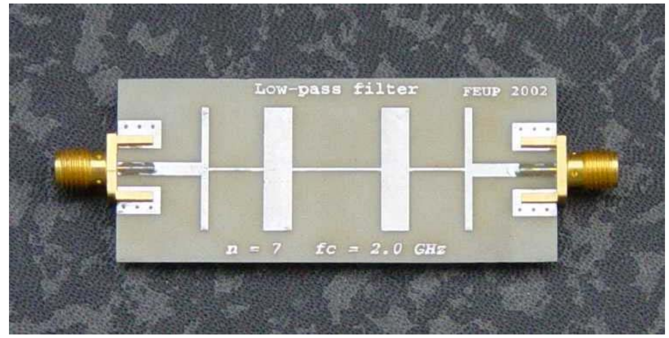
Vector Network Analyzer Measurements



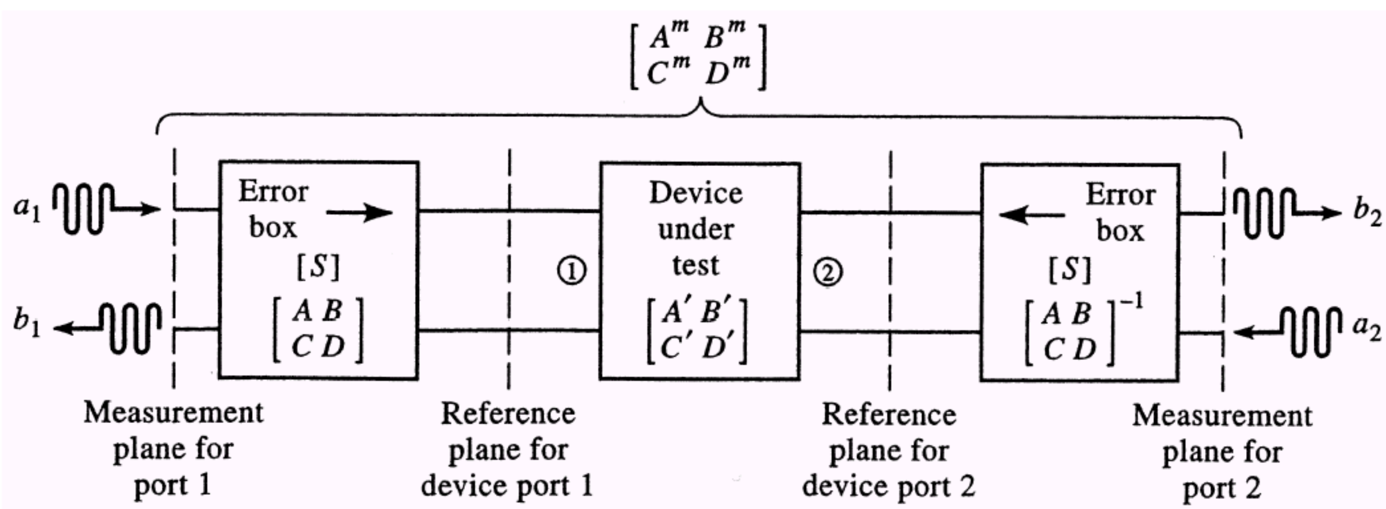
- Scattering Parameter Measurement
  - The scattering parameters of transmission line/waveguide devices can be measured via a Vector Network Analyzer
    - Typically makes 2-port measurements
    - Matched 50 ohm terminations
    - The Vector Network Analyzer (VNA) Measures both the Magnitude & Phase of the Device Under Test (DUT)
    - We have two HP 8753D VNA's in our lab (FPAT 682) which are used for EE523
      - Frequency ranges: 0 – 3 GHz & 0 – 6 GHz

