RF Fundamentals Seminar
Part 3: RF Components and Measurements

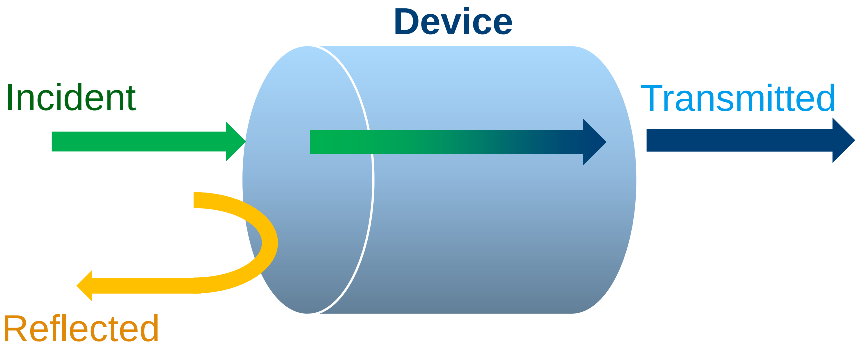
ROHDE&SCHWARZ

Make ideas real

RF Components and Measurements

- Topics
  - Reflection and Transmission
  - Smith Chart
  - S-Parameters
  - Instrument Measurements
  - Components

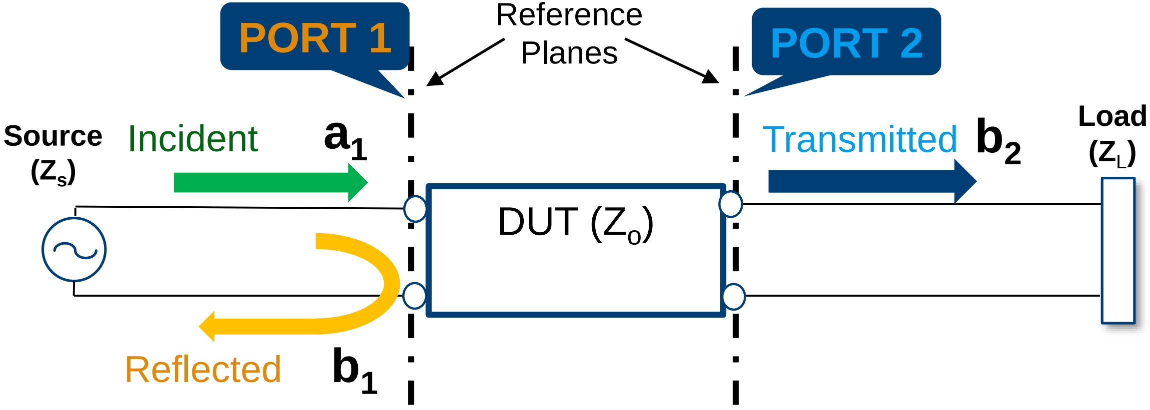
RF Device Characterization



$$\textbf{REFLECTION} = \frac{\text{Reflected}}{\text{Incident}}$$

$$\textbf{TRANSMISSION} = \frac{\text{Transmitted}}{\text{Incident}}$$

Measurement – 1 Port and 2 Port



REFLECTION $= \dfrac{\text{Reflected}}{\text{Incident}} = \dfrac{b1}{a1}$

Expressed as:
- Return Loss (dB)
- SWR
- Impedance/Admittance (R+jX / G+jB)
- Reflection Coefficient (G, r)
- S-Parameters (S11, S22)

TRANSMISSION $= \dfrac{\text{Transmitted}}{\text{Incident}} = \dfrac{b2}{a1}$

Expressed as:
- Gain / Loss (dB)
- Insertion Phase
- Group Delay
- Transmission Coefficient (T, t)
- S-Parameters (S21, S12)

Transmission Parameters

$$\text{Transmission Coefficient}(\text{T}) = \frac{V_{transmitted}}{V_{incident}} = \tau\angle\theta$$

$$\text{Insertion Loss (dB)} = -20\log\left|\frac{V_{transmitted}}{V_{incident}}\right| = -20\log\tau$$

$$\text{Gain (dB)} = 20\log\left|\frac{V_{transmitted}}{V_{incident}}\right| = 20\log\tau$$

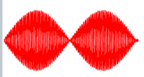
Transmission Measurements

Reflection Parameters

$$\text{Reflection Coefficeint } (\Gamma) = \frac{V_{reflected}}{V_{incident}} = \rho\angle\Phi = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$\text{Return Loss} = -20\log\ (\rho) \qquad \rho = |\Gamma|$$

$$\text{Voltage Standing Wave Ratio (VSWR)} = \frac{\text{Vmax}}{\text{Vmin}} = \frac{1+\rho}{1-\rho}$$



Reflection Measurements

No reflection
($Z_L = Z_0$)

0 — ρ — 1

∞ dB — **RL** — 0 dB

1 — **VSWR** — ∞

Full reflection
(Z_L = open, short)

**Scalar Reflection Coefficient (ρ), Return Loss, and VSWR are calculated from measured Vector Reflection Coefficient (Γ)*

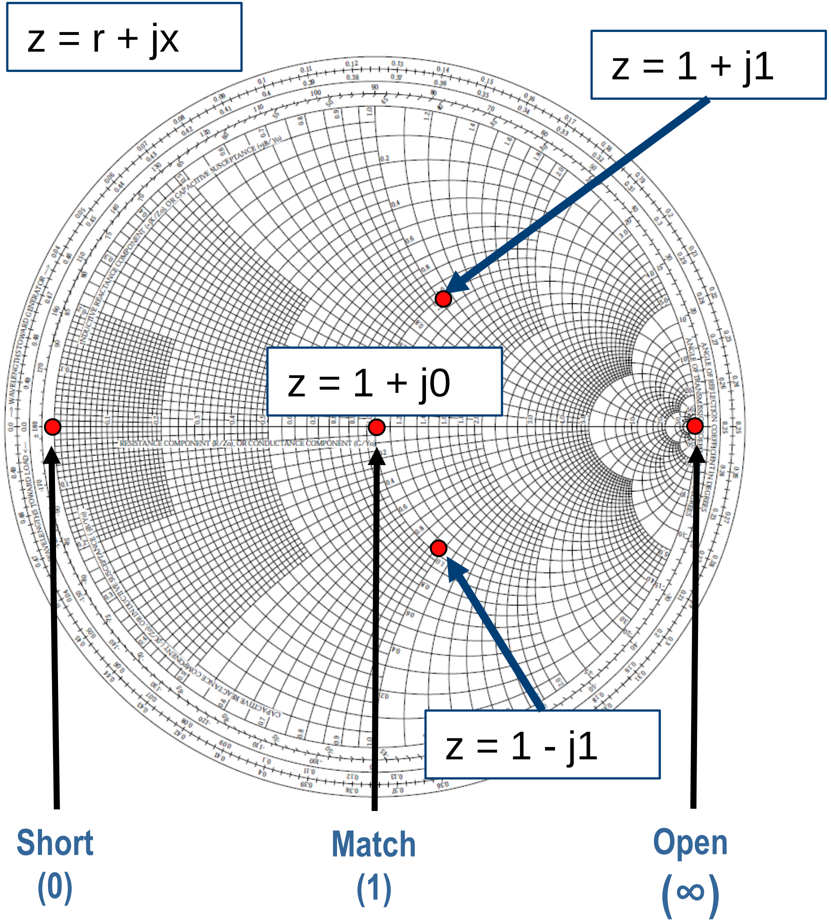
Smith Chart

- ► Published by Phillip H. Smith of Bell Labs in 1939
- ► Plot of normalized **complex impedances**
  - – **z = r + jx** where ***z = Z$_L$ / Z$_0$***
  - – **r** = real component, resistance (r = 1 = 50/50)
  - – **x** = imaginary component, reactance
- ► Used extensively in impedance matching

