# NanoVNAs – Part 1: Background and Theory

Brian Flynn GM8BJF

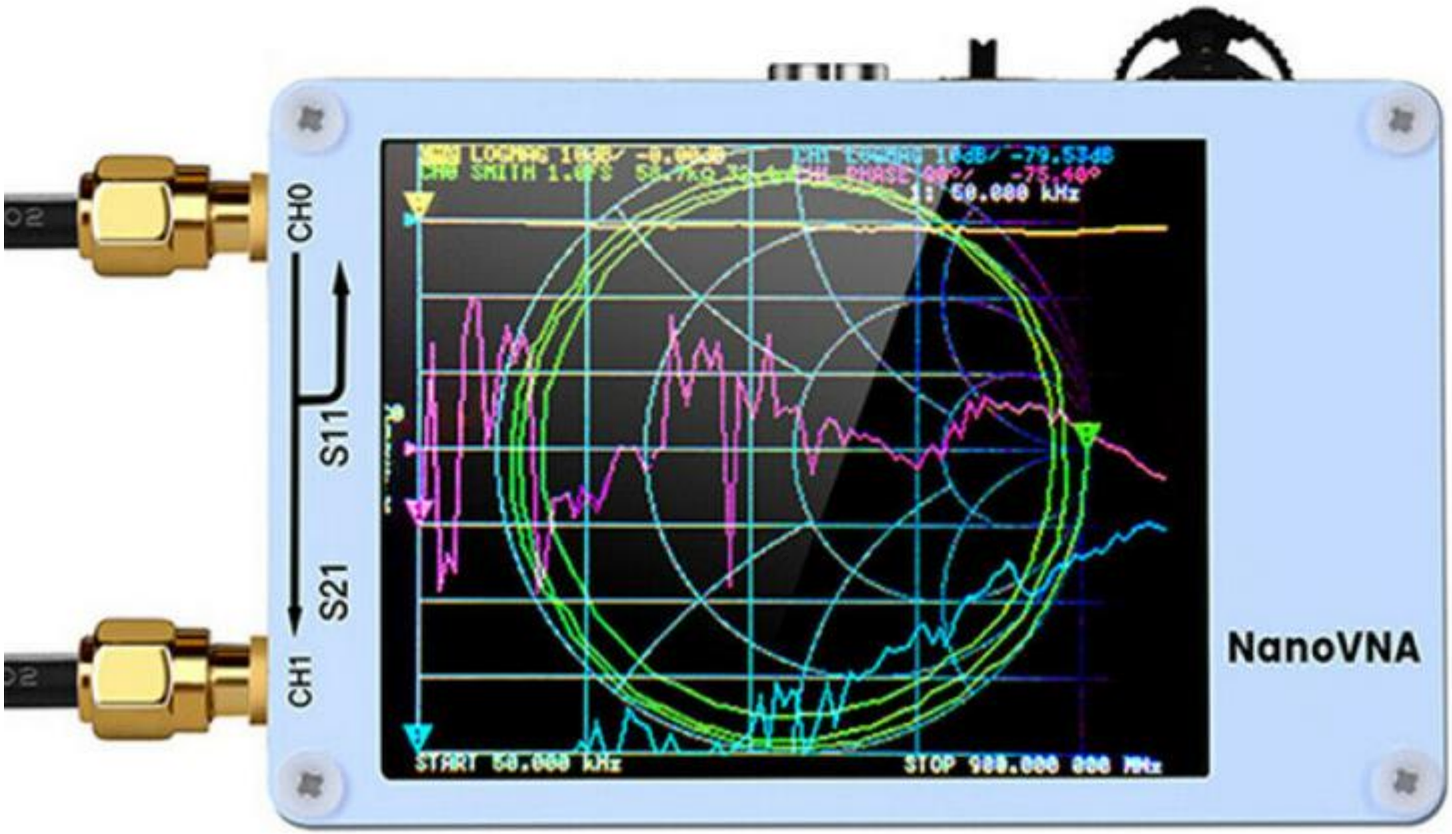
# Organisation and Topics

- Part 1 : looks at the background to Vector Network Analysis – the origins of the VNA-the origins of the NanoVNA - S-parameters – the Smith chart- finally a demo of a NanoVNA
- Part 2 : Utility of a NanoVNA – the design of a NanoVNA and variants – Calibration and calibration standards – combining with a computer and CAD of circuits.

# What is a NanoVNA ?

- A small portable low cost VNA aimed at the Hobby market.
- Started life  as an open source hardware/software project in Japan and later China.
- Eddy555 (Japan) started producing self- assembly kits in 2016.
- Hugen (China) took original design and relaid the PCB and produced assembled units which were available on Tao Bao.
- Soon afterwards a rash of copies appeared on most auction sites.

# 50kHz to 900 MHz NanoVNA



# Origins of the VNA

- Vector Network Analysis was large pioneered by the Hewlett-Packard measurement instrument company in the late 1960s.
- The earliest model to see widespread adoption was their HP8410. Variants of this were able to measure to around 20 GHz and higher in some cases.
- Back then lower frequency units were commoner.

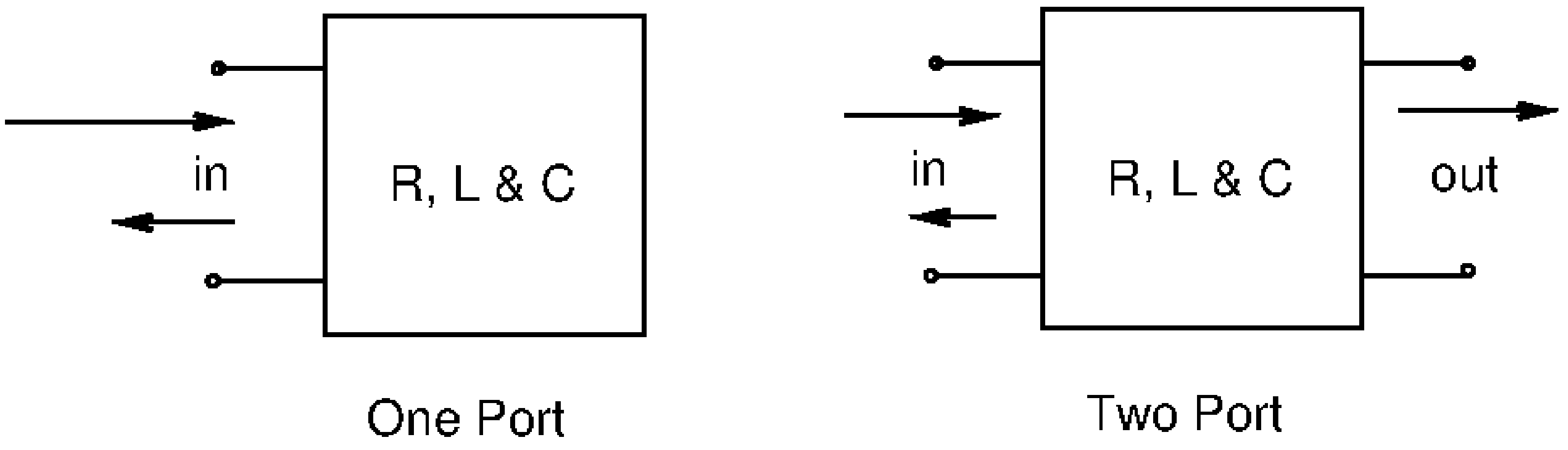
# Typical HP 8410 setup.

