Lecture #4 : Impedance Measurement

1. **Introduction**
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   - o **Measurement by S Parameter is Better than by Others**

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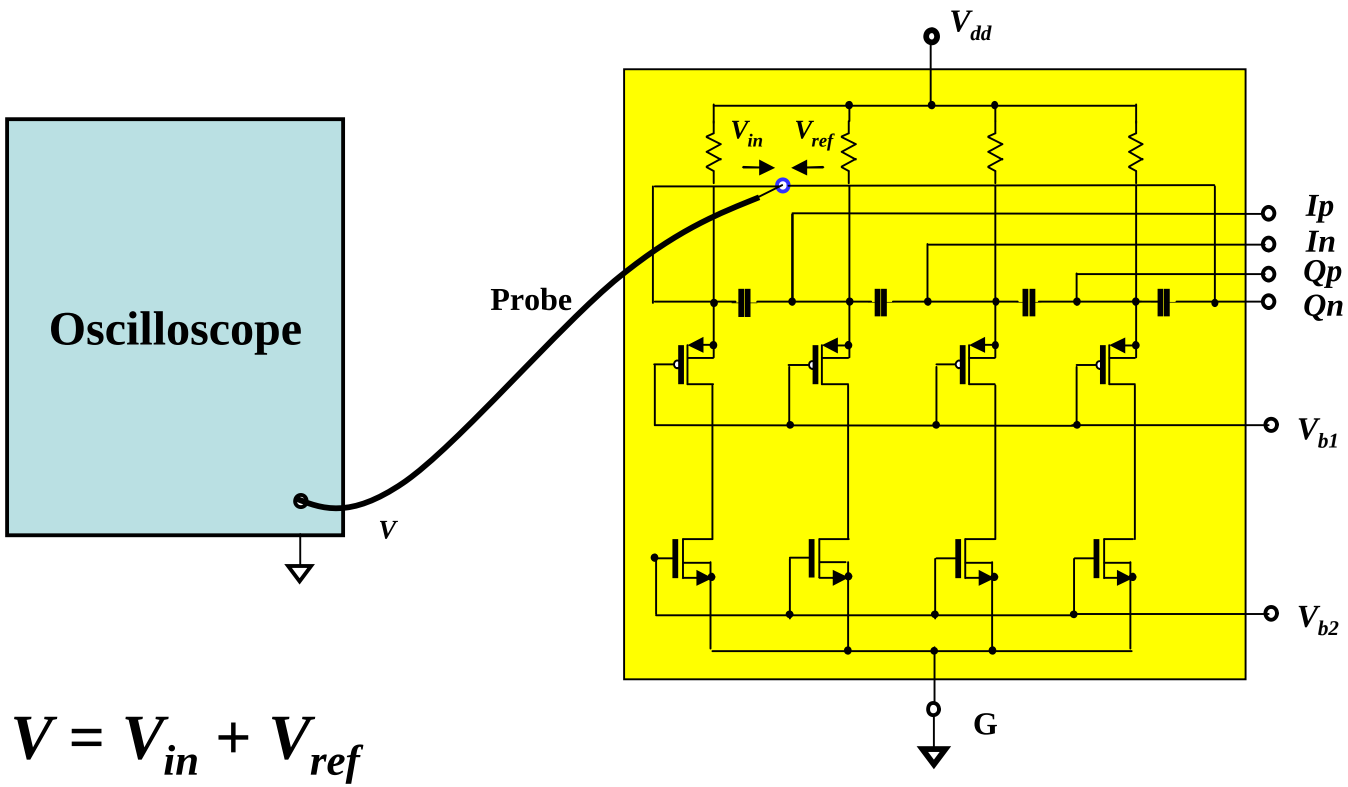
4. **Impedance measured by means of circulator**

