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Vector Network Analysers (Pt I)

Keith Rawlings G4MIU starts a teach-in on VNAs and their uses.

Hello and welcome to this month's edition of *Antennas*. Correspondence from readers suggests that there is a great deal interest in the use of Vector Network Analysers. It is notable that a fair proportion comes from readers who have left the hobby and returned after a number of years and are therefore not familiar with these devices.

So, this month we will have another look at VNA's, specifically those based on the popular **NanoVNA**, and their uses in the amateur radio shack. We will take a look not only at checking antennas, but also filters, antenna traps, and individual components. Getting to grips and understanding how these little analysers work is not only interesting but also educational and dare I say it, fun!

Like an oscilloscope can help one to 'see' into the workings of an electronic circuit (or network) the VNA can help one visualise what is happening in an RF network.

This is not intended to be a complete in-depth VNA 'tutorial' (there are complete books written on the subject), but more of an overview for readers who are not familiar in the workings and use of a VNA.

Readers may wish to refer to my February 2023 column, which gives an overview of VNA basics.

Introducing the VNA

I will start off by explaining that the 'Network' in the name VNA does not refer to analysing computer networking or even Mobile Phone / Wi-Fi networks as a whole. A VNA measures parameters of RF networks which can be anything like an antenna, a filter, an amplifier, individual components and so on.

Put very simplistically, the device does this by sending an RF wave of known frequency and magnitude into a 'Device Under Test' or DUT. It then measures how much of that wave is reflected back to the VNA, and in the case of a through measurement, how much of that wave passes through the DUT.

The VNA captures both the magnitude and phase of the reflected wave from the DUT and also the magnitude and the phase of a wave that passes through the DUT.

With this information, the NanoVNA in particular, will be able to measure parameters such as **S11 Smith Chart, S21 Polar Plot, S11 Return Loss, S21 gain, |S11|, |S21|, S11 |Z|, S21 phase, S11 phase, S21 Real / Imaginary, S11 VSWR, S11 & S21 LogMag, S11 R + jX, TDR, S11 Quality Factor, S11 Real / Imaginary.**

We will explore some of these terms as we go along.

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A VNA that has two Ports, such as the NanoVNA, can make single port reflection measurements, like those that would be carried out on an antenna or components such as inductors or capacitors and also two port measurements, where the wave from port one travels through the DUT which may be something such as a filter, attenuator or amplifier and onward to port two on the VNA.

All measurements are calculated within the VNA based on the magnitude and phase of the reflected and transmitted wave.

In the case of analysers such as the popular RigExpert series that have a single connector, these are single port devices and can make reflection measurements only, but these are still very capable instruments.

So basically, these devices transmit a known signal into the DUT and then measure how this 'network' responds to it.

In addition to VNA's there are 'Large Signal VNA's, which measure the performance of devices under large signal conditions, and there are also what are called Scalar Network analysers which measure in magnitude only.

As well a dedicated analysers, companies like Rigol and Siglent have a tracking generator option for their Spectrum Analysers which enables them to work as Scalar Analysers.

Results are generally displayed on a screen inbuilt to the device but there are 'black box' VNA's that require a computer to display the results.

The amateur seems to be spoilt for choice for analysers and even the most expensive VNA can still be affordable as the majority of the more popular designs are based on the NanoVNA in one way or another.

The NanoVNA is, depending on model, a small or slightly larger than small(!) battery-powered hand-held device with an inbuilt touchscreen display that can also be controlled by PC software. While just a fraction of the price of a commercial VNA they still offer great accuracy and my discussion here will be mainly based around this model.

Although I don't have a NanoVNA per se, I have a Nano based VNA-3G, **Fig. 1**, which will be very similar but there may be some differences, and there are various firmware versions available for NanoVNA's too, so menu structures may be different to what I describe.

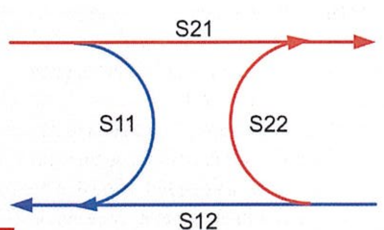

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Fig. 1: The VNA-3G Outfit. With SOL standards, SMA adaptors, two 200mm Pigtails and USB lead.
Fig. 2: Diagram indicating S-Parameters
Fig. 3: Calibration procedure.
Fig. 4: Example of an S11 configuration for VSWR, Return Loss and so on.
Fig. 5: Example of a through measurement on a filter.

