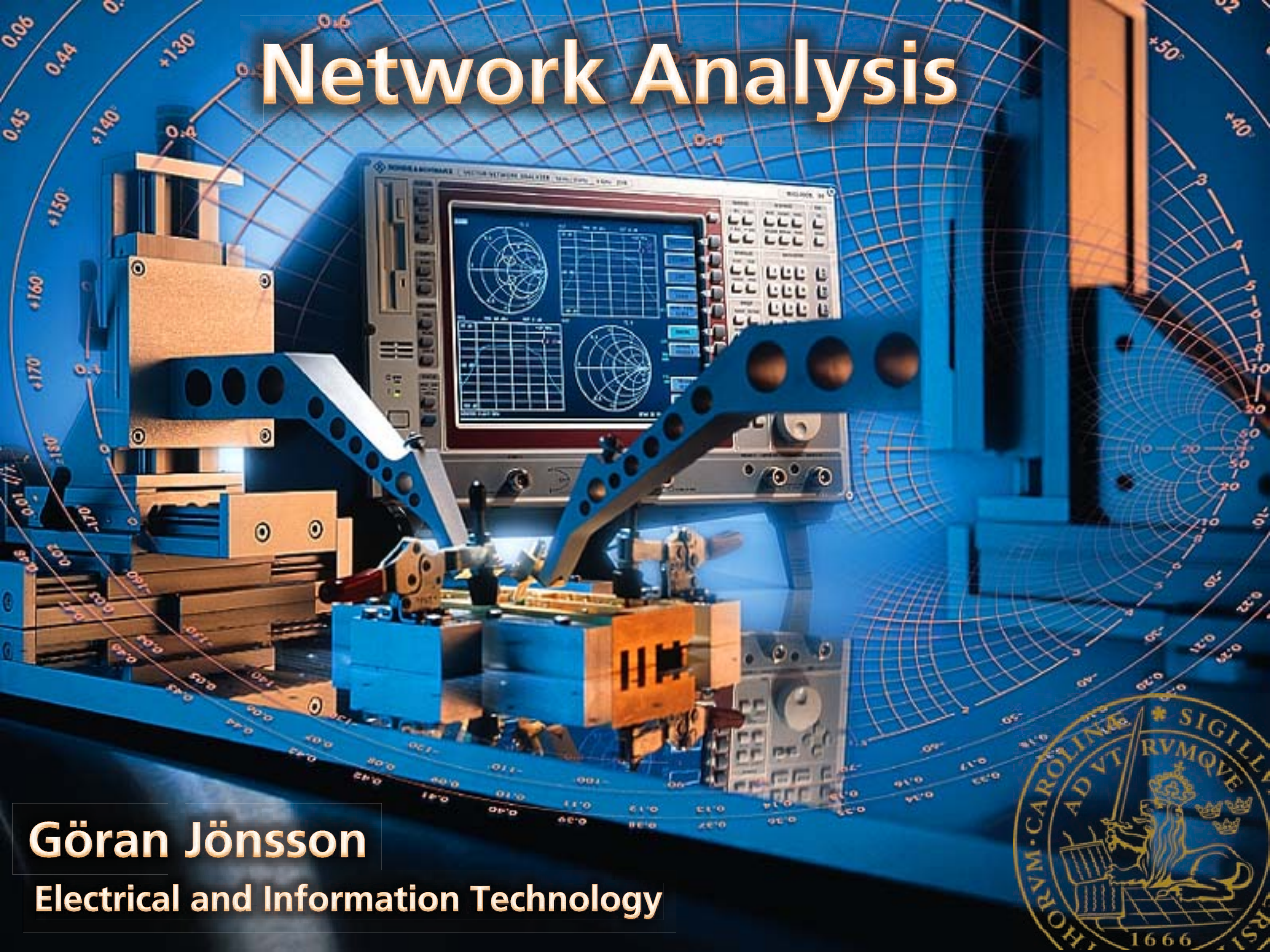
Network Analysis



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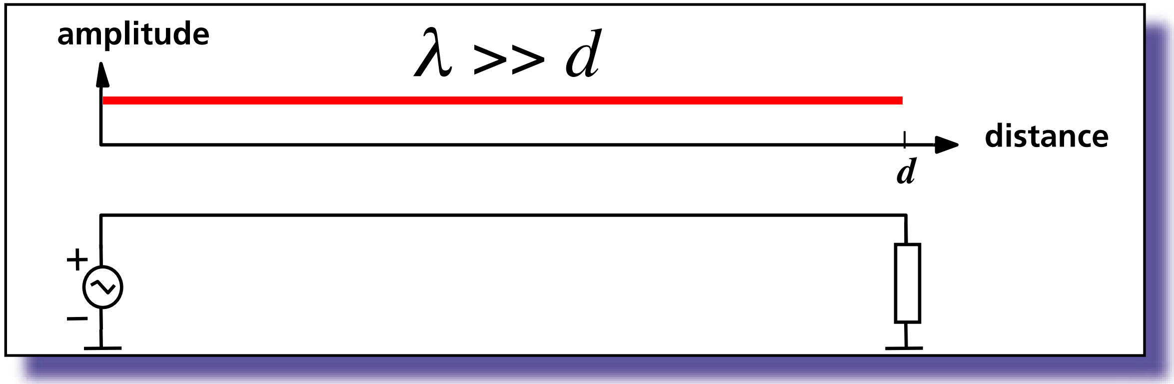
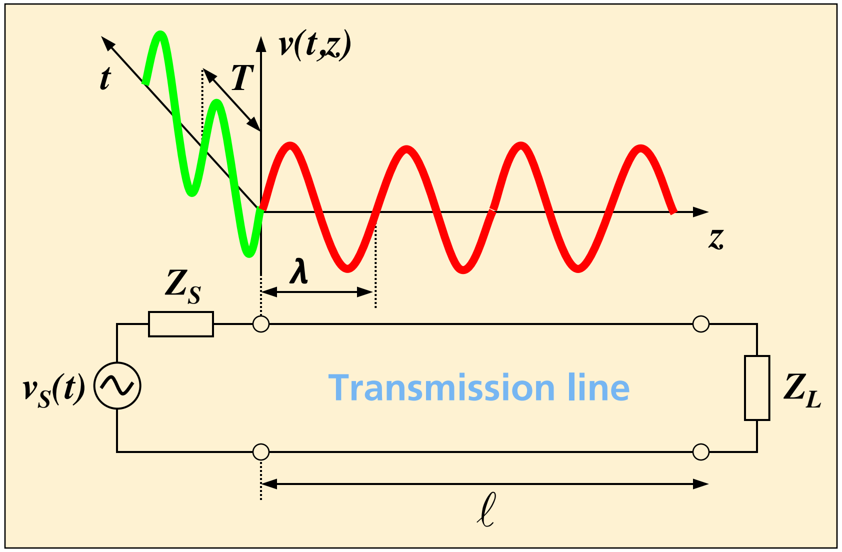
- **Transmission Lines**
- **The Smith Chart**
- **Vector Network Analyser (VNA)**
  - ✓ structure
  - ✓ calibration
  - ✓ operation
- **Measurements**

Waves on Lines

- **If the wavelength to be considered is significantly greater compared to the size of the circuit the voltage will be independent of the location.**



but this is not true at short wavelengths = high frequencies…



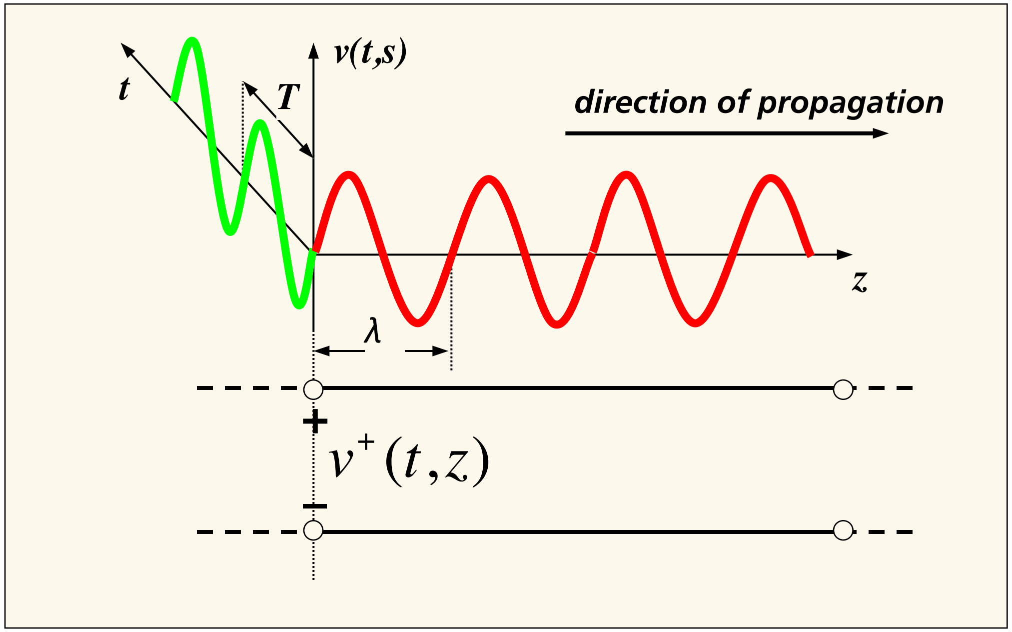
$$v = \frac{\lambda}{T} = \lambda \cdot f$$

$$\Rightarrow \lambda[\mathrm{m}] = \frac{v}{f} = \frac{300}{f[\mathrm{MHz}]}$$

The voltage or the current is a function of both **time** and **distance**

simulation

Travelling Voltage Wave on a Lossless Line



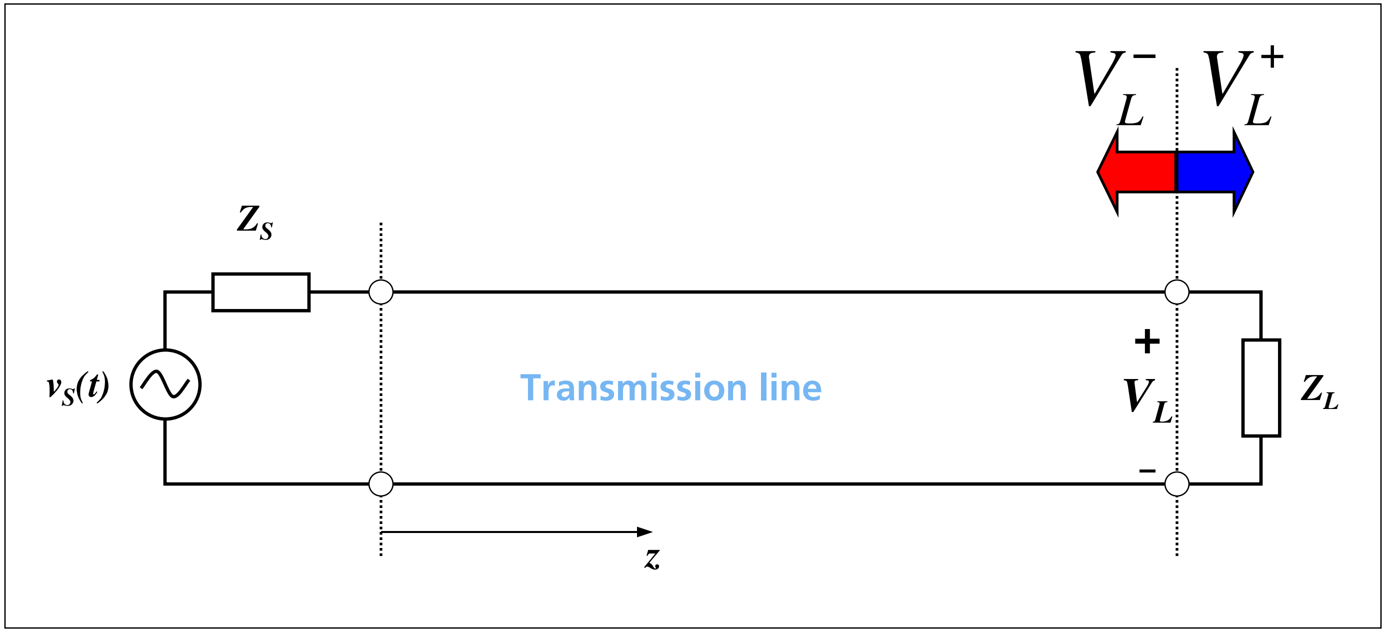
$$v^+(t,z) = \left|V_0^+\right| \cos(\omega t - \beta z + \phi_0^+) = \mathrm{Re}\left[V_0^+ e^{j(\omega t - \beta z)}\right]$$