5. **Impedance matching and matching of a mixer**

1. Introduction

o Voltage Measurement at One Point



$$V = V_{in} + V_{ref}$$

Figure 4.1 Voltage measured at one point is a resultant entity of incident and reflected voltage

o Measurement by S parameters is better than by others

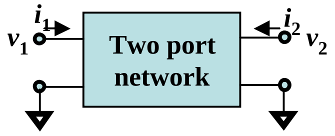
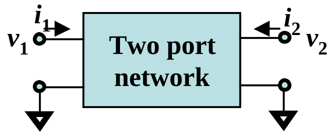
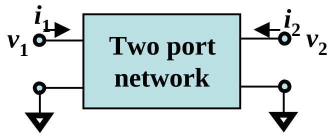
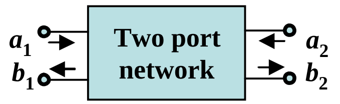
Parameters	Matrix	Coefficients	Block
Z	$v_1 = z_{11}i_1 + z_{12}i_2$ $v_2 = z_{21}i_1 + z_{22}i_2$	$z_{11} = v_1 / i_1 \mid_{i2=0}$ --- ---	
Y	$i_1 = y_{11}v_1 + y_{12}v_2$ $i_2 = y_{21}v_1 + y_{22}v_2$	$y_{11} = i_1 / v_1 \mid_{v2=0}$ --- ---	
h	$v_1 = h_{11}i_1 + h_{12}v_2$ $i_2 = h_{21}i_1 + h_{22}v_2$	$h_{11} = v_1 / i_1 \mid_{v2=0}$ $h_{12} = v_1 / v_2 \mid_{i1=0}$ ---	
S	$b_1 = s_{11}a_1 + s_{12}a_2$ $b_2 = s_{21}i_1 + s_{22}b_2$	$s_{11} = b_1 / a_1 \mid_{a2=0}$ --- ---	

Figure 4.2 The various parameters to characterize a two port network.

2. Impedance Measured Directly by NewworkAnalyzer

- **Theoretical background of impedance measurement by parameters, S_{11}, S_{22}**