# Later model the HP8510 (~$100k!)

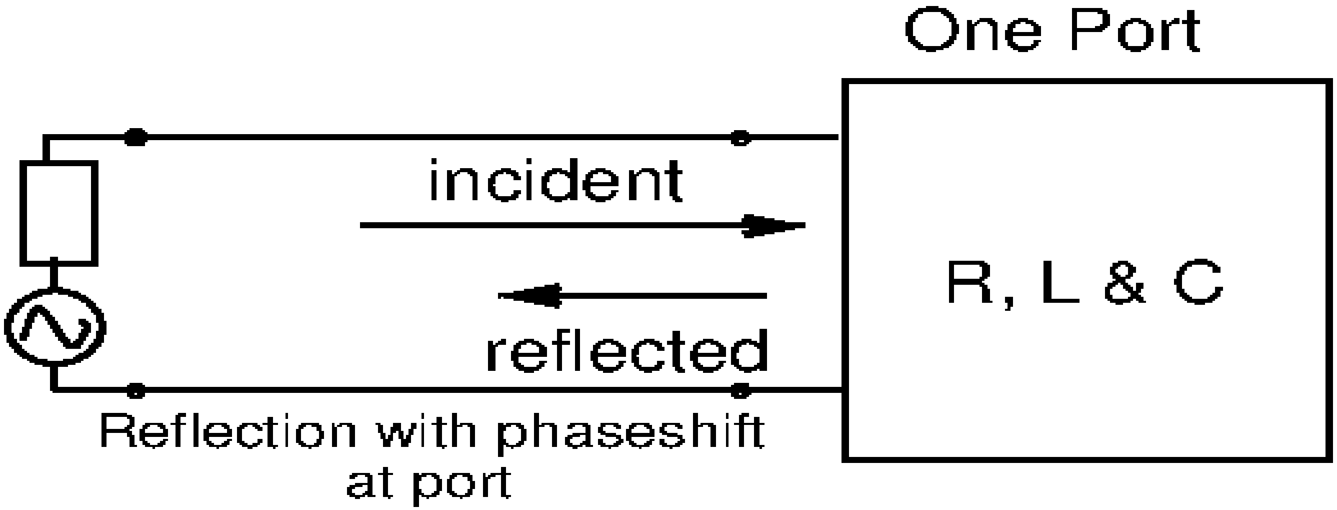
# What does a VNA do?

- It is an instrument that measures the properties of a electrical network by applying signals to its ports and observing the transmitted and reflected signals.
- Sounds messy but it is really just an extension of measuring an antenna (a one port network) with an SWR bridge to determine its match which you all will be familiar with.

