Int. J. Nonlinear Anal. Appl. 13 (2022) 1, 3917-3928
ISSN: 2008-6822 (electronic)
http://dx.doi.org/10.22075/ijnaa.2022.6191

An experimental study by employing Nano VNA in microwave devices

Laith F. Jumaa[a], Yaqeen Sabah Mezaal[a,*], Aqeel A. Al-Hilali[a]

[a] *Medical Instrumentation Engineering Department, Al-Esraa University College, Baghdad, Iraq*

(Communicated by Madjid Eshaghi Gordji)

Abstract

To achieve precise measurements, a vector network analyzer can compensate for the instrument's systematic flaws, the features of cables, adapters, and test fixtures. To check the vector reflection coefficient of microwave devices, we used a low-cost portable VNA (NanoVNA) analyzer with a frequency range of 50 kHz to 4.4 GHz. VNAs are more versatile than oscilloscopes and may be used to explore a wide range of frequency components based on scattering characteristics, smith charts, phase response, and complex numbers. We did some experimental investigations for reported filters and antenna to evaluate the NanoVNA performance and suitability, especially its nonlinear scattering responses.

Keywords: NanoVNA, Non-Linear Analysis, S Parameters, Experimental Analysis

1. Introduction

When measuring microwave devices, a vector network analyzer is the best tool available. This includes RF and microwave devices like filters, antennas, and amplifiers, to far more complicated modules like those found in communications satellites or medical devices. An RF engineer's network analyzer is the most complex and versatile test equipment. For research and development and production testing purposes, it is employed. It becomes a radar system when paired with one or more antennas. Without X-rays, designs of this type can identify material faults invisible to the naked eye [9].

They've just kept on getting more popular, and they'll keep on getting more popular as time goes on. In addition to the spread of microwave, gigabit, and wireless communications in our daily lives,

*Corresponding author
Email address: Yaqeen@esraa.edu.iq (Yaqeen Sabah Mezaal)

Received: July 2021 *Accepted:* October 2021

radar imaging and proximity detection in safe environments, as well as dielectric materials, tissues, and composites are also driving our advancements. The vector network analyzer supports all of our data flow, communications, food, healthcare, and defense systems.

The VNA must be able to handle a wide range of frequencies, ports, and dynamic ranges, as well as a variety of functions, to meet these needs [9, 4, 1].

2. How does a Vector Network Analyzer (VNA) work?

Device-under-test (DUT) changes to the known stimulus signal can be detected by a VNA, which has both a source and a network of receivers.

DUT is injected with a stimulus signal, and VNA measures both the signal reflected from the input side and the signal passing through to the output side. The receivers of the VNA measure the results and compare them to the known stimulus signal. Afterward, either an internal or external PC processes the measured data and sends it to a display.

VNAs can provide several precise measurements of any RF sensor available. VNA measurement errors are exacerbated by poor quality or damaged testing port cables, which dramatically reduces measurement accuracy. The test port cables will constrain a VNA's sound quality it is connected to, just as you would expect if you connected a high-end audio receiver to low-cost speakers. Your measurement findings are likely to be inaccurate even if you use the most accurate VNA in the world and low-quality wires to connect to the DUT (device under test).

Dedicated RF cables, such as those employed with spectrum analyzers or signal generators, are essential for RF measurements. On the other hand, some RF cables are not suited for use with a VNA. While semi-rigid or conformable coax cables may perform well at first, they quickly degrade over time because they are supposed to be attached once and then left in place. Since the cable connector interfaces are not reinforced at a cable connector junction, and a connector interface wears out after a slight number of connections, conformable cables lose phase stability after a few bends [8, 9].

An Oscilloscope and a VNA are two completely different devices. An oscilloscope is a device that measures an external signal and displays the waveform as a function of time on a computer screen [3].

An oscilloscope and a Spectrum Analyzer share many features, such as the ability to measure and analyze external signals.

With frequency transform functions as FFT that newer oscilloscopes deliver, their usefulness is mixed with a Spectrum Analyzer.