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

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

When $\Gamma_S = \Gamma_L = 0$,

Or, $S_{12} = 0$,

Or, $S_{21} = 0$,

$$\Gamma_{in} = S_{11}$$

$$\Gamma_{out} = S_{22}$$

$$Z_{in} = \frac{1+\Gamma_{in}}{1-\Gamma_{in}} = \frac{1+S_{11}}{1-S_{11}}$$

$$Z_{out} = \frac{1+\Gamma_{out}}{1-\Gamma_{out}} = \frac{1+S_{22}}{1-S_{22}}$$

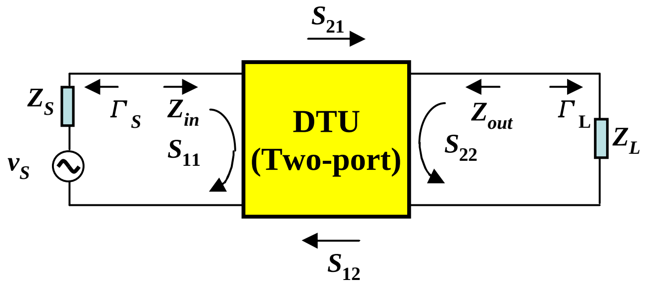


Figure 4.3 Relationship between S_{ij} and Γ_k

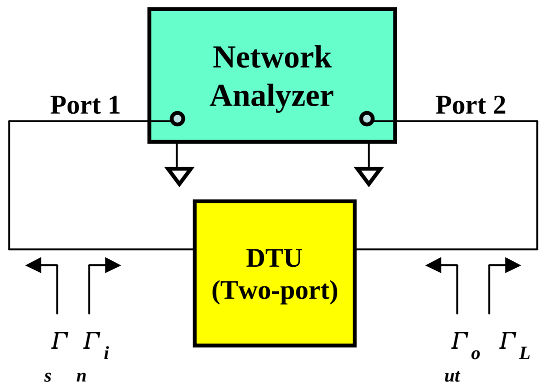


Figure 4.4 Impedance measured by network analyzer

o Smith Chart

* Impedance coordination

$$\Gamma = U + jV$$

$$\Gamma = \frac{Z - Z_o}{Z + Z_o} = \frac{z-1}{z+1}$$

$$z = \frac{Z}{Z_o} = r + jx$$

$$z = \frac{1+\Gamma}{1-\Gamma}$$

$$\Gamma = U + jV = \frac{(r-1) + jx}{(r+1) + jx}$$

$$U = \frac{r^2 - 1 + x^2}{(r+1)^2 + x^2}$$

$$V = \frac{2x}{(r+1)^2 + x^2}$$

$$[U - r/(r+1)]^2 + V^2 = \frac{1}{(r+1)^2}$$

$$(U-1)^2 + (V - 1/x)^2 = \frac{1}{x^2}$$

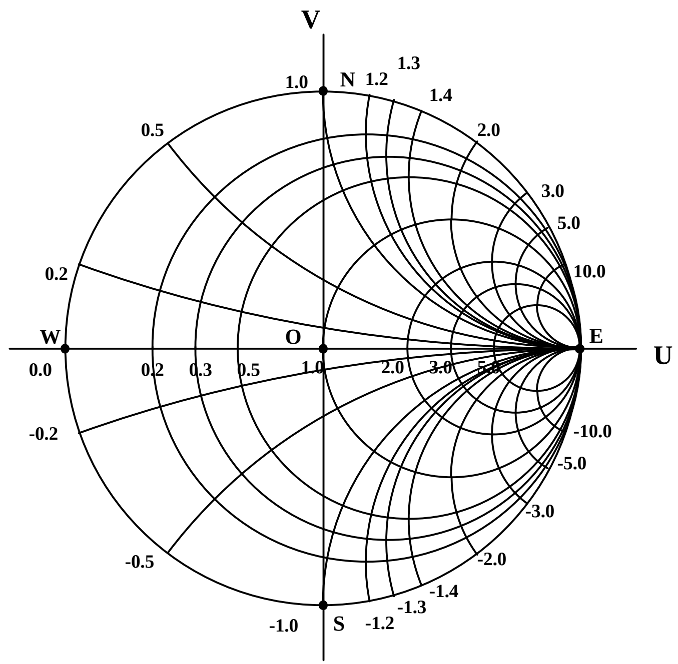


Figure 4.5 Impedance coordination of Smith Chart

*** Admittance coordination**

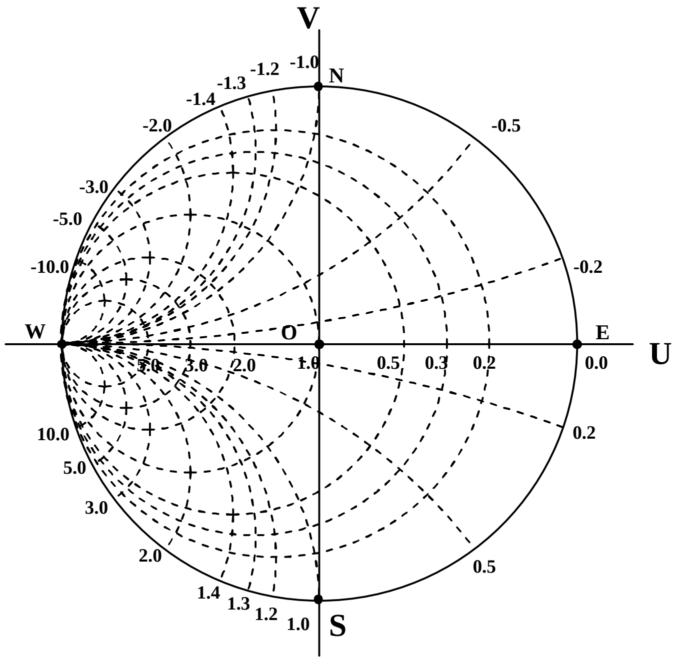