# Examples of “Networks”



# Simple One-port Network

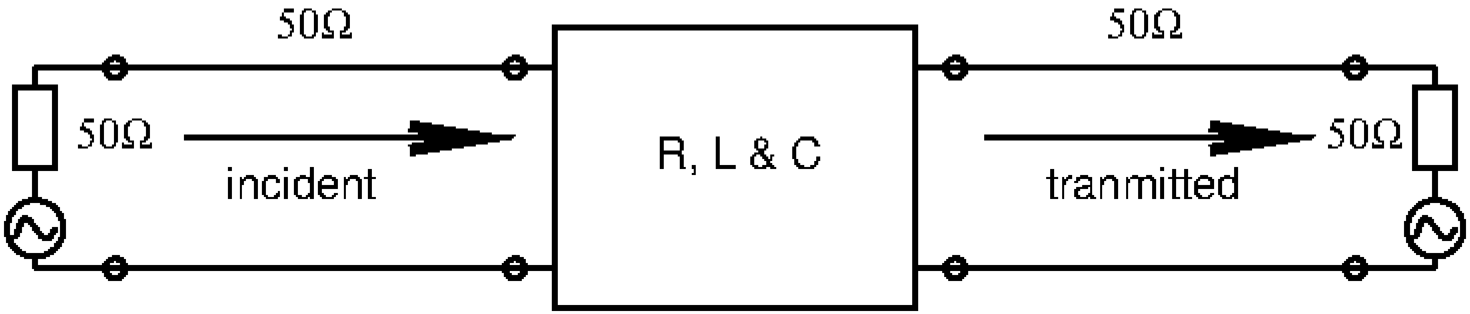



$$\rho = S_{11} = \frac{reflected}{incident} + phaseshift$$

$$Magnitude / \; Angle^{o}$$

$$Magnitude = |\,0\,| > |\,1\,|; \; Angle = 0 > 360^{o}$$

# Simple Two-port network




$$S_{21} = \frac{transmitted}{incident} + phaseshift$$

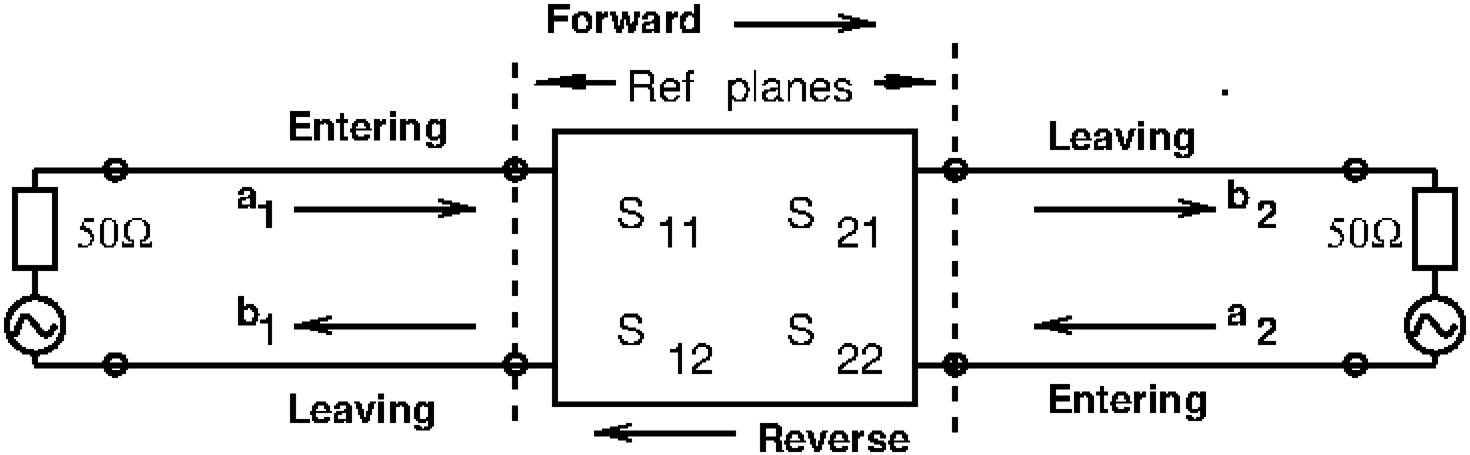
$$= Magnitude / Angle^{o}$$

$$|1| > |0|; 0 > 360^{o}$$

# Scattering or S Parameters

- Based on the idea that you can fully characterise a network if you know the amplitude and phase of all the signals entering and leaving it.
- If you know all of the reflection and transmission coefficients for the network it can be fully described or characterised.

# S-Parameter Definition




$$\text{Input reflection cofficient} = S_{11} = \frac{b_1}{a_1}$$

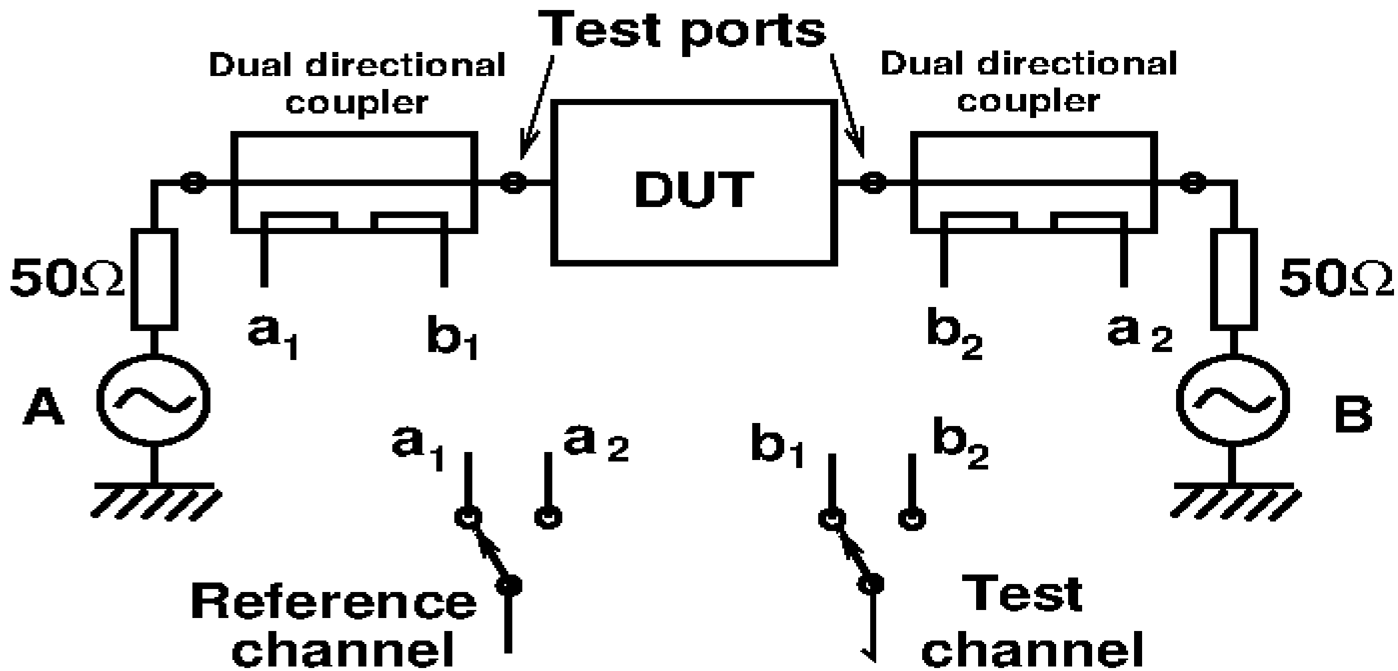
$$\text{Output reflection coefficient} = S_{22} = \frac{b_2}{a_2}$$