Table 1: Comparison between VNA and Oscilloscope:

VNA	Oscilloscope
Enhances space; you can store 40%-50% more inventory.	Bits of information can be retrieved and stored quickly.
Suitable for uses requiring less storage than that provided by a pallet.	The input signal can be turned into a low-frequency signal using sampling techniques. To make the display more effective, additional circuitry is needed.
Tremendous productivity in complete pallet retrieval	Using a sampling oscilloscope is advantageous because it can measure electrical signals at fast speeds.
This device can all measure carrier power level, sidebands, harmonics, and phase noise.	It's used to test components, circuits, devices, and subassemblies for known signals.
It employs higher IF bandwidth filters.	It employs lower IF bandwidth filters.
Using a marker to measure anything on display is simple, but interpreting the data might be challenging.	While using a marker to take measurements on display is tricky, reading the results is a breeze.
It has the possibility of demodulating and measuring complex signals.	It has a pf source and receiver for measurement.
They may have receivers only with a single channel	To measure reflection and transmission coefficients, they must have both a reference input and signals that have been reflected and transmitted back.
Only scalar component measurements can be made with this tool. They aren't used for determining the phase.	It can be employed for amplitude and phase measurements
It does not have innovative error correction	It has advanced error correction.
A model RSA3408A from Tektronix stands for real-time spectrum analyzer	8757D stands for a Scalar Network Analyzer, and Model E5072A stands for a Vector Network Analyzer from Keysight Technologies.
It employs only frequency sweeping for measurement.	It employs both frequency sweeping and power sweeping for measurement.

3. Types of measurement errors and Calibration

Measurement uncertainty is a statistical deviation from the actual value of a measured result. Keeping this in mind is vital before proceeding. There are two types of uncertainty in the measuring domain: random and systematic. Random errors change throughout time, making them impossible to forecast. Although they can be defined, calibration will not remove them. Instrument noise and the repeatability of switches, wires, and connectors are the most common causes of random mistakes. Systematic errors, on the other hand, occur in a repeatable fashion. Calibration can be used to remove them because they are caused by VNA defects that can be characterized. After calibration, the VNA's performance fluctuates due to changes in ambient temperature, resulting in another type of mistake called drift. However, extra calibrations can be used to eliminate these mistakes. Even though random errors cannot be eliminated through calibration, it is possible to lessen their impact by using good measurement practices such as letting the instrument to reach thermal steadiness, by means of high-quality cables and connectors, keeping step attenuator magnitudes as low as possible, choosing a small IF bandwidth, and feasibly employing averaging to reduce the system noise figure. The last consideration is that the connector is a critical component in obtaining accurate measurements because of its role in interfacing with various test system components. Despite their appearance, connectors are fragile, precision-machined parts [7].

The calibration process is straightforward, but measurement accuracy can be harmed in various ways.

Every connector type should have a calibration kit available. Like other mechanical components, calibration standards need to have their qualities checked regularly. They can also be inspected while checking the VNA calibration's measurement uncertainty. When it comes to calibration, it's essential to stick to a routine. Several factors determine the calibration frequency, including desired measurement accuracy, temperature stability, and cable quality [10, 6].

Before using the VNA for any measurements, you must calibrate it to eliminate potential mistakes. Before calibrating a VNA, it's essential to know how to minimize measurement errors, as not all errors can be eliminated this way. Measurement inaccuracy can be divided into three categories (Figure 1).

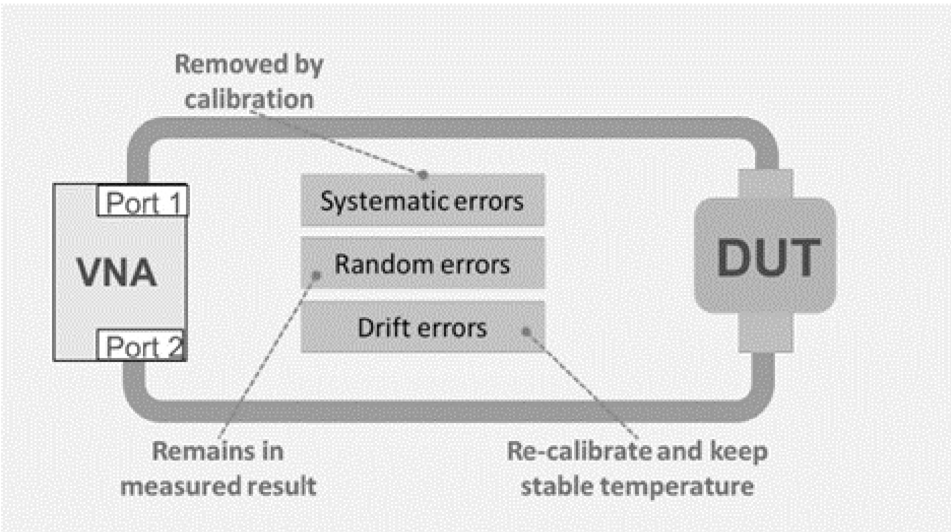

Figure 1: Foremost kinds of measurement error

Systematic, random, and drift errors are all examples of measurement errors. Equipment or setup flaws can lead to predictable errors known as systematic errors. The VNA receiver's frequency response can be affected by fluctuations in output power or ripples across its frequency range. The RF connections that connect the DUT to the VNA also have a significant power loss that increases with frequency.

