Amateur Radio RF Test Equipment 2025

Some alternative RF equipment purchase strategies

by DON WESTACOTT VE6HQ

Don has pursued a lifelong interest in science and engineering beginning as a youth in western Canada. He received his first amateur radio license at the age of 15 while attending high school in Edmonton, Alberta, Canada.

I read with great interest the technical article "Test Equipment and an Easy CW Decoder Project" by Kevin McQuiggin, VE7ZD/KN7Q. The article, published in The Communicator, May-June 2024 edition described radio frequency test equipment, principally a Spectrum Analyzer and RF Signal Generator. The author presented an excellent review of advanced RF instrumentation and its application within our amateur radio community.

The VE7ZD article suggested

"As for cost, it is a fact that brand new, state of the art test equipment can be very (very!) expensive. Used equipment, however, is readily available if you know where and how to look for it and may be purchased at a fraction of the cost"

The article also stated *"Purchase price for a high-quality used signal generators in working condition, with reasonable frequency coverage and recent factory calibration will probably be in the range of $1K to $1.5K. Similar quality spectrum analyzers will be about $1.5K to $2K. Obviously, this is a significant cost, but this option is always there if you don't have any academic or corporate contacts."*

After reading this excellent article, I developed a number of concerns and have taken the opportunity to document them and importantly suggest possible alternative RF equipment purchase strategies that may be helpful.

Disclaimer:

The information provided about hardware or software products does not imply any financial association or sponsorship. We do not endorse or have any financial interests in the products mentioned. Our reviews and opinions are based on independent analysis and research to provide informative content to our audience. It's important to make your purchasing decisions based on your own research and needs.

My principal areas of concern include:

Economic Costs

An internet search confirmed the $ 3K plus price tag for the Spectrum Analyzer - RF Signal Generator combination. In general, purchase of used equipment does impose some risk for operational status and accuracy of the unit.

Test Measurement Equipment Utilization

Directly associated with the economic cost is a second term I describe as “cost of ownership”. RF test equipment is commonly used sporadically in the typical amateur radio operation. The ratio cost / utilization places additional stress in our equipment purchases decision process.

Obsolescence

The so called “legacy” equipment may present additional technical challenges. Component or equipment failure rate tends to increase with age. In general, replacement parts and equipment repairs are expensive. Calibration of the equipment may require additional equipment that adds complexity and associated expense.

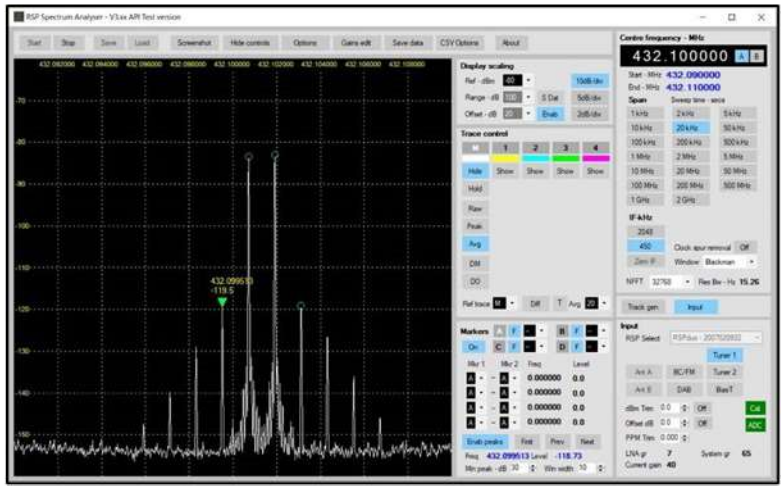
Path Forward

Significant technology advancement has occurred since I first entered the amateur radio community 57 years ago. Introduction of digital signal processing, low-cost computers that exhibit extraordinary computational power plus graphical presentation of data and solid-state integrated RF devices “chips” have changed the landscape of our amateur radio operations. This article explores additional and current hardware and software combinations that provide “fit for purpose” RF Test Equipment and significantly lower cost for entry.

Spectrum Analysis

The introduction of Software Defined Radio (SDR) technology is widely adopted within amateur radio. Importantly, this technology provides the hardware building blocks for a high-quality Spectrum Analyzer.

In this example, a SDRplay RSPdx (purchase price ~ $300 CDN), RSP Spectrum Analyzer software (Andrew Developments, available for free download) and a Windows 10 PC computer are combined to yield a functional RF spectrum analyzer.



The illustration depicts intermodulation distortion (IMD) measurements for a 70 cm amplifier I had constructed.