$$\text{Forward transmission coefficient} = S_{21} = \frac{b_2}{a_1}$$

$$\text{Reverse transmission coefficient} = S_{12} = \frac{b_1}{a_2}$$

# A Scalar Reflectometer!

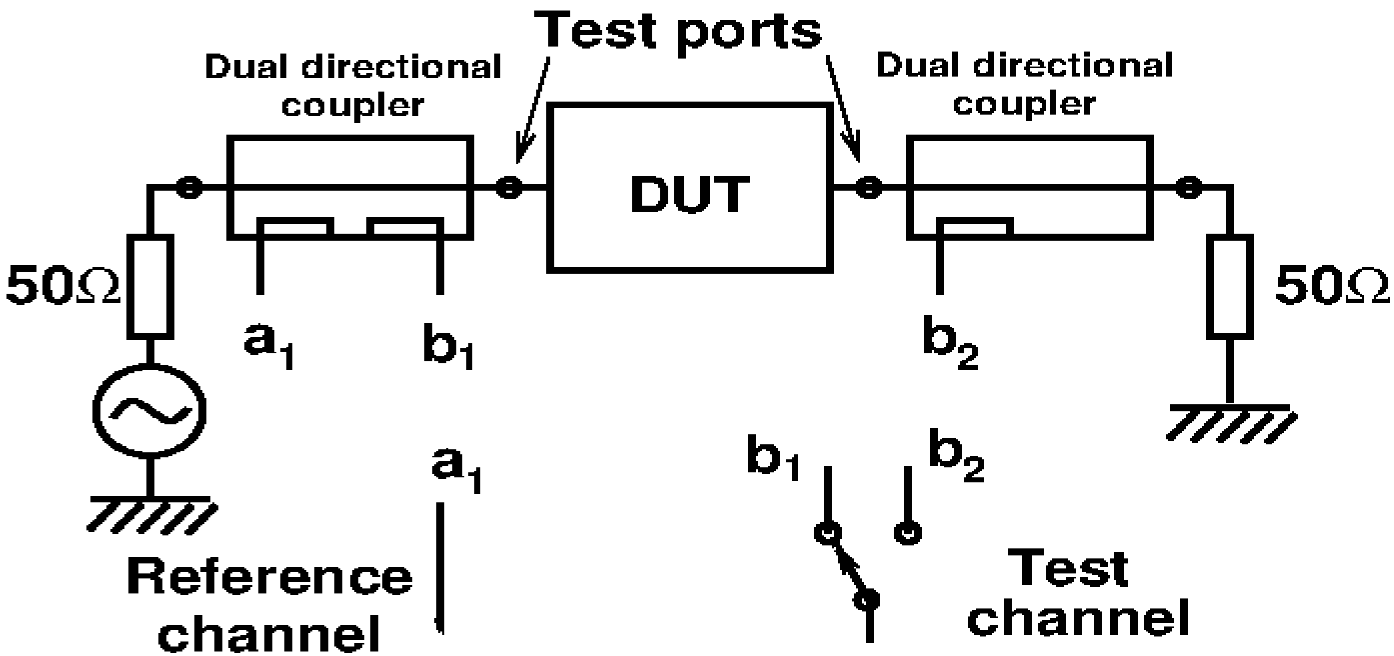
# Measurement of S-parameters




$$S_{11} = \frac{b_1}{a_1} / \theta_{11}{}^{o} \ldots\ldots\ldots S_{21} = \frac{b_2}{a_1} / \theta_{21}{}^{o}$$

$$S_{12} = \frac{b_1}{a_2} / \theta_{12}{}^{o} \ldots\ldots\ldots S_{22} = \frac{b_2}{a_2} / \theta_{22}{}^{o}$$

# NanoVNA Architecture

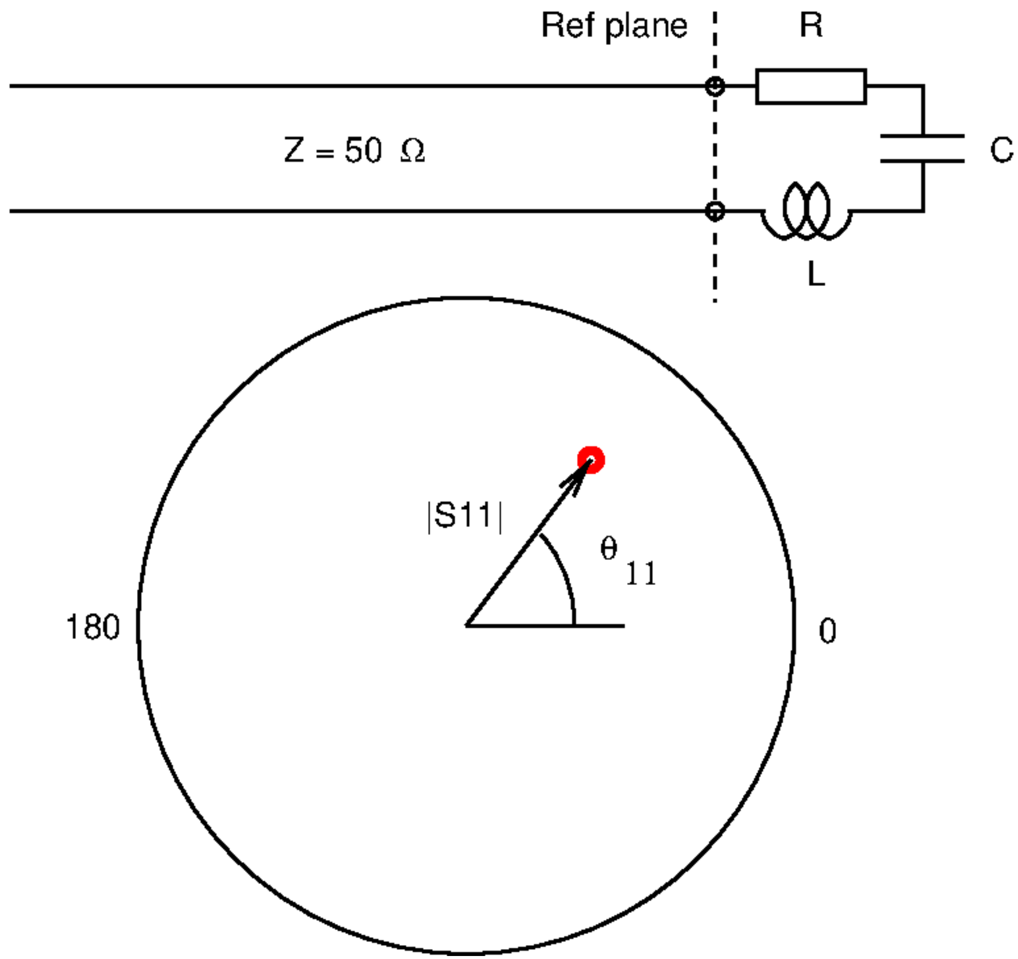



$$S_{11} = \frac{b_1}{a_1} / \theta_{11}{}^{o} \ldots\ldots\ldots S_{21} = \frac{b_2}{a_1} / \theta_{21}{}^{o}$$