It's easy to account for these faults because they're predictable and because they're inherent in the technology itself. Random error is the second source of measurement inaccuracy.

Time-varying noise from test equipment or test setups might create this inaccuracy.

This error number will remain in the measured result after a user calibration, determining how accurate your measurement can be. Consequently, this error quantity is critical.

As explained earlier, trace noise is an example of a random error. Drift error is the third source of the mistake, which is related to changes in measurement over time.

This results from a user calibration error in the test setup and the test equipment. A few examples are temperature swings, humidity swings, and mechanical setup movement.

It's possible to lessen drift error over time by using temperature and humidity-regulated facilities. How much your test setup drifts over time impacts how often you need to readjust your test setup [9].

4. Vector network analyzer block diagram

A rudimentary block diagram of the test instrument might help you better understand how a vector network analyzer works. Among the earliest components depicted in the diagram are the VNA's signal ports, signal separation blocks, receiver detector, and the processor and display [4].

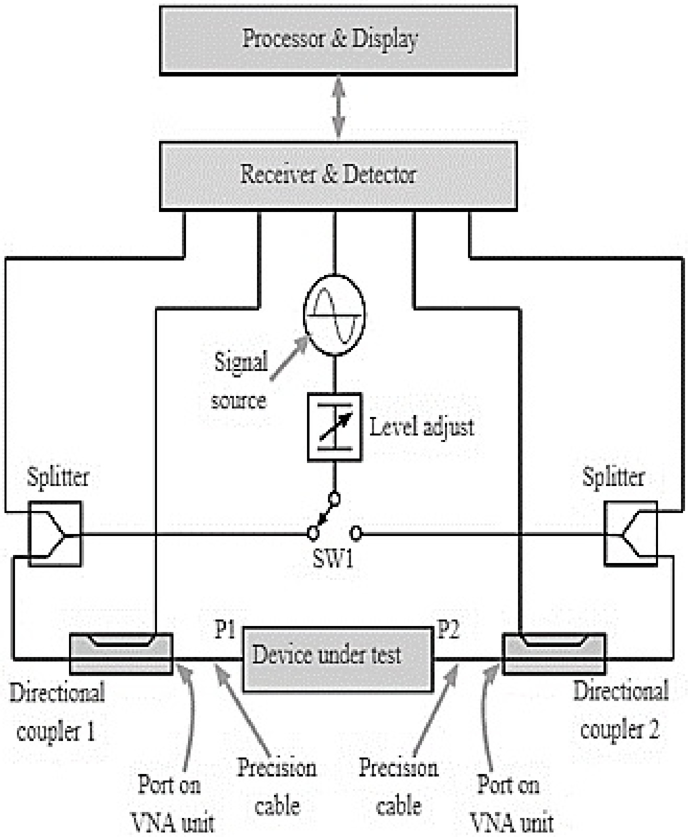

Figure 2: Block diagram of Vector Network Analyzer

5. NANO VNA

Portable but high-performance vector network analyzer: NanoVNA is a tiny handheld Vector Network Analyzer (VNA). It is a battery-powered, self-contained LCD gadget.

NanoVNA was first designed to operate at frequencies between 50 kHz and 300 megahertz (MHz) in its early stages. To operate effectively, NanoVNA's mixer SA612A requires a 5V power supply. It is not possible to directly power the battery. A USB power supply is needed for the initial version of NanoVNA. Hugen remade the NanoVNA using the edy555 schematic and added a DC-DC circuit so that the NanoVNA could operate independently. Using harmonics, Hugen attempted to expand the NanoVNA's measuring frequency to 900MHz. NanoVNAs can be made or purchased at a low price. This project has become the most active vector network analyzer and antenna analyzer in the community [5, 2].

The specifications for the employed NanoVNA are as follows:

It has a frequency range of 50 kHz to 3 GHz and can be extended to 4.4 GHz. Not only the antenna's standing wave impedance may be tested, but it can also be used to debug the duplexer, measure the insertion loss of the filter, and measure cable attenuation and phase shift. Screen flipping in the display can be done to reveal the menu.

