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Measurement and Analysis of Vector Network Analyzer

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***Abstract**: One of the main instrument used in the microwave communication laboratory is analyzer. Particularly, network analyzer, which is used for testing the RF components. Here in this paper the vector network analyzer design study and measurement analysis is discussed. The introduction to Vector Network Analyzer (VNA), working, types, blocks, function, measurements and specifications are presented as revisiting the technologies. As a DUT, a fractal antenna is connected to VNA and its results are presented.*

***Keywords**: Analyzer, Microwave, Network, RF, Vector.*

I. INTRODUCTION

The term 'network' generally is used in wireless, mobile and computer clouds etc. But instrument in high frequency electrical networks is discussed. RF Vector Network Analyzer, (VNA) is a measuring instrument that measures frequency response of a element or a network composed of many components as vector: real & imaginary parameters, which can be both passive and active. so that its function can be characterised. It will be present in the microwave laboratory, which is shown in figure 1.

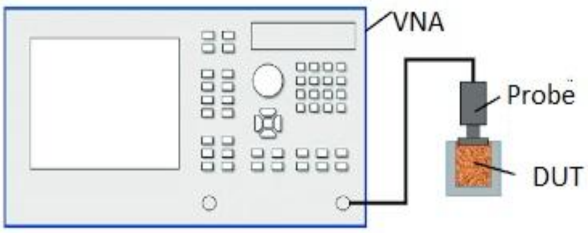

Fig. 1.Vector Network Analyzer front panel

The network analyzers do test components in the name Device Under Test (DUT) like Filters, RF switches, couplers, cables, amplifiers, antennas, isolators, mixers. The fundamental operation of VNA is presented in figure 2. VNA contains source, signal, and receivers. DUT is connected to VNA. Display or external PC is used to display the measurement of input output signal. About this instrument, theoretical study is presented in this paper. Various research works are surveyed and given in the following section.

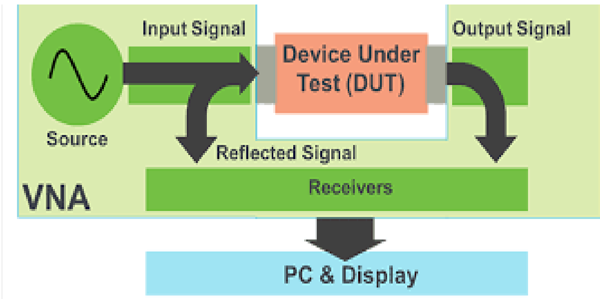

Fig. 2.Vector Network Analyzer operation

II. LITERATURE SURVEY

VNA measurement research survey is done and presented in this section. Peter L. Tokarsky (2020), represented antenna analysis by using a two-port networks[1].

G. G. S. Forte, et al (2018) proposed Antenna Polarization Characterization with Vector Network Analyzer Measurements. Several parameters were measured by using antennas in laboratory environments and compared with simulated parameters. Both the presented results agree to expected values[2]. J. Verhaevert et al (2017) presented, a low-cost VNA working design. The design used is a Direct Digital Synthesizer (DDS) to generate signals. integrated detectors are used to measure phase and magnitude differences. The design needs embedded software programs, to be written in C language on an ARM processor, for the smith chart measurements using an LCD display[3]. L. Brunetti, et al (2016) compared Material measurements using the vector network analyzer with simulated data at radio and microwave frequencies. The material permittivity is computed with scattering parameters. The assessment made for measured and simulated values by applying the VNA test setup measurements[4]. A. Estrada, (2012) reviewed the VNA is a modern piece of test gear that was once relegated to specialized measurements in the RF lab. It is reported that the instrument was big, costly, and mainly used by the RF designers[5]. J. Martens, et al (2005) presented Multiport vector network analyzer measurements. Ports are increased as multiport devices, in the RF bands. the vector network analyzer (VNA) measurements must be modified to perform S-parameter measurements quickly and precisely[6].