This hardware - software combinations provide frequency coverage from 1KHz to 2 GHz

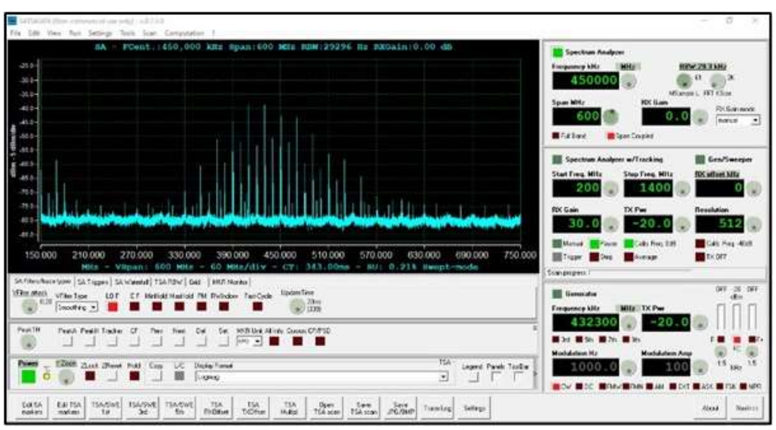
A wide range of signal processing functionality is included within the software that I would suggest rivals many higher priced commercial models. Since we are using software and a computer to process and display the spectral data, we may resize the display to our entire screen size (or multiple monitors). This is a significant advantage compared to traditional spectrum analyzer having a screen size of 9 inches or less. In addition, results of analysis may be saved to a computer file providing the ability to catalog measurements and refer to prior test results. Since we are controlling the hardware through a computer, the SDR radio / spectrum analyzer may be controlled remotely.

To address the challenge/concern of equipment utilization, it is noted that this SDR device is a broadband receiver (1KHz to 2 GHz) and when combined with a range of available software may provide an excellent secondary or even primary receiver system in your daily amateur radio operations.

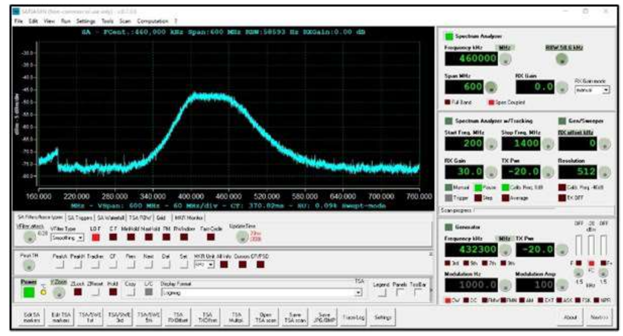
A second SDR is the Pluto Plus (purchase price ~ $450 CDN) is described. This SDR transceiver provides 2 independent receivers (Rx) and two independent transmitters (Tx) within a compact metal encased package.

The Pluto+ SDR may be computer controlled through PC software. Importantly this SDR device may be programmed either as a Spectrum Analyzer, RF Signal Generator or Spectrum Analyzer plus Tracking Generator.

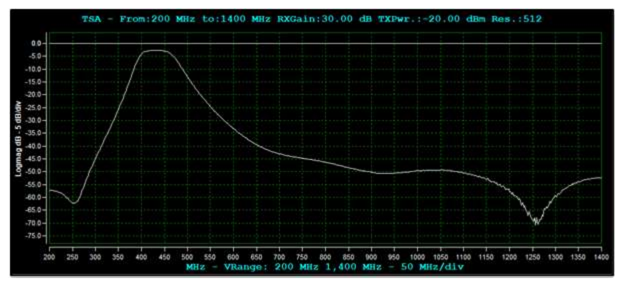
In this example, the OCXO 10 MHz square wave fundamental frequency is inspected after passing through the 70 cm bandpass RF frequency filter.



Alternatively, a low-cost RF noise source may be used as a signal source and frequency response of the 70 cm bandpass filter determined. Once again, all data and measurements results may be saved to a computer file for additional inspection or future review.



