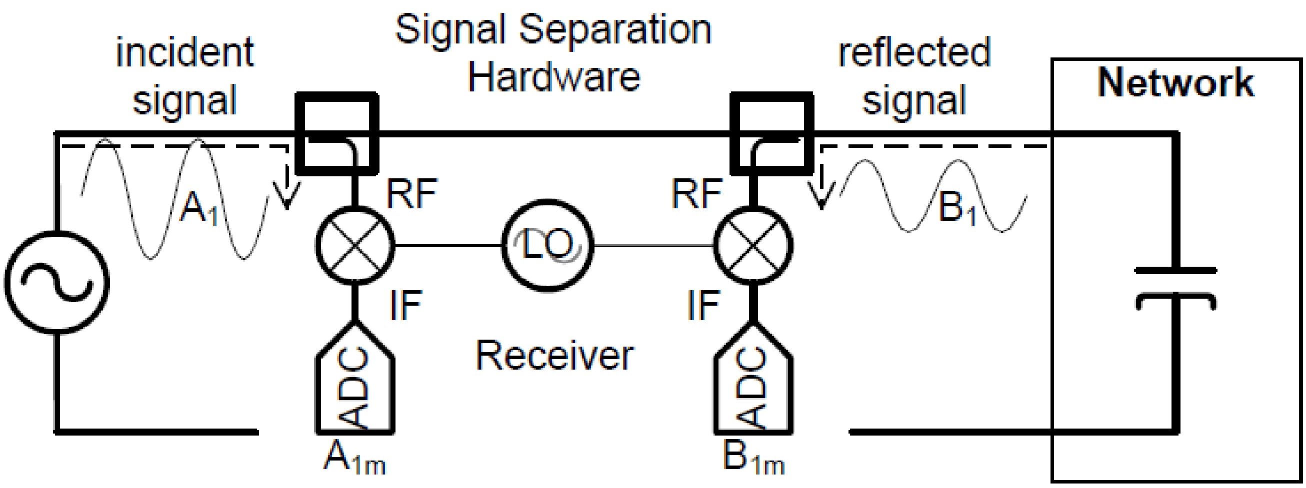
In its simplest form, a Vector Network Analyzer is an instrument used to measure impedance. At lower frequencies, you can measure impedance with relatively simple tools, including a sine wave generator, a volt meter, a current meter, and a calculator. Using these tools, you can measure the ratio between voltage and current and calculate the resulting impedance, as shown here:



$$\text{Impedance} = \frac{\text{Voltage}}{\text{Current}}$$

At radio frequencies, measurements of voltage and current become more complex. As a result, a VNA uses a more complex design to measure incident and reflected waves. In many ways, the VNA brings together the principles of basic impedance measurements with hardware appropriate for high frequencies.

When using a VNA to measure the impedance or the reflection factor, a sine generator stimulates the Device Under Test (DUT). In addition, two receivers take the place of the combination of a volt meter and current meter. These receivers, with the help of signal separation hardware, characterize the response of the device by measuring the phase and amplitude of signals that are both incident to and reflected from the DUT. Finally, calibration capabilities are required to eliminate systemic errors and compute the appropriate ratios (similar to the impedance) necessary to produce S11, which is one of the S-parameters. The architecture of this simplified VNA is illustrated below.