Measurement Error

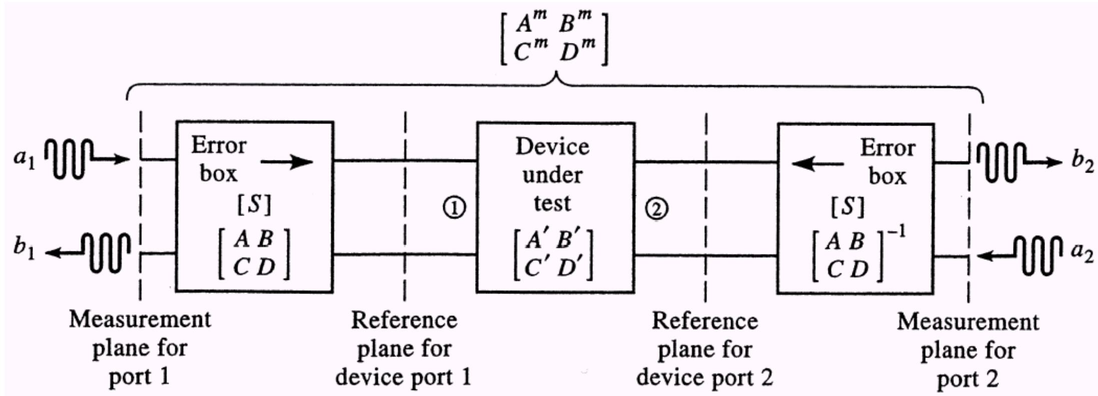
- There is inherent error in the measurement of a VNA
  - Errors can be quite large, and corrupt the measured data
  - It is desirable to remove the error through compensation for the sources of error.
- Types of error:
  - Systematic:
    - Errors due to cable lengths, connector miss-matches, other discontinuities. This type of error is repeatable
  - Environment:
    - Random errors due to EM noise, thermal drifting, humidity
  - Equipment wear/stress
    - Connector repeatability, varying cable positions, connector stress.
- Systematic error can be removed for the most part using Calibration techniques
- Proper user care can minimize Environment/Equipment Error

Calibration

- Systematic errors inherent to the test fixture can be largely removed via an appropriate Calibration procedure
  - The calibration assumes a general model to represent the systematic error
  - Proper calibration will include all the effects of the test fixture (same cable lengths, connectors, etc.) up to a reference plane of the device under test.



Calibration (continued)



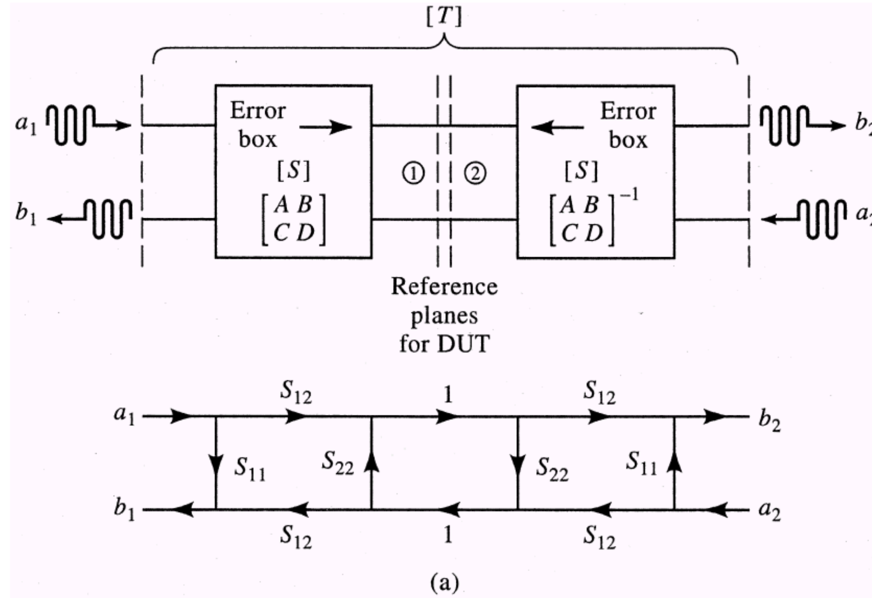
- The concept of calibration is to measure a set of known Standards, which are used as a reference, in order to extract a two-port network that represents the cables/connectors/defects through a measurement reference plane for the DUT
  - This two-port network is referred to as the Error Box
  - The Error box is extracted over the full frequency range desired for measuring the DUT.
  - It is advisable to re-calibrate periodically to account for changes in the environment and equipment (cable stress, etc.)