– **where** $V_0^+ = \left|V_0^+\right| e^{j\phi_0^+}$ **= the complex amplitude of** $v^+(t,z)$ **at** z **= 0**

Reflection Coefficient

- **Definition:**

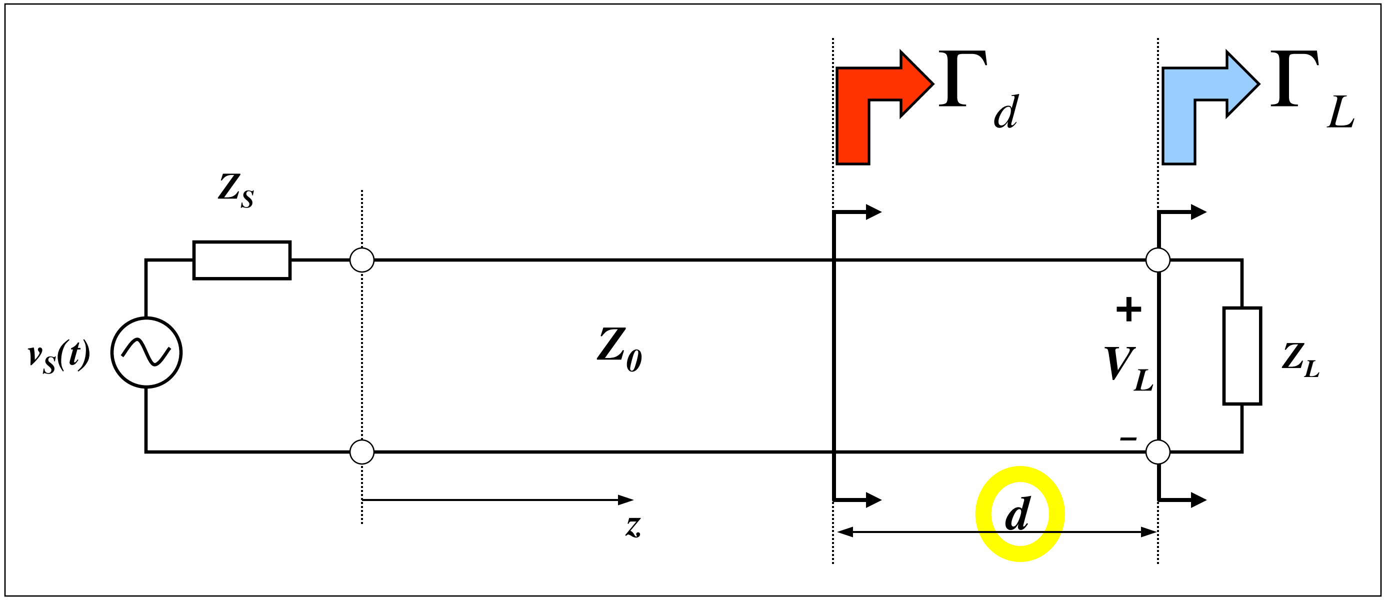
$$\Gamma = \frac{\text{reflected voltage wave}}{\text{incident voltage wave}} = \frac{V^- e^{\gamma z}}{V^+ e^{-\gamma z}}$$