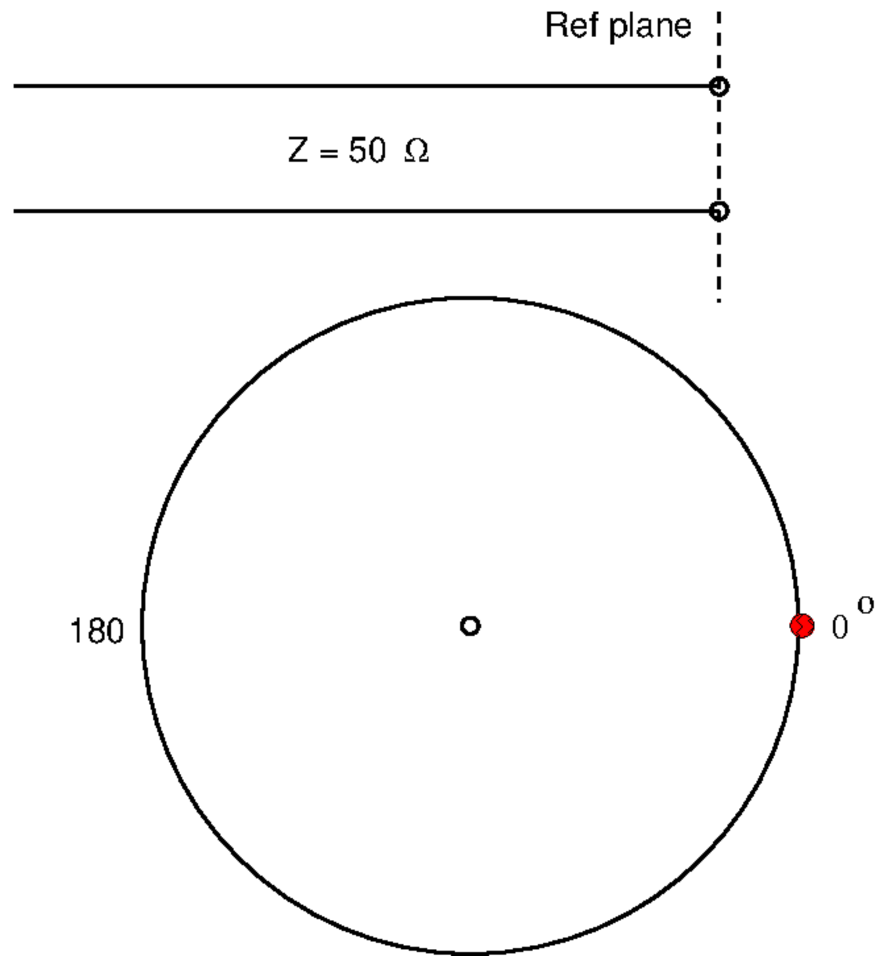
# The Vector Bit!

- The normal measurement of VSWR  or gain (Or attenuation) only considers the magnitude of S the S-parameter. Using a VNA also get the phase information.
- Each S-parameter has two bits of information Magnitude and Phase.
- For a 2-port network there are eight bits of information at each frequency of measurement.
- Starts to be a lot of data if doing wideband measurements.

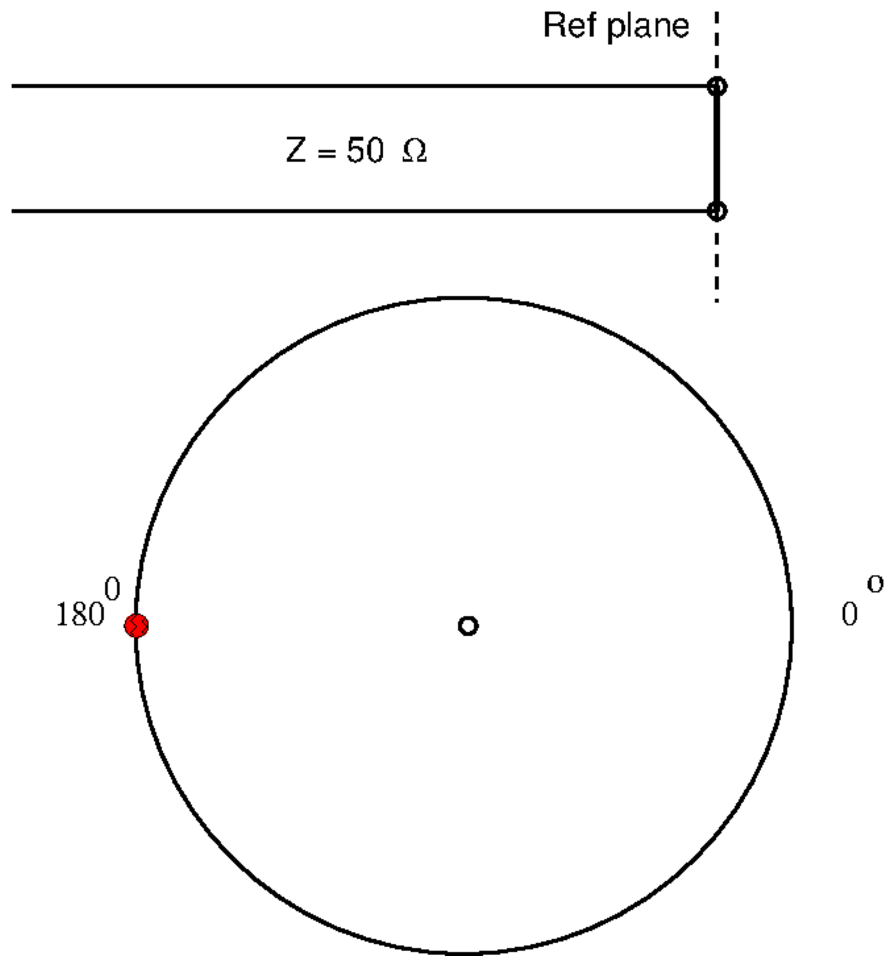
# Polar plots of S11 : Random Load Impedance