From this survey works, it is explored that the importance of VNA and its development in architectures with testing calibration for measurements and their basics are revisited in this paper. The method of working and block details are following in the next section.

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III. METHODOLOGY

A. Analyzers

They are classified as spectrum analyzer and vector network analyzer. A vector network analyzer is an electronic instrument. That measures the frequency response of a component or a network composed of many components like transmission parameters, reflection parameters and S-parameters. The components can be both passive and active. The general way of connecting DUT with VNA is shown in figure 3. The recent models are active VNAs.

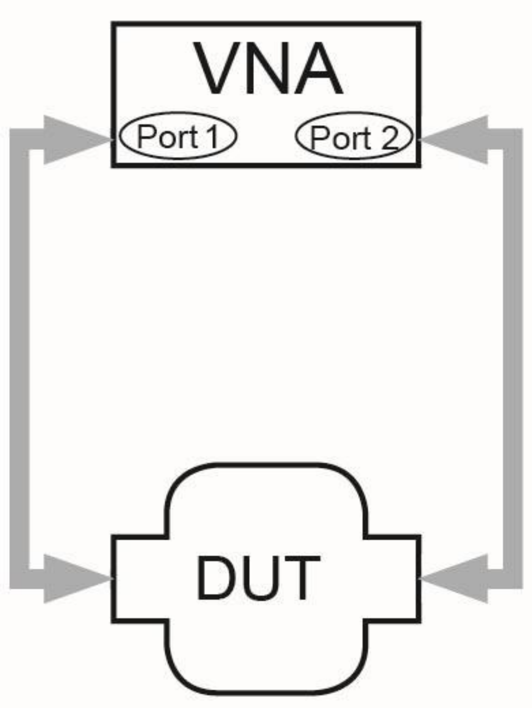

Fig. 3.General connection to VNA

An ideal vector network analyzer can reduce cross noise, matching defects by using error correction techniques. it is understood that, in common, a network analyzer can make more correct measurements compared with a spectrum analyzer used in this way[7].

B. Purpose and concept

The Vector Network Analyzers are used to test component specifications and verify design simulations to make sure systems and their components work properly together. Nowadays the network analyzer is utilised to express tools for a different modern networks. The blocks connected to it are shown in figure 4.

The vector network analyzer follows the concept of measuring the transmitted and reflected waves as a signal allowed through a device under test (DUT). Measuring the transmitted and reflected signals across DUT, enables the characteristics of a device to be determined. DUT is characterised by the above transmitted and reflected signals. This can form a key part of any design or test for an RF circuit[8].

C. Block diagram

VNA is shown in dotted lines. along with DUT, VNA contains swept oscillator, variable attenuator, signal processing, band pass filter, analog to digital converter, mixer biasing circuits.

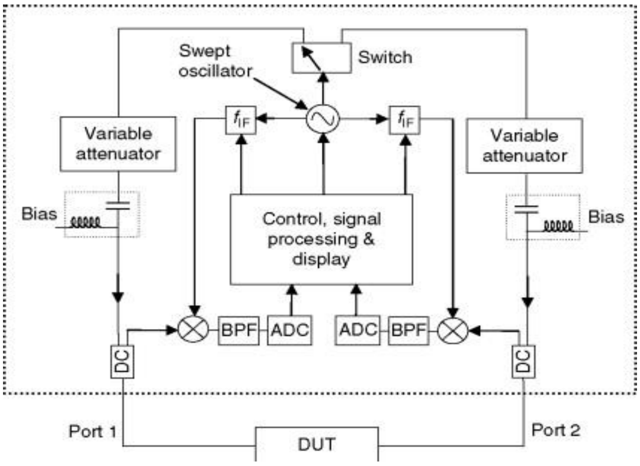

Fig. 4.Network analyzer block diagram

D. Working principle

The receivers in Vector Network Analyzer analyze the resulting signals and do comparison with the known stimulus signal. Working can be understood in the form of four phases:

- VNA Stimulus
- Signal Separation
- Receiver & Signal Detection
- Processor & Display

VNA is an active instrument, which generates test signal and then measures the response. The sources can be open Loop VCO or Digitally synthesized. VCO type has good Phase Noise Performance, Low Frequency Accuracy and Flexibility Digital one is expensive than VCO but provide exact Frequency signal.