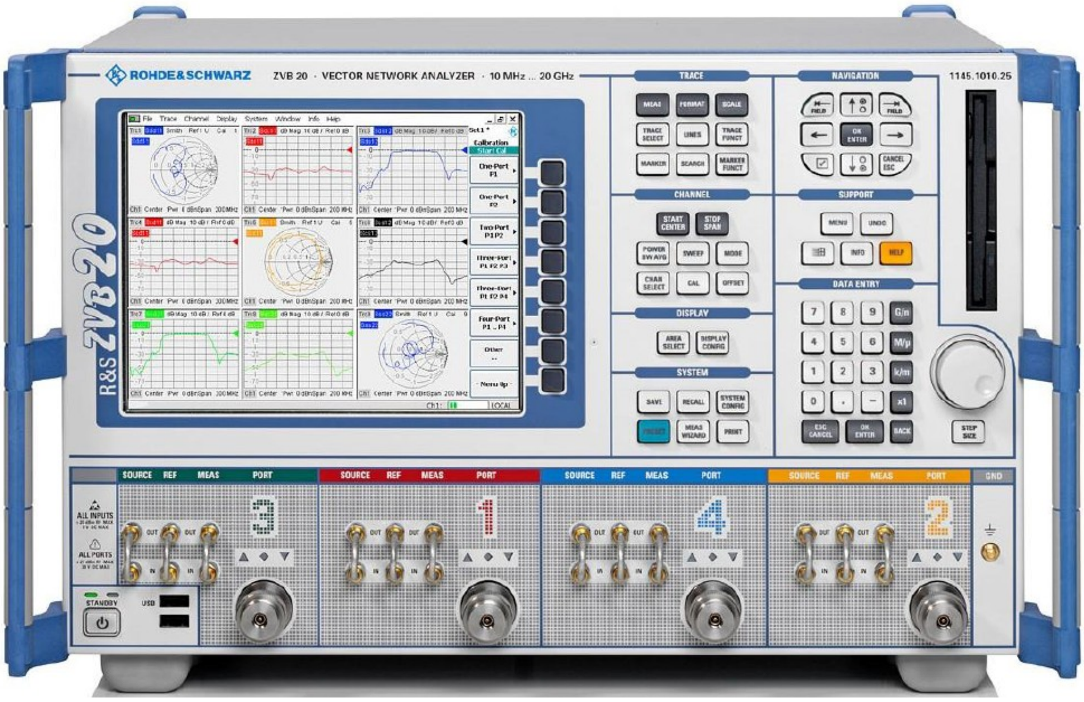


$$\text{Reflection Coefficient} = S_{11} = G = \frac{B_1}{A_1}$$

The primary use of a VNA is to determine the S-parameters of many passive components, including cables, filters, switches, diplexers, duplexers, triplexers, couplers, bridges, transformers, power splitters, combiners, circulators, isolators, attenuators, antennas, and many more. In addition, VNAs can also characterize active devices such as transistors and amplifiers using S-parameters, as long as they are operating in their linear mode of operation. High-frequency devices can have one, two or more ports.

This VNA costs $8000 on ebay:

This one costs as much as a house, each site I checked said ”Request a quote”:



I saw a similar one which was listed at about $240,000.

NanoVNA: HARDWARE VERSIONS

There are several versions and clones of the NanoVNA although they are all based on the same open source NanoVNA project created by edy555. The original NanoVNA was not properly cased, but was supplied as a "sandwich board". Even today, you can buy clones without a case (Fig. 1).

Different hardware versions of NanoVNA use different firmware.

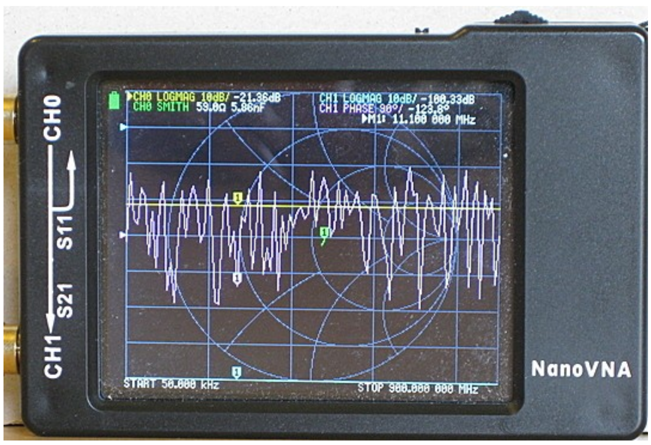
Figure 1

Figure 2

Hugen’s improved models, the NanoVNA-H 2.8’’ and NanoVNA-H4 4’’, come in a proper plastic case. We call Hugen's models "classic" models (Fig. 2, 3 and 4).