In partnership with OwOComm, a 3GHz vector network analyzer was developed. According to OwOComm's original technical specifications, it is made per the v2 2 files given by the S-A-A development department.

However, the NanoVNA V2.2 has a different technical design. The SAA-2N/NanoVNA V2.2 does not automatically interpolate the calibration data after the user changes the frequency and must be recalibrated or called back after each startup and frequency change.

-70 dB (50KHz-1.5GHz) and -60 dB (50KHz-1.5GHz) are the S21 transmission measurements . S11: Reflection Measure -50dB (50KHz-1.5GHz), -40dB (1.5GHz-3GHz).

For Linux, Windows, and Mac OS, the VNA-QT program can control the device directly. Nanovna-Saver can also extract the data and save it to Touchstore files. For RF and microwave devices to function together efficiently, a VNA is used to characterize them. Each component in a radio frequency (RF) system operates optimally when its output impedance matches the input impedance of the following element. Impedance measurements and matching are critical for antennas, which might have many impedances. The block diagram of NanoVNA is depicted in Figure 3.

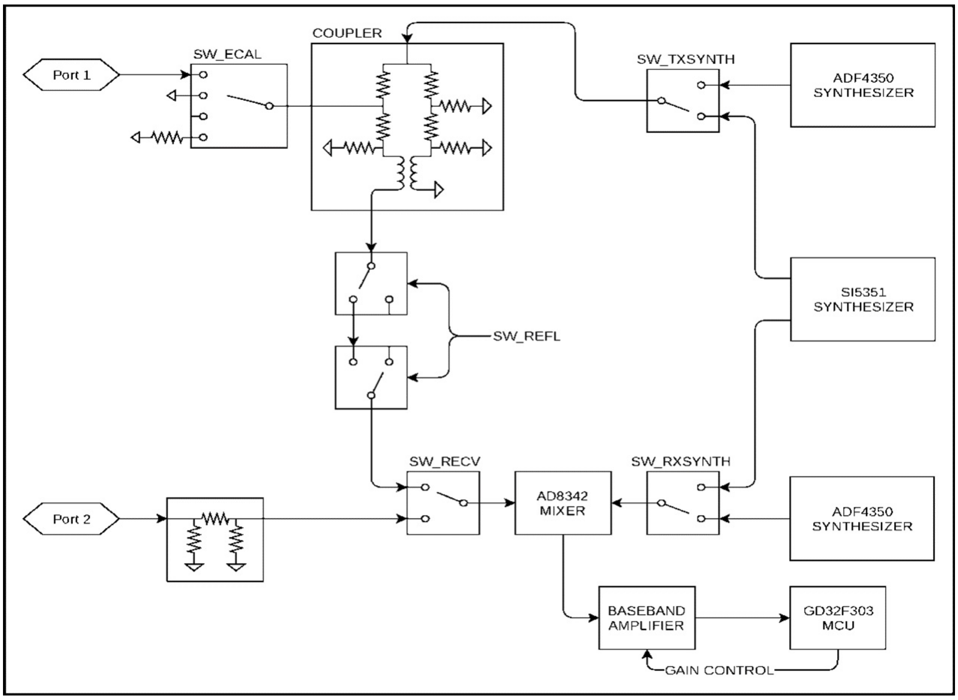

Figure 3: Circuit diagram of NanoVNA

Some Types of NanoVNA are as follows:

1. Nanovna Vector Network Analyzer VNA UV VHF UHF HF Antenna Analyzer 50KHz-900MHz

2. RF Demo Kit NanoVNA RF Tester Filter Attenuator FOR Vector Network Analyzer
3. NanoVNA Vector Network Analyser Antenna Analyser Shortwave MF HF VHF UHF UV VNA
4. 1950mAh 4" Touch Screen NanoVNA NanoVNA-H4 Network Antenna Analyzer For Android
5. 50K-1.5GHz NanoVNA-H HF VHF Vector Network Analyzer Antenna+LCD+Battery+Case Kit
6. NanoVNA-H Vector Network Antenna Analyzer 50KHz-900MHz MF HF VHF UHF Tool UK
7. Nanovna 50K-1.5GHz Vector Network Analyzer UHF VHF MF HF VNA Antenna Analyzer
8. VNA 1MHz-3GHz Vector Network Analyzer Kit VHF/UHF/NFC/RFID RF Signal Generator
9. R&S ZNB4 2port Network Analyzer/ 2port 4GHz.