Types of Calibration

- There are two types of calibration that are commonly used:
  - Short-Open-Load-Through (SOLT)
    - HP Cal Kit in the Lab
  - Thru-Reflect-Line (TRL)
    - Our own home-grown standards
- TRL Calibration:
  - Thru: A straight microstrip line (two port). The center of this line represents the reference plane
  - Reflect: A microstrip line half the length of the thru standard terminated in a short circuit
  - Line: A straight microstrip line approximately $\lambda/4$ longer than the thru standard at the center point of the cal-range

The Thru Standard

- The S-matrix of the thru standard is represented by [T].
  - The reference plane is the center of the thru. Thus, it is a “zero-length Thru”.
  - The error boxes are the network parameters through the center of the thru-line.
  - Note:
    - In the figure, the Error boxes of ports 1 and 2 appear to be the same. This is not assumed when doing an actual calibration.
    - The Error box is reciprocal. Thus, $S_{21} = S_{12}$.

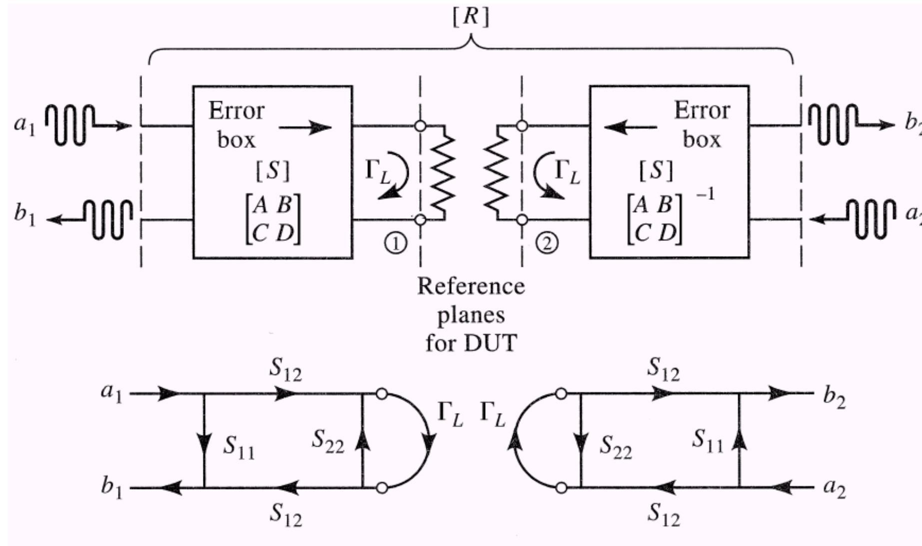


$$T_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} = S_{11} + \frac{S_{22}S_{12}^2}{1-S_{22}^2}$$

$$T_{12} = \left.\frac{b_1}{a_2}\right|_{a_2=0} = \frac{S_{12}^2}{1-S_{22}^2}$$

The Reflect Standard

- The reflect standard assumes an arbitrary load in the reference plane.
  - Our load is a short circuit, however, this actually need not be known.
  - The S-matrix of the Reflect network is [R].



(b)

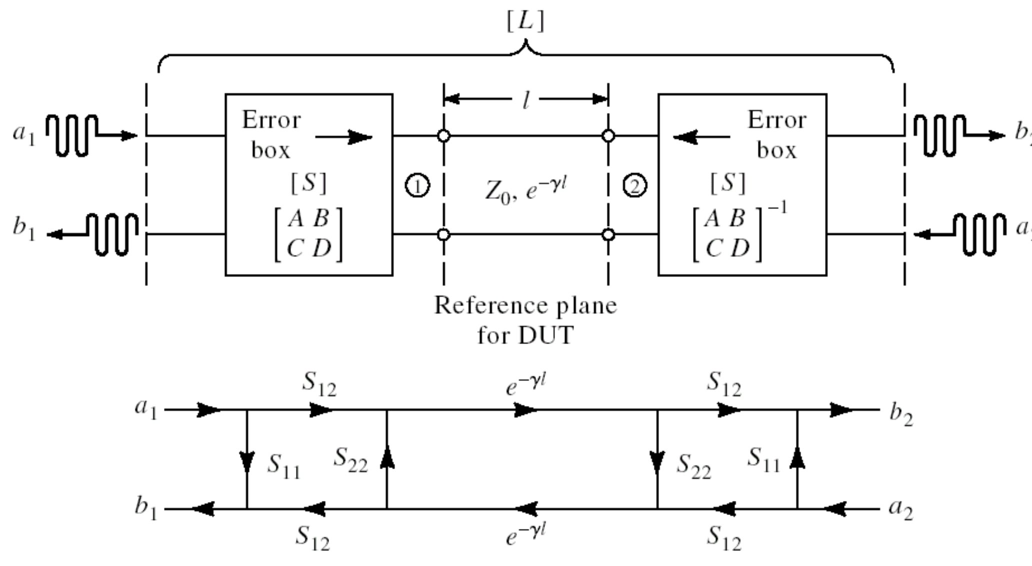
$$R_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} = S_{11} + \frac{S_{12}^2\Gamma_L}{1-S_{22}\Gamma_L}$$

$$R_{12} = R_{21} = 0$$

- For simplicity, here $R_{22} = R_{11}$

The Line Standard

- The Line standard is longer than the thru by some length ℓ
  - Note: It is not required to know the length of the line, nor it be lossless. These parameters are determined via the calibration process.
- The S-matrix of the line is [L].



