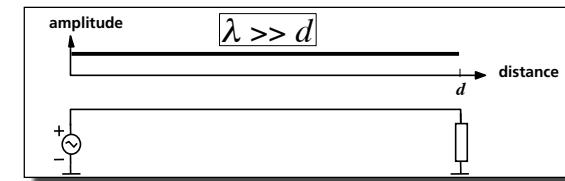


Contents

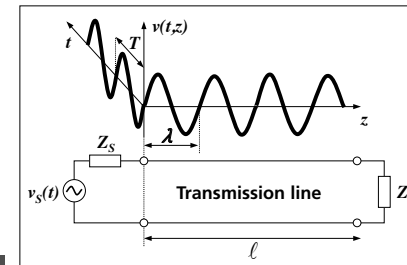
- Transmission Lines
- The Smith Chart
- Vector Network Analyser (VNA)
 - structure
 - calibration
 - operation
- Measurements

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...



The velocity of the wave is $v = \frac{\lambda}{T} = \lambda \cdot f$

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

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

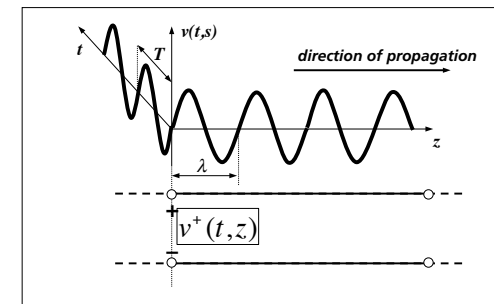
simulation

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Vector Network Analysis

3

Travelling Voltage Wave on a Lossless Line



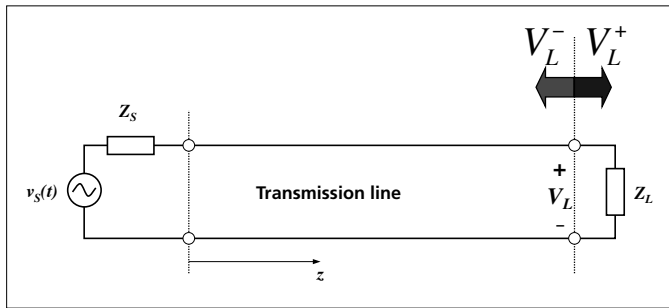
$$v^+(t, z) = |V_0^+| \cos(\omega t - \beta z + \phi_0^+) = \text{Re} \left[V_0^+ e^{j(\omega t - \beta z)} \right]$$

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

Reflection Coefficient

- Definition:

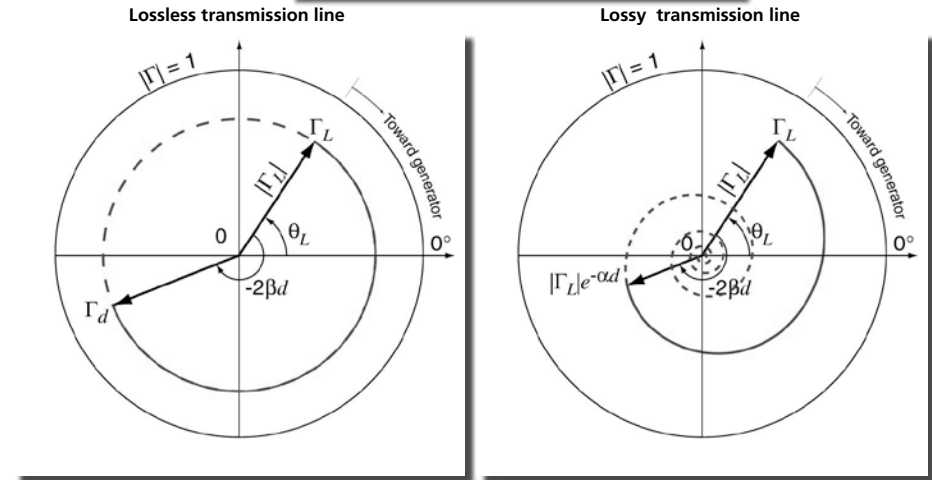
$$\Gamma = \frac{\text{reflected voltage wave}}{\text{incident voltage wave}} = \frac{V^- e^{\gamma z}}{V^+ e^{-\gamma z}}$$