Figure 4.6 Admittance coordination of the Smith Chart

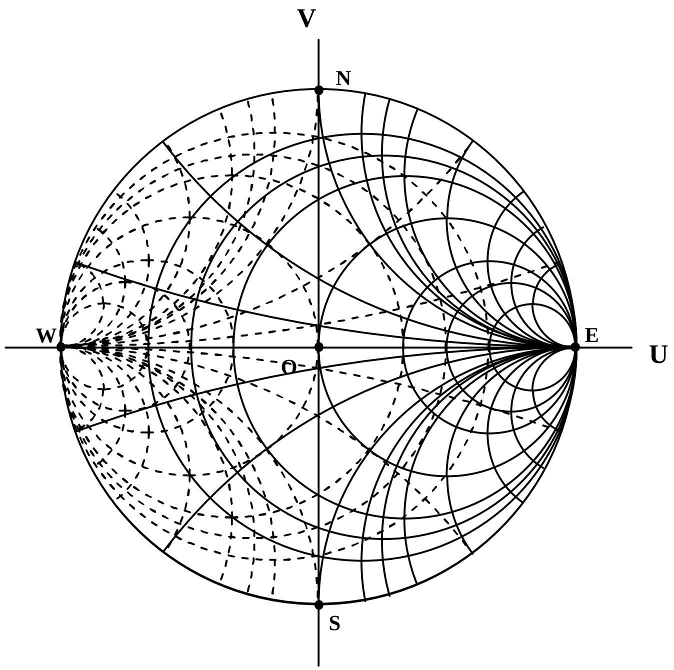
$$y = g + jb$$

$$y = \frac{1}{z} = \frac{1 - \Gamma}{1 + \Gamma}$$

The y curve can be obtained by rotating of z curve with 180^{o} because

$$y = \frac{1}{z} = \frac{1 - \Gamma}{1 + \Gamma} = \frac{1 + \Gamma e^{jp}}{1 - \Gamma e^{jp}}$$

* Impedance and admittance coordination together



——— **Solid line** $z = \frac{Z}{Z_o} = r + jx$

------- **Dashed line** $y = \frac{Y}{Y_o} = g + jb$

Figure 4.7 Impedance and admittance coordination of Smith Chart

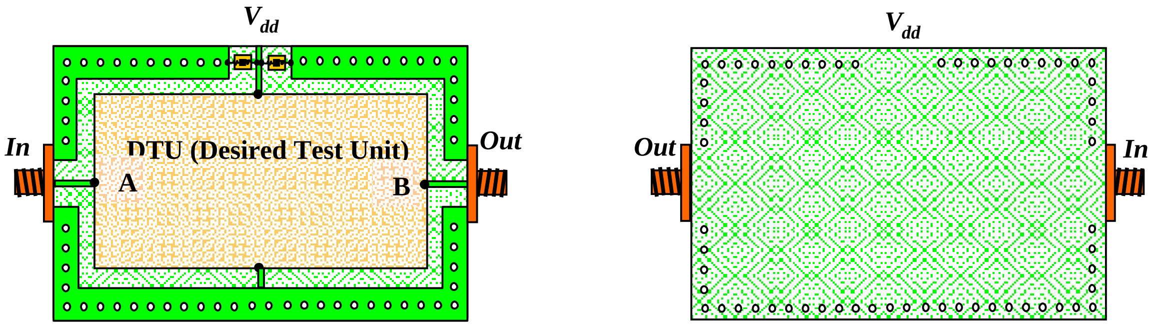
* Scales on Smith chart

Some scaled parameters are attached below the Smith Chart :

- **Reflection coefficient of power,** G^2**,**
- **Return loss in dB,** **-10log(**G^2**),**
- **Reflection loss in dB,** **-10log(1-**G^2**),**
- **VSWR (Voltage Standing Wave Ratio),** **(1+**$|G|$**)/(1-**$|G|$**),**
- **VSWR in dB,** **20log(1+**$|G|$**)/(1-**$|G|$**),**
- **Transmission loss coefficient,** **(1+**$|G|^2$**)/(1-**$|G|^2$**).**

o Calibration of network analyzer

* A test PCB



(a) Test PCB (Top side) (b) Test PCB (Bottom side)