Reflection Coefficient

- At an arbitrary location *d* at the line the reflection coefficient is

$$\Gamma_d = \Gamma_L e^{-2\gamma d} = \Gamma_L e^{-2\alpha d} e^{-2j\beta d}$$



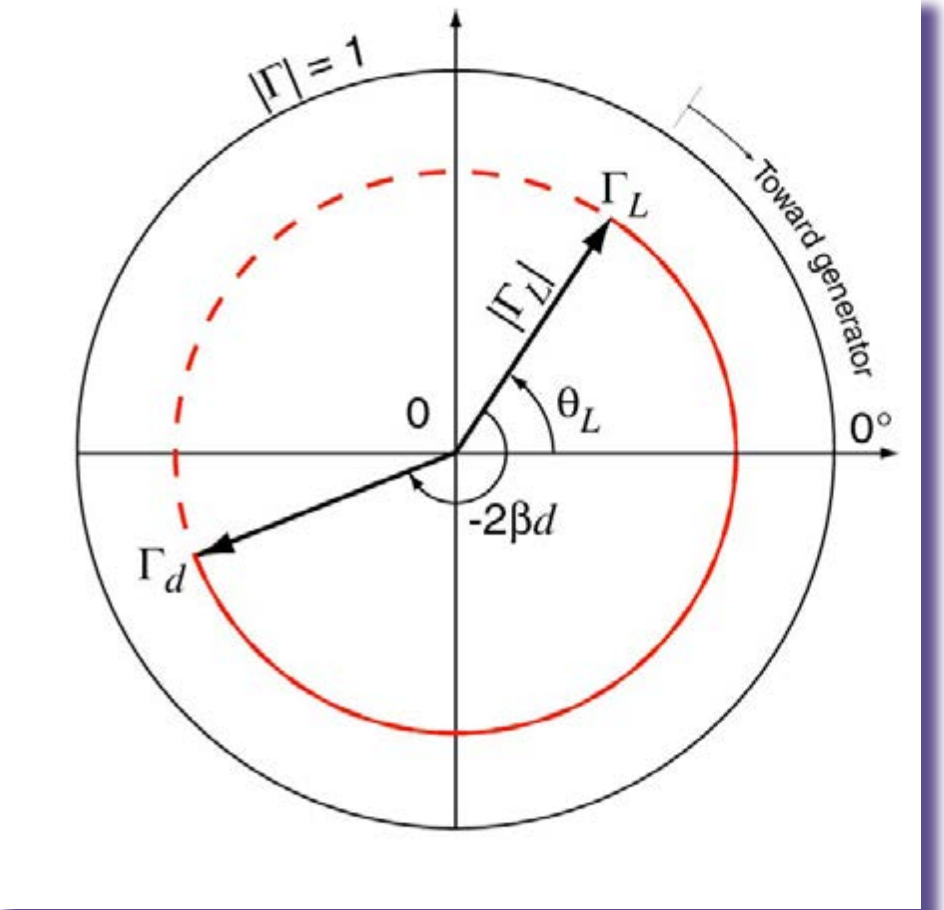
Reflection Coefficient

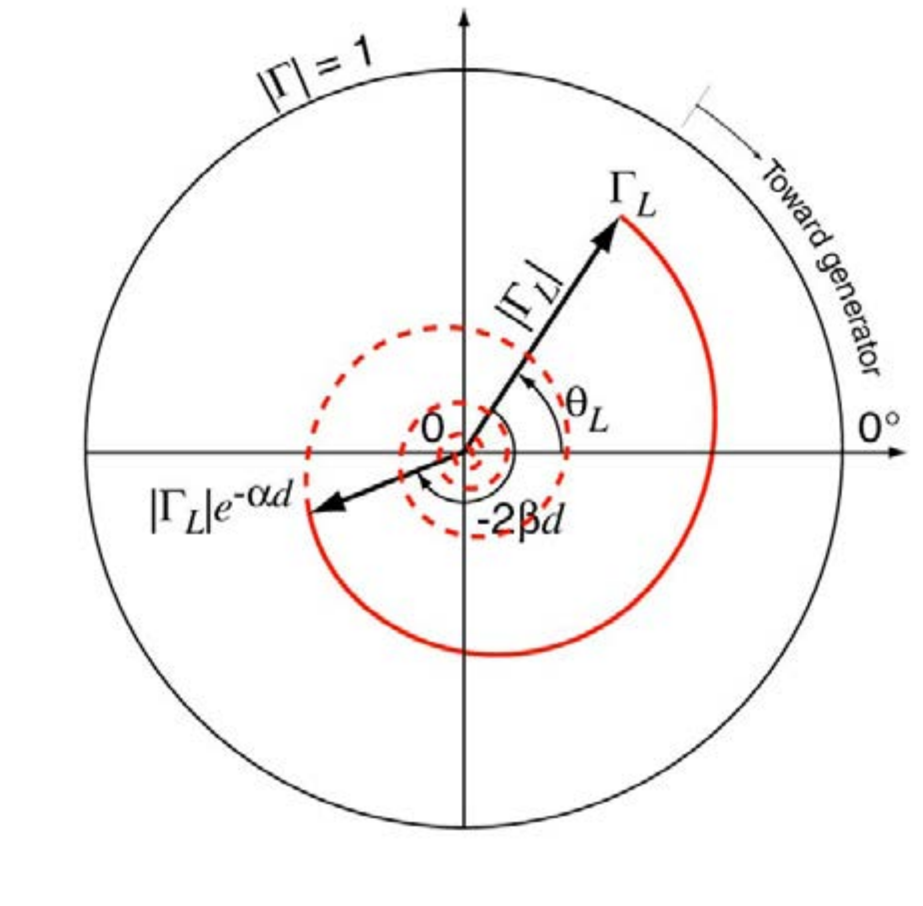
Implies a rotation in the polar Γ-plane

- **Polar diagram**

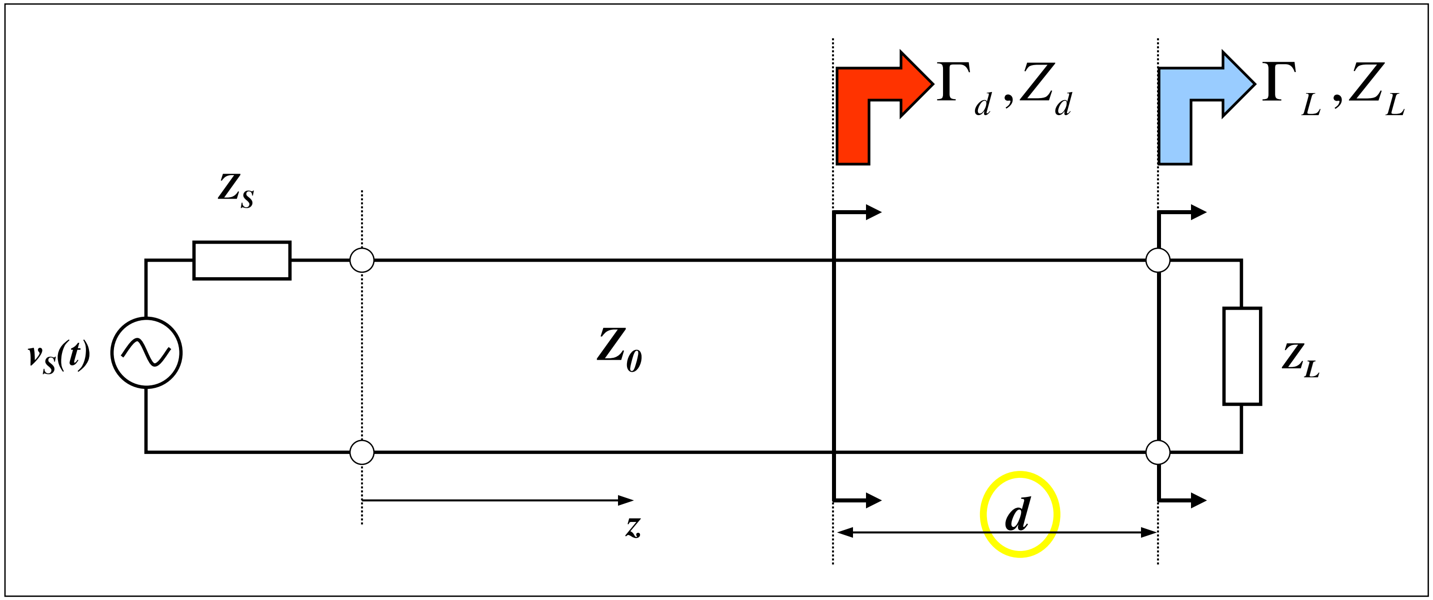
$$\Gamma_d = \Gamma_L e^{-2\gamma d} = \Gamma_L e^{-2\alpha d} e^{-2j\beta d}$$

Lossless transmission line | **Lossy transmission line**



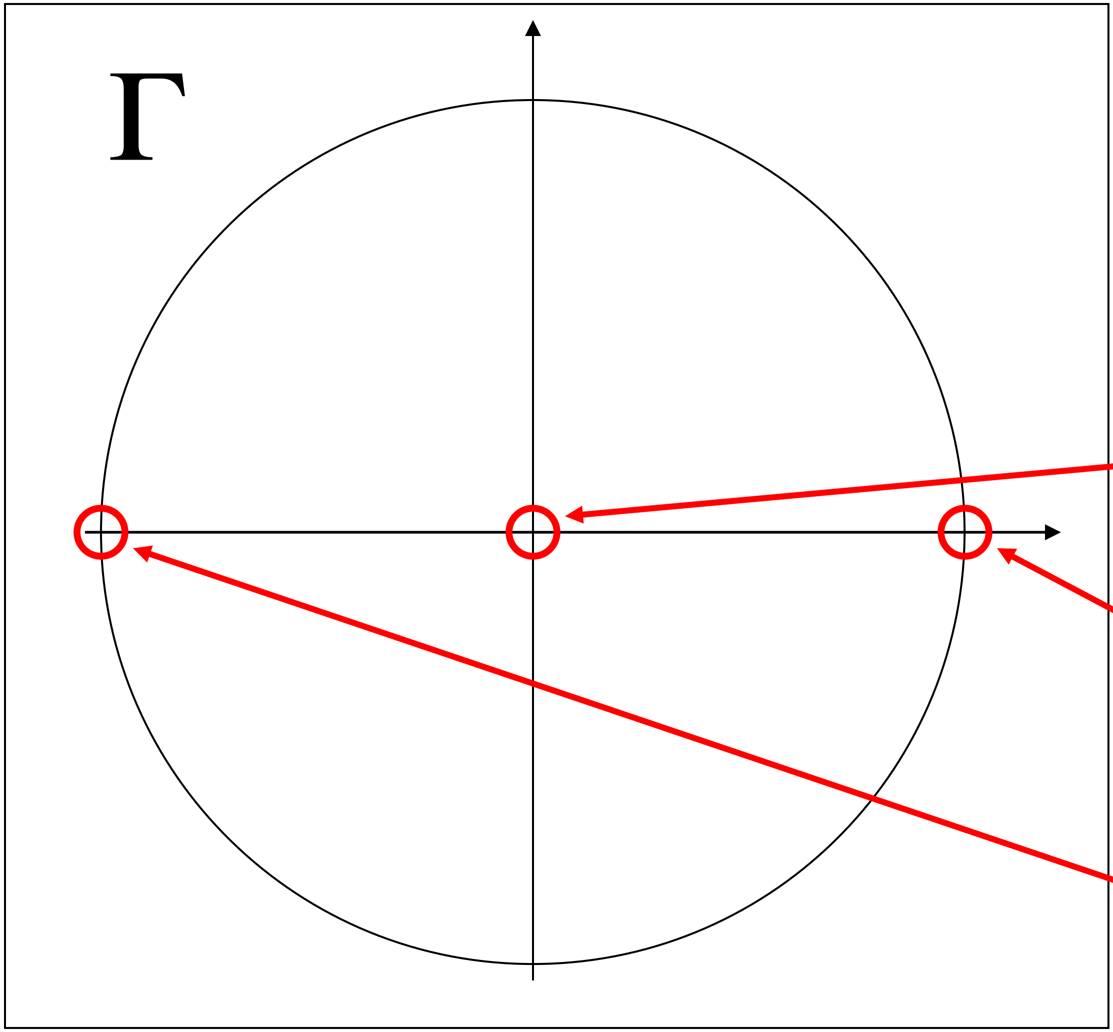


Conversion of Reflection Coefficient to Impedance



$$\Gamma_d = \frac{Z_d - Z_0}{Z_d + Z_0} \quad \Rightarrow \quad Z_d = Z_0 \frac{1 + \Gamma_d}{1 - \Gamma_d}$$

Reflection Coefficient – Load Impedance



$$Z_L = Z_0 \frac{1+\Gamma_L}{1-\Gamma_L}$$

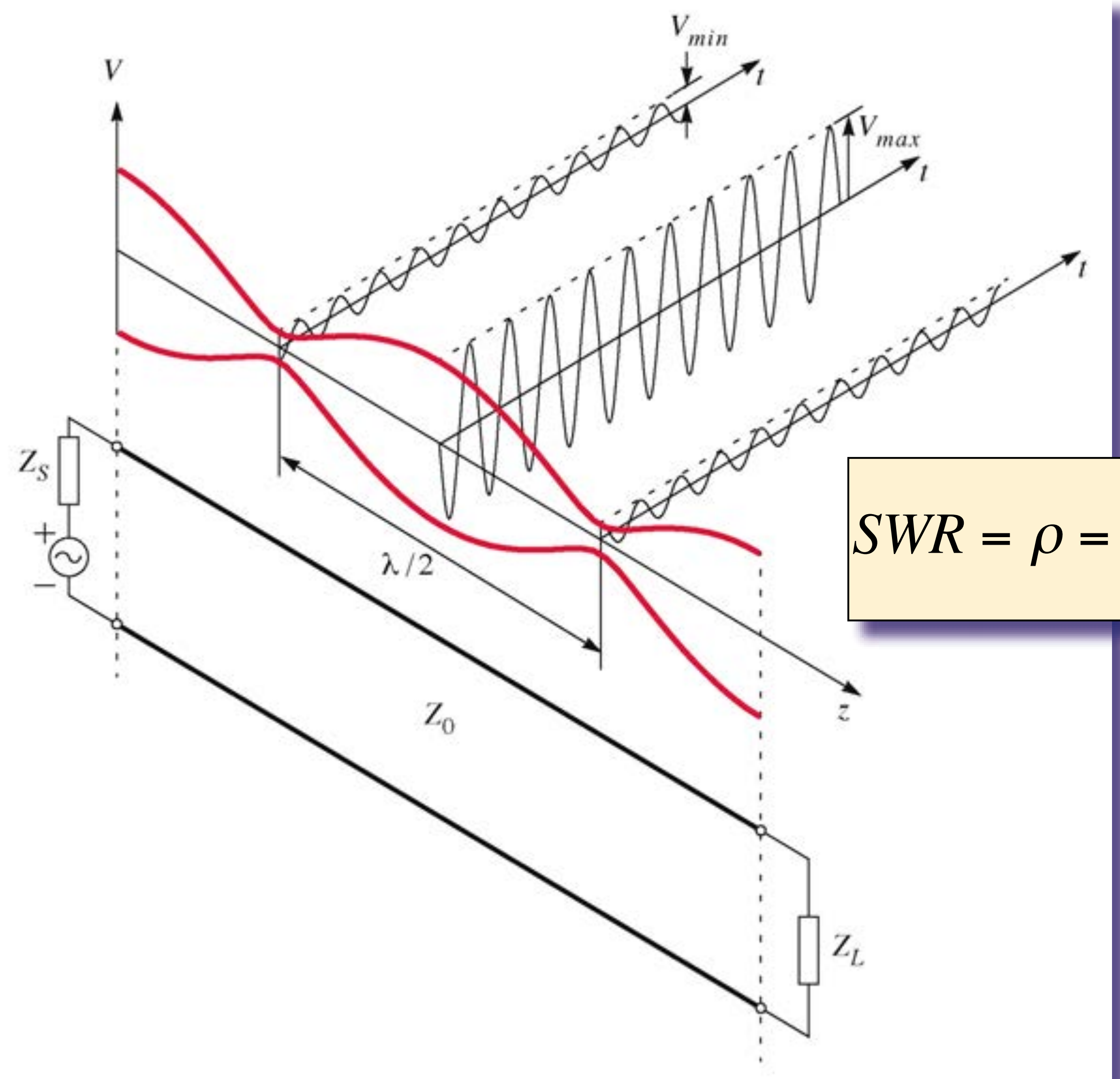
$$\Gamma_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$\Gamma = 0 \Rightarrow Z = Z_0$