6. Results and Discussion

The NanoVNA (S-A-A-V2), as in Figure 4, has been employed to investigate several RF and microwave devices in this section. Microstrip bandpass filters and antenna are among the microwave devices. With a frequency range of 50 kHz to 4.4 GHz, NanoVNA can provide scattering characteristics, phase responses, and even smith charts with nonlinear features. Changes in the input frequency have no direct relationship to changes in the scattering responses in a nonlinear relationship as in Figures 8, 9, 10 and 12.

Figure 4: The Employed NanoVNA (S-A-A-V2) in this study

S11 (return loss) and S21 (insertion loss or transmission) parameters are measured. In theory, while a few devices or circuits are inserted amid a supply and a load, a number of the signal power from the supply is dissipated via the circuit additives due to their resistive nature that results in losses. Consequently, not all the conveyed signal power is transferred to a load while the load is attached to the supply. The losses, therefore, came about is known as Insertion Loss. Applied circuit attention constantly suffers a definite stage of mismatch amid the impedance of the signal supply and a device's load (this load can be a transmission line, antenna, diplexer, filters, or any RF or microwave device). Some parts of signal power inserted are reflected because of mismatch among systems. This fraction of power loss is known as return loss [11, 12, 13, 14, 15, 16].

Small measured bandwidth magnitudes of about 100, 60, and 140 MHz are detected for reported filters in [11] within -3 dB in Figures 5-7 for the ISM band at 2.4 GHz to filter signals. For wireless systems, avoiding interference from strong signals operating in adjacent bands is crucial. These bandwidth values are of interest.

Figures 8-10 show the scattering results of the NanoVNA measurements for all of the filters used in this investigation, which exhibit tolerable performances and agreed well with [11] with minor differences, especially in insertion loss (deeper than -3 dB) due to limited points of employed NanoVNA (101 points), noise in the lab environment, impedance mismatch attributable to soldering and manufacturing tolerance for the reproduced filters.

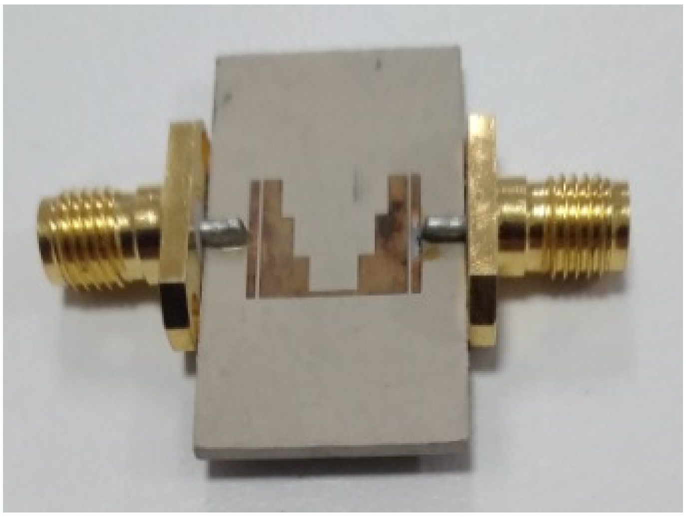

Figure 5: Photograph of reproduced single-pole stair step patch resonator BPF based on [11].

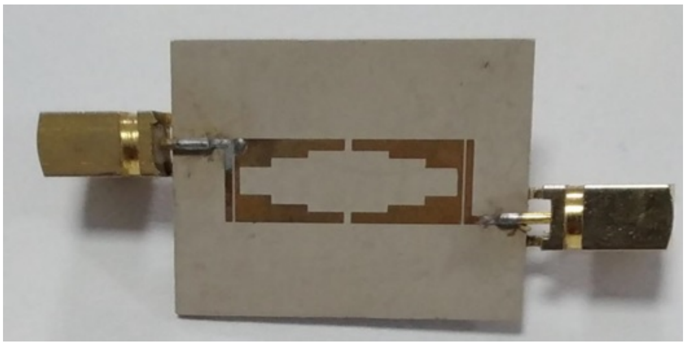

Figure 6: Photograph of reproduced dual-edge coupled stair step shaped resonator BPF based on [11].