NanoVNA-H2.8'' display ''classic model'' by Hugen

Figure 3

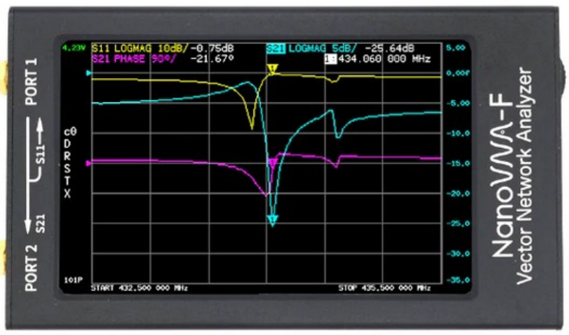


NanoVNA-H4
4'' display up to 1.5 GHz
''classic model'' by
Hugen (Fig. 4).

Figure 4

NanoVNA-F in an aluminum box
4.3-inch display
manufactured by BH5HNU

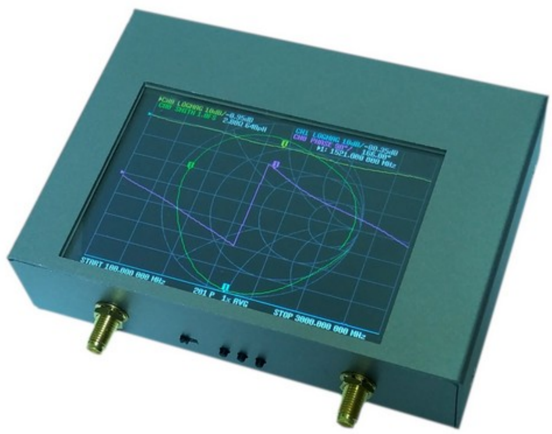
Figure 5



NanoVNA V2 with push buttons (S-A-A-2)
by OwOComm V2 Plus V2.3
2.8'' display
50 kHz – 3 GHz
Figure 6

NanoVNA V2 with push buttons (S-A-A-2)
by OwOComm V2 Plus4 V2.4
4'' display metal box
frequency range extended to 4 GHz

Figure 7



NanoVNA V2 SAA-2N with N connectors 4'' display metal box 50 kHz – 3 GHz

Figure 8

OVERVIEW

Depending on where you purchase it, the NanoVNA comes with a calibration set (3 pcs - open, short, load), two SMA male to male cables, USB C to USB-2 cable, SMA female-female adapter, guitar pick to operate the menu system and, if you are lucky, you have got printed NanoVNA Menu Structure Map. Otherwise, you can download this map from the *nanovna-users* group files section. Folder ''Miscellaneous'', file: *nanoVNA Menu Structure v1.1.pdf* by Larry Goga.
https://groups.io/g/nanovna-users/files/Miscellaneous

There are several versions of NanoVNA but the main parts on all are the same (Fig. 9). The screenshots in this document were taken from the classic NanoVNA-H. You may have another NanoVNA model and/or have different firmware installed, so the screenshots on your NanoVNA may be slightly different, but in principle there are no differences.