$\Gamma = 1 \Rightarrow Z = \infty$

$\Gamma = -1 \Rightarrow Z = 0$

Standing-Wave Ratio

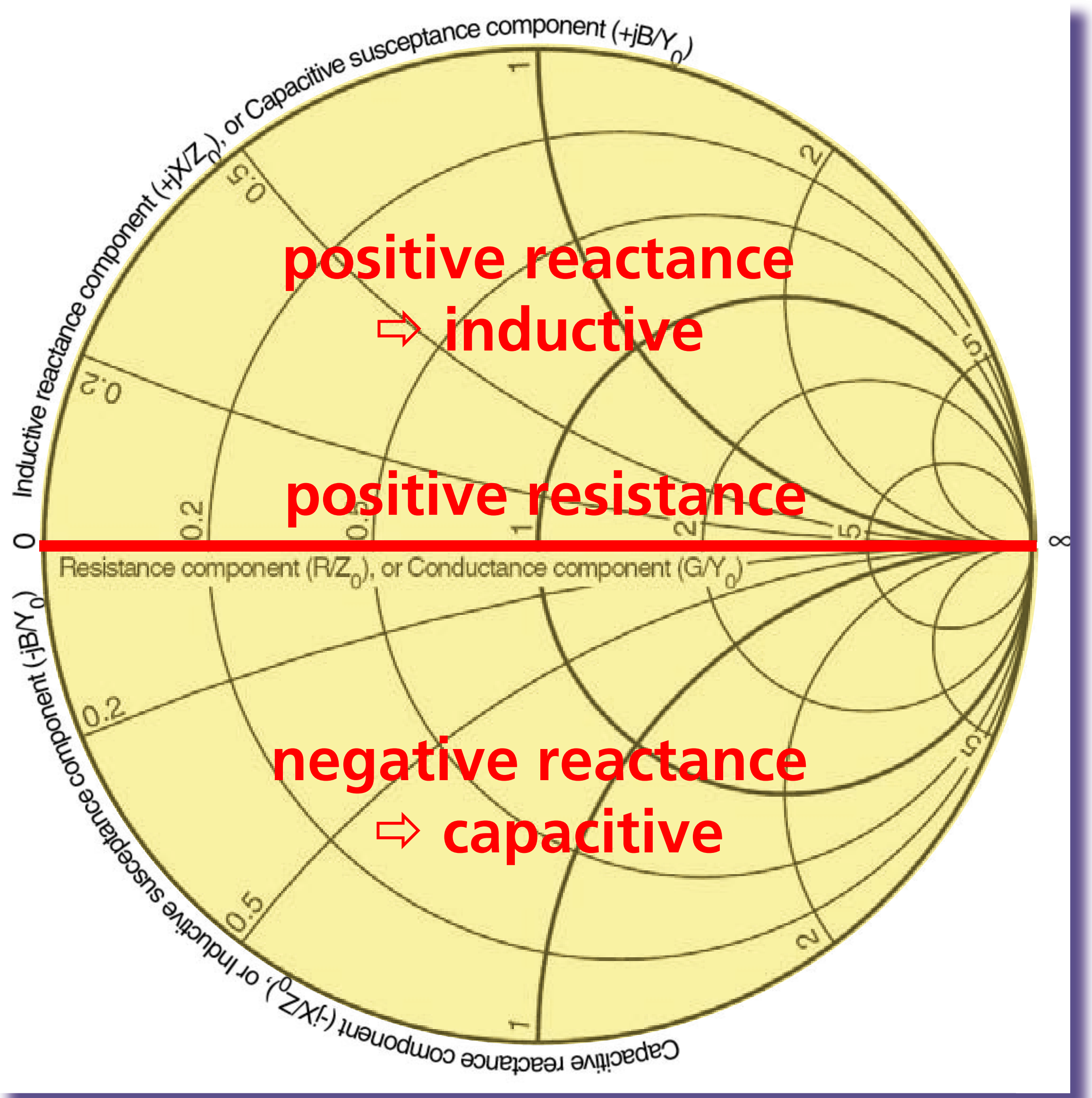


$$SWR = \rho = \frac{V_{max}}{V_{min}} = \frac{I_{max}}{I_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|}$$

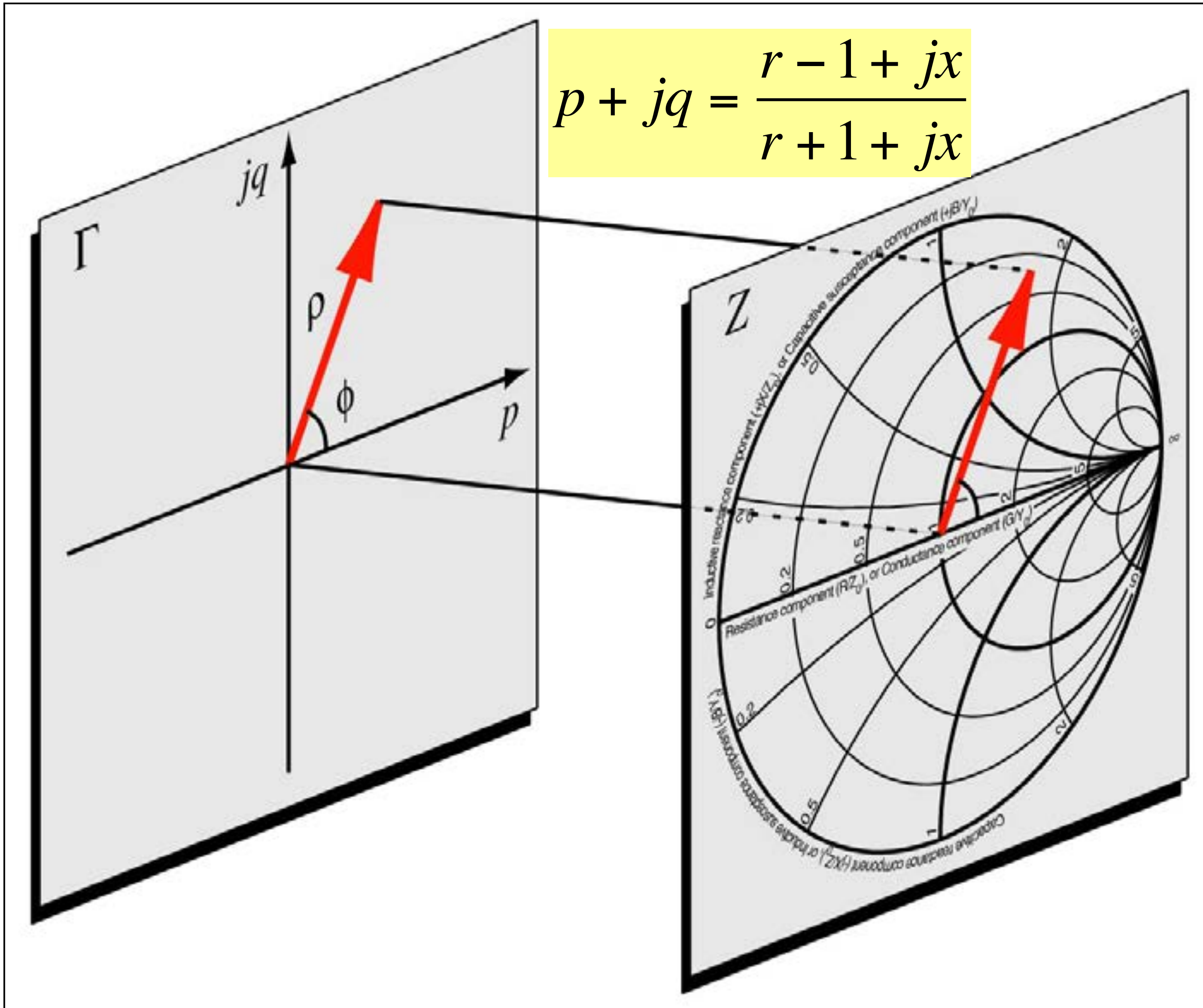
The Smith Chart

The chart was invented by Phillip Smith in the early 1930-ties

Transform between Γ- and Z-plane



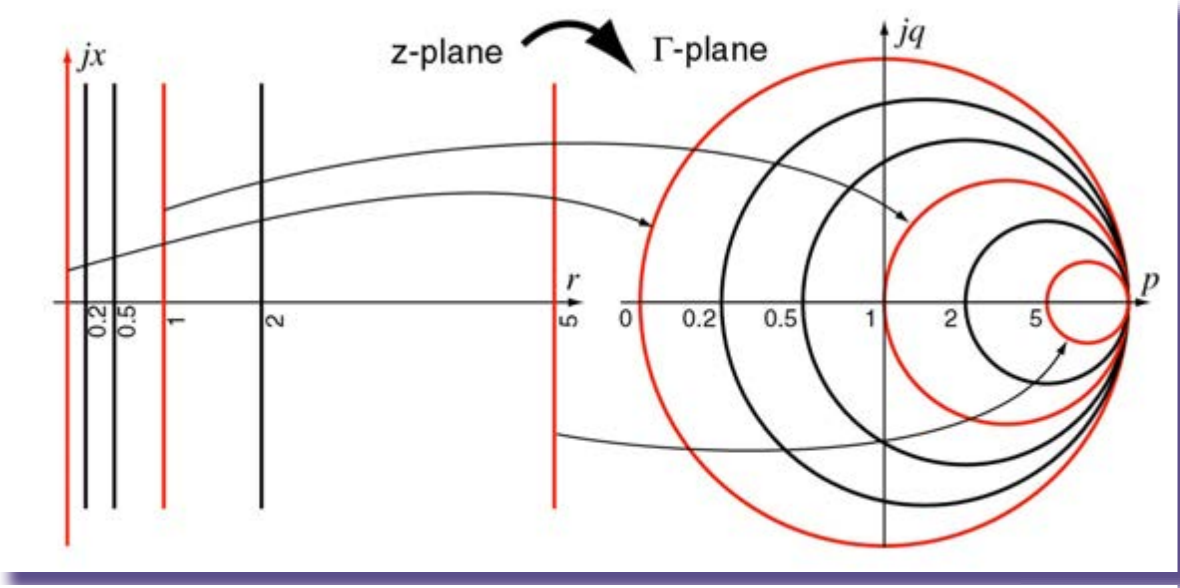
The Smith Chart



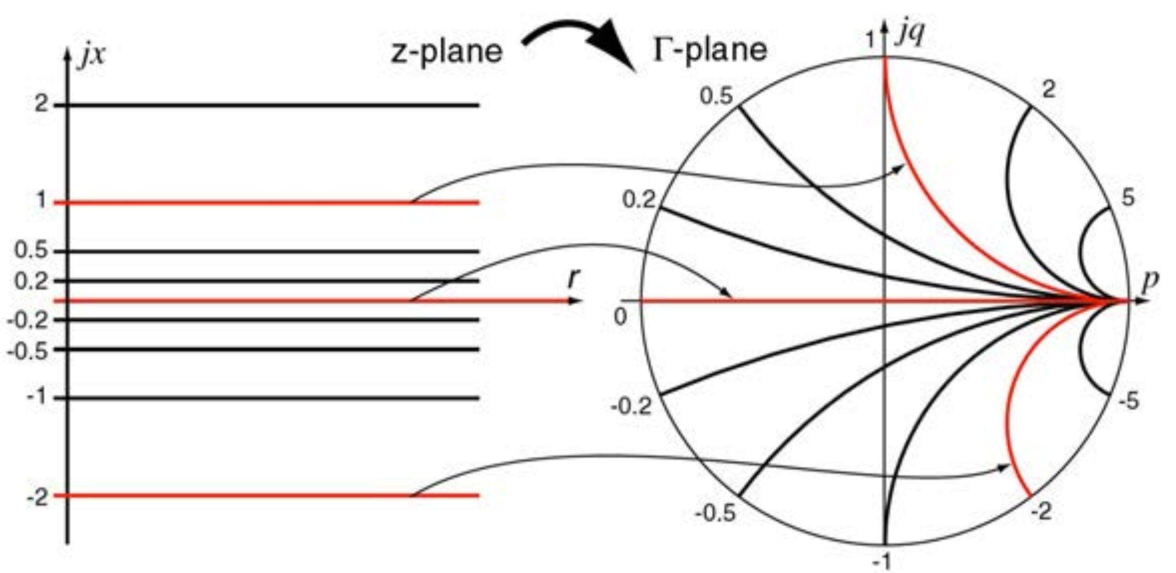
$$p + jq = \frac{r - 1 + jx}{r + 1 + jx}$$

