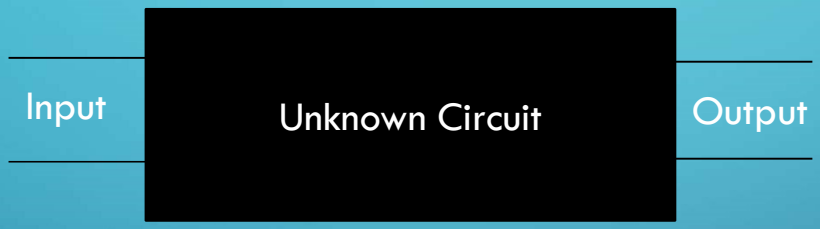
THE VECTOR NETWORK ANALYSER

A SERIOUS TOOL FOR THE TECHNICAL RADIO AMATEUR

WHAT IS A VECTOR NETWORK ANALYSER (VNA)

- A piece of test equipment which measures complex multi-port S parameters



- 2 Port analysis assumes an input and an output and anything inside must be linear
- It can be passive or active circuitry
- This analysis can be extended to n ports but becomes mathematically extremely complex

WHAT IS A VECTOR NETWORK ANALYSER (VNA)

- There are also scalar network analysers (SNA)
- SNAs measure the real components of S parameters
- These components represent energy transferred not stored
- They are less complex and so less expensive (a relative term)
- An SNA is really the same functionality as a spectrum analyser with a tracking generator and a directional coupler
- An common low cost amateur example of an SNA is the original MFJ Antenna Analyser

WHAT IS A VECTOR NETWORK ANALYSER (VNA)

- What are S parameters?
- Developed as a result of Radar design in WWII by Vitold Belevitch
- Popularised in the 1960's by Kaneyuki Kurokawa for Microwave analysis
- A 2 port network may be characterised by 4 parameters
- These parameters provide a mathematical model for the network in the box
- What we measure are V_{in}, I_{in}, V_{out}, I_{out} for each port
- So mathematically we can represent the 2 port network as a 2 x 2 matrix

WHAT IS A VECTOR NETWORK ANALYSER (VNA)

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \times \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

This is really our old friend Ohm's Law

$$V = R \times I$$

WHAT IS A VECTOR NETWORK ANALYSER (VNA)

- In the general case all of the Z elements are complex numbers
- Each of the Z elements is of the form $R \pm jX$ (Rectangular form) or $R(\cos\Theta \pm j\sin\Theta)$ or $Re^{j\theta}$ in polar form
- This matrix can be also used to represent admittance parameters (Y)
- Also used is the hybrid parameter representation (H)
- And the inverse hybrid parameters (G)
- For more brain frying information see:

https://en.wikipedia.org/wiki/Two-port_network

WHAT IS A VECTOR NETWORK ANALYSER (VNA)

- Now that we have this representation what are S parameters?
- S parameters are referred to as scattering parameters
- S parameters address the problems of measurements at UHF and above frequencies where measurements may depend on where they are made
- The following is taken from Wikipedia

For the S-parameter definition, it is understood that a network may contain any components provided that the entire network behaves linearly with incident small signals. It may also include many typical communication system components or 'blocks' such as amplifiers, attenuators, filters, couplers and equalizers provided they are also operating under linear and defined conditions.

An electrical network to be described by S-parameters may have any number of ports. Ports are the points at which electrical signals either enter or exit the network. Ports are usually pairs of terminals with the requirement that the current into one terminal is equal to the current leaving the other. S-parameters are used at frequencies where the ports are often coaxial or waveguide connections.