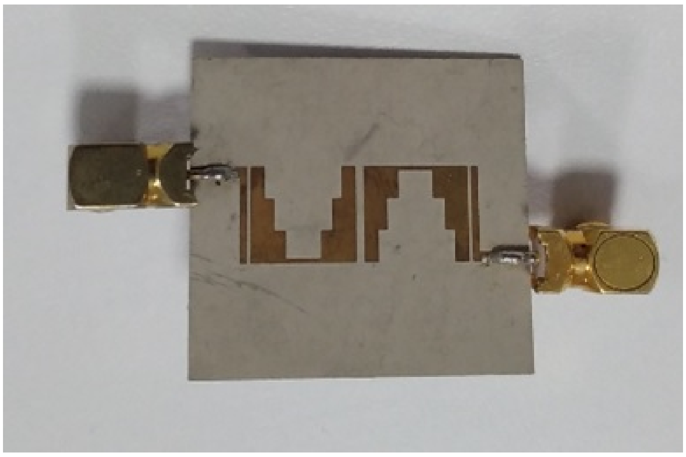

Figure 7: Photograph of reproduced dual cross-coupled stair step-shaped resonator BPF based on [11].

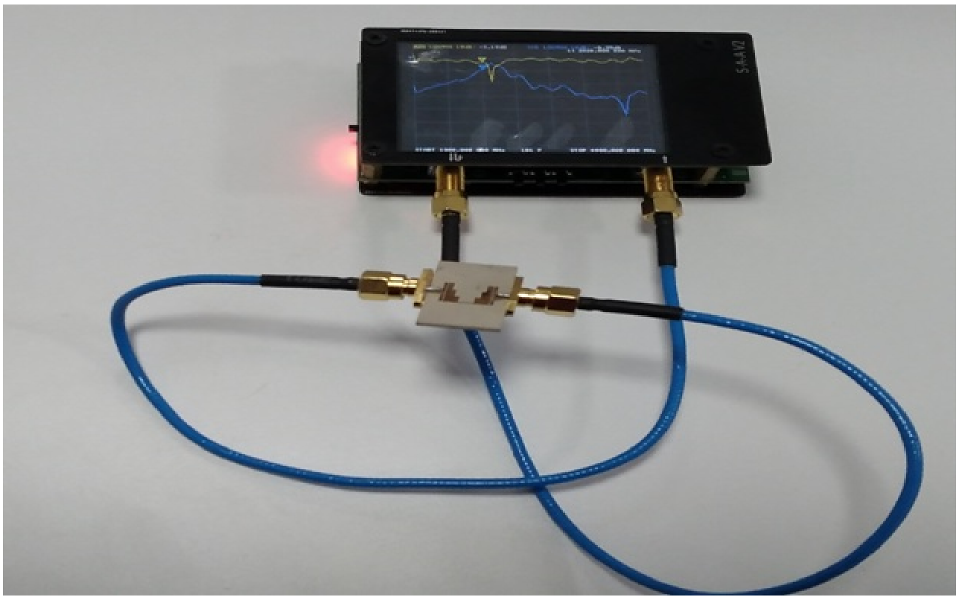

Figure 8: Measured results of BPF in Figure 5

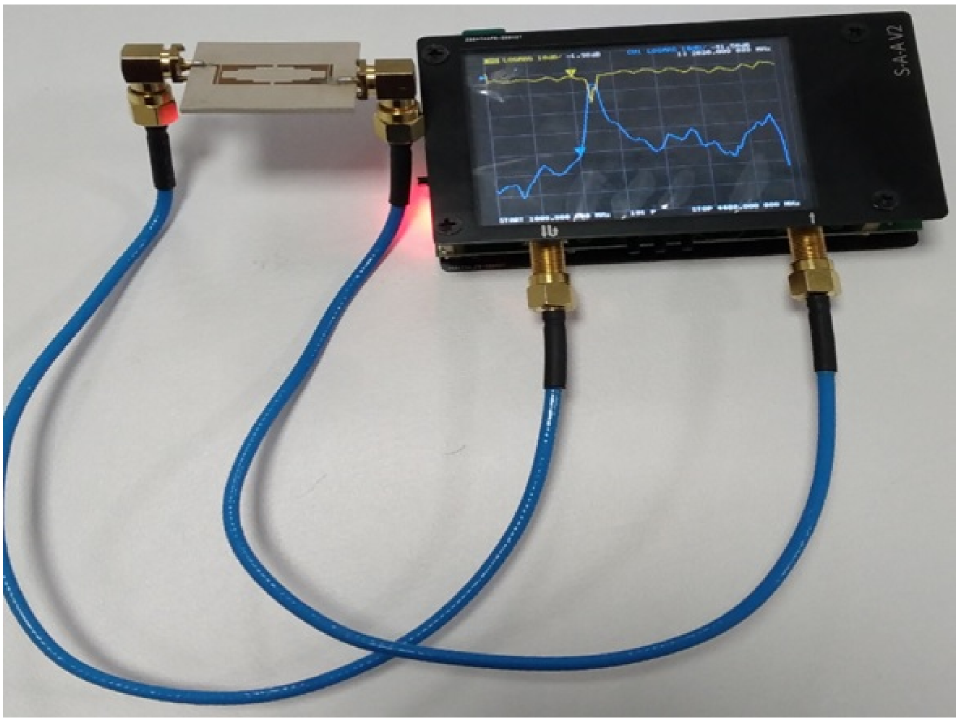

Figure 9: Measured results of BPF in Figure 6

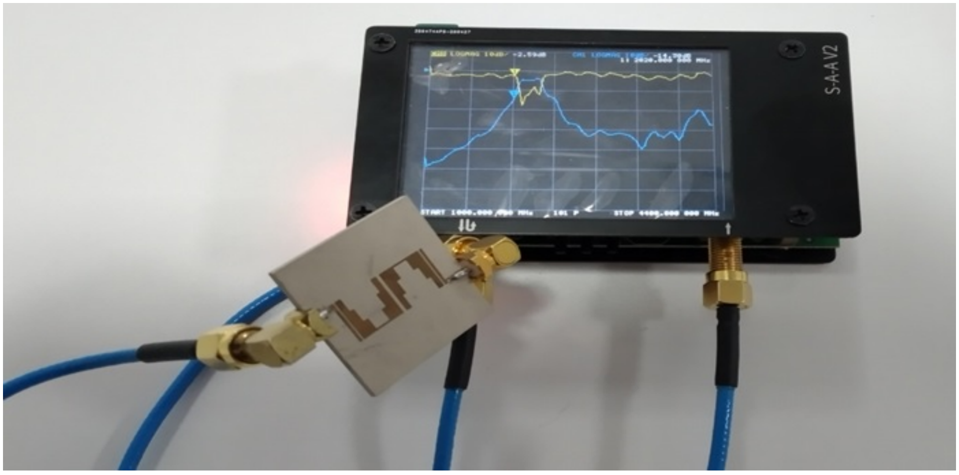

Figure 10: Measured results of BPF in Figure 7

Figure 12 shows the measured findings for the ultra-wideband (UWB) antenna illustrated in Figure 11 [12]. There are a few tremors in the data. This is because the dielectric substrate constant has an unknown effect in some practice settings, such as the efficiency of SMA connectors, low softening effects, and