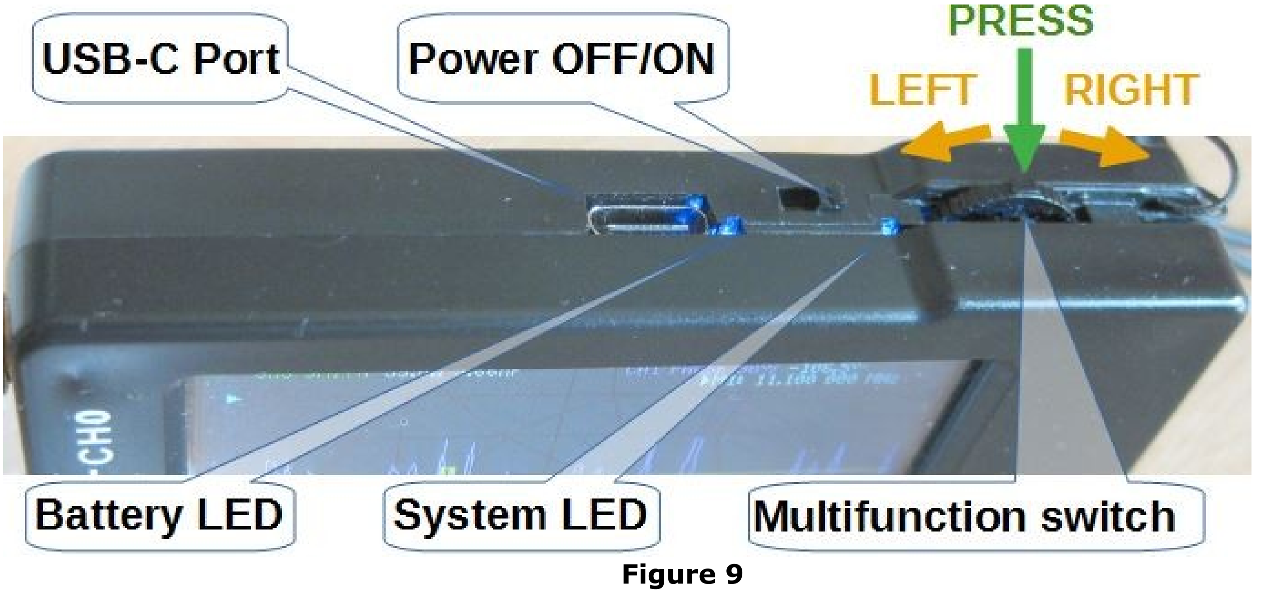


Figure 9

Power OFF/ON switch turns the NanoVNA on and off. After switching off the battery LED stays on for a while. It's normal.

USB-C port is used to charge the battery and send data to a PC. It doesn't matter how the USB cable is inserted.

The **multifunction switch** has multiple functions, such as selecting and executing commands and moving markers.

- press the multifunction switch to open the menu or to execute the selected menu command
- slide the multifunction switch to the right or left to select a command from the menu
- slide the multifunction switch to the right or left to move selected marker along the trace on the screen

Battery LED - constant light is an indication of a charged battery. It flashes when the battery is charging. During normal operation, flashing indicates low power - connect the charger to charge the battery.

System LED flashes during normal NanoVNA operation.

A BRIEF THEORY OF THE VNA

A Vector Network Analyzer, VNA, is an instrument that measures network parameters of electrical networks, such as antennas or antenna systems, filters, individual components, etc. The VNA sends a known signal (an electromagnetic wave of known magnitude and frequency) into a device under test and measures how much of that wave reflects from the device (reflection) and how much transmits through the device (transmission). The VNA captures both magnitude and phase of reflected wave from the DUT or magnitude and phase of the wave that has passed through the DUT.

When measuring one port devices, such as an antenna or individual components, the VNA transmits a signal of known magnitude and frequency from it's Port 1 into the DUT and measures magnitude and phase of the reflected signal from the DUT on the same port, VNA Port 1.

When measuring two ports devices, e.g. filters, the VNA transmits a signal of known magnitude and frequency from it's Port 1 into the DUT and measures the magnitude and phase of the signal passed through the DUT to the VNA other port, Port 2.

All other ''measurements'' are calculated in the VNA based on measurements of the magnitude and phase of the reflected and transient signal.

(*That's a very simplistic explanation but enough to get us started*).

NanoVNA can display up to four traces simultaneously, one of which can be a Smith Chart. Each trace has its own marker that we can move along the trace. By moving the marker (changing marker's position) we select the frequency of interest.

The numerical values corresponding to the active marker of each trace are displayed at the top of the screen. Depending on the installed firmware, the active channel is highlighted (reverse video) or marked with a triangle.

The measured value at the marker position is shown in Fig 10. It is shown as **CHANNEL – FORMAT – SCALE - Current value**. Below this line is another line (not shown) which shows the frequency at the marker position. Remember that the marker can be moved to any position along the trace.