S-Parameters

To be able to make its calculations a VNA will use what are called Scattering or S-Parameters to describe the behaviour of the ports of a network. I don't have enough room for a full description of S-parameters but, suffice to say; the four parameters S11, S21, S12 and S22 can describe a two-port linear network, **Fig. 2**.

S21 describes the wave travelling 'straight on' though the network being tested, S11 represents the reflected wave. S12 and S22 as depicted in Fig. 2 are not represented in the NanoVNA as far as I know as it is a Single Path VNA.

An analyser such as the DG8SAQ VNWA3E, on the other hand, can perform S12 and S22 measurements.

As a lot of the work we do uses S11 and S21, S11 for reflection and S21 for through, the NanoVNA is perfect for this.

Using S11, the reflection at the input can be measured as this represents a complex reflection factor consisting of real and imaginary parts.

Therefore, parameters such as VSWR and impedance Z can be derived mathematically by the VNA. On most analysers these parameters may also be presented by means of a Smith Chart, which adds a visual way to assess results.

Calibration and port extensions

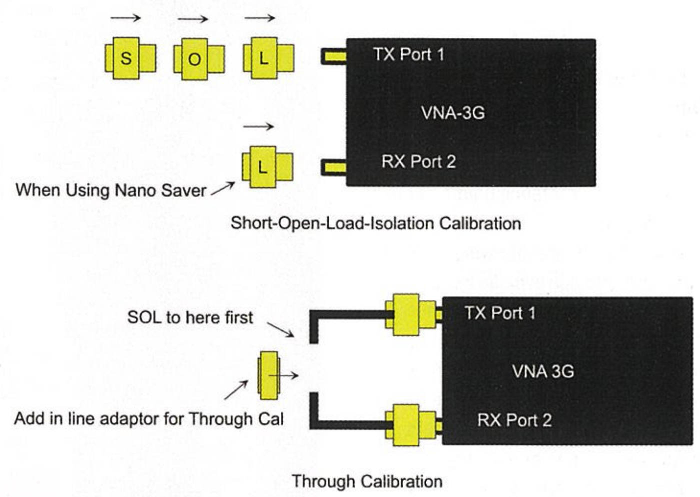
Calibration procedure

Calibration of any VNA is essential before use. This should not be mistaken for an instrument calibration; it is actually a user calibration made after the parameters for the required measurement are set, and it establishes a fixed measurement plane. Magnitude and phase are normalised at this point so we are measuring these parameters at this position only. Everything up to this point, such as a cable, is ignored by the VNA.

To set up parameters for a measurement we need to set the frequency sweep to match the frequency span required. (This is set under 'Stimulus' on the Nano.)

The Nano allows up to four traces to be shown so the next thing would be to decide how many traces are needed. I find it is best to keep these to a minimum to avoid a cluttered display so for a VSWR test, as an example, two are usually OK, one set for VSWR and the other set to Smith.

Next the traces have to be set to the appropriate channel, Channel 0 (Port1) would be for reflection e.g. S11 and Channel 2 (Port 2) would be Through e.g. S21, and each



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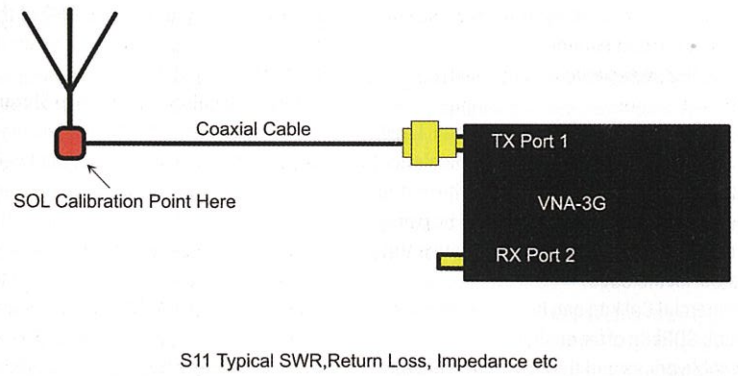