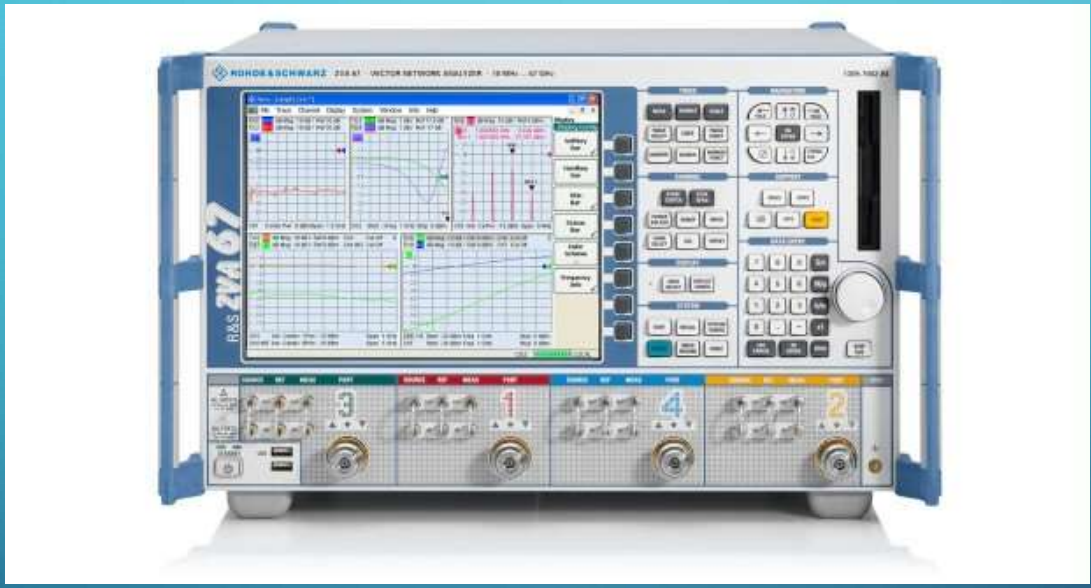
The S-parameter matrix describing an N-port network will be square of dimension N and will therefore contain N^2 elements. At the test frequency each element or S-parameter is represented by a unitless complex number that represents magnitude and angle, i.e. amplitude and phase. The complex number may either be expressed in rectangular form or, more commonly, in polar form. The S-parameter magnitude may be expressed in linear form or logarithmic. When expressed in logarithmic form, magnitude has the “dimensionless unit" of decibels.
The S-parameter angle is most frequently expressed in degrees but occasionally in radians. Any S-parameter may be displayed graphically on a polar diagram by a dot for one frequency or a locus for a range of frequencies.
If it applies to one port only (being of the form S_{nn}), it may be displayed on an impedance or admittance Smith Chart normalized to the system impedance. The Smith Chart allows simple conversion between the S_{nn} parameter, equivalent to the voltage reflection coefficient and the associated (normalized) impedance (or admittance) 'seen' at that port.

WHAT IS A VECTOR NETWORK ANALYSER (VNA)

- Now that you all have had a severe headache from this I can honestly say that you don't really need to know this because that is what computers are for
- In general S_{xy} is the effect at port x from the signal at port y
- The take away from this is that in a 2 port network:

  S_{11} is the input port voltage reflection coefficient (VSWR)
  S_{12} is the reverse voltage gain or loss
  S_{21} is the forward voltage gain or loss
  S_{22} is the output port voltage reflection coefficient

SO WHAT IS A VECTOR NETWORK ANALYSER?



A Rohde & Schwarz 4 port 8GHz Vector Network Analyser

Price New approximately $150,000 AUD and up!

VNAs COME IN VARIOUS CONFIGURATIONS

- 1 Port – Antenna Analysers (not the scalar variety)
- 2 Port – General VNA (the professional workhorse)
- 4 Port – Laboratory Microwave VNA (very expensive!)
- Manufacturers – Rhode & Schwarz, Anritsu, Keysight, Tektronix