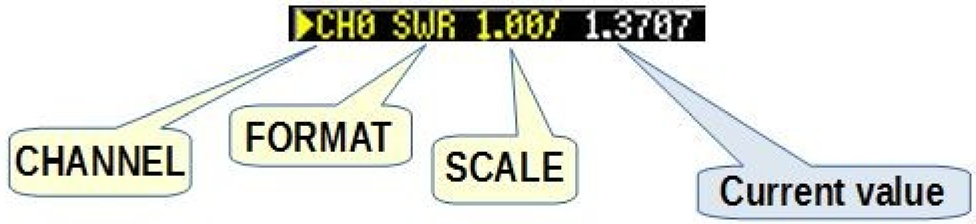


Figure 10

CHANNEL - the channel from which the measurement was taken (CH0 or CH1)
FORMAT - measurement type (SWR, PHASE, SMITH, RESISTANCE, etc.)
SCALE - number of units of measure per division (between each horizontal line on the screen)
Current value - measured value at the selected frequency

FREQUENCY SWEEP RANGE

VERY IMPORTANT !!!!

NanoVNA does not generate frequencies continuously but in 101 DISCRETE FREQUENCY STEPS in the selected frequency range.

Whenever working with a VNA, we, the users, have to set the frequency range in which VNA measures. So for example, if we set the frequency range from 3 to 30 MHz, the NanoVNA will generate a signal in increments of about 267 kHz (27000 kHz/101 steps). In other words, it measures at every 267 kHz, which may not be accurate enough.

To improve the accuracy of the measurement, we need to narrow the frequency range and thus get a lot more data points. This is not a serious limitation, especially if we carefully choose the frequency span in which we measure.

NanoVNA's PORTS

NanoVNA has two ports labeled: **CH0** (Port 1) and **CH1** (Port 2) (Fig.23).

On CH0 NanoVNA measures the reflected signals from the DUT (e.g. antenna).
On CH1 NanoVNA measures the signals that have passed through the DUT (e.g. filter).

NanoVNA MENU SYSTEM

There are no buttons or knobs on the NanoVNA. Instead, we use a menu system to issue the command. If you did not get printed NanoVNA Menu Structure Map with your device you can download this map from the files section of the *nanovna-users* group, https://groups.io/g/nanovna-users/files/Miscellaneous/nanoVNA%20Menu%20Structure%20v1.1.pdf

Depending on the installed firmware, this menu structure may differ slightly from the menu on your device.

OPENING AND CLOSING THE MENU

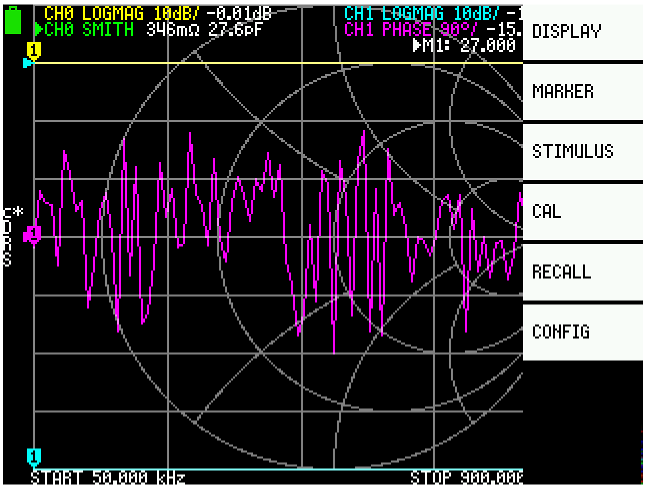


Figure 25

Open the menu by tapping any part of the screen with the stylus or guitar pick or by pressing the multifunction switch. This will open the home menu as shown in Figure 25.

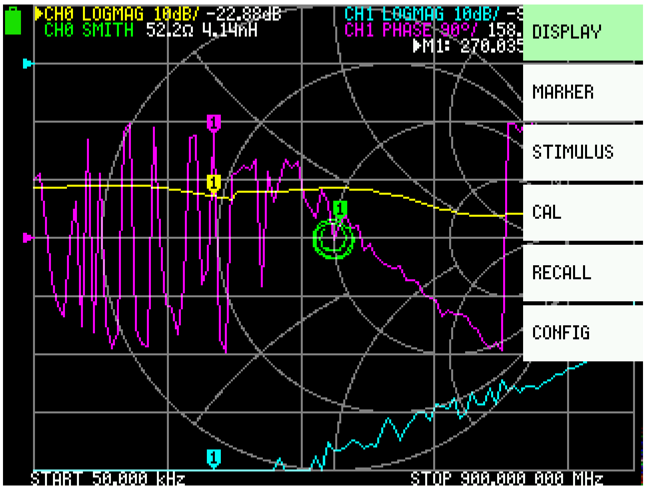
Close the menu by tapping on the screen or by sliding the multifunction switch to the left.