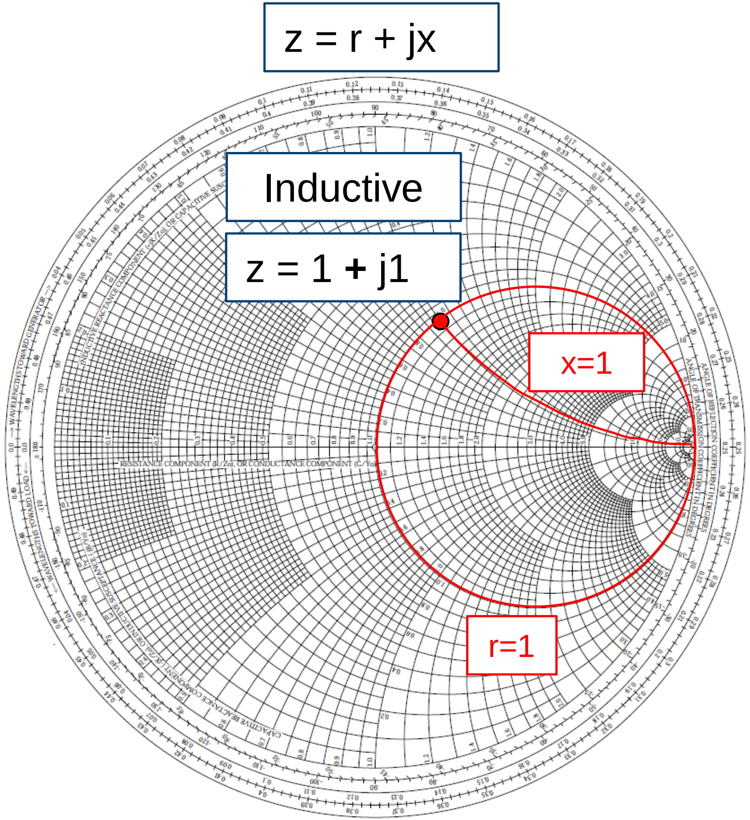
No reflection
($Z_L = Z_0$)

Full reflection
(Z_L = open, short)

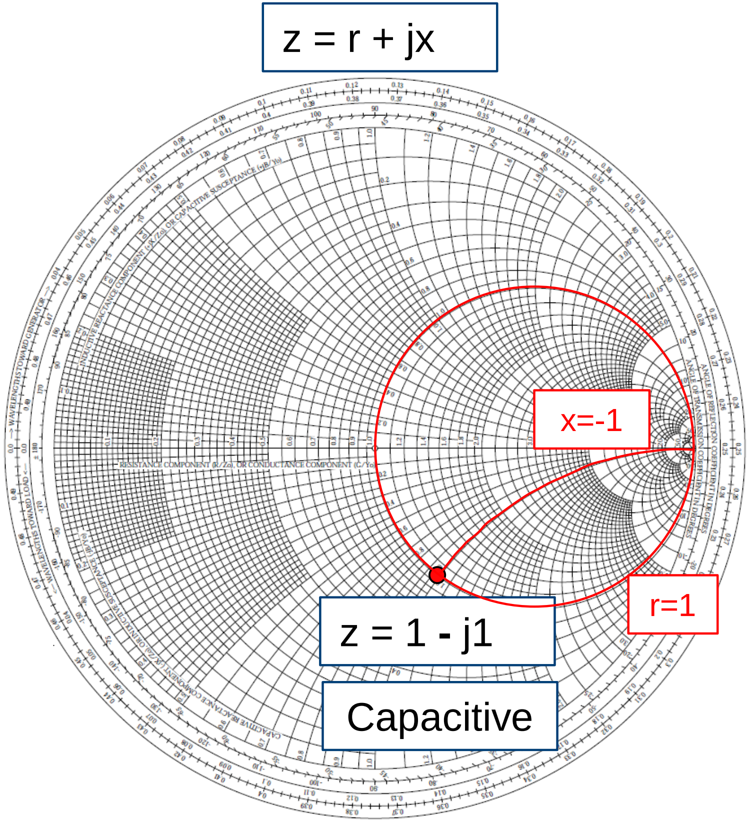
0	ρ	1
∞ dB	**RL**	0 dB
1	**VSWR**	∞



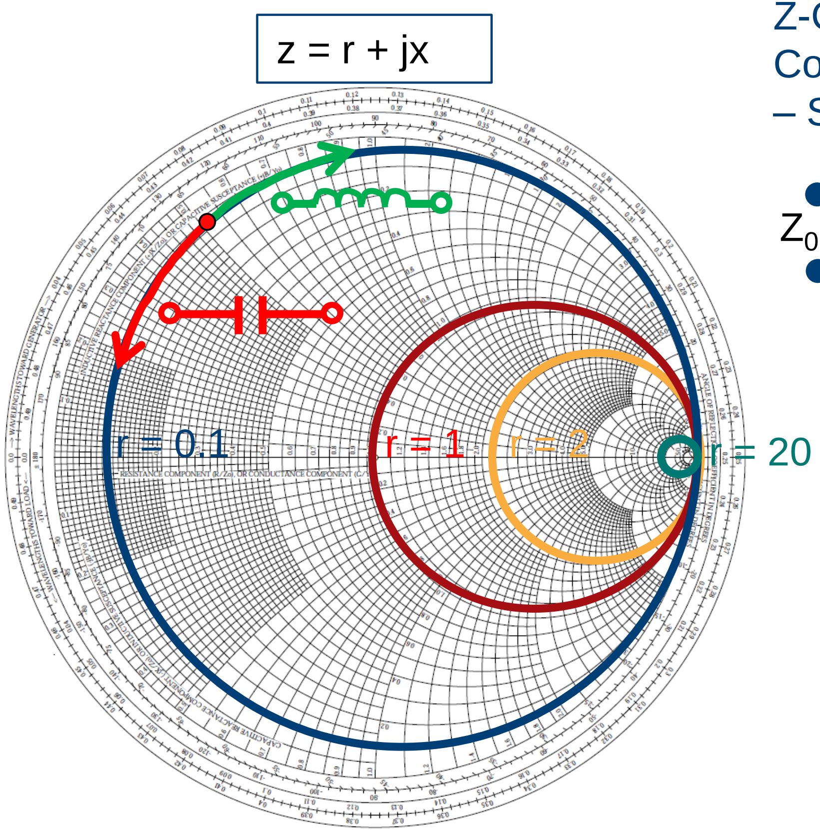
Smith Chart



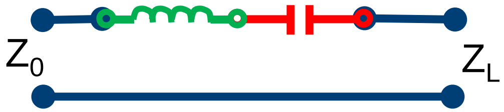
Smith Chart



Smith Chart

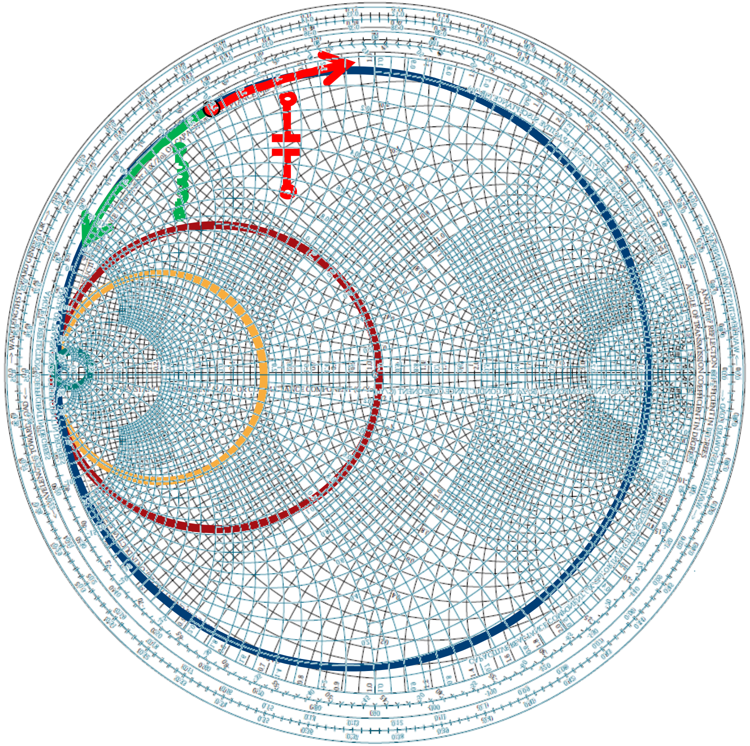


Z-Chart (Resistance)
Constant Resistance Circles
– Series LC Element

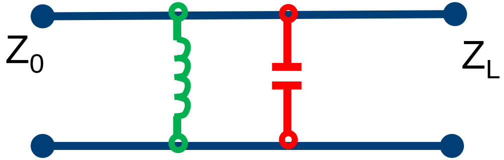


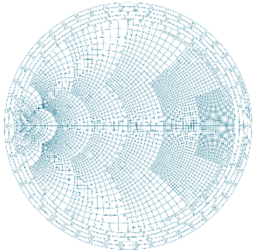
Smith Chart

$$Y = \frac{1}{Z} = G + jB$$



Y-Chart (Admittance)
Constant Conductive Circles
– Shunt LC Element

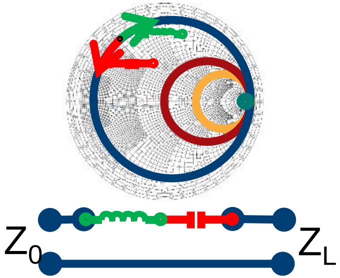




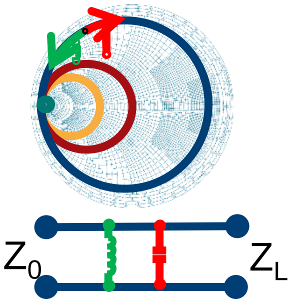
Also called Inverse Smith
Often printed on Smith Chart
but in another color.