Behind the high speed data, communications and computing developments of current decades, the need to characterize high frequency interfaces, devices, multi-path interconnects and antennas has emerged. Once the domain of new, microwave measurements have come of the laboratory, from the manufacturers, it is very useful to the people in the field such as 5G, IoT, radar and tissue and materials imaging[9].

E. VNA varieties

VNA varieties are like this.

- 1-port VNA
- 2-port 1-path VNA
- 2-port 2-path VNA

They are used to characterize the electrical parameters in RF component such as antenna, filters etc. In spite of its core measurement, vector network analysis has changed to the bounds of the expert user and the deep pockets of established business, refusing to fall within simple reach and adoption of the wider markets, embedded applications and the less recognizable user. For example, Pico Technology has produced the laboratory grade 300 KHz to 6 GHz vector network instrument that offers performance, portability, ease of use and affordability.

Signal from the source is sent to DUT, here filter is taken. Because of the incident waves, reflected and transmitted signals are noted and sent to receiver to display the signal.

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The dynamic range, RMS trace noise, four S-parameters are measure parameters in VNA. This performance is considered as a cost-attractive, high dynamic range. Handy size, less in weight and cost and its good performance make it suitable for outside field service, installation test, embedded and training applications.

Undesired measurement contributions from transmission lines, can be eliminated using manual or automatic reference plane offset.

The Pico-company VNA has included software two utilities to handle the often complex distortion measures of gain compression. Good test leads and calibration standards all use robust, high-precision stainless steel connectors.

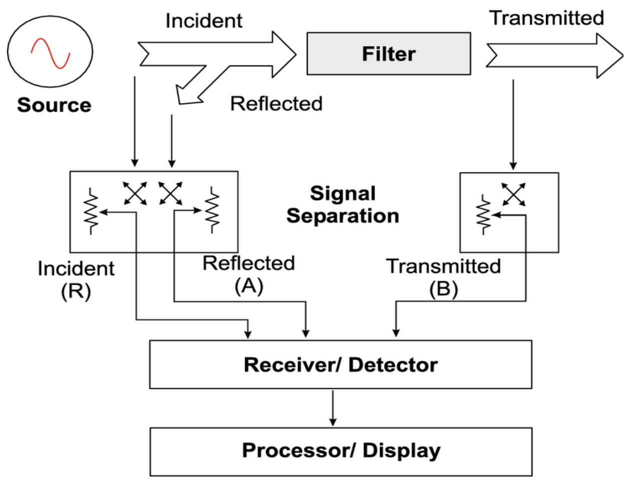

Fig. 5. VNA architecture blocks with filter as DUT.

Vector Network Analyser for Microwave Measurement used by designers to measure the electrical performance of devices, should have maximum efficiency and minimum distortion. Network analysis is concerned with the accurate measurement of the ratios of the reflected signal to the incident signal, and the transmitted signal to the incident signal.

F. Signal separation, signal detection and display

Signal separation consist the function of ratioing. It is computed as to measure a part of the incident signal to give a reference signal. This can be accomplished by using broadband Splitters and Directional Couplers having more directivity. The next one is to filter the forward incident and reverse reflected travelling waves at the DUT input. Directional Couplers are used for this function.

Signal detection is done as the following steps. Tuned Radio Receiver with demodulator/detector working on Super heterodyne principle with good sensitivity and spurious signal reduction is preferred. The signal output from receiver is applied to the analogue to digital converter. Both magnitude and phase information extracted from the Intermediate Frequency (IF) signal. Digital Signal Processing techniques can be used to analyse the signal further.