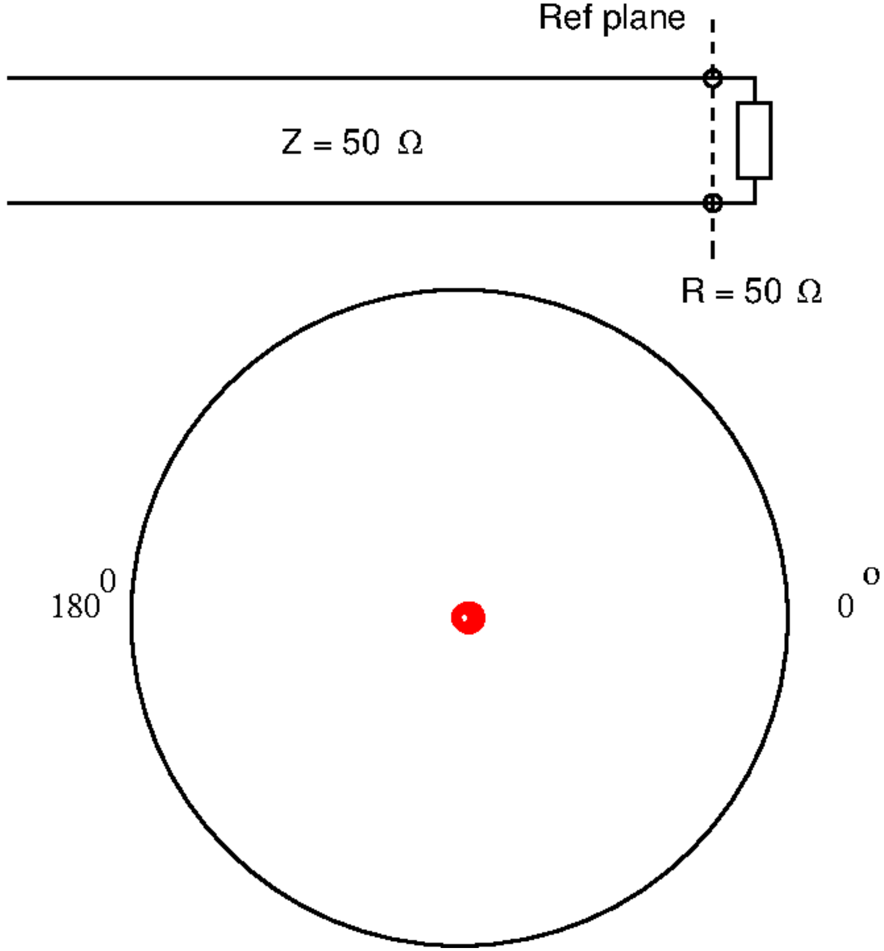
# Polar plots of S11 : Open Circuit



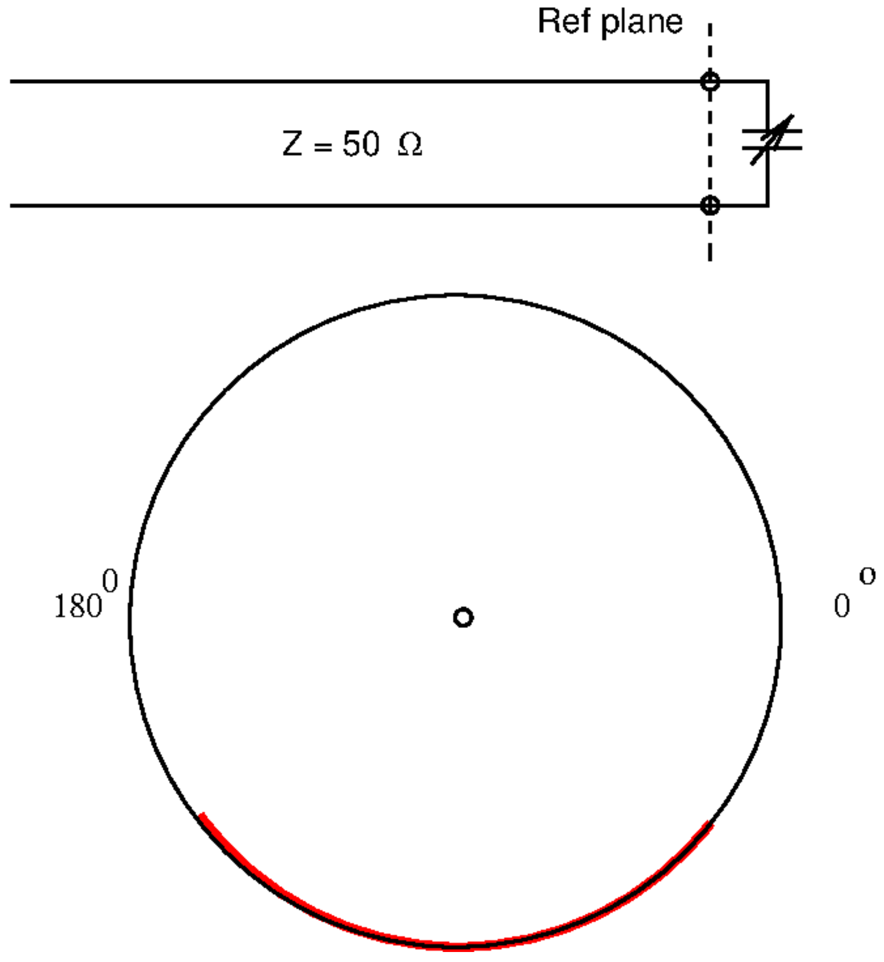
# Polar plots of S11 : Short Circuit



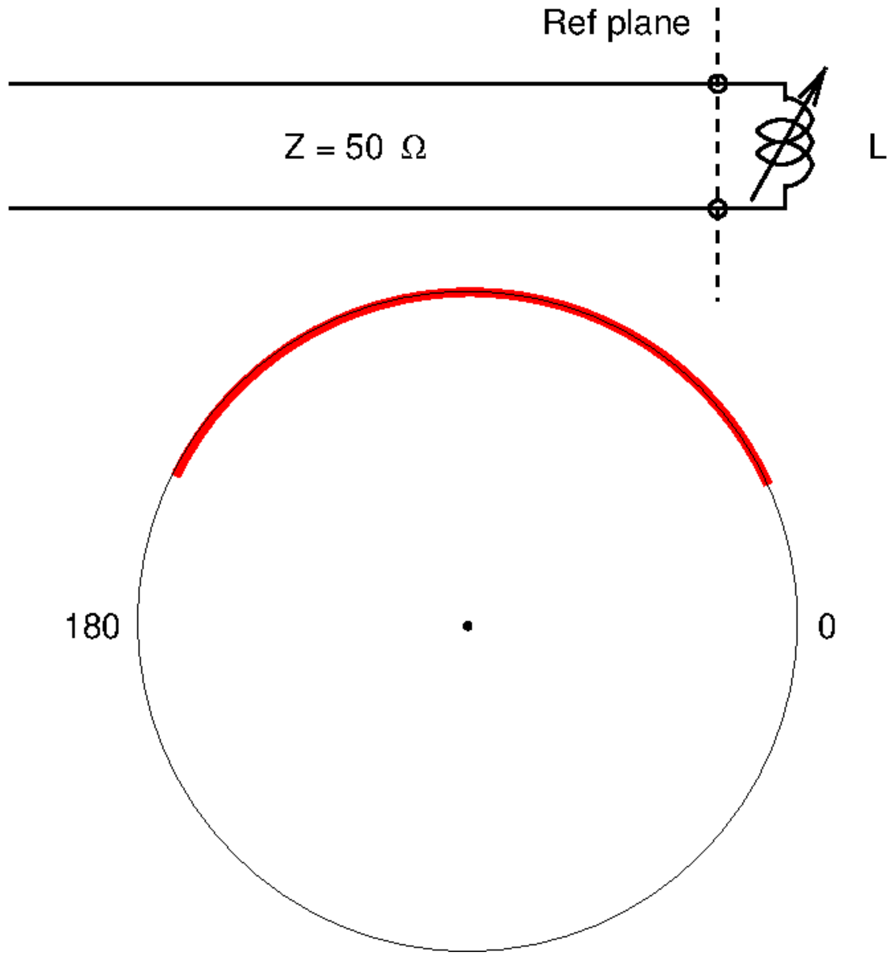
# Polar plots of S11 : Matched Load



# Polar plots of S11 : Variable Cap



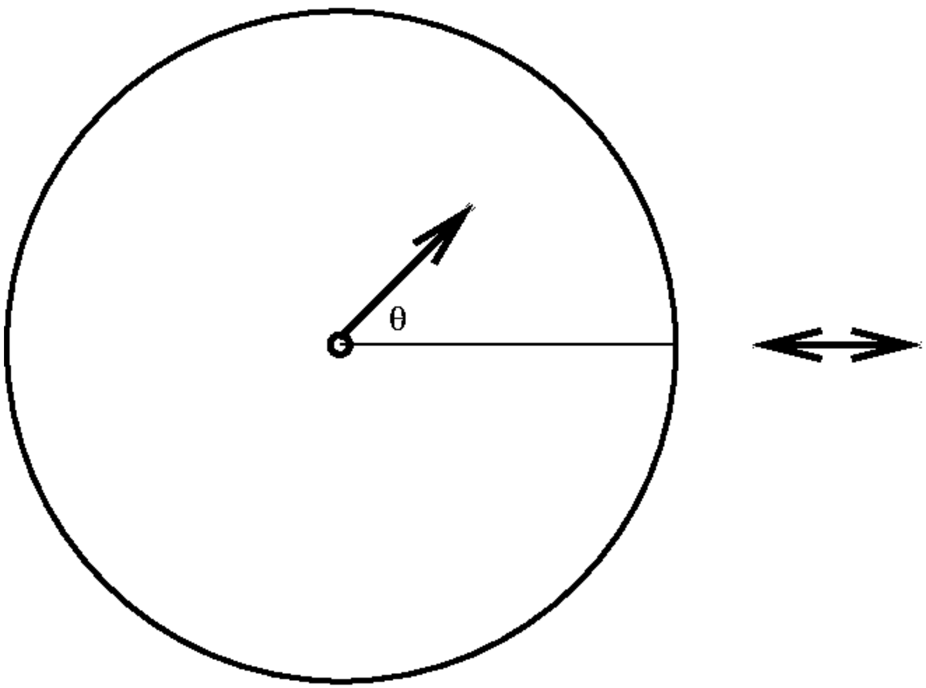
# Polar plots of S11 : Variable Inductor



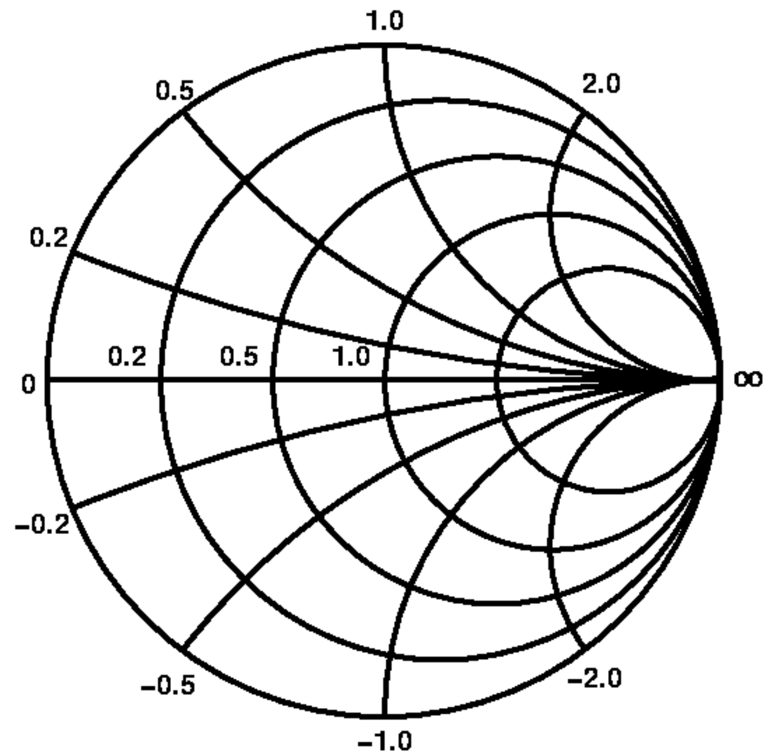
# Equivalence of Reflection Coefficient ρ (or S11) and Impedance.

- For every value of impedance the is a unique value of reflection coefficient
- It is possible to overlay a set of impedance (both resistive and reactive) contours on the polar plot of reflection coefficient.
- This is known as the Smith chart.
- Can be thought of as a chart or nomograph for converting from impedance to reflection coefficient.