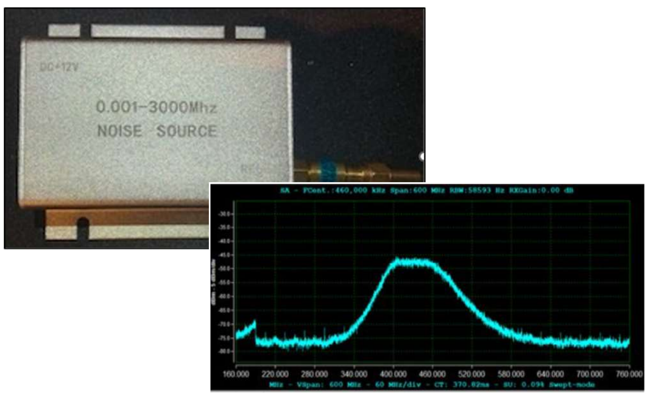
The Spectrum Analyzer plus Tracking Generator function is particularly useful for measurement of RF amplifiers, RF directional couplers, RF filters, RF attenuators.



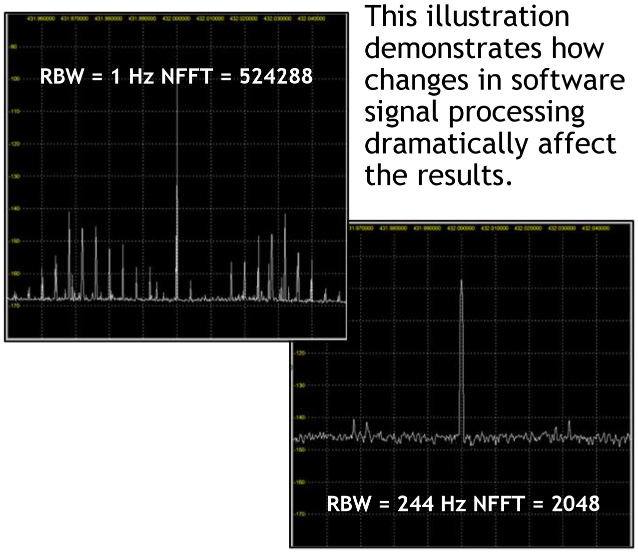
In this example, a Spectrum Analyzer plus Tracking Generator (TSA) scan from 200 MHz to 1400 MHz was conducted on the same 70 cm bandpass filter. The Satsagen software (Alberto Ferraris, IU1KVL) is a free software download that provides extraordinary and extensive functionality to control SDR radios. Importantly, the software systems I have documented continue to be supported and upgraded to add additional features and functionality. The Pluto+ SDR provides a dual role as an effective advanced RF test equipment and a base for an amateur radio VHF-UHF-SHF transceiver (50 MHz to 6 GHz).

Computer control and data processing of modern electronic RF hardware provides additional functionality and reduces cost of ownership since much of the data processing is conducted on the PC computer. For example, the Satsagen software provides unique calibration routines within the TSA application such that coax cables, RF connectors may be corrected providing high confidence measurements for the device under test (DUT).

An RF noise source (purchase price ~ $30 CDN) provides a valuable addition to RF test equipment. Understanding the spectral amplitude versus frequency (flatness) of a noise source is important to ensure quantitative test results of RF devices when using this technology.



Metrology, the scientific study of measurement, teaches us that how we make the measurement greatly affects the measurement results.



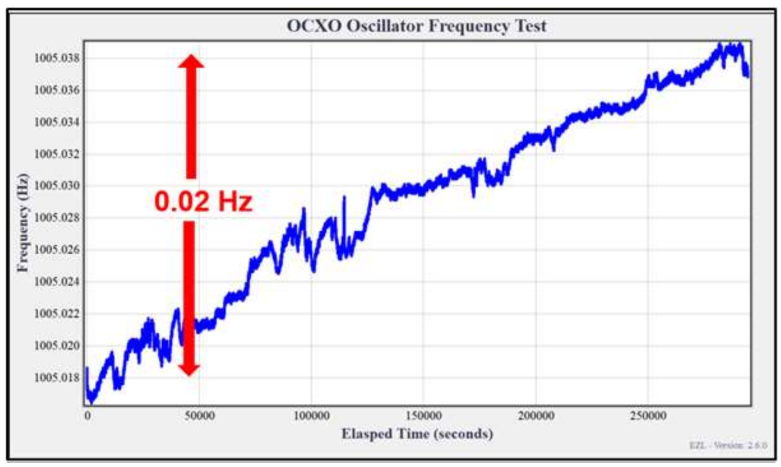
This illustration demonstrates how changes in software signal processing dramatically affect the results.

Understanding of software processing settings and expected results is an essential part of using any technology today. In short, excellent manuals are available to inform , teach and guide all of us in the use of this hardware - software combinations.

Frequency Measurement

Determination of frequency is an essential part of amateur radio communications. Amateur radio operations continue to migrate to higher frequencies as technology and equipment availability expands within the microwave frequency bands. Accuracy, stability and phase noise have become important parameters that characterize modern RF signal sources.