Display is important to display the signal in a format that can be interpreted. The reflection and transmission signal is formatted to allow the information to be interpreted as easily as achievable. Most network analyzers are take account of features including linear and logarithmic sweeps, log formats, Smith charts, polar plots, Trace markers and limit lines.

G. Types Of Analyzers

The main types of network analyzers are listed below.

- Scalar Network Analyser (SNA)
- Vector Network Analyzer (VNA)

Scalar Network Analyser only measures magnitude or amplitude (i.e. scalar properties) of a device. But, Vector Network Analyzer measure both amplitude and phase (i.e. vector properties) of device under test (DUT).

The differences between scalar and vector network analyzers are tabulated in table 1.

Table- I: SNA versus VNA

Scalar Network Analyzer	Vector Network Analyzer
Perform sweeps faster than VNA.	carry out frequency sweep slower than SNA.
Measures only magnitude part.	incident and reflected waves magnitude and phase at ports of DUT is measured.

IV. VNA COMPONENTS SPECIFICATIONS

A. Devices Tested By VNA

Filters, antennas, mixers, directional couplers, duplexers, Microwave and RF components are devices under test in VNA. In microwave measurement using slotted line, both amplitude and phase can be measured but limited to single frequency. Due to the need of broadband frequency range, network analyzer has been designed which measures both the amplitude and phase over the wide frequency range and within reasonable acceptable time. Amplitude and phase of the signal emitted from DUT is measured in the basic setup. The correct reference signal is generated, with the standard reference signal. The Network Analyzer components figure depicts four parts which includes signal source, signal separation device, receiver or detector and signal processor/display section.

- Signal source provides incident signal.
- A device which separates the signals into incident, reflected and transmitted signals is termed as Signal separation.
- Receiver converts microwave frequency to lower IF frequency to make it easy for further processing.
- display or signal processor section which processes the IF signal and display the information on CRT screen. Let us understand network analyzer basics.

Signal source, which produces the incident signal which stimulates the DUT. The test device conveys incident signal by reflecting and transmitting the remaining part. Frequency of the source output of the DUT can be determined by sweeping. The two types of signal sources are sweep oscillator and synthesized signal generator. The second module is used to separate out various signals. After these signals are separated their amplitude and phase calculation are carried out. the differences also can be computed. This task is accomplished with the use of directional couplers, power splitters, bridges or high impedance probes.The another module is the receiver sometimes detector, converts Radio Frequency voltage to lower Intermediate Frequency or non-ac signal to allow more accuracy in measurement.

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The three main techniques to accomplish this is achieved by diode, fundamental mixing and harmonic mixing.

- Diode is broadband detector which converts RF signal to the proportional DC voltage. For amplitude modulated signal, it induces the modulation. This technique is most commonly employed in scalar network analyzer.
- RF signal to the low frequency IF signal is converted by broadband tuned receiver techniques. Both will have BPF at IF frequencies to reject the spurious frequencies and extend the noise floor.

The results are displayed in the final part. Cartesian format indicate magnitude, phase or group delay as a function of frequency. The same can be displayed in polar format as well or in a impedance format in the form of smith chart. The comparison between Spectrum and Vector network analyzers is displayed in Table 2.

Table- II: Network Analyzer versus Spectrum Analyzer

Network Analyzer	Spectrum Analyzer
Contains a source and receiver	Contains a receiver
Measures known signal	Measures unknown signal
Two channels or more	Single channel
Ratioed measurement	No ratioed measurement
More accuracy	Less accuracy
Advanced calibration is offered	Limited calibration
Limited to analog and pulsed signals	Operates well with digitally modulated signals