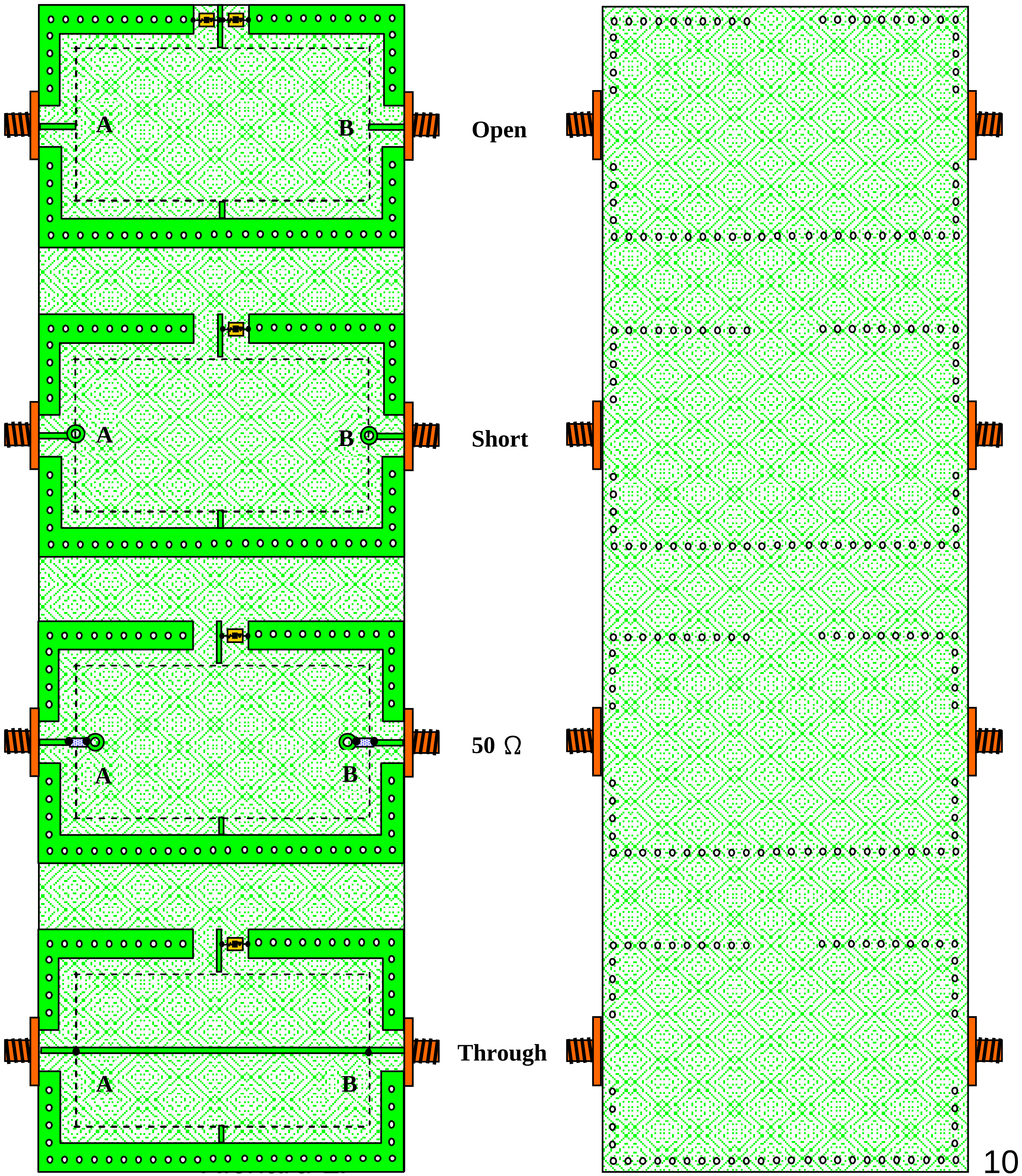
Figure 4.8 Layout of test PCB

- Top metallic area;
- Bottom metallic area;
- Conductive via from top to bottom;
- "Zero" capacitor
- DTU (Desired Test Unit)
- Runner, $Z_o = 50\ \Omega$
- SMA connector