An example of frequency measurement is shown for a 10 MHz oven controlled crystal oscillator **(OCXO)**.



In this example 0.02 Hz (~ 0.002 ppm) frequency drift was noted over an 8 day test period.

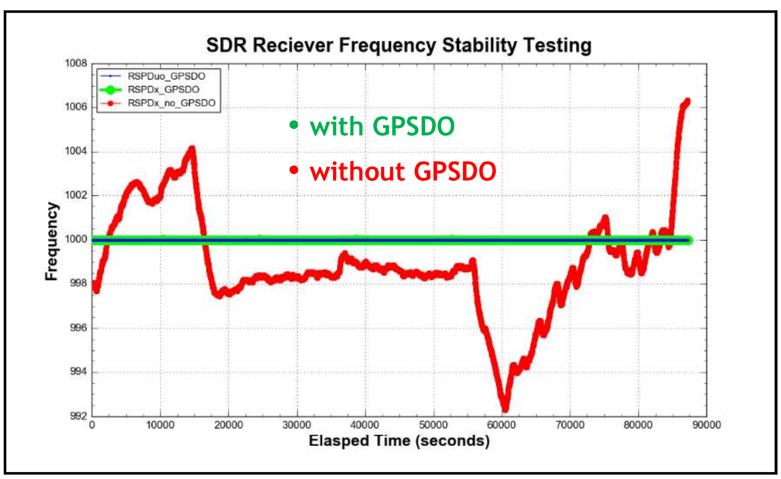
To determine this level of accuracy and resolution is indeed remarkable. To achieve these measurements, a combination of SDR radio and GPS Disciplined Oscillator **(GPSDO)** was applied.

A GPSDO works by disciplining, or steering a high quality quartz or rubidium oscillator by locking the output to a GPS signal via a tracking loop.

The disciplining mechanism works in a similar way to a phase-locked loop (PLL), but in most GPSDOs the loop filter is replaced with a microcontroller that uses software to compensate for not only the phase and frequency changes of the local oscillator, but also for the "learned" effects of aging, temperature, and other environmental parameters.

A GPSDO aims to utilize the best of both frequency sources, combining the short-term stability performance of the oscillator with the long-term stability of the GPS signals to give a reference source with excellent overall frequency stability characteristics.

An experiment was conducted using SDR receiver, in this case a **SDRplay RSPDuo**, with and without a GPS disciplined oscillator connected to provide a frequency control of this SDR device.



This data collected sequentially over a total period of two days. Inspection of this indicates the approximately 12 Hz frequency drift was reduced to essentially Zero with the GPSDO provding the frequency reference clock oscillator for the SDR.

According to the manufacturer *"The Leo Bodnar GPSDO is a popular product used within the amateur radio community.*

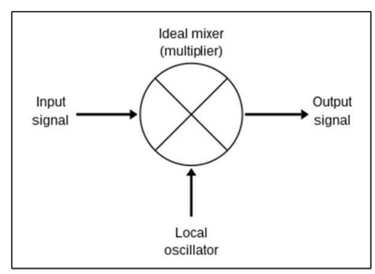
This device outputs high purity signal with frequency locked to GPS.

Frequency stability of its output is defined by the accuracy of GPS satellite onboard Caesium references and approaches 1x10-12 or 0.000001 ppm.

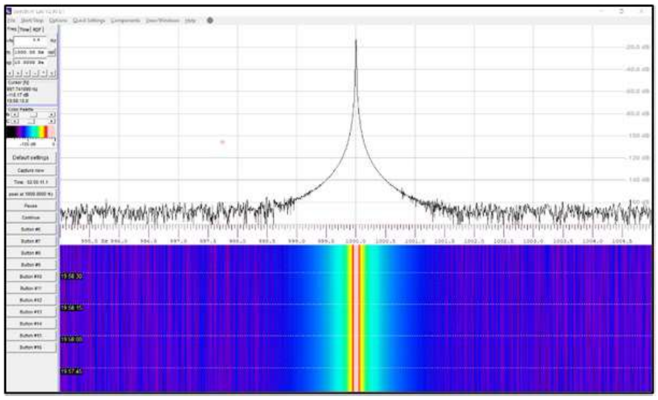
Output phase noise is shaped by high quality internal TCXO, providing clean clock signal with sub-picosecond RMS jitter."

The heterodyne measurement technique is a very useful and effective method for frequency determination. First proposed by Fessenden in 1901, it formed the basis of the superheterodyne receiver introduced by Armstrong in 1919. Fessenden was a remarkable fellow, having received hundreds of patents in various fields, most notably ones related to radio and sonar.