The Smith Chart Circles

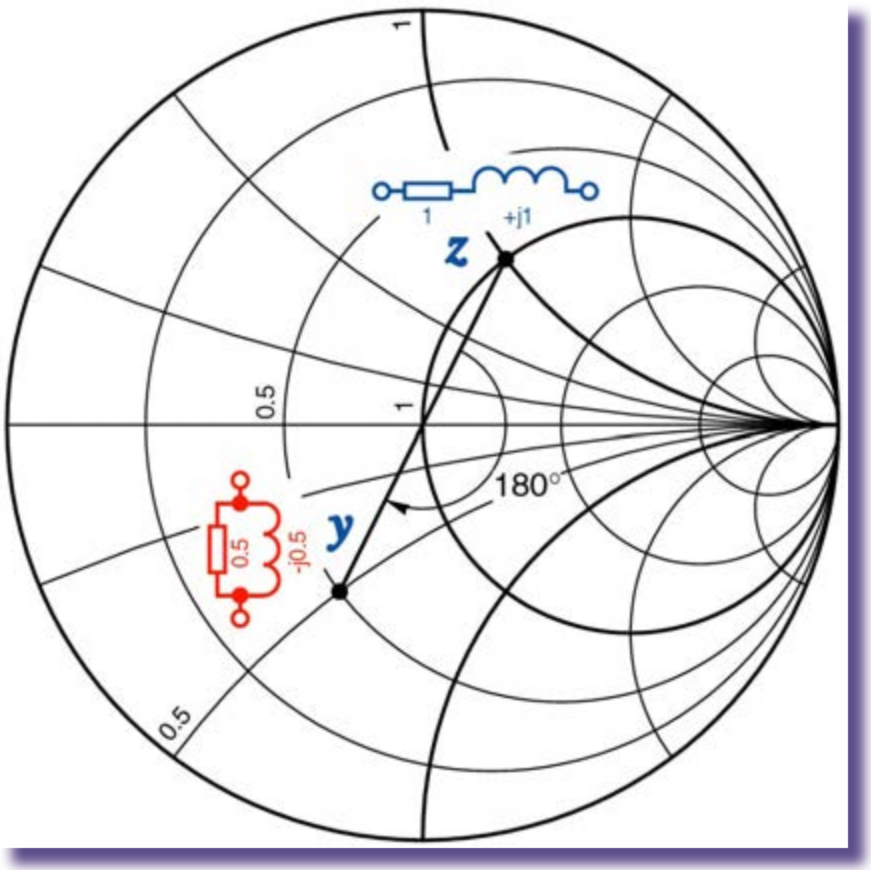
- **Constant resistance lines ⇨ resistance circles**

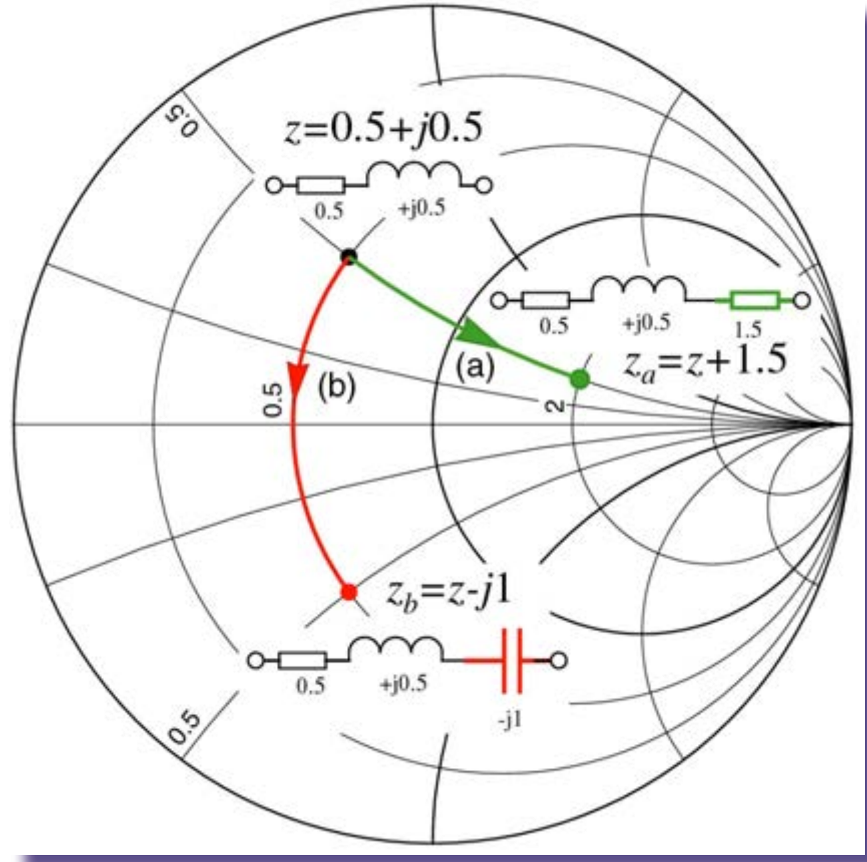


- **Constant reactance lines ⇨ reactance circles**



Example of Smith Chart Usage





Conversion impedance ⇨ admittance

$$z = \frac{1}{y}$$

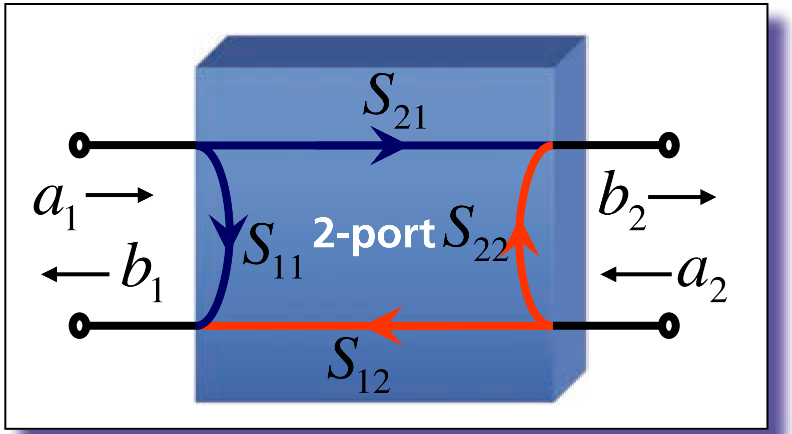
$$\Gamma(y) = \frac{1/y - 1}{1/y + 1} = -\frac{y-1}{y+1} = -\Gamma(z) = e^{j\pi}\Gamma(z)$$

- Series connection
  - Addition of resistance:
    - motion at constant reactance circle
  - Addition of reactance:
    - motion at constant resistance circle

Definition of S-parameters

- **Model:**

a_x = incident wave
b_x = reflected wave



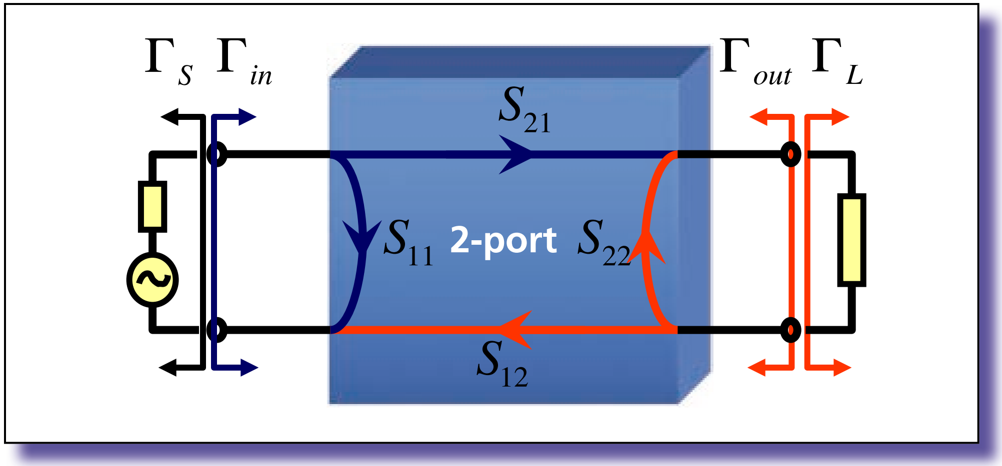
$$\begin{cases} b_1 = s_{11} \cdot a_1 + s_{12} \cdot a_2 \\ b_2 = s_{21} \cdot a_1 + s_{22} \cdot a_2 \end{cases} \qquad \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

$$S_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} \qquad S_{12} = \left.\frac{b_1}{a_2}\right|_{a_1=0}$$

$$S_{21} = \left.\frac{b_2}{a_1}\right|_{a_2=0} \qquad S_{22} = \left.\frac{b_2}{a_2}\right|_{a_1=0}$$

IMPORTANT!
The definition utilizes 50Ω as reference impedance

Measurement of S-parameters



$$\Gamma_{in} = S_{11} + S_{12}S_{21}\frac{\Gamma_L}{1 - S_{22}\Gamma_L} = S_{11}\Big|_{\Gamma_L=0}$$

$$\Gamma_{out} = S_{22} + S_{12}S_{21}\frac{\Gamma_S}{1 - S_{11}\Gamma_S} = S_{22}\Big|_{\Gamma_S=0}$$

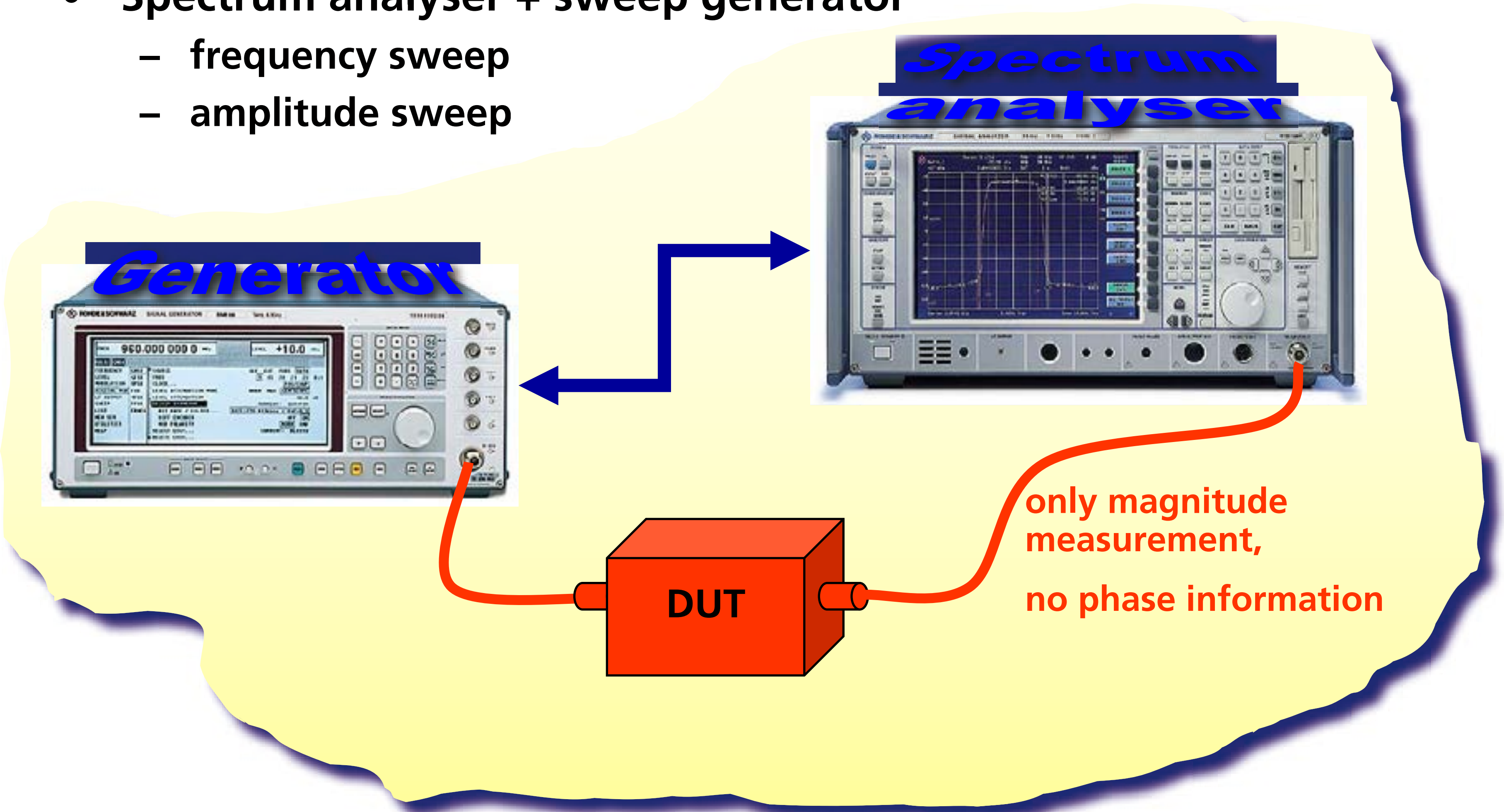
The S-parameters are easily measured if the ports are terminated by the reference impedance $Z_0 = 50\Omega$ (Γ_L respectively $\Gamma_S = 0$)