* Calibration Board for Network Analyzer

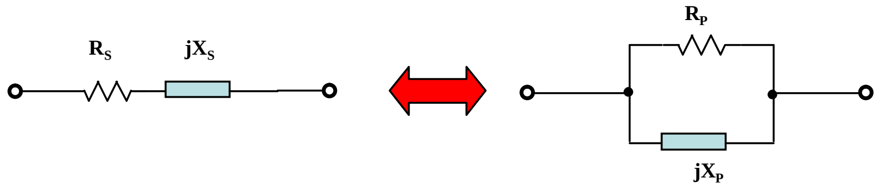
Figure 4.9 Layout of a self-supporting calibration kit

Top metallic area;
Bottom metallic area;
Conductive via from top to bottom
“Zero” capacitor
50 Ω resistor
Runner, Zo= 50 Ω.
SMA connector



(a) Calibration kit (Top side) (b) Calibration (Bottom side)

o Transformation of impedance between in series and in parallel



$Z = R_S + j X_S$ $Z = R_P // jX_P$

Figure 4.10 Transformation of impedance between in series andin parallel

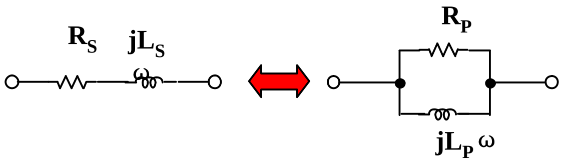
$$R_S + jX_S = R_P // jX_P = \frac{X_P{}^2 R_P + jX_P R_P{}^2}{R_P{}^2 + X_P{}^2}$$

$$X_P = X_S \frac{Q^2 + 1}{Q^2} \cong X_S$$

$$R_P = R_S (Q^2 + 1) \cong \frac{X_S{}^2}{R_S}$$

$$Q = \frac{|X_S|}{R_S} = \frac{R_P}{|X_P|}$$

Note : X_S and X_P could be either inductors or capacitors.

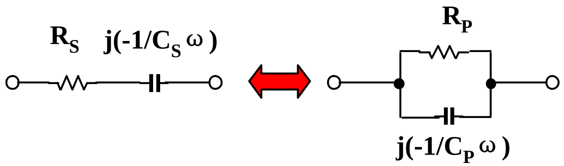


$Z_S = R_S + j\,L_S\,\omega$ $\qquad Z_P = R_P \,//\, jL_P\,\omega$

(a) When X_S and X_P are impedance of inductors

$$X_S = X_{LS} = L_S w$$

$$X_P = X_{LP} = L_P w$$



$Z_S = R_S + j\,(-1/C_S\,\omega)$ $\qquad Z_P = R_P \,//\, j(-1/C_P\,\omega)$

(b) When X_S and X_P are impedance of capacitors

$$X_S = X_{CS} = -\frac{1}{C_S w}$$

$$X_P = X_{CP} = -\frac{1}{C_P w}$$

Figure 4.11 Transformation of impedance between in series andin parallel

$$R_S + jL_S w = R_P \,//\, jL_P w = \frac{L_P{}^2 w^2 R_P + jL_P w R_P{}^2}{R_P{}^2 + L_P{}^2 w^2}$$

$$L_P = L_S \frac{Q^2+1}{Q^2}$$

$$R_P = R_S (Q^2+1)$$

$$Q = \frac{L_S w}{R_S} = \frac{R_P}{L_P w}$$

$$R_S + j\left(\frac{-1}{C_S w}\right) = R_P \,//\, j\left(\frac{-1}{C_P w}\right) = \frac{R_P - jR_P{}^2 C_P w}{R_P{}^2 C_P{}^2 w^2 + 1}$$