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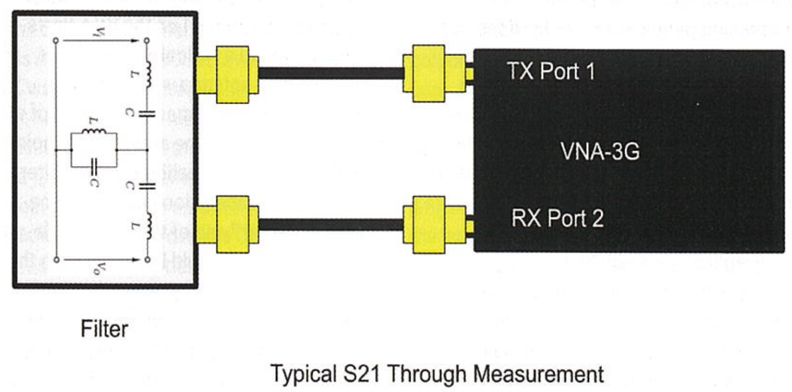

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Fig. 6: Rosenberger Female SMA Calibration Kit.

trace also needs to be set for the appropriate measurement parameter such as VSWR, Z, LogMag etc. This needs to be done for each trace, individually.

It is a good idea to now set the scale per divisions and also the reference points of the traces as needed.

If possible, set the number of sweep points (or data points) the device will use in the sweep, the more points the slower but more detailed the sweep, fewer points result in a faster sweep but at a coarser resolution. A calculation I have seen used for the Nano is Step size = Span width / (number of data points-1). The VNA-3G can be set for up to 1001 sweep points, so if we sweep 1-30MHz then at 30/1000 we will have a 30kHz resolution, the VNA will display measurements in 30kHz steps.

Some versions of the Nano have, I believe, just 101 sweep points so if the sweep width is set too wide the device may miss some aspects of the measurement.

A 1-30MHz sweep would have 300kHz 'steps'.

For calibration we use the Short, Open, Load, Through method (and in some cases Isolation) and this requires a calibration kit of the correct gender to suit the connectors we will be using. A lot of NanoVNA's come as a complete outfit with a Cal kit included.

Commercial Cal kits can be very expensive, although SDRkits offer quality Cal kits at reasonable prices and they come with details of the electrical properties of the kit.

This file contains details of the Open Delay and Short Delay in Pico Seconds and the resistance of the Load in Ohms. (Note loads are not all necessarily exactly 50Ω!)

These details should be entered into the VNA (if possible) otherwise there will be inaccuracies (See below).

Using the NanoVNA in standalone mode I believe no provision has been made to enter these details into the device. When using PC software such as NanoSaver this is a different matter as provision is there to do this.

www.sdr-kits.net

Other suppliers are available!

The Cal kits that come with the NanoVNA generally do not have a property file with them but seem to be of good quality, especially when you consider the whole NanoVNA kit can cost considerably less than most Cal kits!

The calibration of the Nano involves you touching the screen (or thumb wheel) to bring the menu up on the right-hand side. Navigate to the 'Cal' option and select Calibrate.

If you were to calibrate on the ports of the VNA itself, then you would connect the Open component of the Cal kit to CH0 of the Nano and press the 'Open' option. You do the same for the Short and the Load.

If you are going to undertake Through measurements on the Nano I believe you usually have to also connect the Load to CH1 and select 'Isoln' and then connect a cable from CH0 to CH1 and select 'Thru'. (the VNA-3G does not seem to need the 'Isoln' step)

The calibration can then be saved to a Nano Memory. (The VNA-3G has 13 memories)

Ideally a torque wrench is used to tighten SMA connectors but finger tight should suffice.

Procedural diagrams of this process can be seen in Figs 3-5.

Fig. 3 Depicts, at the top, a Short Open Load Isolation calibration on the VNA Port itself, in most cases a calibration would be made at the end of a cable and not on the VNA Ports.