$$S_{11} = \frac{b_1}{a_1}\Big|_{a_2=0} \qquad S_{12} = \frac{b_1}{a_2}\Big|_{a_1=0}$$

$$S_{21} = \frac{b_2}{a_1}\Big|_{a_2=0} \qquad S_{22} = \frac{b_2}{a_2}\Big|_{a_1=0}$$

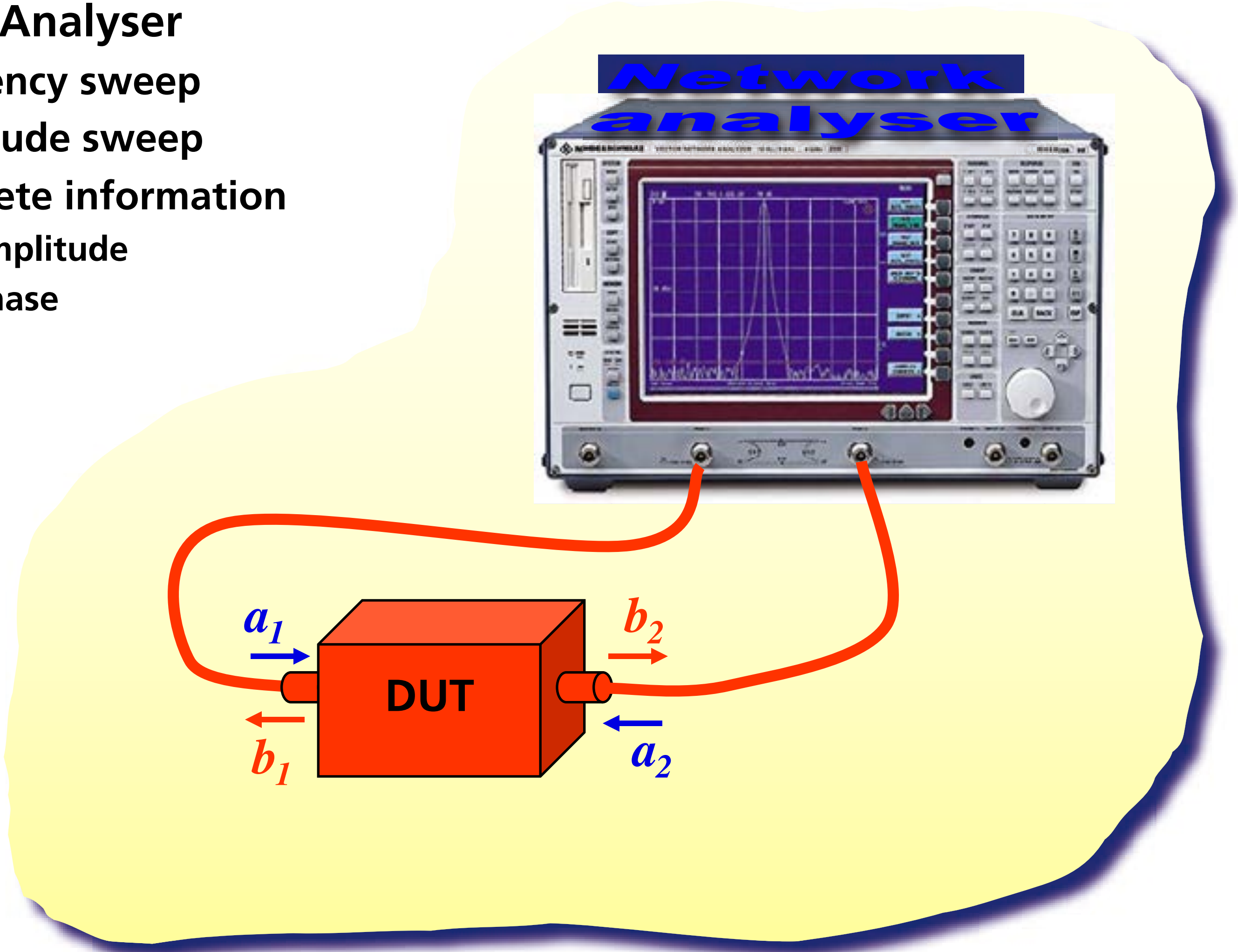
Scalar Network Analysis

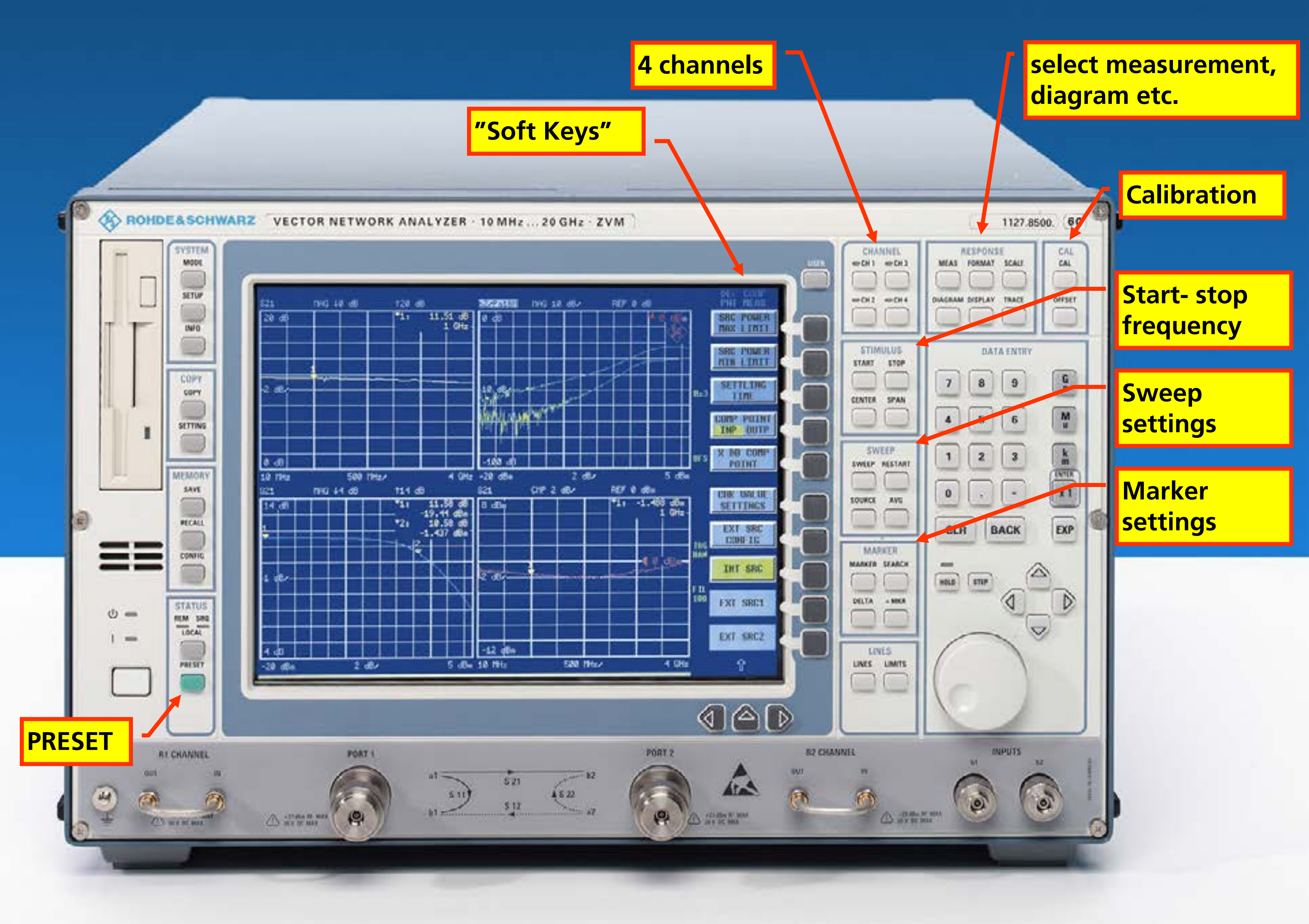
- Characterising the Device Under Test properties
- Spectrum analyser + sweep generator
  - frequency sweep
  - amplitude sweep