A **heterodyne** is a signal frequency that is created by combining or mixing two other frequencies using a signal processing technique called heterodyning, which was invented by Canadian inventor-engineer **Reginald Fessenden**.



Heterodyning is used to shift signals from one frequency range into another, and is also involved in the processes of modulation and demodulation.



Utilizing a GPSDO controlled SDR combined with **Spectrum Lab Software** (Author: **Wolfgang "Wolf" Buescher DL4YHF**) provides remarkable frequency determination. This method, or similar technology, is frequently used for the ARRL FMT contest. With careful procedures frequency accuracy may approach $1X10^{-12}$ (0.000001 ppm).

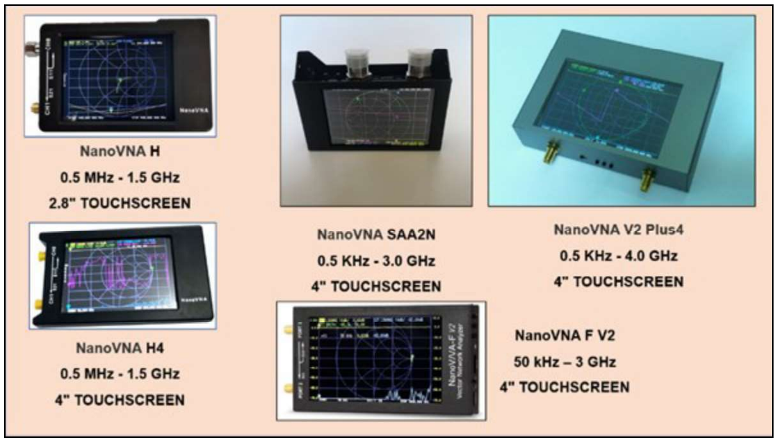
Vector Network Analysis

The first VNA was invented around 1950 and was defined as an instrument that measures the network parameters of electrical networks. The first network analyzer capable of swept amplitude and phase measurements was the Hewlett-Packard 8407 RF network analyzer, which was based on the HP 8405 vector voltmeter. The 8407 allowed comparison of the amplitude and phase of two waveforms up to 110 MHz.

Vector Network Analyzer

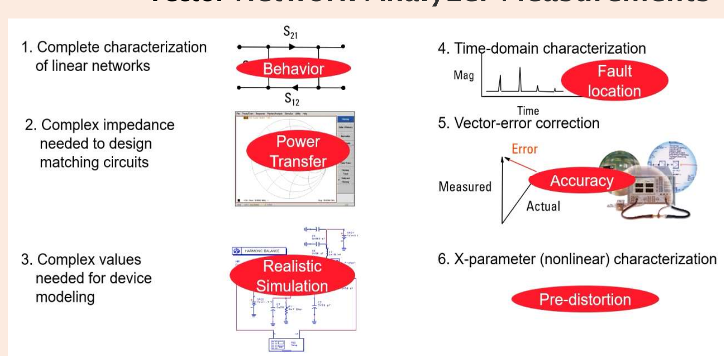
A Vector Network Analyzer **(VNA)** is a device used to measure the electrical properties of RF and microwave devices and networks. It does this by sending a signal down a transmission line and measuring the reflected and transmitted signals. The VNA then uses these measurements to calculate the S-parameters if the device or network.

A step change when the NanoVNA was introduced in 2019 and has gained a wide acceptance in the amateur radio community. I acknowledge that a wealth of information and technical publications currently exist for this device further supporting the utility of this instrument within our community. The nanoVNA technology(~ $50 to $300 CDN) is extremely low cost versus available commercial VNA equipment.