Reflection Coefficient

Implies a rotation in the polar Γ -plane

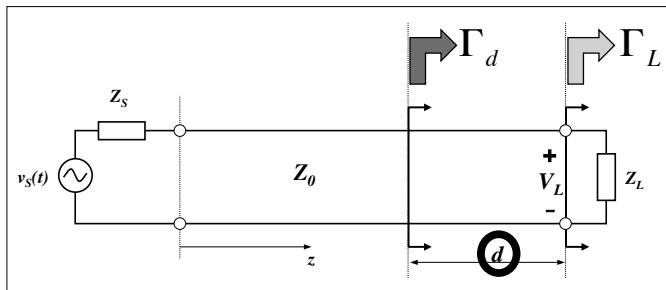
- Polar diagram $\Gamma_d = \Gamma_L e^{-2\gamma d} = \Gamma_L e^{-2\alpha d} e^{-2j\beta d}$



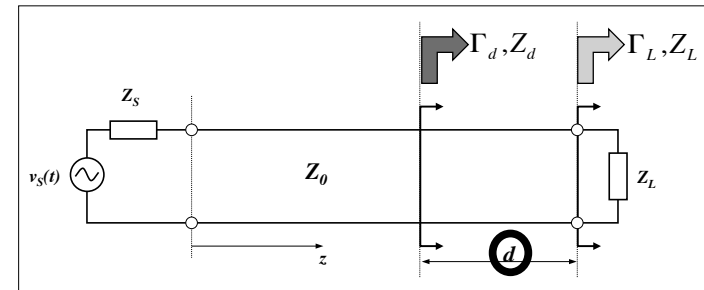
Reflection Coefficient

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

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

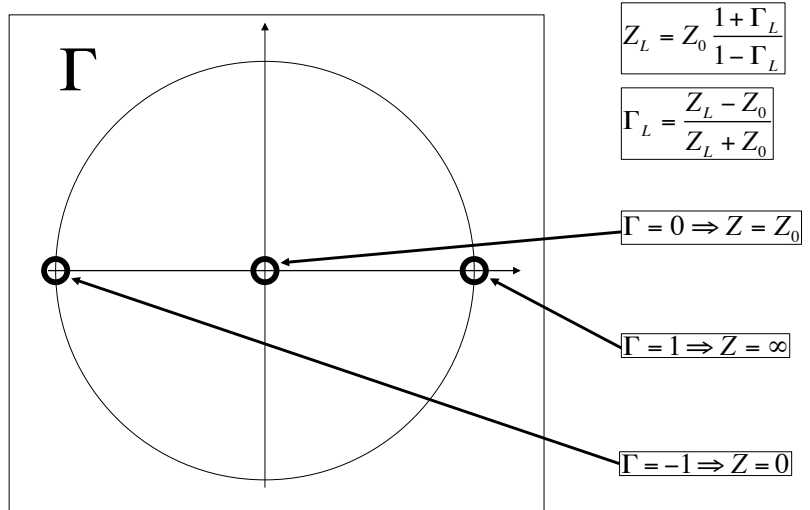


Conversion of Reflection Coefficient to Impedance



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

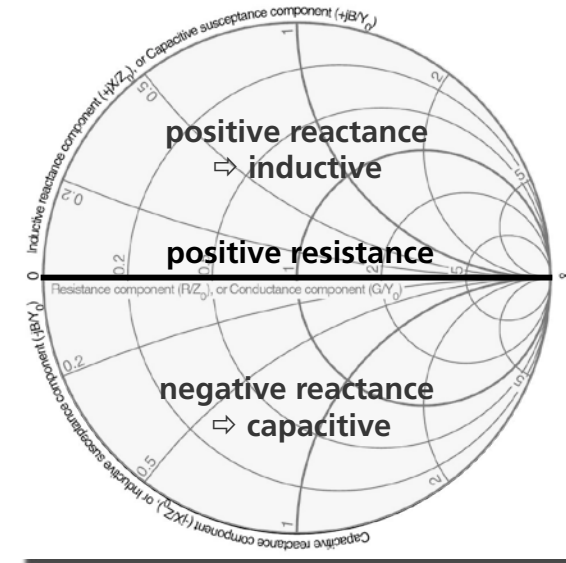