B. VNA Specifications

Based on the following parameters, VNA is mentioned as below. Number of ports, frequency range, dynamic range, trace noise, and measurement speed. These are used to specify VNA. Frequency range determines the frequency range of the measurement results that can obtain. Frequency setting resolution is the smallest frequency step that can be got from the instrument. It confines the resolution of all the above measurements. Measurement accuracy relates to measurement uncertainty of both magnitude and phase. Output power range arrived from the power levels at the test port. DUTs output varies rarely with input power level varies; these ranges are designed according to particular input power. Power resolution is defined as how finely the output power can be adjusted; better power resolution allows for more accurate output power settings. Harmonic distortion and non-harmonic spurious at output port denotes the amount of undesired signals present at the test port. DUT Low distortion or harmonics value bring more accurate results, especially when measuring. Measurement speed makes a large impact on total cycle time when the VNA stimulus settings lead to a long sweep time.

C. Advantages and Limitations

Better accuracy, repeatability are the advantages of VNA. Costly, need skilled person, to be calibrated in periodic time are limitations. Errors occur during the test is systematic errors, random errors and drift errors. By doing calibration systematic errors can be reduced. By careful measurement random errors are controlled. By calibration and keeping VNA temperature constant drift errors are eliminated.

D. Applications

Manufacturing, calibration, distribution and service industries make use of this instrument. Scientific applications also uses these into the materials management, geological survey and life guarding devices, food preservation, tissue imaging and penetrating scans. The VNA with all the functionality and versatility is expected from a modern vector network analyzer. Several VNA is supplied now with Windows software that outputs in one, two or four measurement channels all the familiar measurement and plot formats to be expected for the four dual-port S-parameters or the two single-port parameters: logarithmic and linear magnitude and phase, real and imaginary, Smith and linear polar, SWR and group delay. The VNA software also includes Fourier transformation to the time domain. Desired distance-to-fault capability is added and pulse response is determined. Hardware required for down conversion and RF power detection is relatively simple and inexpensive. VNAs are more difficult compare to SNAs as they need full heterodyne structural design in receiver to measure both magnitude and phase. For this reason VNA are costlier than SNA devices. Some manufacturing companies that make VNAs are OMICRON Lab, Pico, Rohde & Schwarz, Agilent, Keysight, Anritsu, Copper Mountain Technologies and Tektronix[10-12].

V. RESULT AND DISCUSSION

The following measurements are done with Vector Network analyzer.

- Transmission measurements: It includes transmission coefficient, insertion loss and gain measurements.
- Reflection measurements: It includes reflection coefficient, VSWR, return loss and impedance measurements.
- Scattering parameter measurements: S_{11},S_{12},S_{21},S_{22} can be measured.

In this paper, VNA is studied theoretically and a fractal microstrip antenna is taken. It is DUT here. The antenna DUT is connected to the Agilent Technologies VNA and got the measurement of S-parameter, VSWR, trace noise and smith chart and it is shown in figure 6-9.