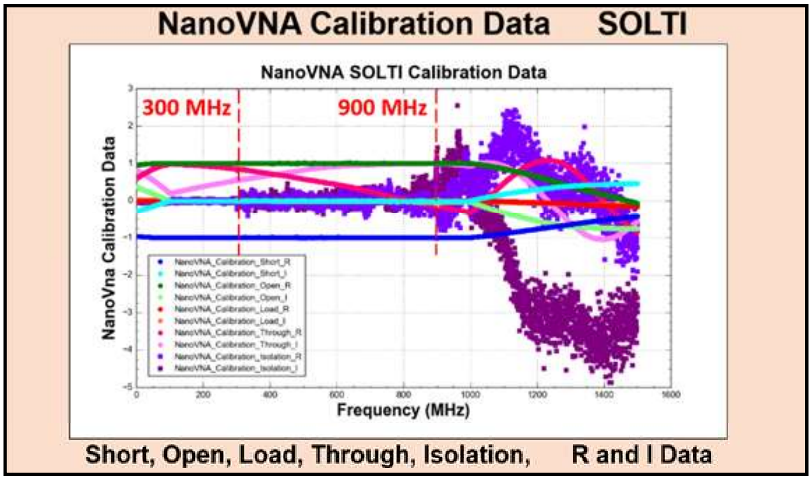


Occasionally a vector network analyzer is described as an antenna analyzer. While it is correct that a VNA can perform critical measurements on an RF antenna system, it is also important to recognize that this technology may be applied to a broad range of RF measurements including RF filters, Transmission lines, Amplifiers, Duplexers, Couplers and more. mixers, and much more.

Vector Network Analyzer Measurements

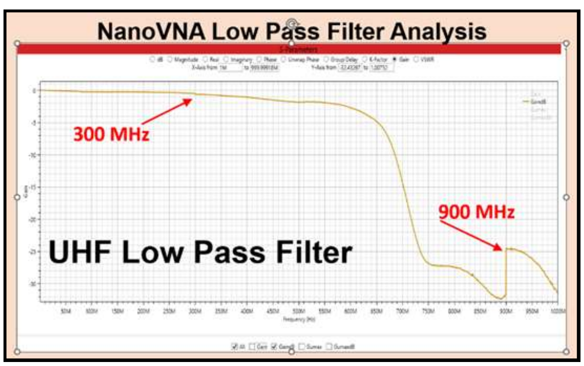


Calibration of the VNA is accomplished using short, open, load, through and isolation measurements.



This calibration data example shows calibration values for the nanoVNA obtained through this procedure.

You may notice a change of characteristic values at 300 MHz and increased data value variation at 900 MHz and beyond.

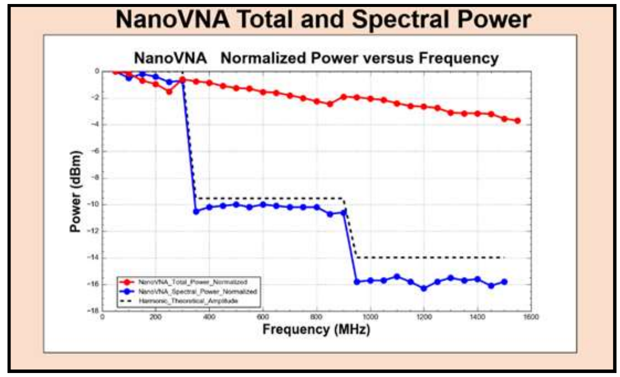


Attenuation versus frequency data is shown

A UHF low pass filter was tested using the 2-port setup for the NanoVNA.

You may observe a small discontinuity at 300 MHz and a much larger discontinuity at 900 MHz.

It is important to acknowledge the NanoVNA signal source has a maximum fundamental frequency of 300 MHz and utilizes odd order harmonics of the square wave signal for these higher frequency measurements.

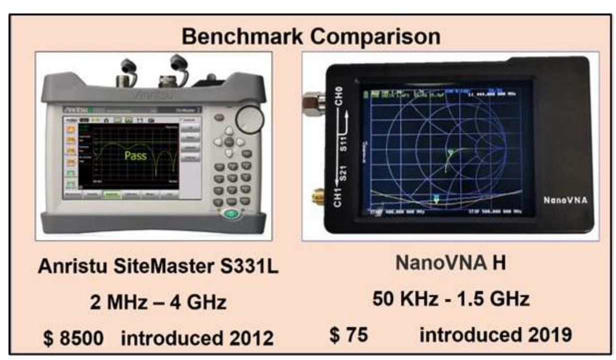


Total and frequency spectral analysis methods were applied to measure RF power levels at specific frequency values. This data shows some 16-decibel reduction in power for frequencies greater than 900 MHz compared to the sub 300 MHz values. This reduction in signal level at elevated frequencies places some limitations on measurement accuracy principally due to reduction of signal to noise values.