# Smith Chart Concept

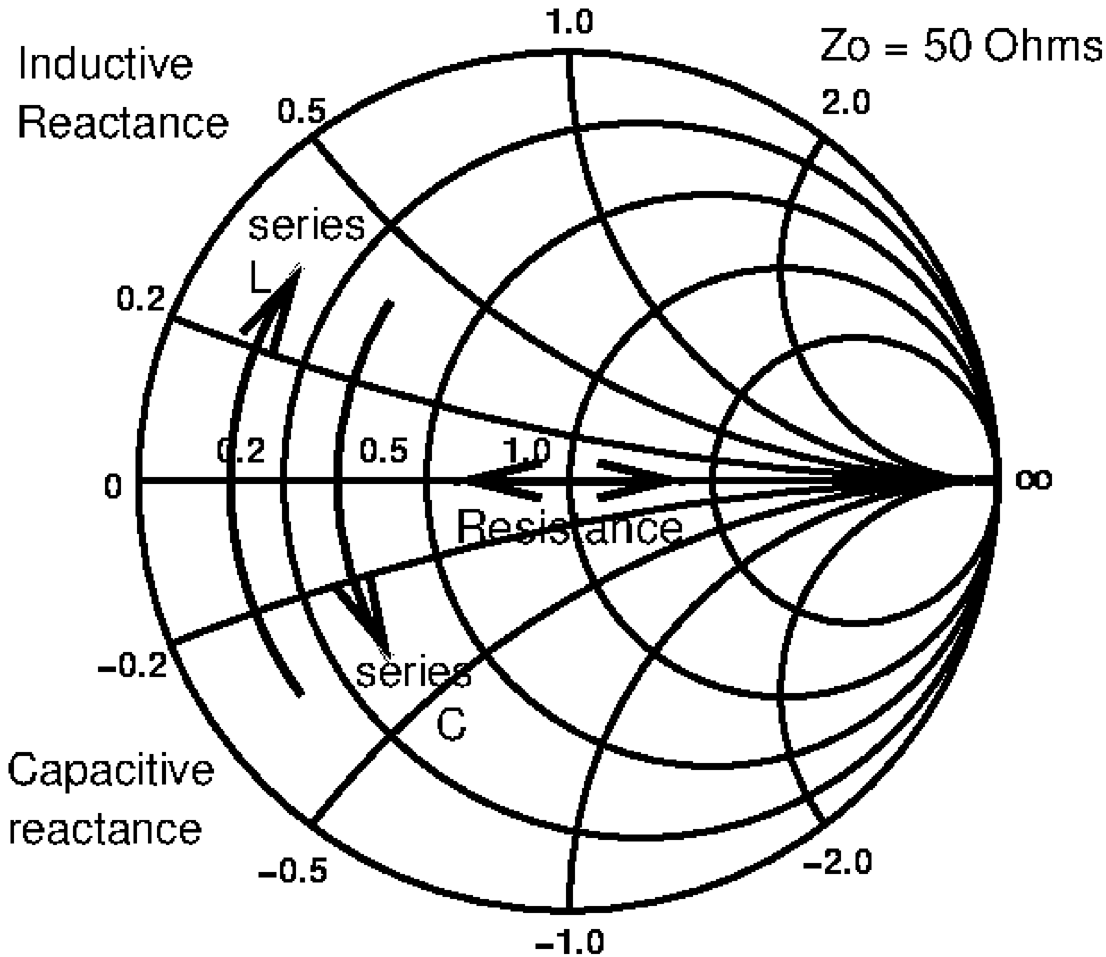



Reflection coefficient




Smith chart

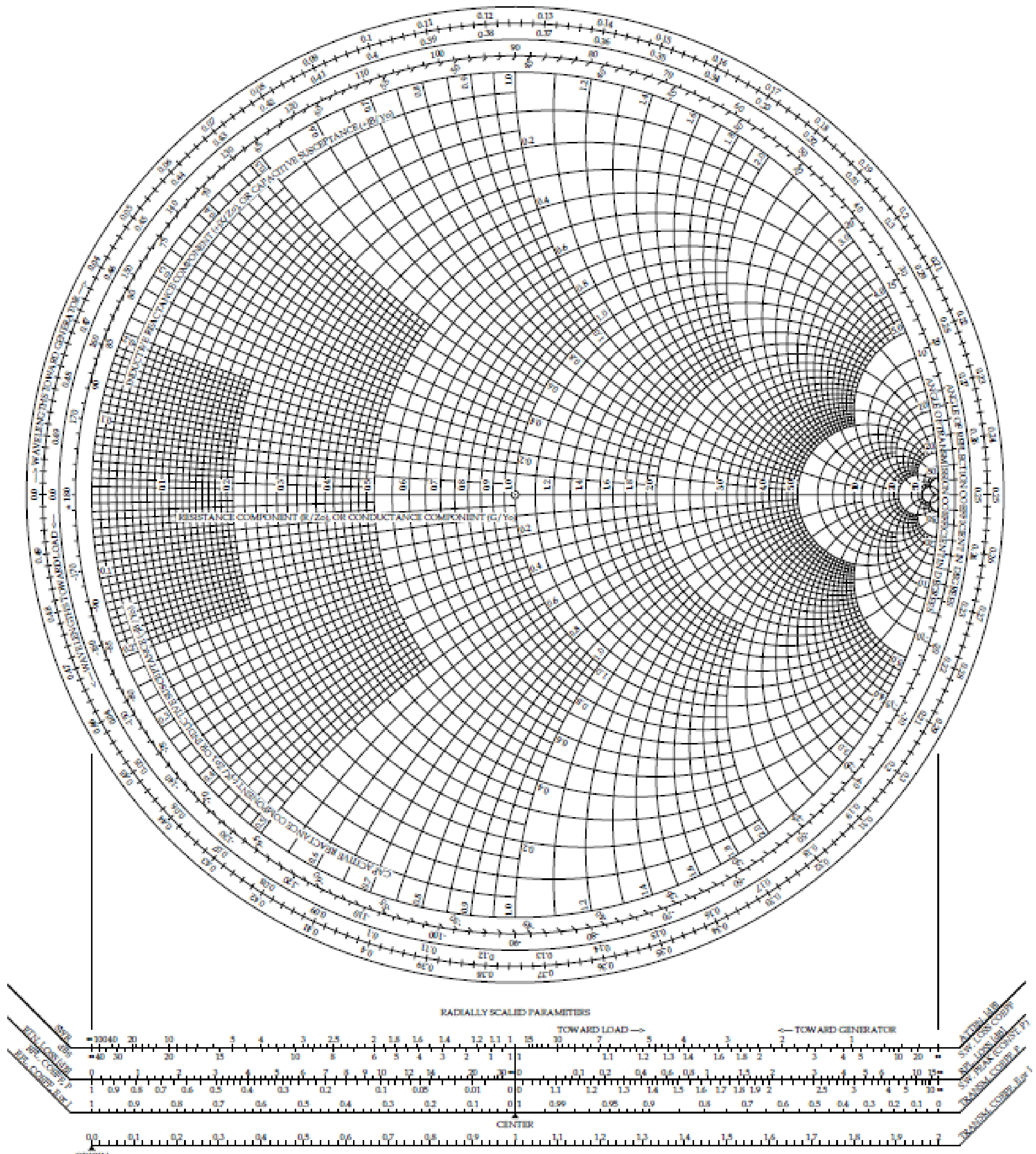
# Smith Chart used to show Resistance and Reactance



# Smith Chart

- Used to "visualise" impedance
- At most basic it can be thought of a chart or nomograph to convert from reflection coefficient to impedance
- Top half inductive reactance
- Bottom half capacitive reactance
- Impedance values are all "normalised" to 50 Ohms (or perhaps 75 Ohms)

# Full Smith Chart in all its Glory!



# Demonstration of Impedance Measurement with a NanoVNA

- And use for evaluating parts.

# Any questions?