SELECTING AND EXECUTING A MENU COMMAND

STYLUS

To select and/or execute a command from the menu, tap the command with the stylus. The command briefly changes the background color and is executed.

MULTIFUNCTION SWITCH



To select a command from the open menu, slide the multifunction switch to the right. The selected command changes its background color. As we can see from Figure 26. the background color of the DISPLAY command is green, which means that DISPLAY is the selected command.

Figure 26

To execute the selected command, press the multifunction switch.

NanoVNA MEASUREMENT CONFIGURATION

Before each measurement we need to configure NanoVNA for the type of measurement:

- which traces we want to display (up to four or three plus Smith Chart)
- trace channel (CH0 REFLECT or CH1 THROUGH) for each trace separately
- trace format (unit of measurement of each format)
- scale (how many units of measurement per each horizontal line, for each trace separately)
- reference position for each trace separately
- sweep frequency (stimulus frequency range)
- calibrate the NanoVNA

The order of the setting is not important except of the calibration. The calibration must be done last. As you will see later, the calibration also saves the display settings, so you can easily recall the whole setup.

SELECT THE TRACE

NanoVNA can display up to four traces or three traces plus a Smith Chart simultaneously. By choosing a trace from the TRACE menu, we select the trace(s) that NanoVNA will display.

DESELECT THE TRACE

Deselect (cancel) the unwanted trace from the TRACE submenu.
Open **DISPLAY | TRACE** and:

WITH STYLUS:
Tap on the highlighted TRACE one or two times.

WITH MULTIFUNCTION SWITCH:
Highlight the TRACE you want to deselect (slide the multifunction switch to that trace),

a) if the trace is not an active trace, press the multifunction switch two times.
b) if the trace is an active trace, press the multifunction switch once.

(The active trace is labeled with a triangle or its channel text is inverted.)

ACTIVE TRACE

We can only change the properties (e.g. format, scale, reference position and channel) of the active trace. The NanoVNA can display up to four traces, but only one is the active trace. We can only activate selected, highlighted, traces. Depending on the installed firmware, the active trace is labeled with a triangle or its channel text is inverted (Fig. 28).

To activate the trace:

> *WITH STYLUS:*
> Tap on the highlighted TRACE once.
>
> *WITH MULTIFUNCTION SWITCH:*
> Slide the multifunction switch to highlight menu option of the trace you want to set active and press the multifunction switch.

TRACE FORMAT

Each trace has its own format. Format is a type of measurement that the trace will display on the screen, such as SWR, Smith Chart, reactance, resistance, etc. To set or change the trace format we have to activate the trace (Fig. 28).

DISPLAY | FORMAT opens the FORMAT submenu as in Figure 29 to select the format you want, e.g. SWR. We can use a stylus or a multifunction switch.

TRACE CHANNEL

NanoVNA has two ports, labeled as **CH0** and **CH1**. On some models the ports may be labeled as Port 1 and Port 2. We need to select at which NanoVNA port (CH0 or CH1) we measure, for each trace separately.

First, activate the trace (see ACTIVE TRACE chapter). The active trace is labeled with a triangle or inverted text. Now, open the home menu:

WITH STYLUS - tap anywhere on the screen.
WITH MULTIFUNCTION SWITCH - press the multifunction switch.

SUMMARY

Can NanoVNA be compared to professional devices that cost several hundred times more? Let's be serious, it can't! Does NanoVNA have any value for the average radio amateur? Definitely YES! For those without electronic and radio engineering background, but willing to learn, there is a great reward waiting just around the corner.

It is the satisfaction of understanding how something works in the world of radio technology that the money can't buy. NanoVNA can greatly help you in claiming the reward.

In these three examples, we just scratched the surface. NanoVNA can do much more. Figuring out everything the NanoVNA can do could take months, even years. But with NanoVNA, learning is a lot easier and more fun.