$$C_P = C_S \frac{Q^2}{Q^2+1}$$

$$R_P = R_S (Q^2+1)$$

$$Q = \frac{1}{R_S C_S w} = R_P C_P w$$

3. Impedance measured alternatively by network analyzer

- o Accurate and inaccurate area of Smith Chart

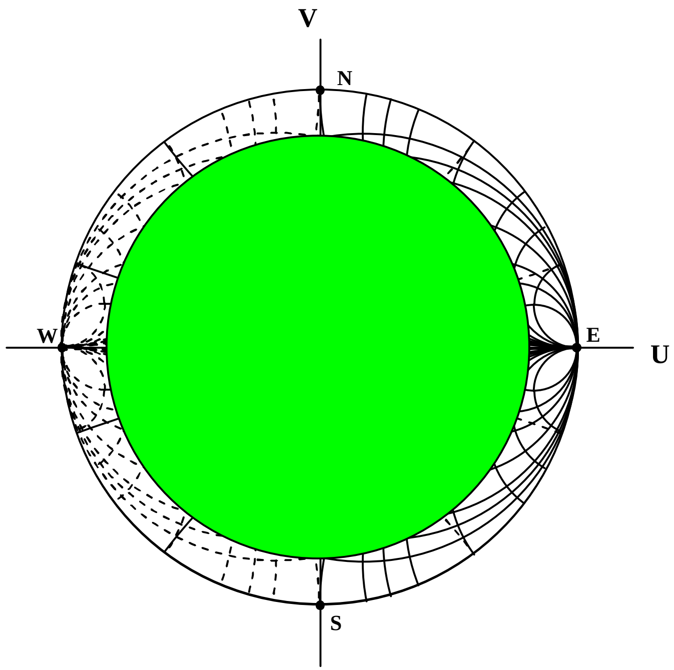
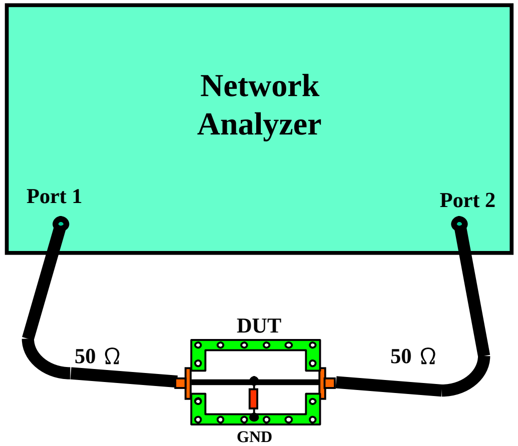


Figure 4.12 Accurate and inaccurate area in Smith Chart

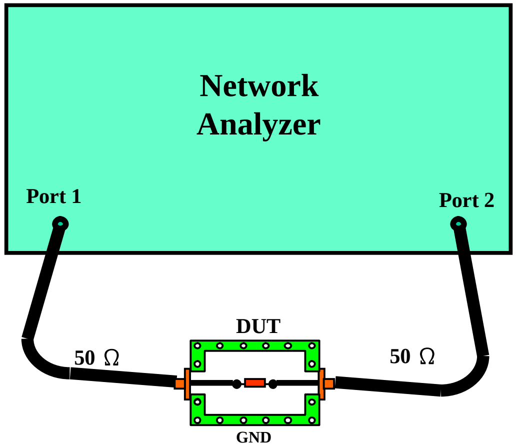
Relatively accurate area

Relatively inaccurate area

- Impedance measured by an alternative way



(a) Testing for low impedance part.



(b) Testing for high impedance part.

Figure 4.13 Testing setup for parts with low and high impedance

DTU (Desired Test Unit)

o Impedance measured by means of circulator

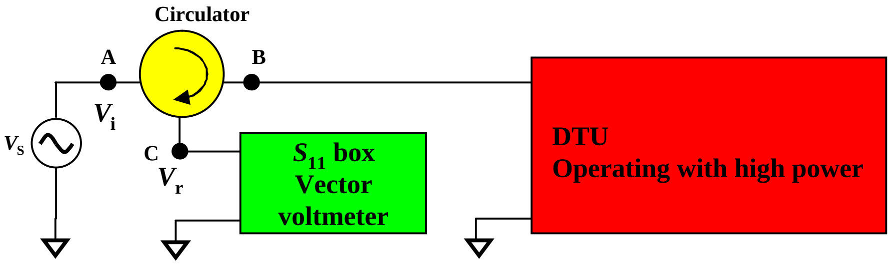


Figure 4.14 Impedance measurement by means of circulator.