manufacturing tolerances. With a bandwidth of >2GHz within -10 dB and 1 to 4.4 GHz sweeping frequency range, this antenna is well-suited to transmitting enormous amounts of data about patients in health monitoring systems. Based on NanoVNA tests, the bandwidth begins around 2.8 GHz. S11 response measured by NanoVNA is agreed well with [12].

Figure 11: The reproduced prototype of the UWB antenna based on [12].

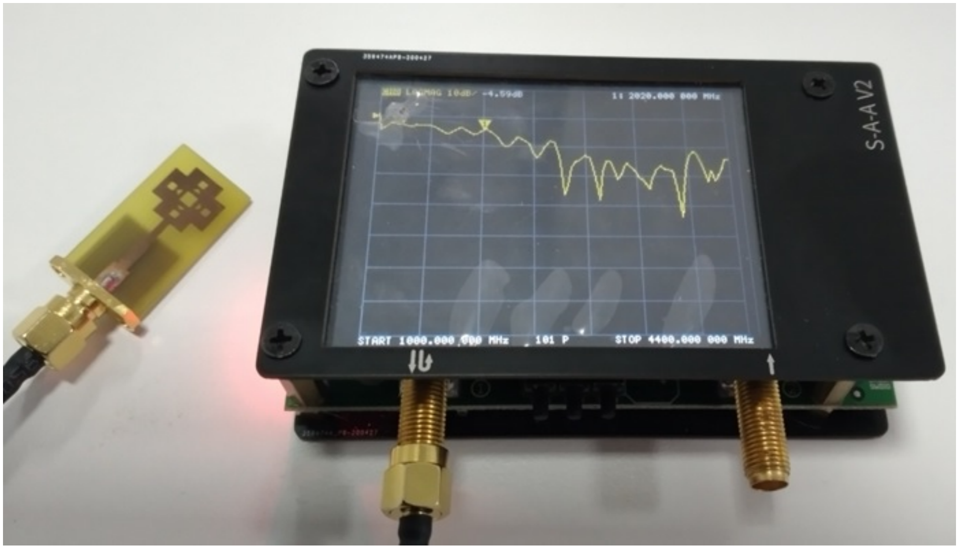

Figure 12: The measurement of UWB antenna by NanoVNA

7. Conclusion

1. The NanoVNA v2 is a fantastic technology that can be employed to discover a wide range of frequency components based on scattering characteristics, smith charts, phase response, and complex numbers.