For further assistance see the *nanovna-users* group Wiki page:

> https://groups.io/g/nanovna-users/wiki

There are plenty YouTube videos about NanoVNA but by far the best are by Alan Wolke W2AEW:

> http://www.youtube.com/w2aew

Look for his NanoVNA videos from #312 to #326

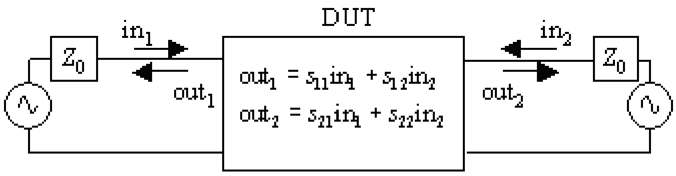
> https://www.youtube.com/playlist?list=PL4ZSD4omd_AylEyNCQYR3RcEb0olukPEJ

All of Alan's videos are outstanding and highly recommended.

Scattering parameters describe the input-output relationships between ports in an electrical system. Specifically at high frequency it becomes essential to describe a given network in terms of waves rather than voltage or current. Thus in S-parameters we use power waves.

In RF design, we can't use other parameters for analysis such as Z,Y,H parameters as we can't do short circuit and open circuit analysis as it is not feasible.

For a two port network, s-parameters can be defined as



$$s_{11} = \left.\frac{out_1}{in_1}\right|_{in_2=0} \qquad s_{12} = \left.\frac{out_1}{in_2}\right|_{in_1=0}$$

$$s_{21} = \left.\frac{out_2}{in_1}\right|_{in_2=0} \qquad s_{22} = \left.\frac{out_2}{in_2}\right|_{in_1=0}$$

S11 is the input port voltage reflection coefficient
S12 is the reverse voltage gain
S21 is the forward voltage gain
S22 is the output port voltage reflection coefficient

The S-parameter matrix can be used to determine reflection coefficients and transmission gains from both sides of a two port network. This concept can further be used to determine s-parameters of a multi port network.

These concepts can further be used in determining Gain, Return loss, VSWR and Insertion Loss.

Return Loss can be thought of as a measure of how close the actual input/output impedance of the network is to the nominal system impedance value.

$$RL_{\mathrm{in}} = 10\log_{10}\left|\frac{1}{S_{11}^2}\right| = -20\log_{10}|S_{11}| \text{ dB}$$

$$RL_{\mathrm{out}} = -20\log_{10}|S_{22}| \text{ dB.}$$

VSWR is defined as, **VSWR** $= \frac{1+|S_{11}|}{1-|S_{11}|}$

Material for this talk from the following (among others):

Absolute Beginners Guide to NanoVNA

http://www.nemarc.org/Absolute_Beginner_Guide_NanoVNA.pdf

Introduction to Network Analyzers www.ni.com/rf-academy

S-Parameter discussion (last page)
https://www.everythingrf.com/community/what-are-s-parameters

W2AEW NanoVNA videos https://www.youtube.com/playlist?list=PL4ZSD4omd_AylEyNCQYR3RcEb0olukPEJ

Introduction to VNAs & the NanoVNA (pdf)
https://www.bay-net.org/uploads/1/2/2/7/122774721/baycon_2021_nanovna_w2aew.pdf

K3EUI Nano VNA presentation (pdf)
https://groups.io/g/nanovna-users/topic/82414179

K3EUI video https://www.youtube.com/watch?v=UlXgZpgE6qk

DG8GB NanoVNA – part 1
https://gunthard-kraus.de/fertig_NanoVNA/English/English_NanoVNA_2020_part%201.pdf

DG8GB NanoVNA (Version H2 / H4)
https://n7tar.org/wp-content/uploads/2021/12/NanoVNA-H2_English-1.pdf

Fundamentals of Vector Network Analysis Rhode & Schwarz
https://www.rohde-schwarz.com/us/products/test-and-measurement/analyzers/network-analyzers/fundamentals-of-vector-network-analysis_253352.html

NanoVNA-App-Setup-v1.1.209-OD15
https://github.com/owenduffy/NanoVNA-App/releases/tag/NanoVNA-App-Setup-v1.1.209-OD15