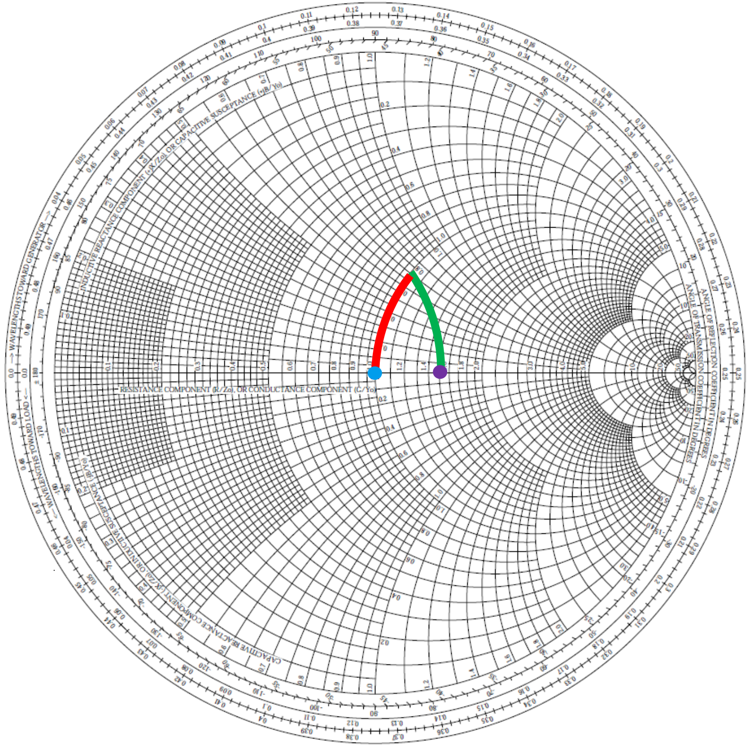
Smith Chart

Series (Z-Resistance)

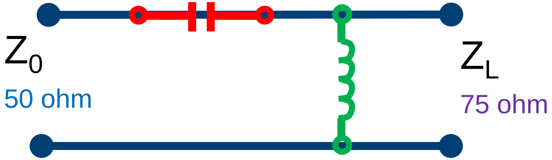


Shut (Y-Admittance)



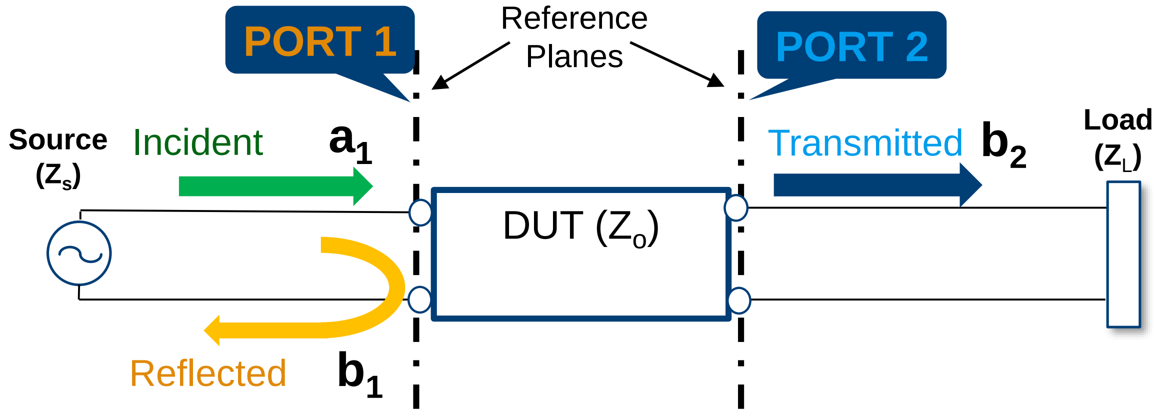


Matching Basic



f = 2.4 GHz
C = 1.9 pF
L = 7 nH

Measurement – 1 Port and 2 Port



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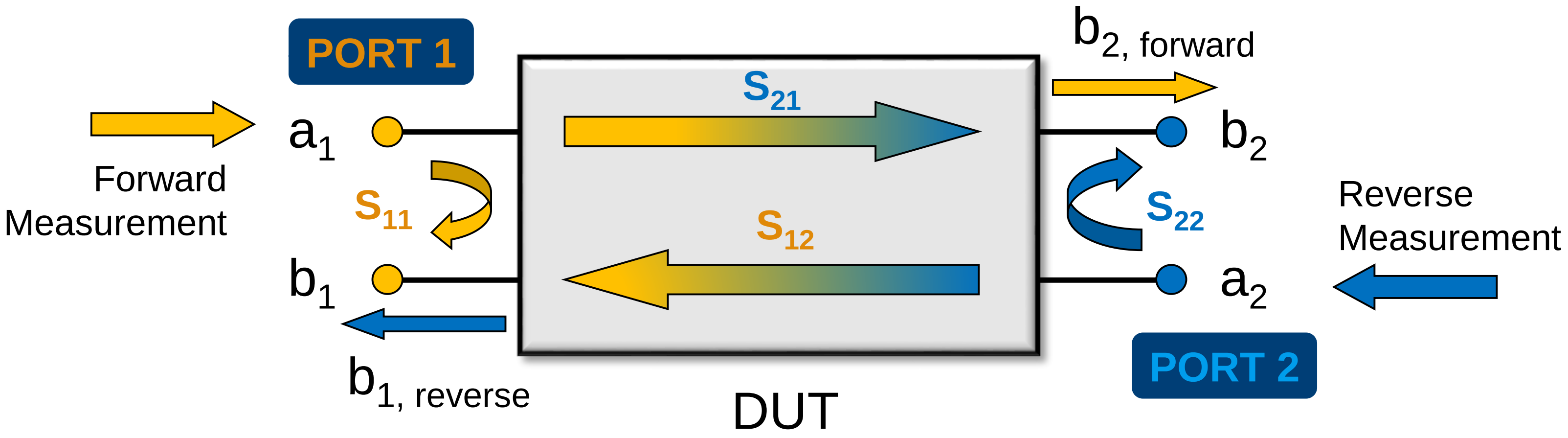
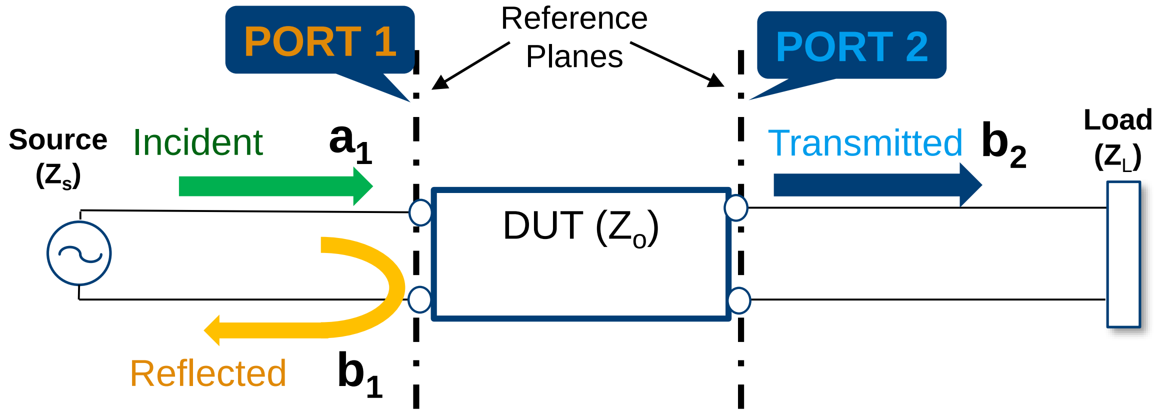
S-Parameters