(c)

$$L_{11} = \left.\frac{b_1}{a_1}\right|_{a_2=0} = S_{11} + \frac{S_{22}S_{12}^2 e^{-2\gamma\ell}}{1 - S_{22}^2 e^{-2\gamma\ell}}$$

$$L_{12} = \left.\frac{b_1}{a_2}\right|_{a_2=0} = \frac{S_{12}^2 e^{-\gamma\ell}}{1 - S_{22}^2 e^{-2\gamma\ell}}$$

Parameterizing the Error Box

- At this point, there are 5 equations for the five unknowns: $S_{11}, S_{12}, S_{22}, \Gamma_L, e^{-\gamma\ell}$
- Applying some algebra, we can conclude:

$$e^{-\gamma\ell} = \frac{L_{12}^2 + T_{12}^2 - \left(T_{11} - L_{11}\right)^2 \pm \sqrt{\left[L_{12}^2 + T_{12}^2 - \left(T_{11} - L_{11}\right)^2\right]^2 - 4L_{12}^2 T_{12}^2}}{2L_{12}T_{12}}$$

$$S_{22} = \frac{T_{11} - L_{11}}{T_{12} - L_{12}e^{-\gamma\ell}} \qquad S_{11} = T_{11} - S_{22}T_{12} \qquad S_{12}^2 = T_{12}\left(1 - S_{22}^2\right)$$

$$\Gamma_L = \frac{R_{11} - S_{11}}{S_{12}^2 + S_{22}\left(R_{11} - S_{11}\right)}$$

- From the scattering parameters, the ABCD parameters of the error box is computed.

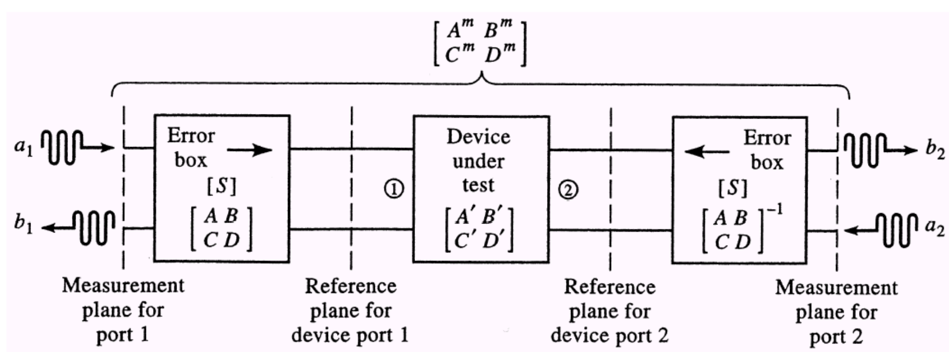
Calibrated Measurement

- The Scattering parameters that are measured included the two error boxes:

$$\begin{bmatrix} A^m & B^m \\ C^m & D^m \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{EB1} \begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix}_{DUT} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{EB2}^{-1}$$

- Having computed the error boxes with the calibration standards, we can extract the network parameterization of the device under test:

$$\begin{bmatrix} A' & B' \\ C' & D' \end{bmatrix}_{DUT} = \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{EB1}^{-1} \begin{bmatrix} A^m & B^m \\ C^m & D^m \end{bmatrix} \begin{bmatrix} A & B \\ C & D \end{bmatrix}_{EB2}$$



Final notes

- It is important to use standards that represent the device under test
  - Same connectors, same waveguide technology up through the reference plane, etc.
- Prior to calibrating the 8753D, choose your frequency range, number of point samples, etc. that you will use for your measurement of the DUT.
- The Error box will then be computed at each frequency point at the end of the calibration process.
- The Calibration will be turned on, and the 8753D will automatically output the calibrated results.