$$\Gamma = \frac{V_r}{V_i}$$

$$z = \frac{1 + \Gamma}{1 - \Gamma}$$

o Impedance measuring and matching of a mixer :

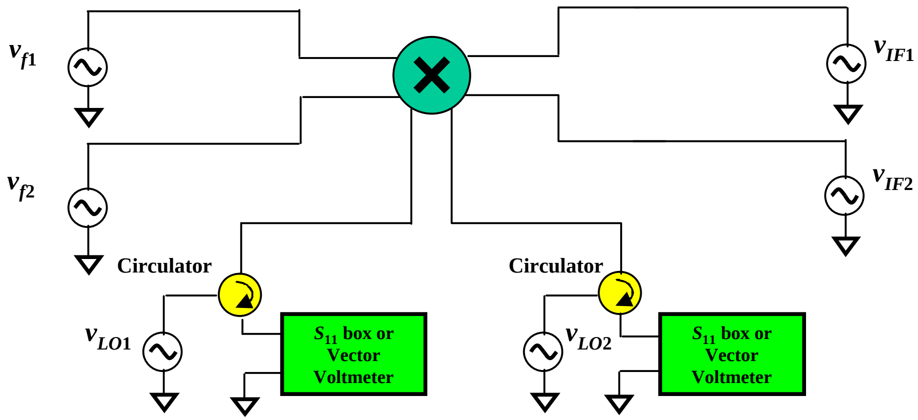


Figure 4.15 Impedance measurement and matching for a differential mixer by means of circulator.

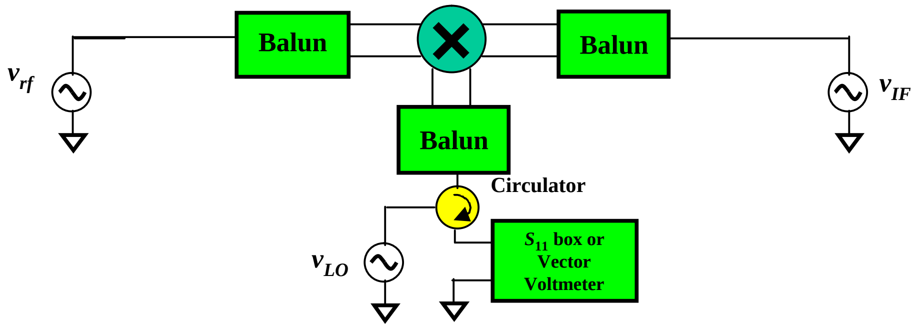


Figure 4.16 Change of impedance measurement and matching fora differential mixer by means of Balun.

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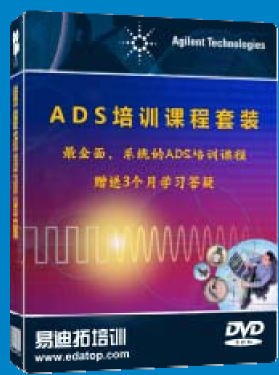

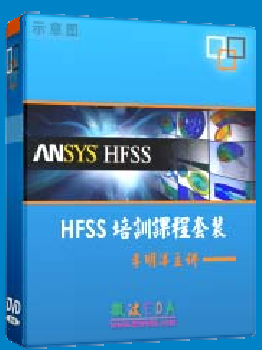

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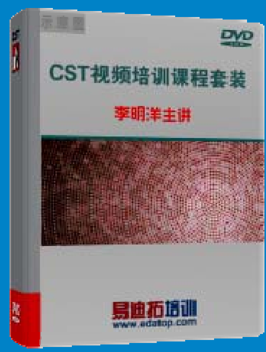

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