S-Parameters (Scattering-Parameters) represent the relationship between scattered waves (a, b)

- S-Parameters are **dimension free** (units disappear but often display as magnitude in dB)
- S-Parameters represent reflection and transmission coefficients
- These coefficients are based on a defined characteristic impedance (usually 50 ohms)
- Displayed as S_{xy} where **x** is measurement port and **y** is the stimulus port

Measurement – 1 Port and 2 Port



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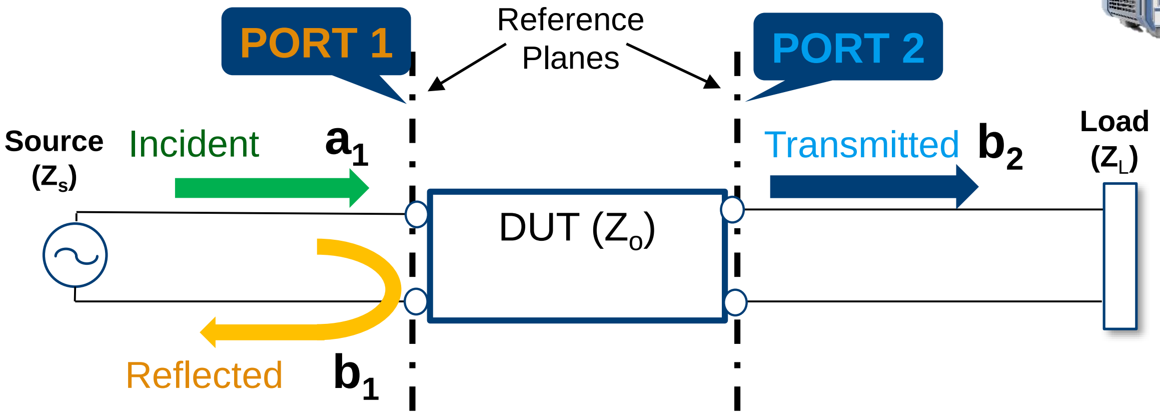
Instrument – Vector Network Analyzer (VNA)



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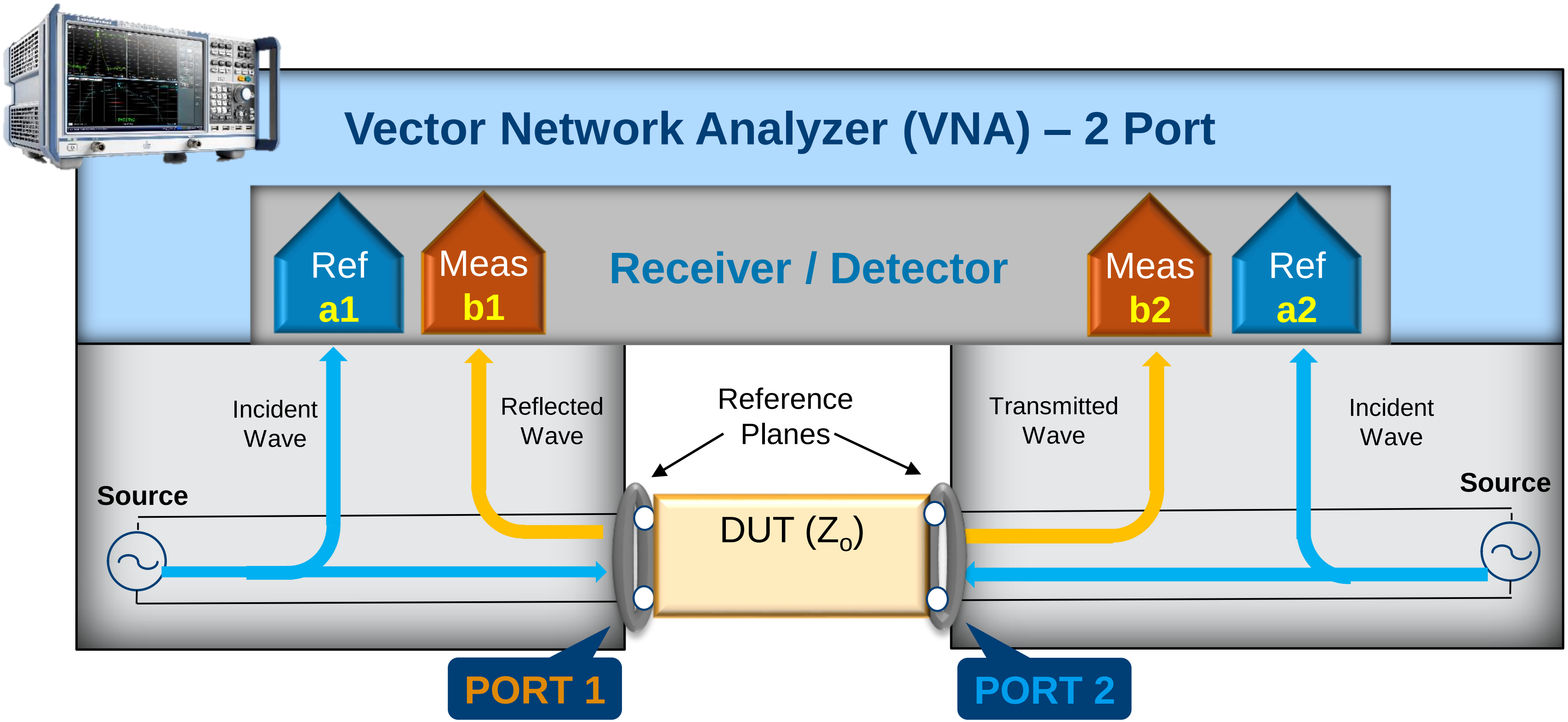
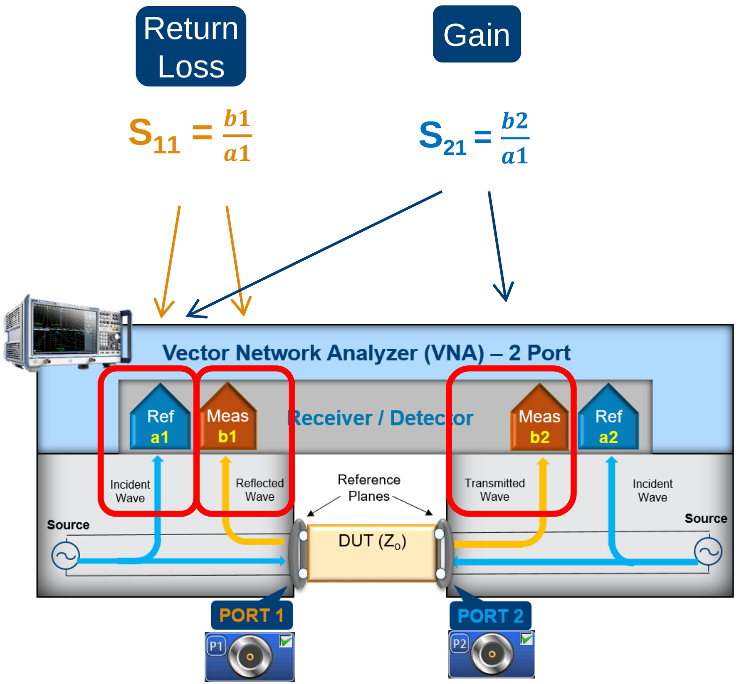
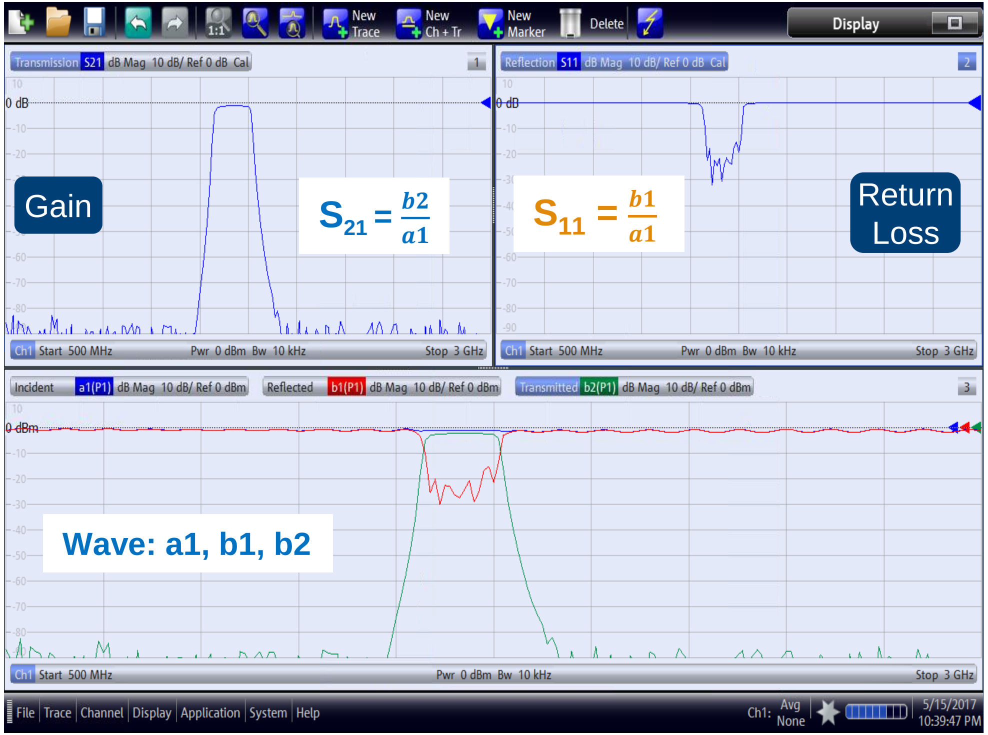