Reflection Coefficient – Load Impedance



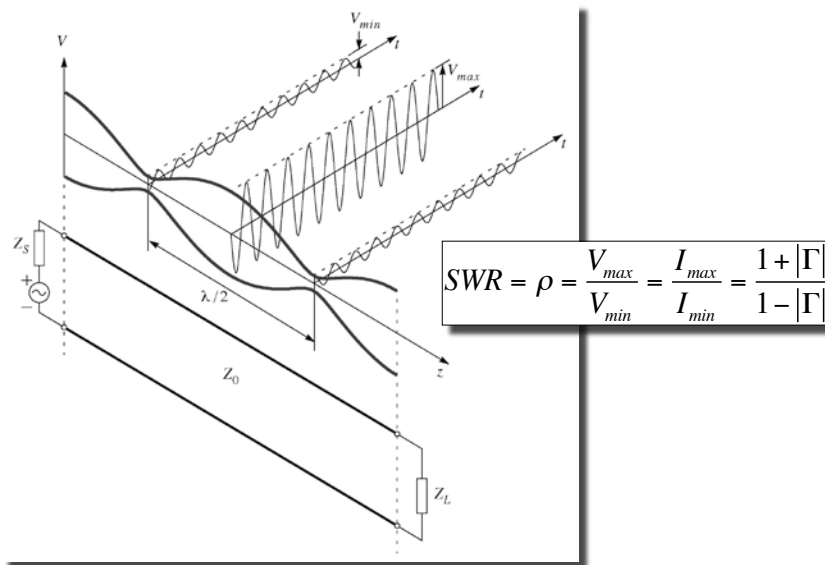
The Smith Chart

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

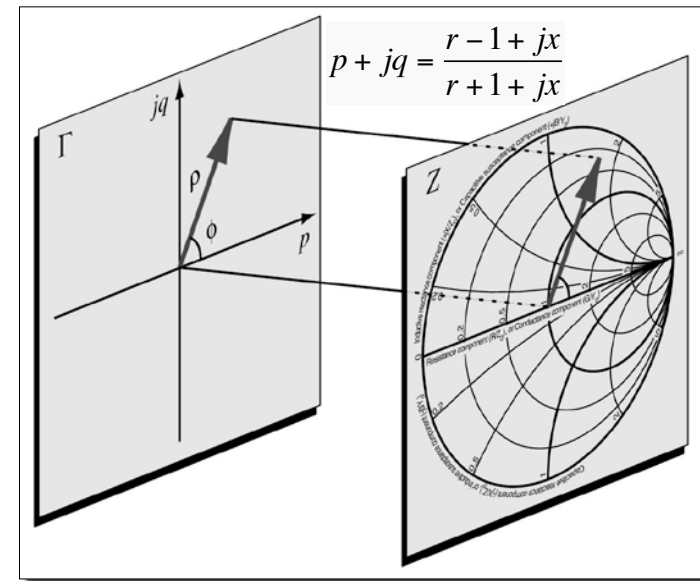
Transform between Γ - and Z -plane



Standing-Wave Ratio

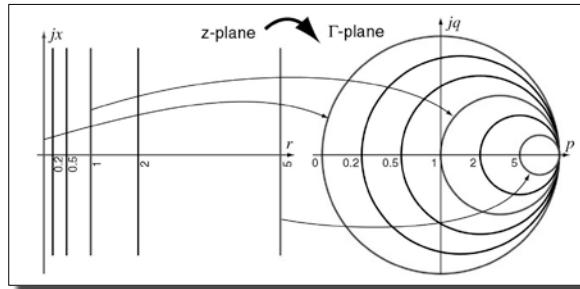


The Smith Chart

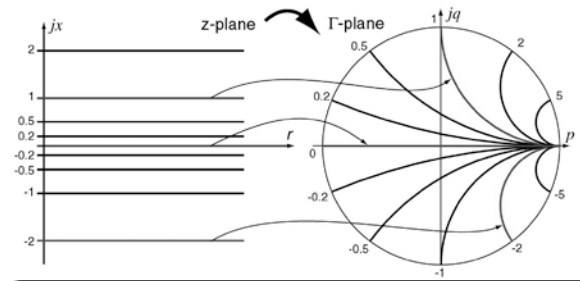


The Smith Chart Circles

- Constant resistance lines \Rightarrow resistance circles

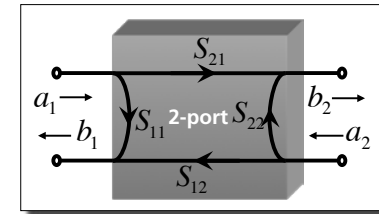


- Constant reactance lines \Rightarrow reactance circles



Definition of S-parameters

- Model:



or in matrix format:

- Definition:

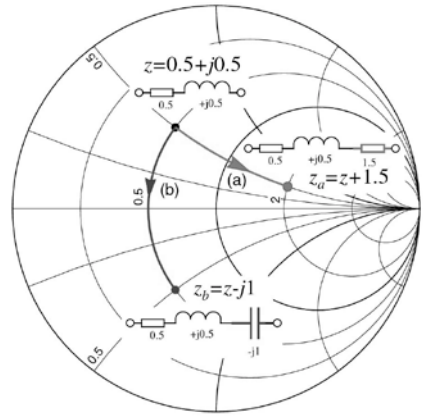
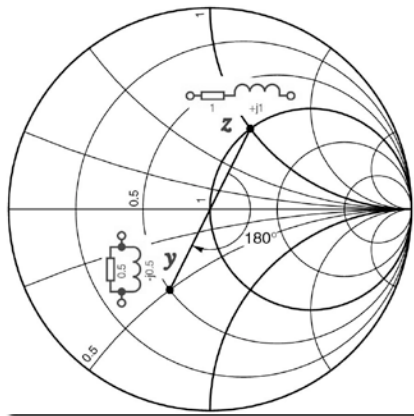
$$\begin{cases} b_1 = s_{11} \cdot a_1 + s_{12} \cdot a_2 \\ b_2 = s_{21} \cdot a_1 + s_{22} \cdot a_2 \end{cases} \quad \begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}$$

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

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

IMPORTANT!
The definition utilizes 50Ω as reference impedance

Example of Smith Chart Usage



Conversion impedance \Leftrightarrow admittance

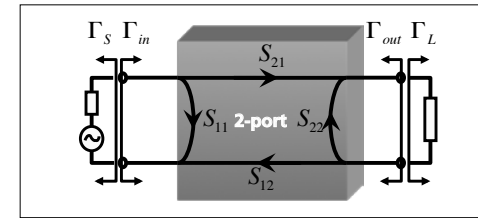
$$\Gamma(y) = \frac{1/y - 1}{1/y + 1} = -\frac{y - 1}{y + 1} = -\Gamma(z) = e^{j\pi} \Gamma(z)$$