Vector Network Analysis

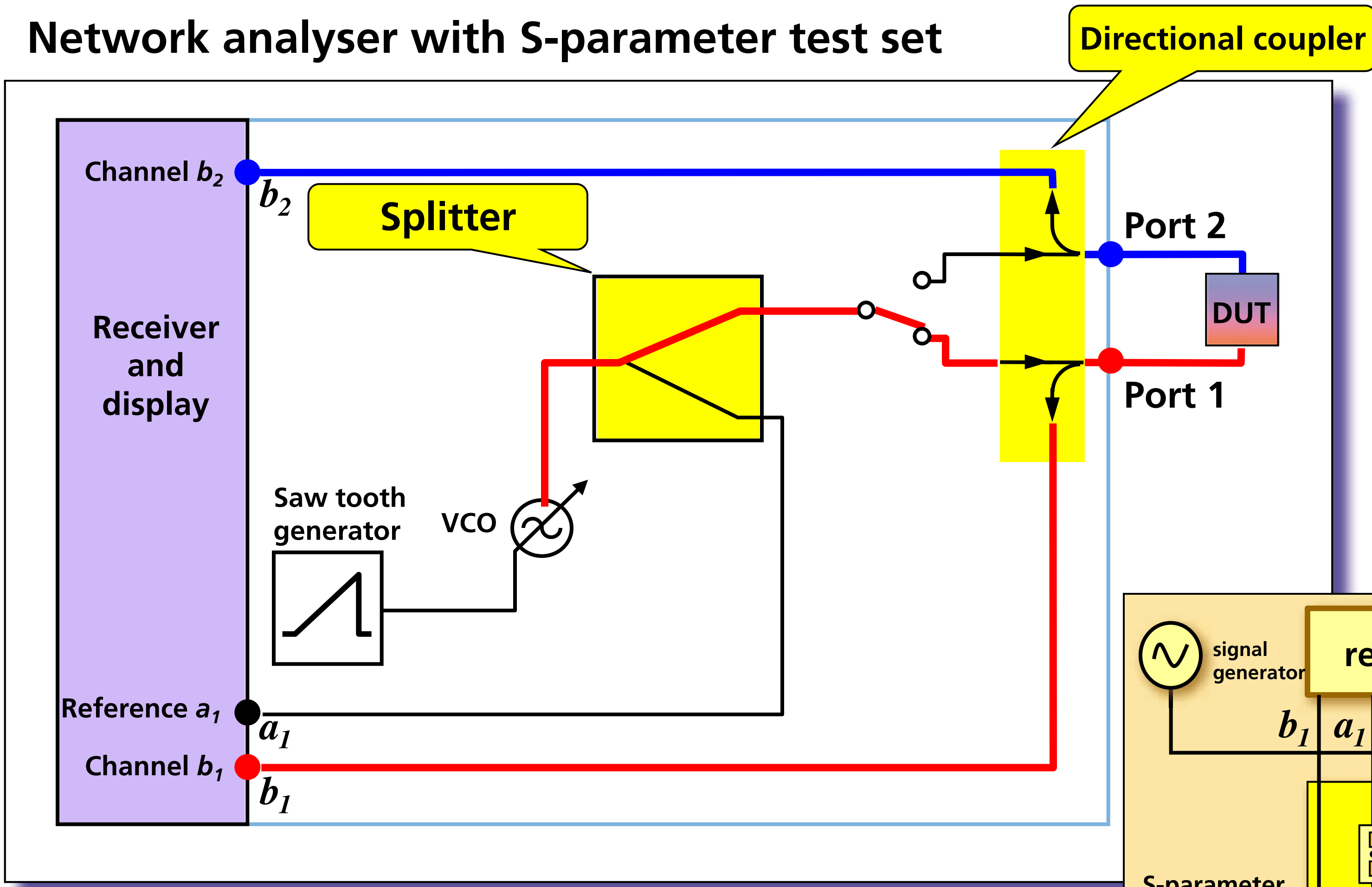
- Characterising the Device Under Test properties
- Network Analyser
  - frequency sweep
  - amplitude sweep
  - complete information
    - amplitude
    - phase

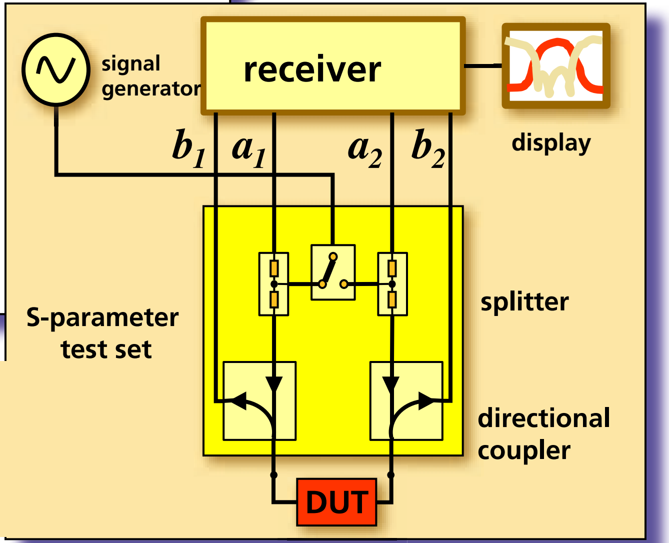



4 channels
select measurement, diagram etc.
"Soft Keys"
Calibration
Start- stop frequency
Sweep settings
Marker settings
PRESET
ROHDE&SCHWARZ
VECTOR NETWORK ANALYZER · 10 MHz ... 20 GHz · ZVM
1127.8500.
SYSTEM
COPY
MEMORY
STATUS
CHANNEL
RESPONSE
CAL
STIMULUS
SWEEP
MARKER
LINES
DATA ENTRY
BACK
EXP
PORT 1
PORT 2
R1 CHANNEL
R2 CHANNEL
INPUTS

The Vector Network Analyser Structure

Network analyser with S-parameter test set

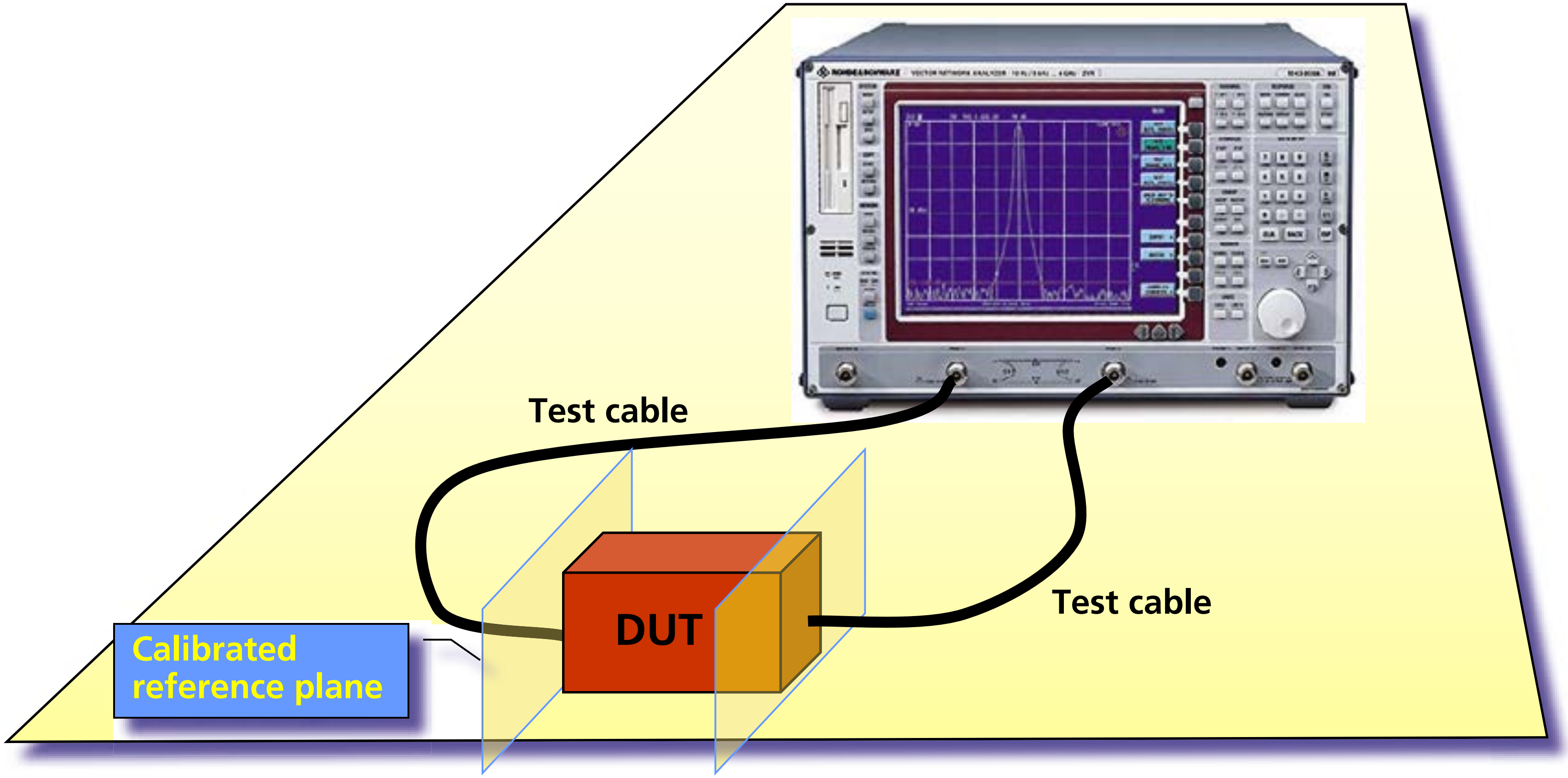




Modern network analysers are often equipped with four receivers which provides more efficient methods for calibration.

Calibration

- **Attenuation and phase shift in the test cables must be compensated**
- **Calibrated reference planes are therefore created where the device under test will be connected**



Before the Calibration

Before you proceed with the calibration you must

1. **Connect the test cables to be used**

   After the calibration you are not allowed to change anything concerning the test cables, adding adapters etc.

2. **Set/check the frequency range**

   If the range is increased the calibration will be turned off and you need to recalibrate.

   If the span is decreased the analyser will interpolate the calibration data (CAI).