VNA – S-Parameters



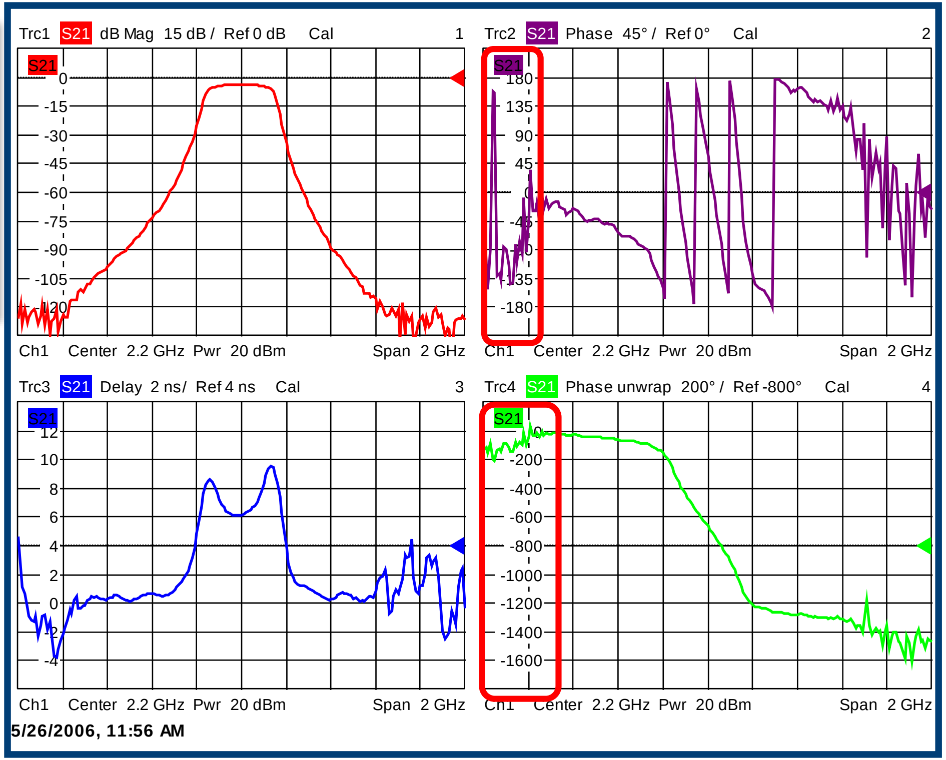
Filter Measurement



VNA – Transmission Measurement

Gain Loss

Group Delay



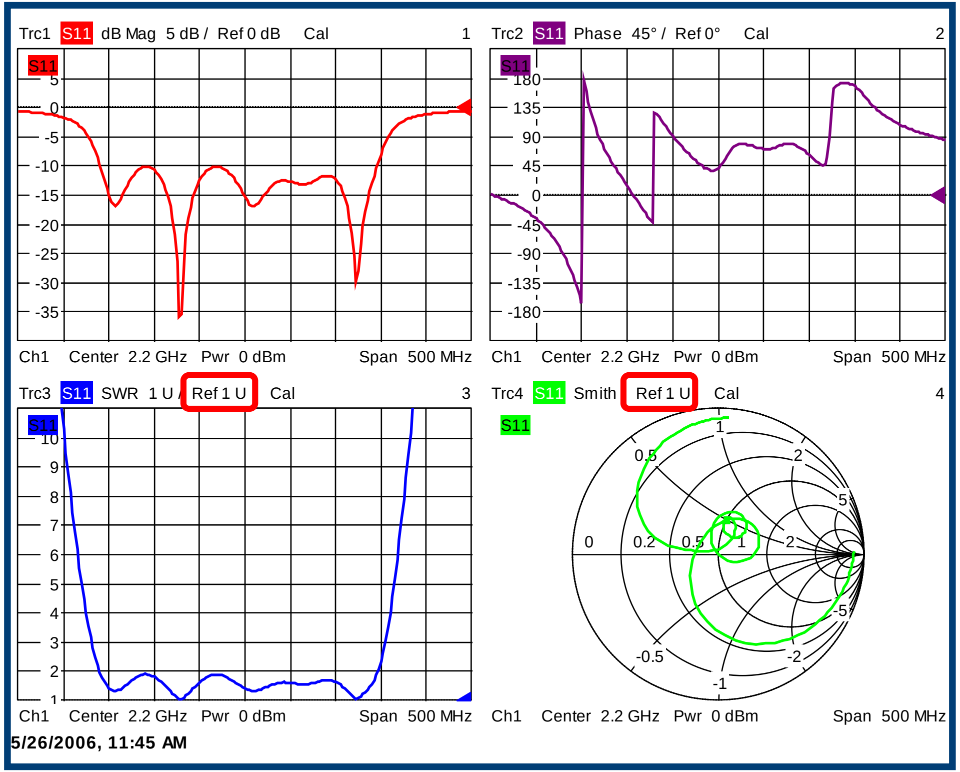
Transmission Phase

Transmission Phase Unwrapped

VNA – Reflection Measurement

Return Loss

VSWR

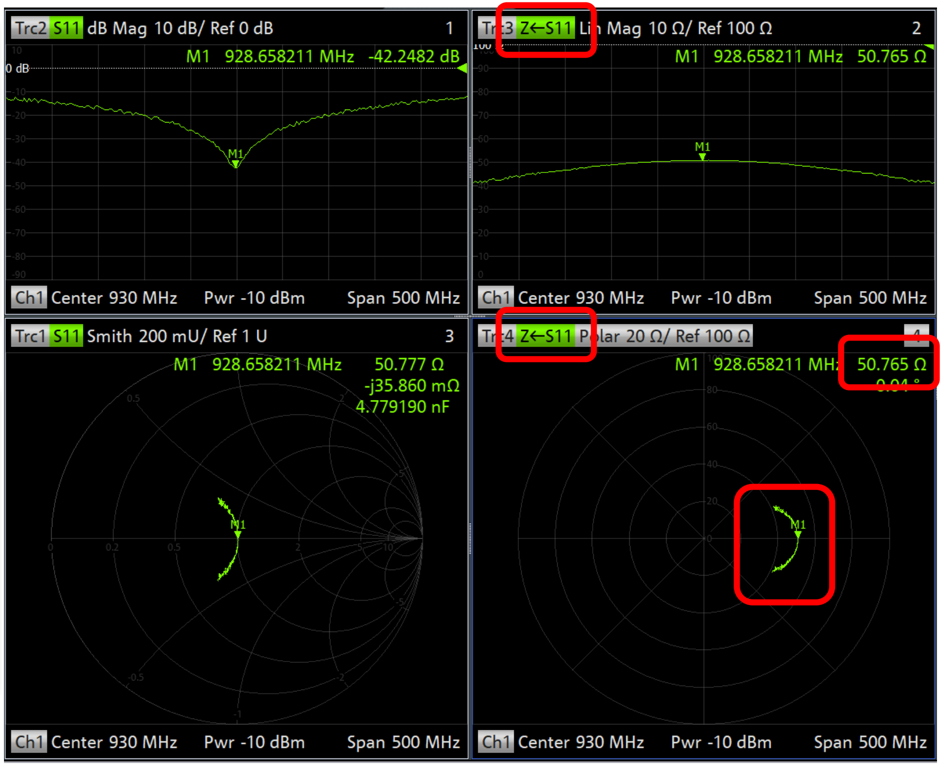


Input Phase

Input Impedance

VNA – Reflection Measurement

Return Loss (S11)