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

- Series connection

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

Measurement of S-parameters



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

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

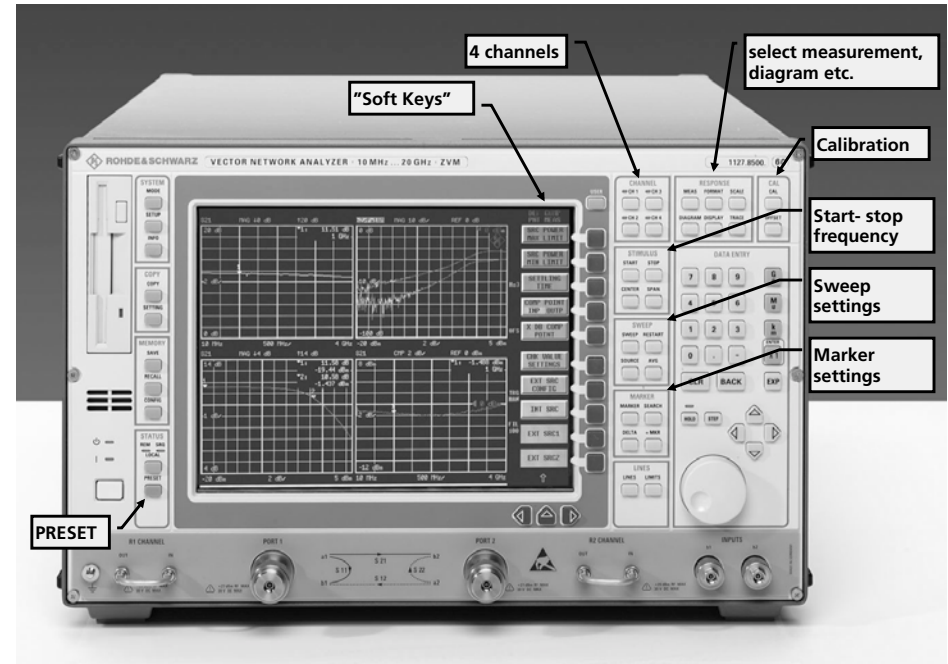
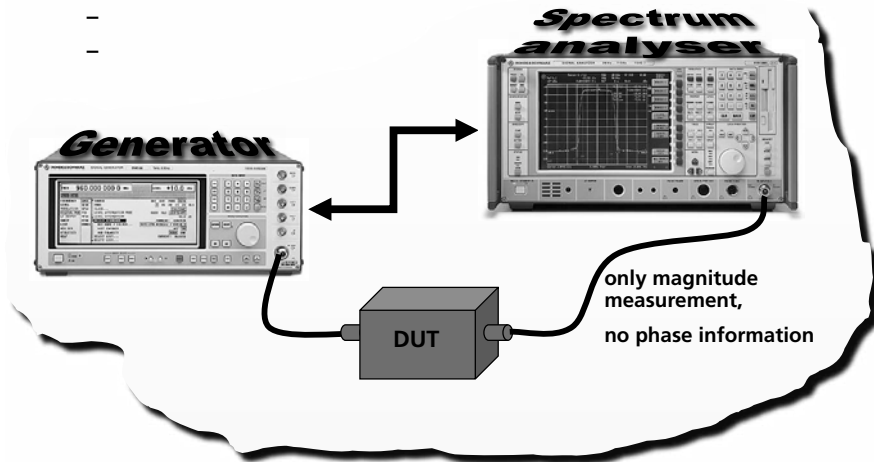
The S-parameters are easily measured if the ports are terminated by the reference impedance $Z_0 = 50\Omega$ (Γ_L respectively $\Gamma_S = 0$)