Fig. 4 Depicts a typical S11 setup for measuring an antenna where the SOL calibration has been made at the end of a cable which will attach to the antenna feedpoint.

Fig. 5 is a through calibration of a filter. Here the SOL calibration point would be made at the DUT end of the Port1 cable, and an inline adaptor would be added as in the image depicted in Fig. 2, lower for the Through calibration. The adaptor would be removed and the DUT put in its place. Here we can make both S11 and S21 measurements.

Port extensions

Once we have made a calibration, that calibration will be valid to the Reference Plane of the Cal kit. For greater accuracy, what is being measured must be connected at that point, which, in some cases might be impractical, but if we don't do this, Phase Shift errors will be introduced to our measurement.

How much these measurements are affected by this error depends on the frequency and the distance from the calibration plane to the point of measurement in the DUT. Wavelength comes into play here, the shorter the wavelength, then the more the distance from the calibration plane we get the worse the error.

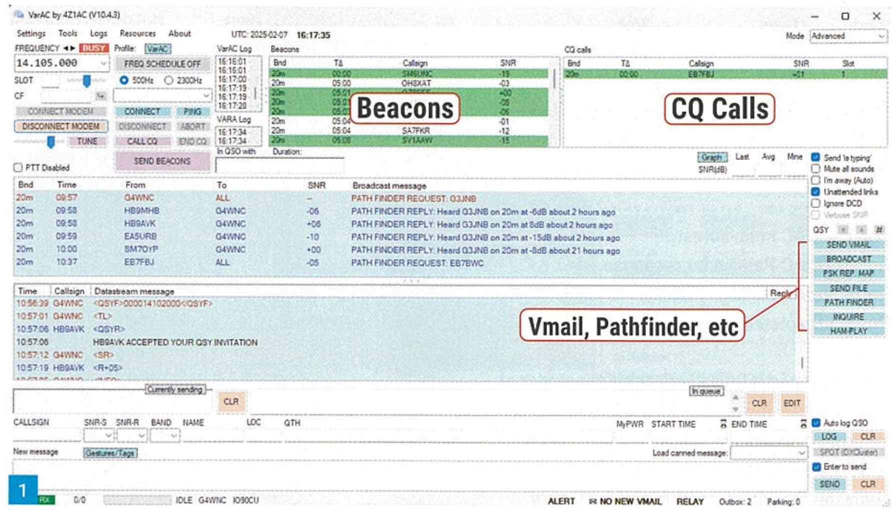
Say we add a PL259 to SMA adaptor to the cable in Fig. 5 at the point where the calibration is set. This may add something like, say, 30mm between the calibration plane and the point of measurement. Clearly if we were checking this filter on topband, 30mm with respect to wavelength is not a great deal and would only make a small difference but if we were doing the same at 70cm, 30mm is a fair percentage of the wavelength.

To overcome this, we can add a 'Port Extension' which will shift, or extend, the calibration plane 'electronically' in the software, in this case 30mm, from our calibration point to the end of the adaptor, thus the VNA will not know about our added 30mm adaptor.

This same technique can be used, for example, when we characterise a component on a test board, where the component is mounted some distance from the calibration plane.

The NanoVNA calls a Port Extension an Electrical Delay and this is manually entered in either Pico Seconds or Nano Seconds. Unfortunately, this has to be done by trial and error on the device and is something else we will discuss next time.

Fig. 6 shows A Rosenberger SMA Calibration kit from SDRKits. **PW**



VarAC Update

Mike Richards G4WNC has the latest on VarAC as well as news of some free spectrum analyser software.

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Despite not mentioning VarAC in a few columns, the development team has been busy adding new features to this increasingly sophisticated keyboard chat mode. At the time of writing, it's version 10.4.3, and seeing so much effort by the development team to respond to user requests is encouraging.

As with all data modes that are not FT8 or 4, locating active stations is half the battle. VarAC approaches this in several ways. At the top of the main screen, **Fig. 1**, are panels marked Beacons and CQ Calls. The Beacons are typically sent every 15 minutes, indicating online stations but not necessarily those accepting QSOs. In addition to showing the callsigns of received stations, the list has a column marked TΔ, which shows the elapsed time since the specified beacon or CQ was last heard. This helps ensure you're looking at current information. Each entry also contains the band and SNR result. The latter helps ensure you choose a station that's likely to be able to hear you!