Input Impedance Z Mag

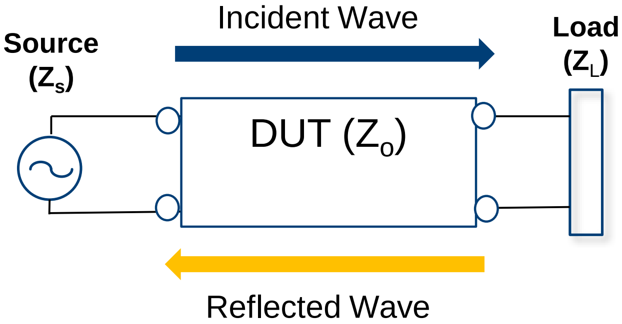
Input Impedance (S11)

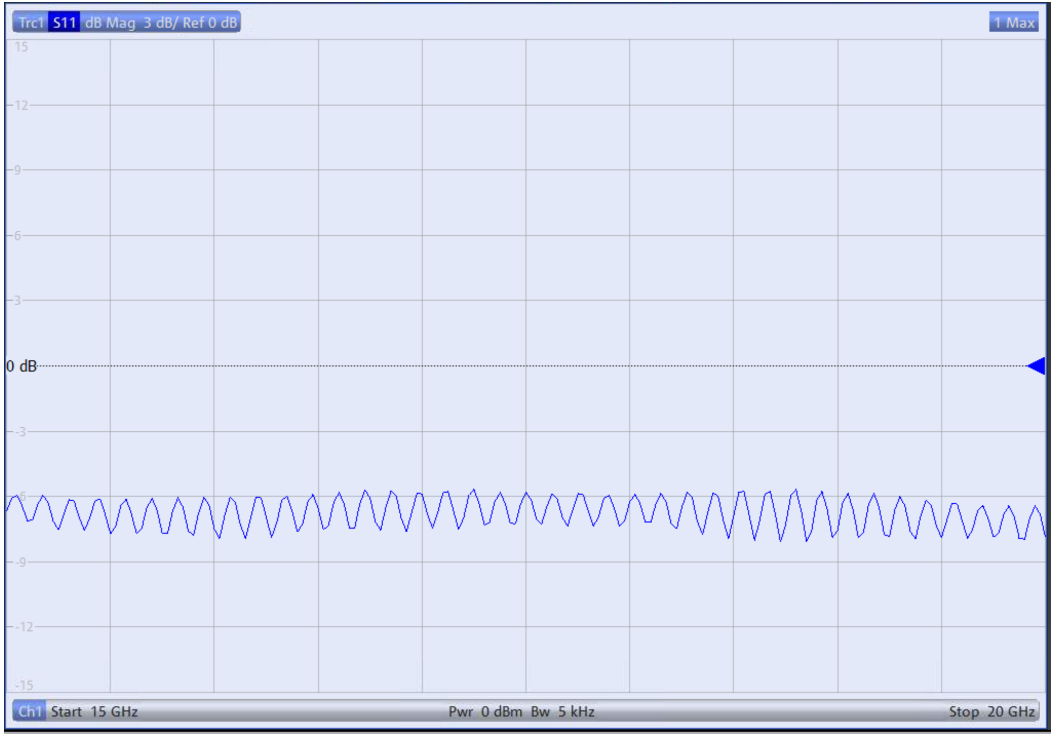
Input Impedance Z Complex

VNA – Measurement Ripple?

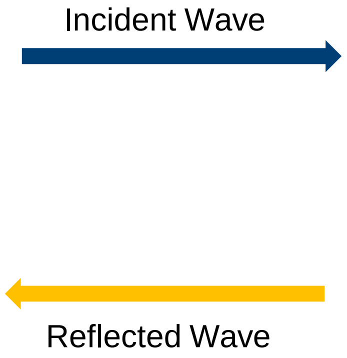
Standing Wave

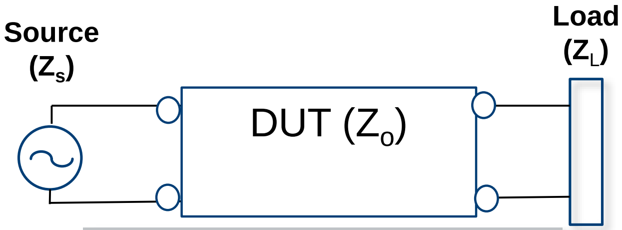
For any mismatch a standing wave is created by the reflecting wave



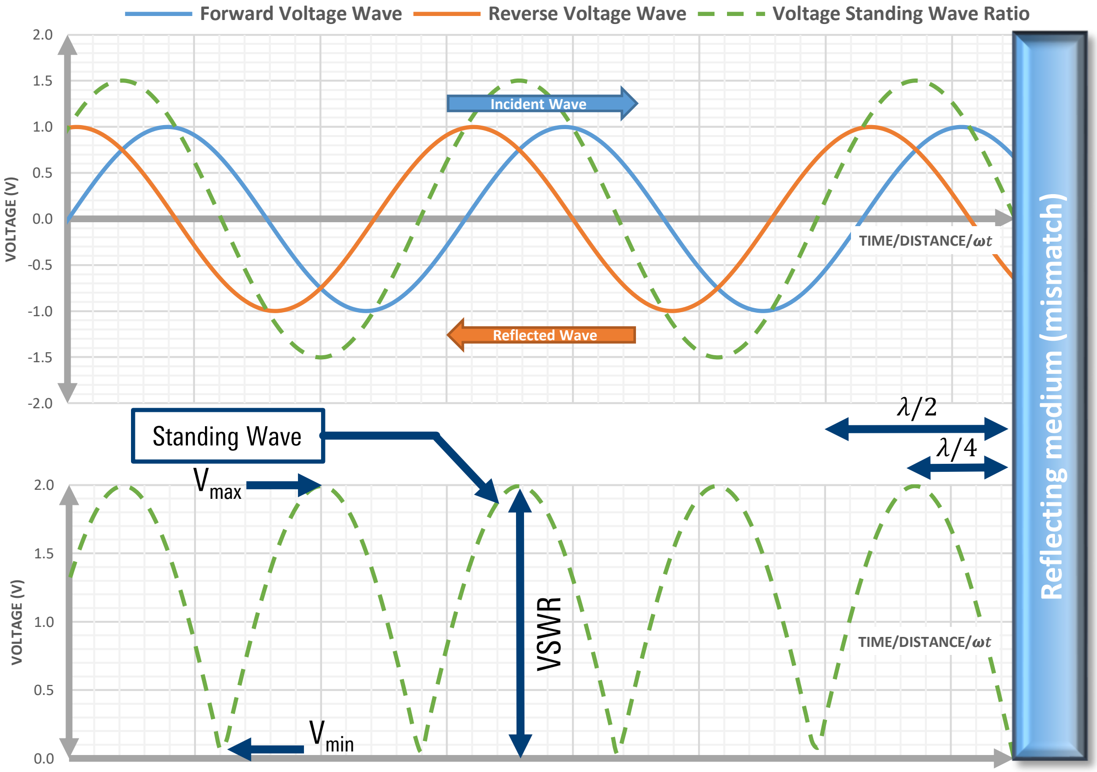


VNA – Standing Waves





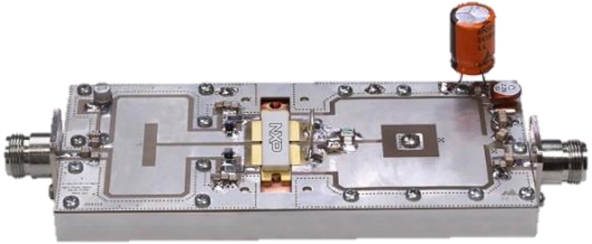
$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+\Gamma}{1-\Gamma}$$



Components

Components – Change the Signal or Signal path.
Transmission Lines – Transport signals, can be a component.