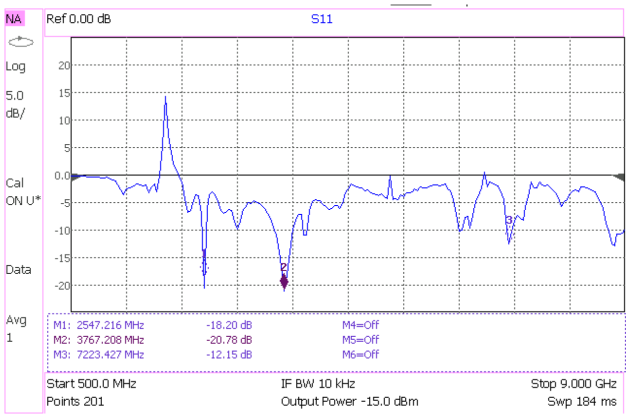

Fig. 6.VNA Tested S_{11}-parameter values and frequency range of antenna

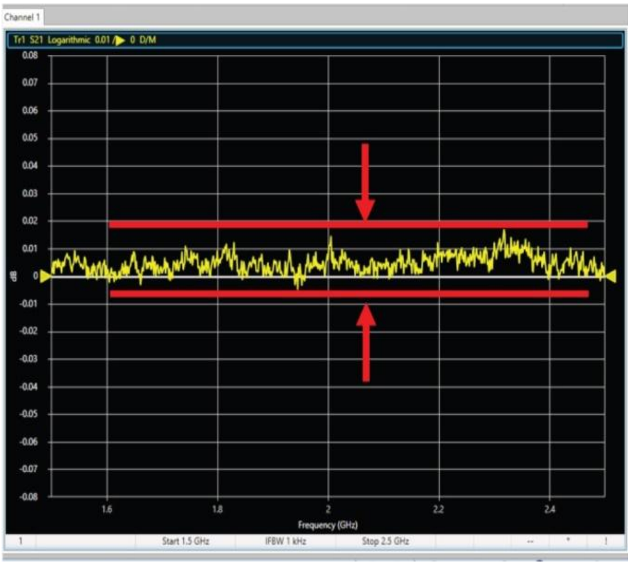

Fig. 7.Trace noise displayed from VNA. (Frequency Vs dB)

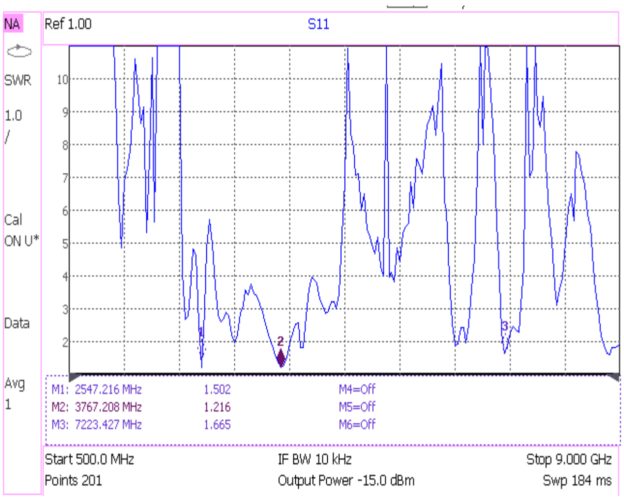

Fig. 8. VSWR measurement in VNA. (Frequency Vs SWR)

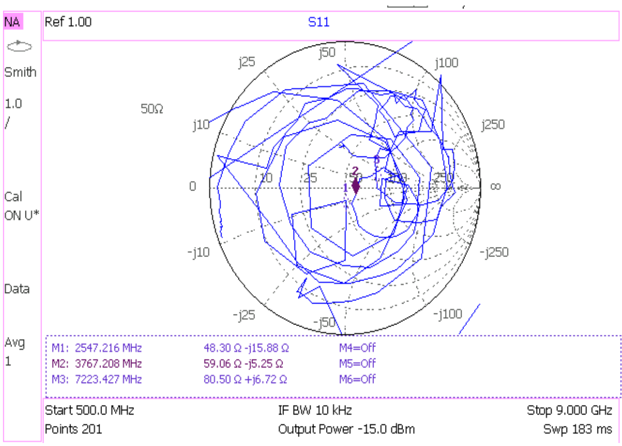

Fig. 9. Smith Chart measurement of VNA.

VI. CONCLUSION

The Vector Network Analyzer, VNA study in the RF components is discussed and measure with antenna and its results are presented here. VNA is a test instrument that process the response of a network as vector: real & imaginary parameters so that its performance can be analysed. A known stimulus signal is provided to DUT, and made as to measure the electrical characteristics. Designing a VNA starts with the selection of outstanding building components, including RF circuits like mixers, attenuators, and oscillators. An outstanding design combines these into efficient units including directional couplers, RF sources, and digital processing circuits. It is the addition of all these elements, in grouping with versatile and feature-rich interfaces, that makes for a laboratory-class, good VNA. This work is intended to focus more on the instrument.

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