Additionally, the CQ panel includes the Slot number. With VarAC, the convention is to call CQ on the calling channel and then automatically QSY to an adjacent frequency to await a response. These QSY frequencies are pre-allocated, given a slot number and selected as part of the CQ calling process. The slot number is helpful, as you can tune to that slot to see if the station is now in a QSO. If they're not, double-clicking on their call will retune your rig to the appropriate Slot frequency and initiate a call. This level of automation makes new contacts a breeze.

Another helpful activity aid is the PSK Rep Map button. When pressed, this opens a PSK Reporter window with the filters ready populated to show all VarAC stations that have heard you across all bands in the last six hours. Once the window opens, you can change the search parameters and make new searches. This is great for checking how well you're being heard and seeing who's on air.

Vmail support is enhanced with the ability to save draft emails. Also, if you attempt to call an online station, but the operator isn't accepting calls, you'll receive a pop-up where you can leave a Vmail message for the operator.

The Vmail Path Finder system has also matured and is working very well. I recently wanted to surprise my dear friend **Victor G3JNB** by sending him a Vmail. Due to my using a vertical antenna with a very low take-off angle, I don't have a good path to his location. The only way to get a Vmail through to Victor is to relay via another station, but which one? This is where Path Finder is so good. It was simple: activate Path Finder from the right-hand menu and enter the desired callsign. VarAC then takes over and sends a Path Finder request as a special broadcast message on the calling channel. All stations hearing my broadcast will automatically check their stations heard list and send a response if G3JNB has been heard. They don't need to have worked Victor, just received a beacon or similar. I've shown the response to my Path Finder response in **Fig. 2**.

As you can see, besides confirming the call, the report includes the band, SNR, and the approximate time heard. The next step is to prepare a Vmail message using the send Vmail button on the right-hand menu and save it to the Outbox when complete. Next, I selected the strongest station to have heard G3JNB, which was HB9AVK. If I right-click on that call, one of the options is connect, so I clicked that. This started a connection, even though HB9AVK was away and unavailable for QSOs. However, his station, like many, is available to relay messages. The first prompt I got was the option to QSY from the calling channel, which I accepted. This starts an automated routine where you can select the desired QSY slot and shift both stations to the new frequency without breaking the connection. It sounds complicated, but it's largely automated with excellent instructions. Once the QSY was complete, I opened my Vmail, right-clicked and selected Relay via Connected Station. This automatically uploaded my Vmail to HB9AVK's station, where it will sit until Victor is heard again by HB9AVK. As soon as Victor is heard, HB9AVK will broadcast a message to say the Vmail is waiting. Victor can then connect with HB9AVK at his leisure and retrieve the Vmail. This is a very well-thought-through system that works well. While the Vmail and relay options are very convenient for general use, they become essential when using VarAC in emergency Comms mode. VarAC makes it easy to set up a fully error-corrected radio-based (HF or VHF/UHF) text messaging system that doesn't require the internet. This has great potential for use in real emergencies.

The new eQSL generator seems to be a great idea. This is accessed via the Tools menu, followed by Callsign History. This brings up the panel shown in **Fig. 3**. Here, you enter the call of the station you want to QSL, select the QSO you wish to confirm and click the QSL Card button. You will then see a basic QSL card already populated with the contact details. At this point, you can customise the card by changing the background image or maybe altering text colours, etc. When the card is complete, **Fig. 4**, copy it to the clipboard so you can paste it into an email, and you're done. Once you've added a background image to a QSL card, VarAC will remember that choice for future QSL cards, which will be handy. You can, of course, change the image at any time.

If you'd like to give VarAC a try, the download is free and available from:

www.varac-hamradio.com

Free versatile tracking spectrum analyser!

A spectrum analyser with a tracking generator is a luxury for any radio amateur, and the cheapest commercial units usually cost well over £1000 and are generally pretty bulky items. However, **Alberto Ferraris IU1KVL** has been working on the SATSAGEN software project for several years