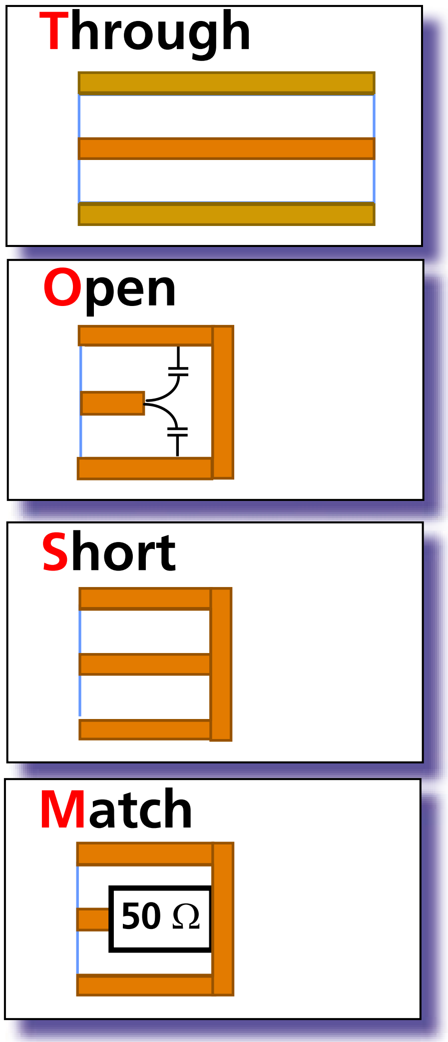
3. **Set/check the SOURCE POWER**

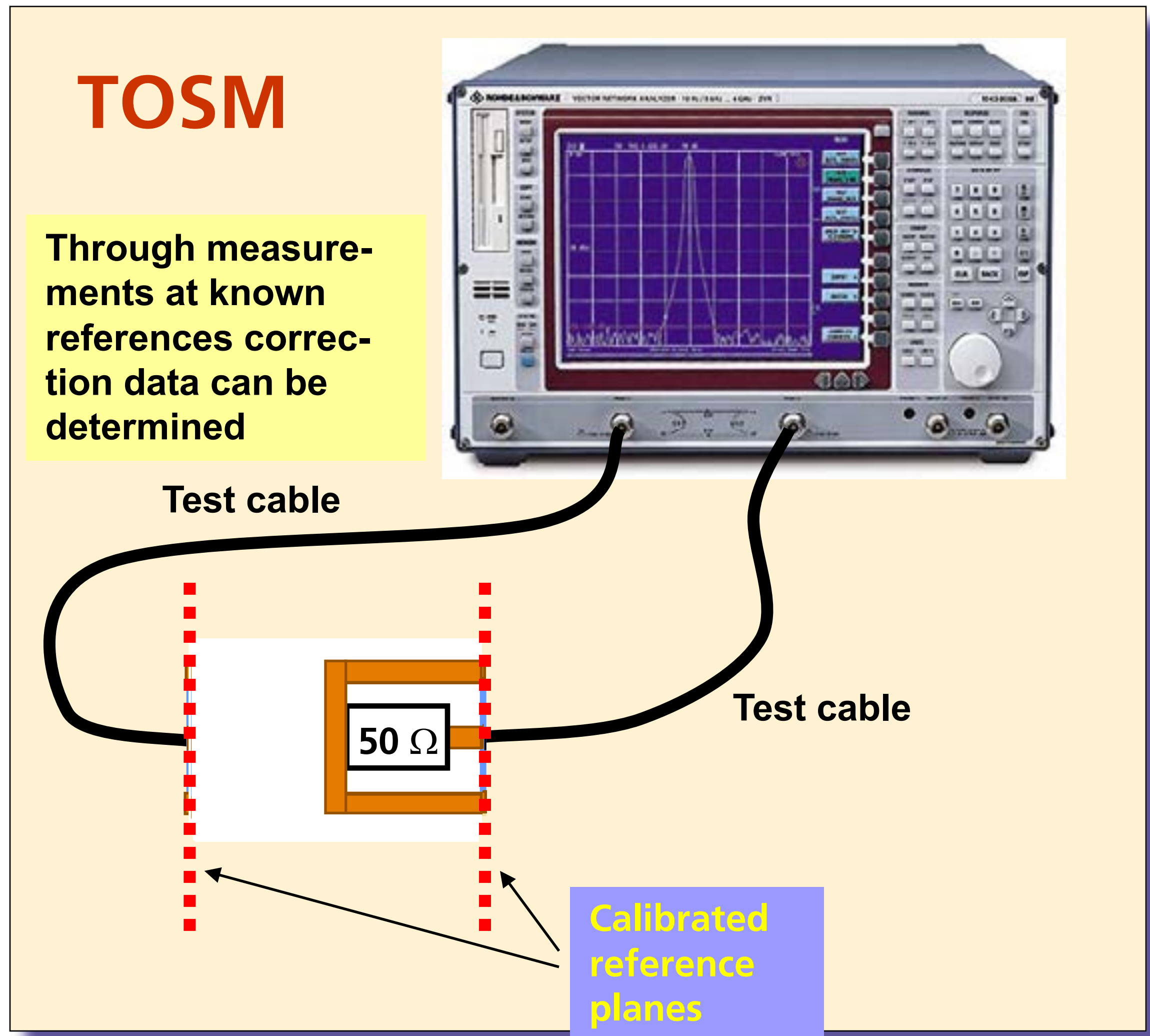
   For linear measurements of active devices you normally need to reduce the SOURCE POWER to avoid compression.

If you forget any of these items you probably must redo the calibration

Calibration

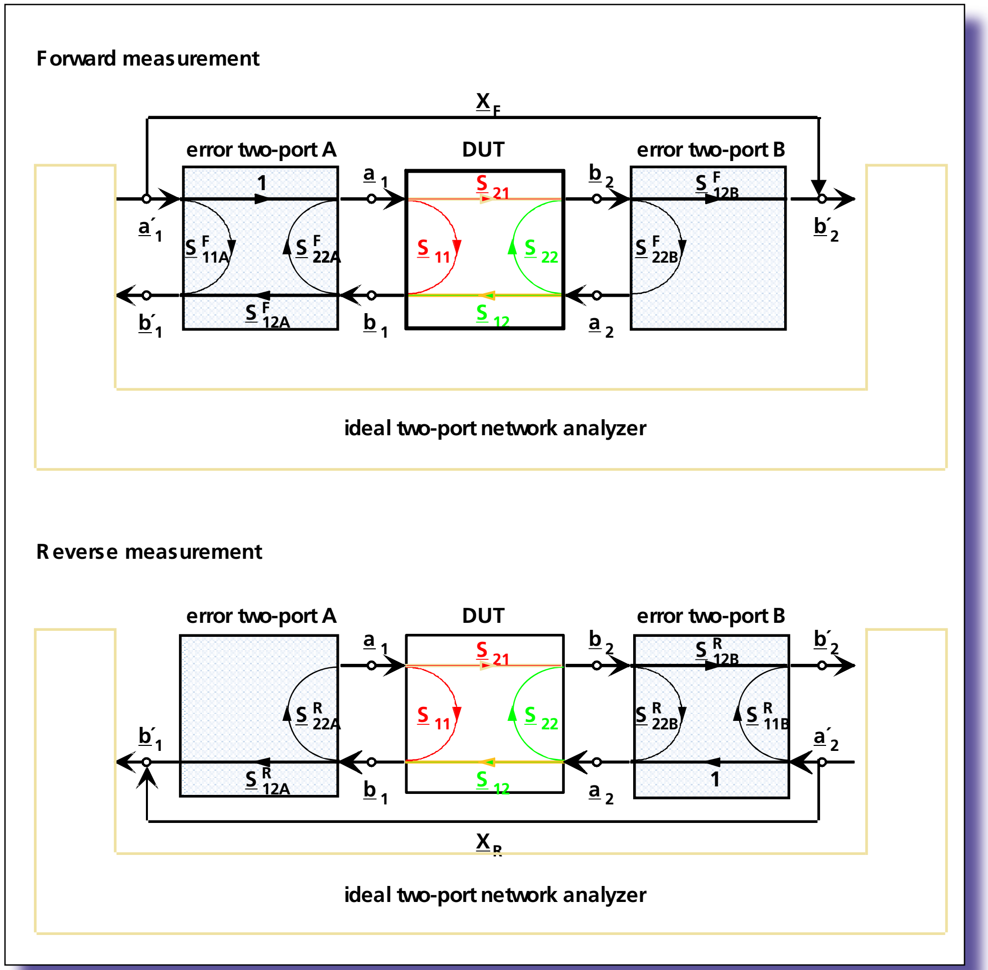
- Calibrated reference planes will be created where the DUT is to be connected





Calibration

TOSM - Classical Full Two-Port Calibration



Extension of the one port error model by 3 additional error terms for forward direction yields 6 error terms. Adding a similar model for reverse direction yields the classical

⇨12-term error model (TOSM)

- Load matches
- Transmission losses of receiver
- Device independent crosstalks

Standard Connectors

- **BNC - 4 GHz**

  outer diameter: 14.3 mm

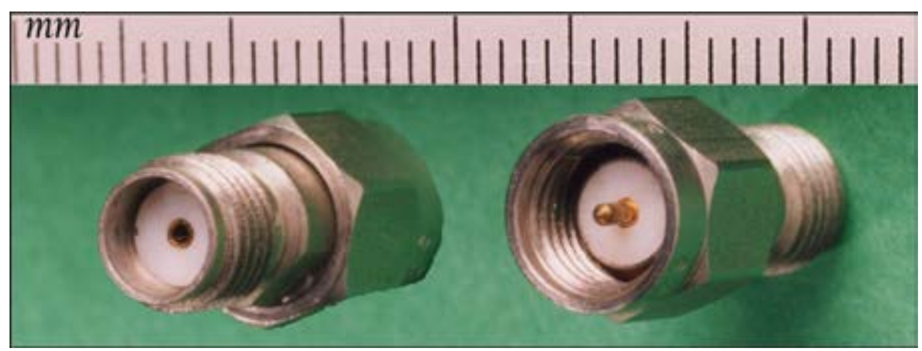
- **N - 11 GHz**

  outer diameter: 20.2 mm



- **SMA - 18 GHz**

  outer diameter: 8.25 mm
- **56 Ncm**



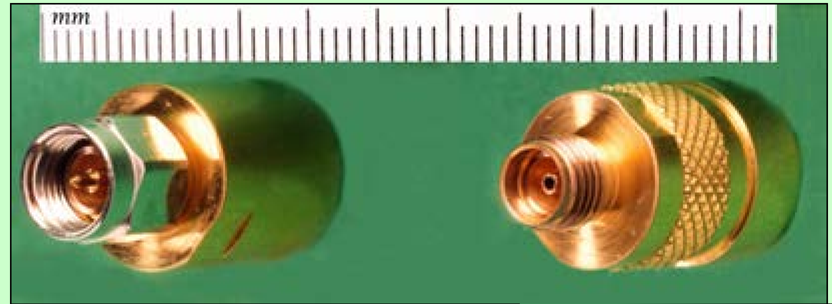
Precision Microwave Coaxial Connectors

Precision Connectors

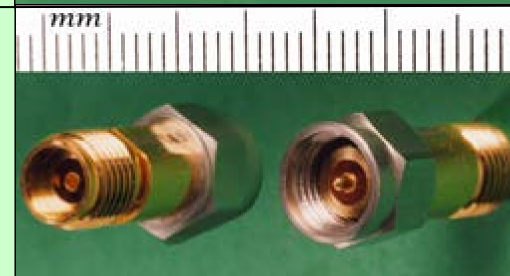
To connect an
SMA male to a 3.5 mm female, use 56 Ncm
3.5 mm male to a SMA female, use 90 Ncm

Connectors in each of the shaded areas have the same size outer conductor and therefore can safely be mated together!

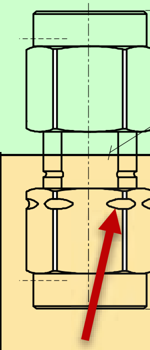
3.5 mm
- 34 GHz
- 90 Ncm



2.92 mm or Type K
- 40 GHz
- 90 Ncm



SMA
or
2.92

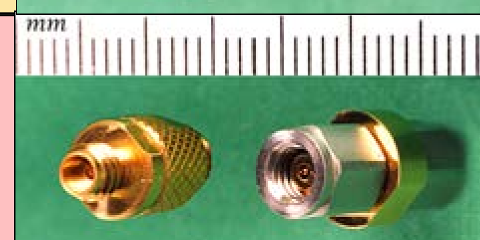


2.4 or 1.85

2.4 mm
- 50 GHz
- 90 Ncm

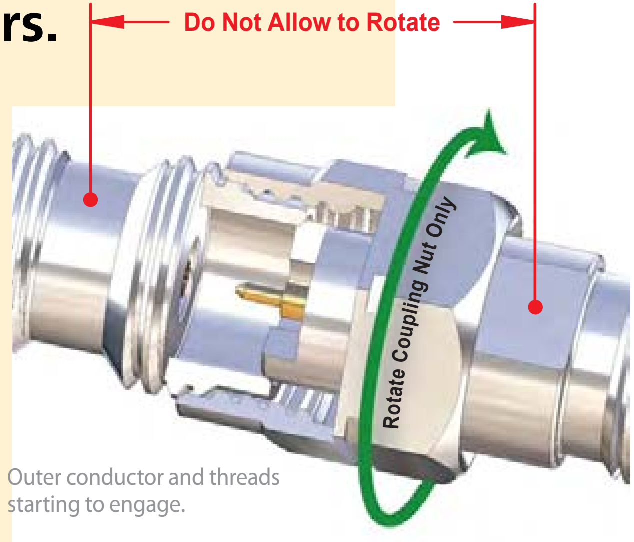
1.85 mm or Type V
- 70 GHz
- 90 Ncm

1.0 mm
- 110 GHz
- 56 Ncm



Be careful about torn connectors!

- The wear and tear when connectors are connected and disconnected may result in measurement errors.
  - always check that the connectors are clean
  - only turn the socket or the nut
    - the contact pin may never spin round
  - only use your thumb and index finger or a torque wrench
    - the connector may never be fastened by other tools if you tighten up to hard the thread is harmed



- Test cables and connectors for professional use are only used for a limited period until they will be exchanged or reconditioned.