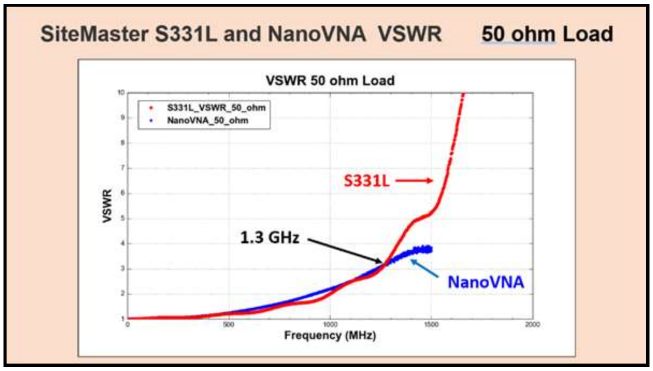
It is important to recognize that the total power measurement reflects power in fundamental and all harmonic frequencies generated by the square wave RF source. In contrast, the spectral power data reflects RF power at the identified specific frequency and eliminates all harmonic components.

A benchmark comparison of the nanoVNA versus the Sitemaster S331L instrument was conducted.

It was noted that the "*As New*" purchase price difference is a factor of 100 between these instruments. In addition, the tested nanoVNA exhibits a maximum frequency of 1.5 GHZ versus 4 GHz for the S331l.



An extensive number of identical tests and experiments were conducted on both VNA devices.

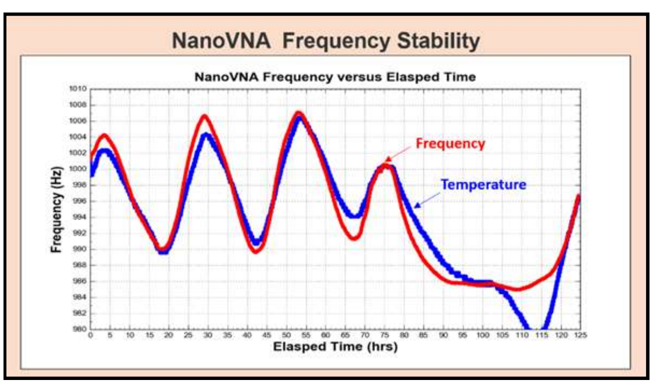


The results of this extensive testing are too numerous to document here, however in summary the nanoVNA compared favorably to the S331L for frequencies less than 900 MHZ. For frequencies above 900 MHz, the nanoVNA exhibited increased variation when referenced to the S331L data results.

Importantly, significant recent hardware advances in the nanoVNA technology are expected to reduce / eliminate these differences for the higher frequency values.

As with previously described RF technology, the nanoVNA may be controlled by a host PC computer. This has a number of advantages that enhance calibration and measurement accuracy and resolution. Once again, results may be saved on the PC computer for comparative purposes and the 4-inch display size of the device no longer becomes a limitation.

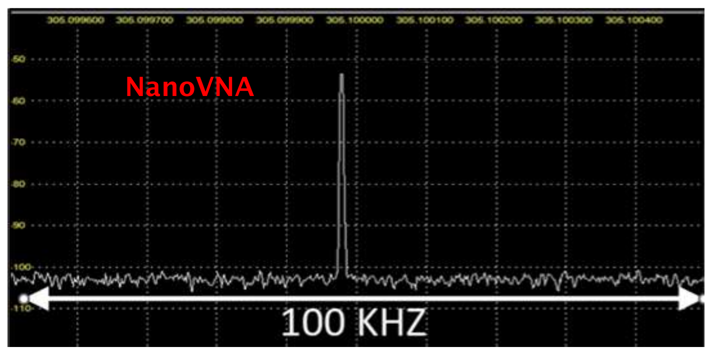
The NanoVNA was placed in CW mode with a frequency of 432.2 MHz. Frequency data was obtained using the heterodyne technique and a GPSDO controlled SDR receiver. Data obtained over a 5-day interval shows frequency variation of approximately 20 Hz, (0.05 ppm). NanoVNA absolute accuracy averaged 50 Hz (0.1 PPM).

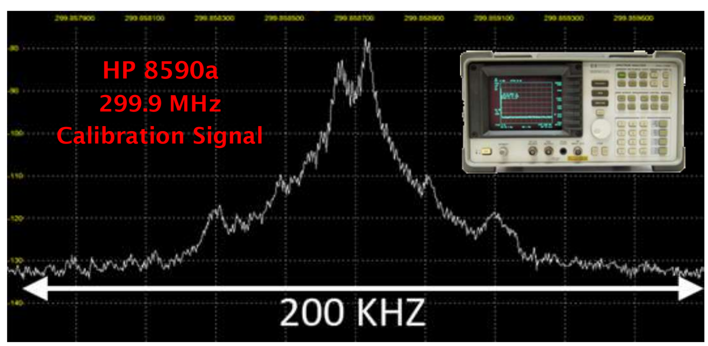


I carried out this frequency experiment in a non-temperature-controlled environment to stress the nanoVNA with large temperature swings while recording frequency. Recorded temperature versus time data clearly indicates that improved frequency stability would be expected in a normal temperature-controlled setting.