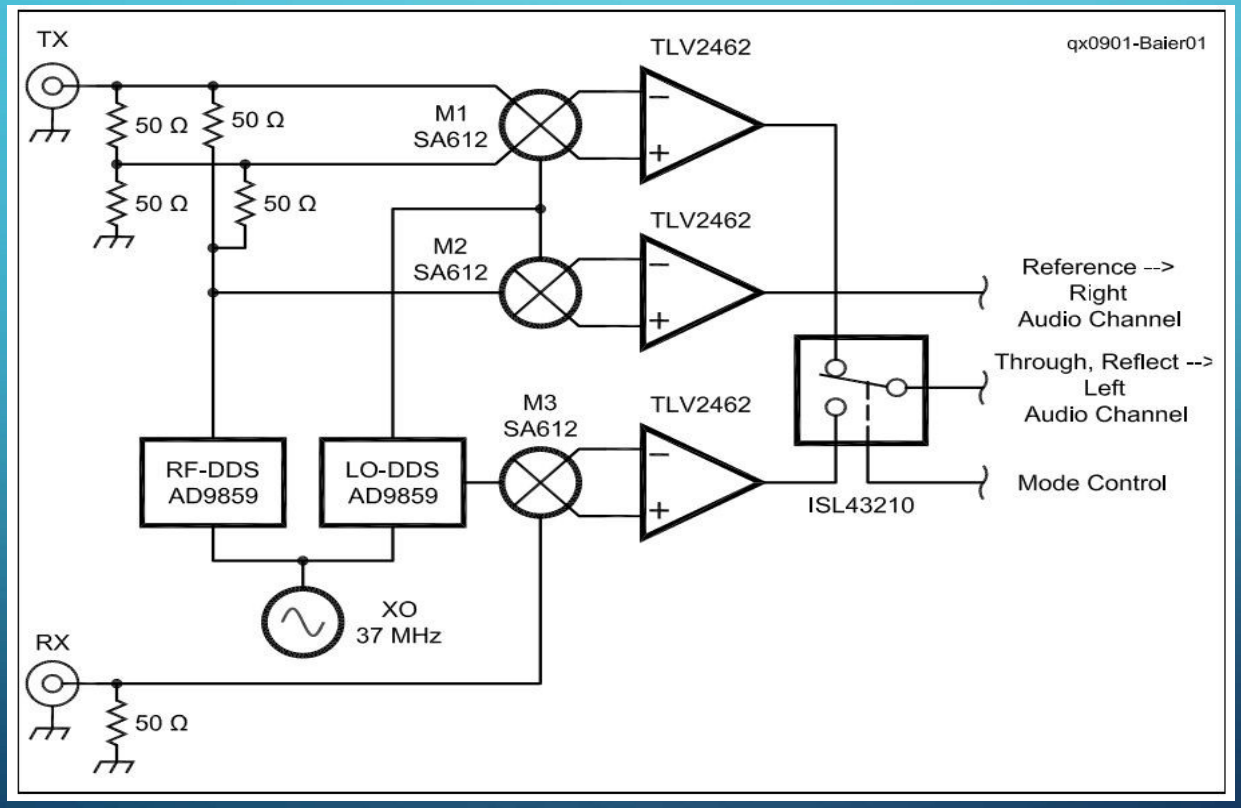
WHY ARE WE EVEN LOOKING AT A VNA?

- Modern ICs have lowered the cost of building a VNA with modest specs
- PC software can provide a large part of the analysis with minimal hardware
- Well within the reach of the serious amateur radio enthusiast
- What are we talking about …

LOW COST VECTOR NETWORK ANALYZERS

VNA developed by DG8SAQ approximately $500 AUD

VNA BLOCK DIAGRAM



HOBBYIST VNA SPECIFICATIONS

- Coverage from 1 kHz to 1.3 GHz: Up to 500 MHz with dynamic range of up to 90dB
- S-Parameter S11, S12, S21 & S22, VSWR, Smith Chart
- Logarithmic and Linear sweep: up to 8192 points with sampling time adjustable from 0.2 mS to 100 mS
- Network Matching Tool, Complex Calculator & Crystal Parameter tool
- Basic Spectrum Analyzer - useful up to 100 MHz
- Basic Signal Generator - max RF Output as signal generator -17dBm - no harmonic filtering
- Power requirement - USB 1.1 or USB 2 Interface 5V DC max 400mA
- 12 MHz TCXO Master Clock - stability of 2 ppm
- Microprocessor: Atmel ATMega 328P with - 16K Flash memory - clocked at 16 MHz
- Connectors: SMA x 3, Mini USB-B
- Power requirement - USB 1.1 or USB 2 Interface 5V DC max 400mA

PROFESSIONAL vs HOBBYIST VNA

- $150,000 vs $500
- Dynamic Range 145 dB vs 90 dB
- Frequency Range 10MHz-110GHz vs 1MHz-1.3GHz
- Oscillator spectral purity -65 dBc close in & stability .05 ppm vs 2 ppm (temperature, power & aging)
- Port characteristic matching to a very tight degree
- External control and automation
- High end specifications cost money to design and build for repeatability
- “You get what you pay for!”

DEMOS

- 1 port – Antenna characterisation
- 2 port – Pi Chebyshev Low Pass Filter characteristics
- Not Demonstrated
- 3 port network – Diplexer, microwave power combiner/splitter
- 4 port network – Microwave directional coupler, Quadrature Hybrids
- Note: 3 and 4 port networks can be analysed by a 2 port VNA by terminating unused ports with system impendence loads