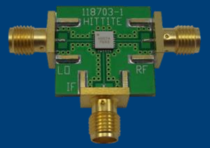
Two basic types of components
- Passive – Change Signal without external power
- Active – Require external power to change signal



Common Components

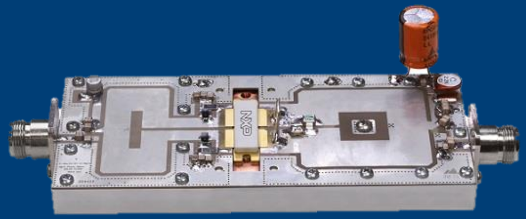
Common Passive Components

- Transmission Line
- Attenuators
- Filters
- Couplers
- Combiners
- Power dividers
- Antennas
- Circulator
- Isolators
- Duplexers and Diplexers
- Mixers



Common Active Components

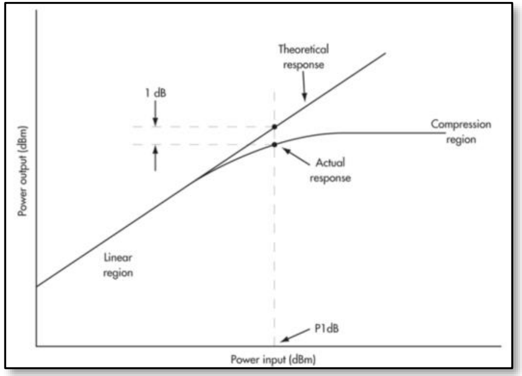
- Switches
- Power amplifiers
- Low noise amplifiers
- Oscillators
- Mixers

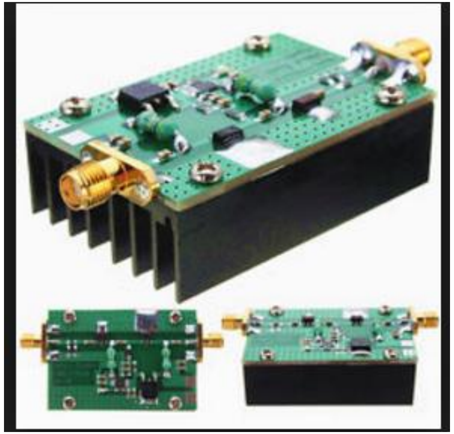


Active Components

Common Active Components Measurements

- Gain
- Pass band flatness (amplitude and group delay)
- Bandwidth
- Isolation
- 1 dB compression (could be .1 dB, 3 dB, etc)
- Harmonics
- TOI (3rd order distortion)
- Noise figure



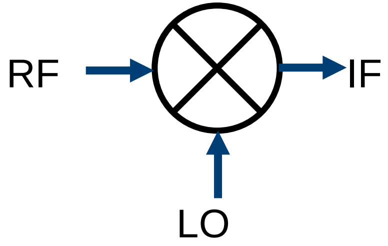


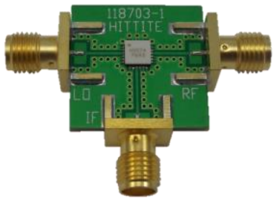
Components – Mixers

- Mixers change the frequency of signal while preserving other characteristic such as amplitude and phase.

- Common Mixer Frequency Setups
  - Fixed RF, Swept LO and IF
  - Fixed LO, Swept RF and IF
  - Fixed IF, Swept LO and RF (used in spectrum analyzers)

- Upconversion
  - Output frequency is higher than Input frequency
- Downconversion
  - Output frequency is lower than Input frequency

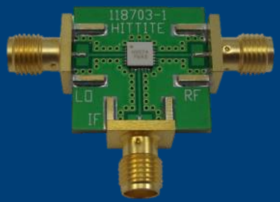




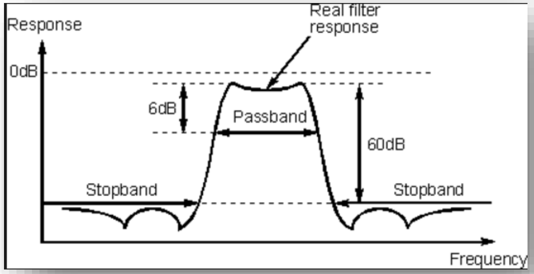
Components – Mixers

Common Mixer Measurements

- Conversion Loss
- Image rejection
- LO-IF isolation
- RF-IF isolation
- Pass band flatness (amplitude and group delay)
- Harmonics and 3rd order products
- Group delay