Temperature variation ranged from 67 degF to 79 degF.

This data indicates that the nanoVNA may also be used as a low-cost RF signal generator with possible power output controlled by a step attenuator system.



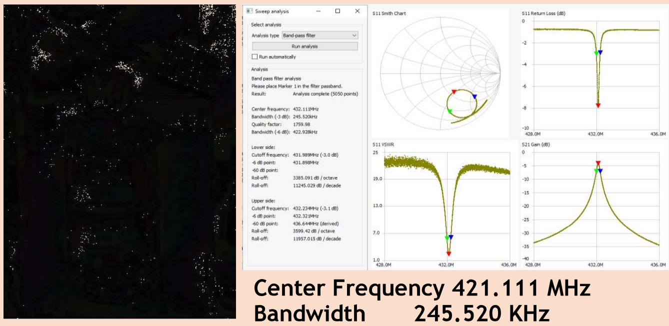


I thought it interesting to conduct a spectral comparison of a RF signal generated by the nanoVNA versus the nominal 300 MHz calibration signal generated by the legacy HP 8590a technology.

I was a bit shocked with the HP results and currently examining the validity of the calibration process for this vintage technology.

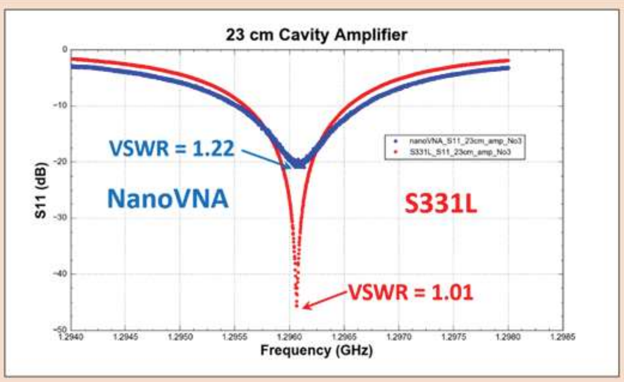
This example illustrates the NanoVNA used to characterize a UHF resonant cavity filter device.

UHF Resonant Cavity Bandpass Filter Testing



Center Frequency 421.111 MHz
Bandwidth 245.520 KHz

This is somewhat similar functionality to the spectrum analyzer – tracking generator measurements previously described; however, this method has an entry price of less than $ 50.



As previously described, when conducting measurements above 900 MHZ some differences were noted between nanoVNA and S331l results. The data shows S11 measurements conducted on a 23 cm 1296 MHz) resonant cavity. It is likely this difference would be resolved using a more current nanoVNA model versus the original model H that I used for these tests.

Conclusion

Alternatives to the purchase of RF test equipment is presented within this document. Multifunctional equipment that provides both daily use for amateur radio RF receiver and transmitter requirements combined with advanced RF test measurements that are conducted in a “as required” environment is documented. The combination of current hardware interfaced to computer software control shows significant advantage in providing an enhanced user interface and data documentation / retention benefits. Importantly, significant equipment cost reduction from 1/5 to 1/10 of that previously described by the purchase of legacy hardware is stressed. To be clear, the alternatives presented may not achieve the accuracy and resolution specifications for laboratory grade RF test instrumentation. An individual operator is encouraged to research equipment specifications versus his / her requirements to make an informed purchase decision.

~ Don VE6HQ

About the Author

Don has pursued a lifelong interest in science and engineering beginning as a youth in western Canada. He received his first amateur radio license at the age of 15 while attending high school in Edmonton, Alberta, Canada.

Don continued this interest and graduated from the University of Alberta receiving a Bachelor Science in Electrical Engineering. During the last 41 years he has worked in energy industry in Canada, the United States, Europe, South America, the Middle East and the Far East.

His technical area of interest lead to publications of nuclear magnetic resonance applied to reservoir characterization. He was granted numerous US patents for developments of pressure core technology. Don was honored to be the Distinguish Speaker at the Harvard University Energy Conference. During 2020, Don received the prestigious Hart Energy Innovators Award.

I obtained an amateur radio license in 1967 as VE6ANW, a year later achieved the advanced certification as VE6RI. I initially pursued 20-meter DX working. Soon after, I became interested in weak signal UHF propagation. After more than 50 years have passed, I have rejoined the amateur radio ranks and currently active on 20 meters and VHF / UHF bands.