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

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

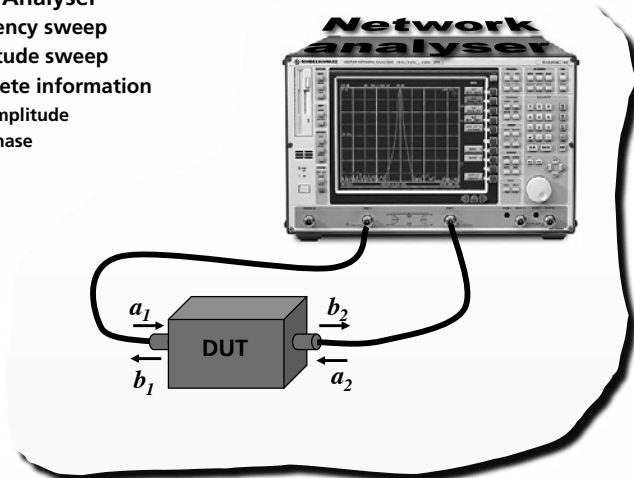
Scalar Network Analysis

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

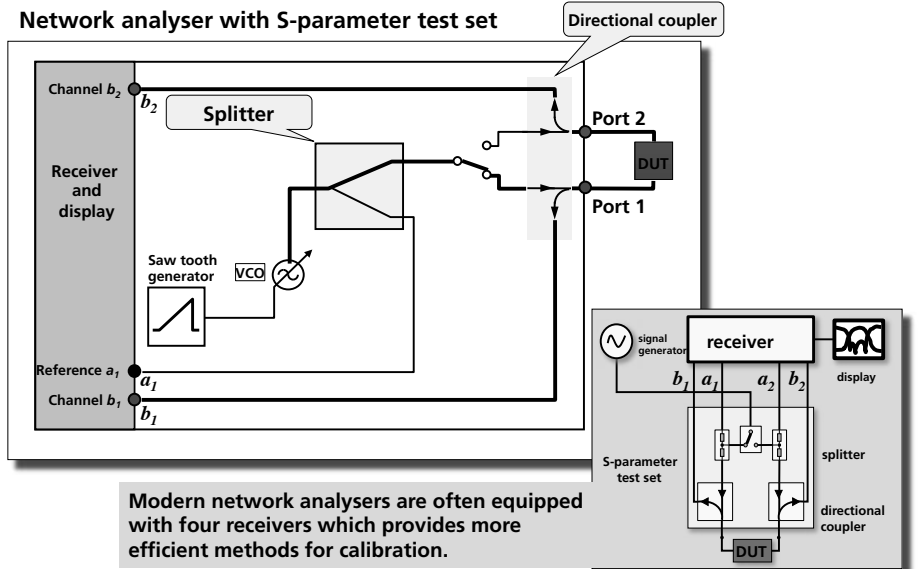


Vector Network Analysis

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

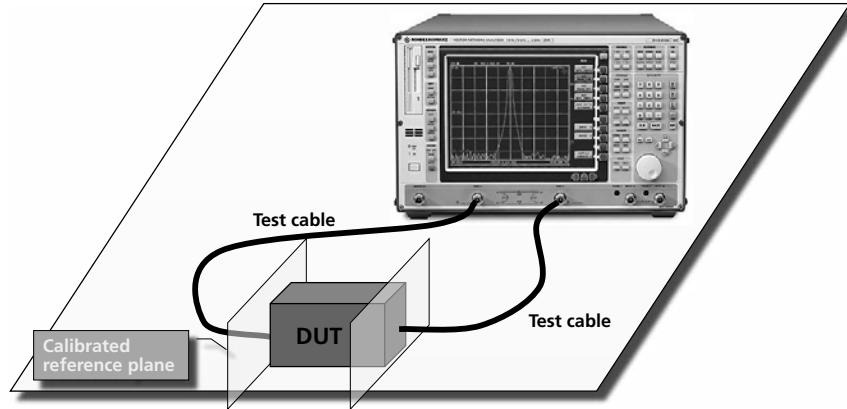


The Vector Network Analyser Structure



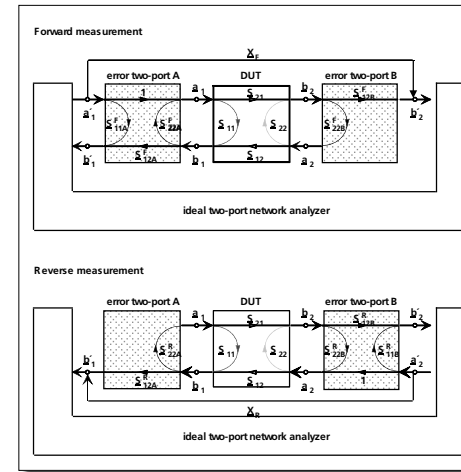
Calibration

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



Calibration

TOSM - Classical Full Two-Port Calibration

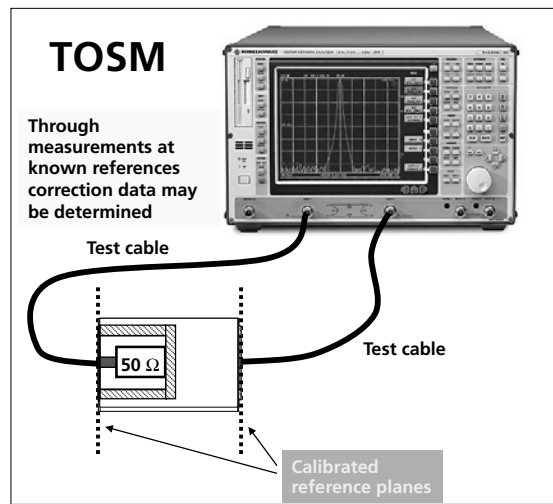
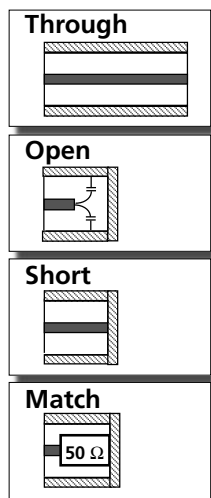


Extension of the one port error model by 3 additional error terms for forward direction yields 6 error terms. Adding a similar model for reverse direction yields the classical 12-term error model (TOSM)

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

Calibration

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



Be careful about torn connectors!

- and disconnected may result in measurement errors.
 - check that the connectors are clean
 - only turn the socket or the nut
 -
 - always use a torque wrench
 - 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.