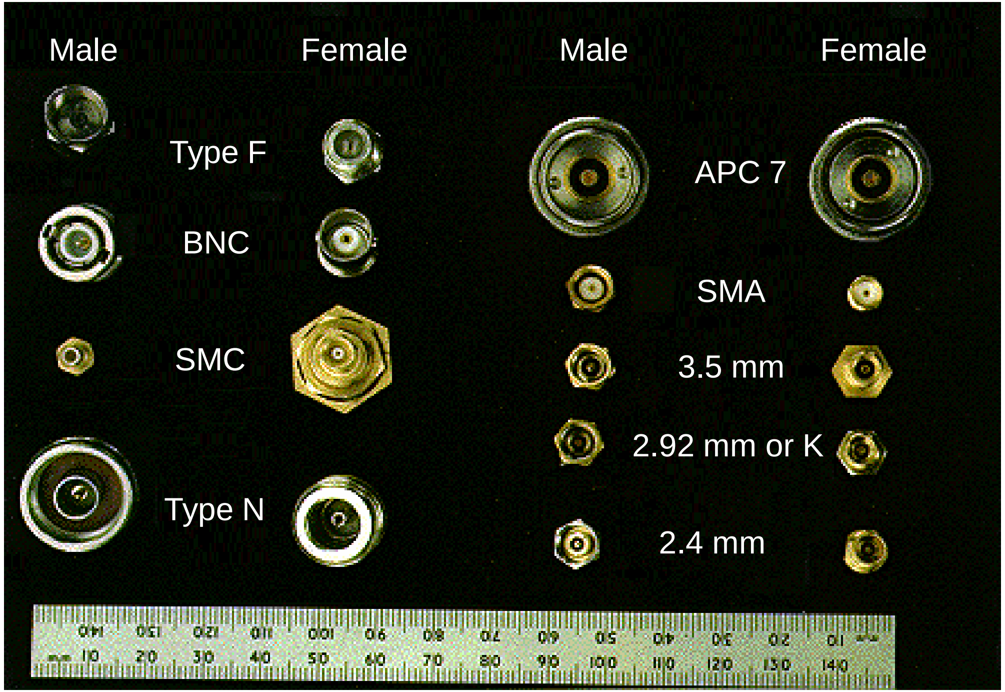


- 4-port VNA can simplify the characterized of a mixer

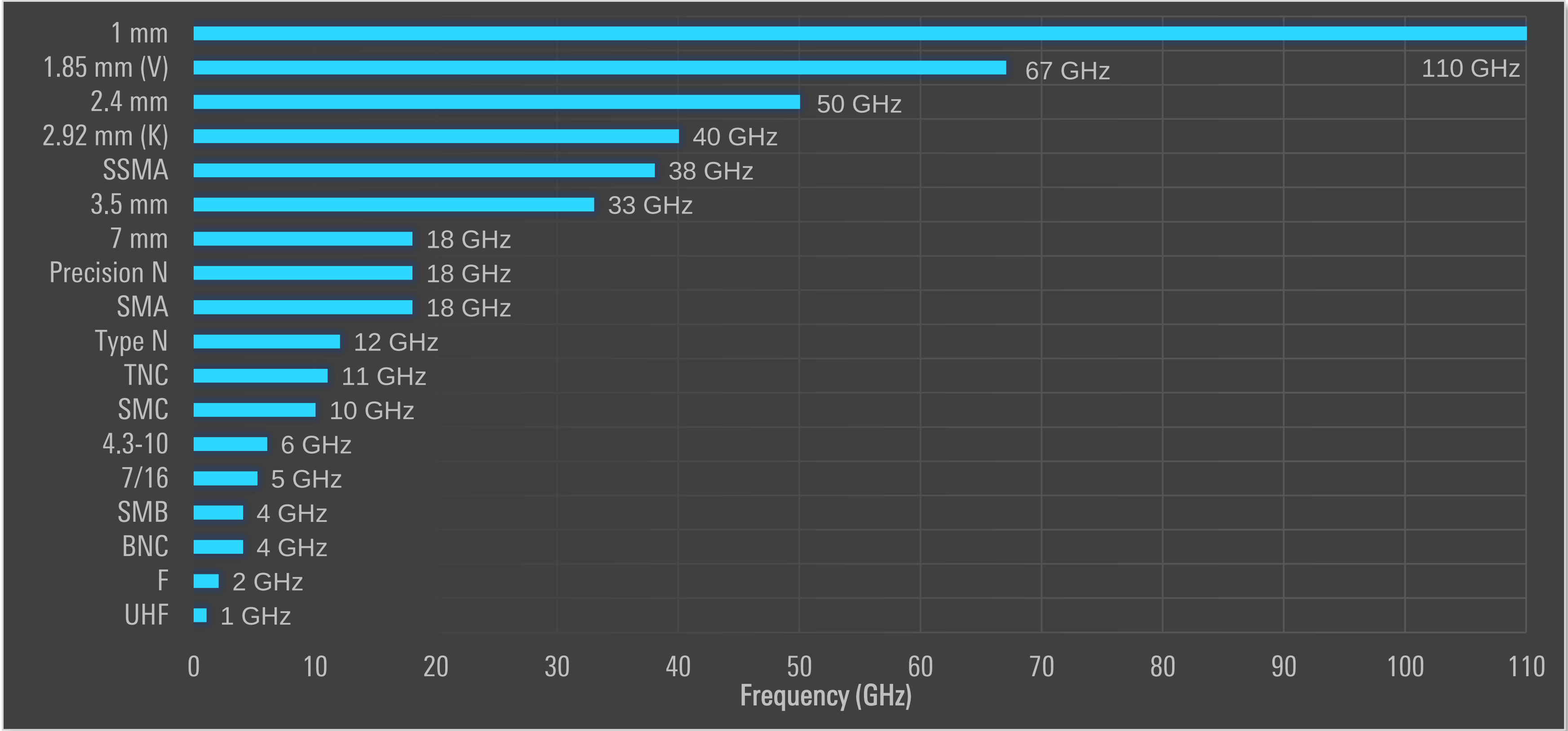


Connectors

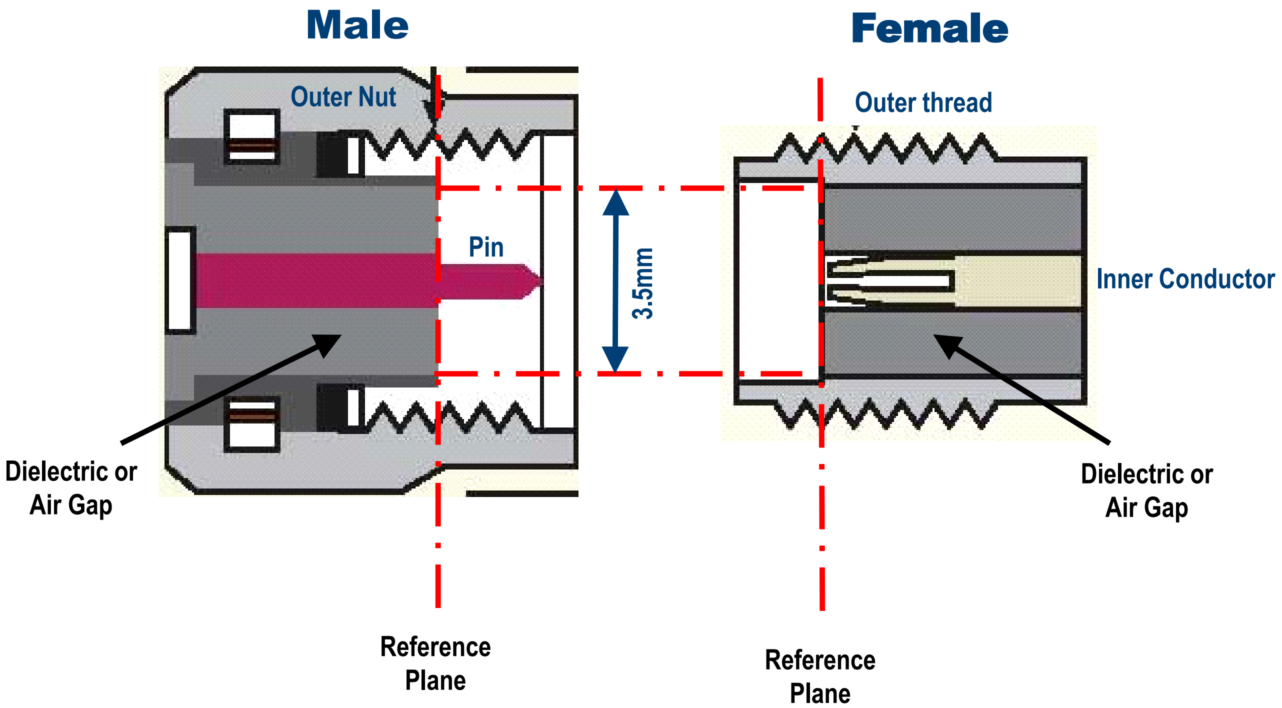
- Connectors are selected for **frequency** range, quality, and ruggedness.
- Can connectors cause mismatch?



Connector Frequency Ranges



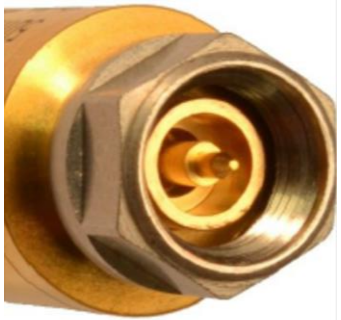
Connector Construction



Connector Compatibility

SMA, 3.5 mm, and 2.92 mm connectors are mechanically compatible and can be mated interchangeably. 2.4 mm and 1.85 mm connectors are also mechanically compatible.

*Recommend using Male of high frequency connector because of higher precious to inner pin structure. *Example: Male 3.5 mm with Female SMA*

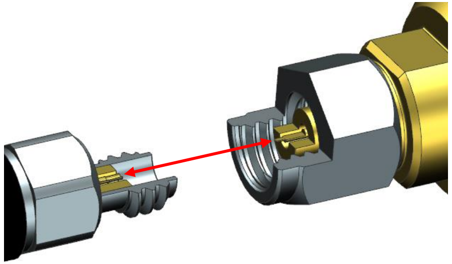


Recommended Torque for Common Connectors

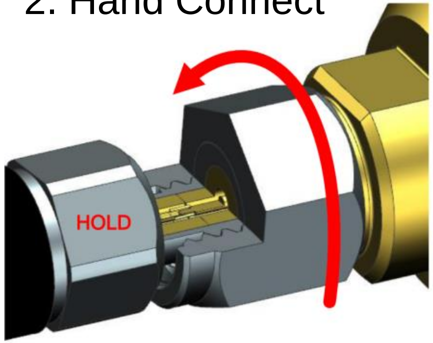
Connector	Torque (in-lb)
Type N	13.3
SMA	5
3.5 mm	8
2.92 mm	8
2.4 mm	8
1.85 mm	8
1.0 mm	4

Connectors – Proper Mating Technique

1. Align

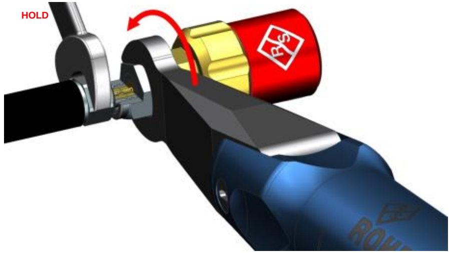


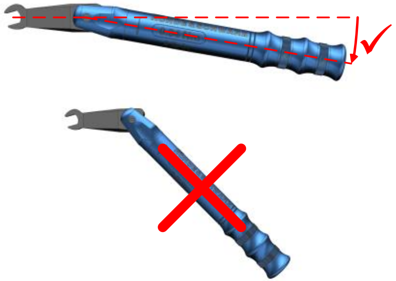
2. Hand Connect



- DON'T TURN CABLE
- Turn only the coupling nut!!
- If you feel resistance, disconnect and inspect connectors
- Be sure to keep the body of the female connector stable
- Continue until finger tight

3. Proper Torque





Recap – RF Components and Measurements

- There are two main type of components measurements: **Reflection** and **Transmission**
- There are many ways to display the same measurement; some display opposite values for the same measurement. Reflection Coefficient (r) = 0 is same as VSWR =1
- Smith Chart plots the normalized impedance and is useful tool for matching impedance.
- VNA (Vector Network Analyzer) is the primary instruments for components measurements.
- S-Parameters are use for majority of the measurement on a VNA.
- Two main type of components, **Passive** and **Active;** Active components require external power.
- Connector are components and can could same mismatch issue as other components.

Thank you for Attending

RF Fundamentals:

SIX-PART WEBINAR SERIES

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