2. To get the most out of your computer, you'll need to invest in high-quality peripherals. This includes things like high-quality cables and adapters as well as other components. 4.4 GHz is the upper limit of the NanoVNA v2's frequency range.

3. The device is not a professional measuring instrument and is intended for beginners, moderate level measurements and amateur radio applications. The reflection bridge degrades beyond 3GHz, although it employs an exciter capable of 4.4GHz.

8. Recommendations

1. By merging two or more designed VNA modules, a multi-port VNA can be constructed to simultaneously measure the DUT's reflected and transmitted signal strengths. A low-cost multi-port VNA might be employed in breast microwave imaging and body bio-impedance measuring.

2. Internet of things and cloud computing can be integrated with NanoVNA to measure RF and microwave devices and save their data reliably in the specific servers.

3. Field-programmable gate array (FPGA), genetic algorithm (GA) and particle swarm optimization (PSO) can be future trends to advance the portable VNA performance, sweeping frequency points, and applied frequency ranges to higher than 6 GHz.

References

[1] S.P. Abhijit and R.B. Ghongade, *Design of bioimpedance spectrometer*, Int. Conf. Adv. Comput. Commun. Inf. (ICACCI), 2016, pp. 2724–2728.
[2] *About NanoVNA*,`https://nanovna.com/?page_id=21`
[3] C.D.M. Ambatali, *Implementation of an oscilloscope vector network analyzer for teaching s-parameter measurements*, IEEE Region 10 Human. Technol. Conf. (R10-HTC), 2018, pp. 1–6.
[4] D. Byrne, M. Sarafianou and I.J. Craddock, *Compound radar approach for breast imaging*, IEEE Trans. Biomedical Eng. 64(1) (2016) 40-51.
[5] D. Derickson, X. Jin and C.C. Bland , *The NanoVNA vector network analyzer: This new open-source electronic test and measurement device will change both remote and in-person educational delivery of circuits, electronics, radio frequency, and communication laboratory course delivery*, ASEE Pacific Southwest Conf. Pushing Past Pandemic Pedagogy: Learning from Disruption, 2021.
[6] J.P. Dunsmore, *Handbook of Microwave Component Measurements: with advanced VNA techniques*, John Wiley & Sons, 2020.
[7] M. Hiebel, *Vector network analyzer (VNA) calibration: the basics*, White Paper, 2008.
[8] Operating Manual, *Vector Network Analyzer ZVR/ZVRE/ZVRL*, Rohde & Schwarz, 2001.
[9] P. Roblin, *Nonlinear RF Circuits and Nonlinear Vector Network Analyzers: Interactive Measurement and Design Techniques*, Cambridge University Press, 2011.
[10] A. Rumiantsev and N. Ridler, *VNA calibration*, IEEE Microwave Maga. 9(3) (2008) 86–99.
[11] Y.S. Mezaal and A.S. Al-Zayed, *Design of microstrip bandpass filters based on stair-step patch resonator*, Int. J. Electron. 106(3) (2019) 477–490.
[12] E.D. Hussein, Y.S. Mezaal and B. Oguz, *Design of miniature UWB-based antenna by employing a tri-sectional SIR feeder*, Comput. Syst. Sci. Eng. 41(3) (2022) 1157–1172.
[13] Y.S. Mezaal and J.K. Ali, *Investigation of dual-mode microstrip bandpass filter based on SIR technique*, PLoS One 11(10) (2016) e0164916.
[14] Y.S. Mezaal, H.T. Eyyuboglu and J.K. Ali, *Wide bandpass and narrow bandstop microstrip filters based on Hilbert fractal geometry: Design and simulation results*, PLoS One, 9(12) (2014) e115412.
[15] Y.S. Mezaal and A.S. Al-Zayed, *Design of microstrip bandpass filters based on stair-step patch resonator*, Int. J. Electron. 106(3) (2019) 477–490.
[16] Y.S. Mezaal, H.T. Eyyuboglu and J.K. Ali, *A novel design of two loosely coupled bandpass filters based on Hilbert-zz resonator with higher harmonic suppression,* IEEE Third Int. Conf. Adv. Comput. Commun. Technol. 2013, pp. 343–347.