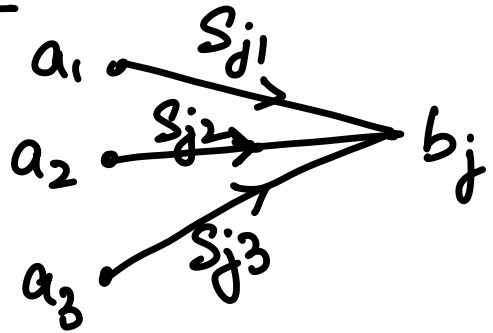




VNA Calibrate

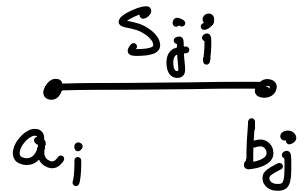
Signal Flow Graphs

$$b_j = \sum_{i=1}^3 S_{ji} a_i$$



Nodes: Wave amplitudes.

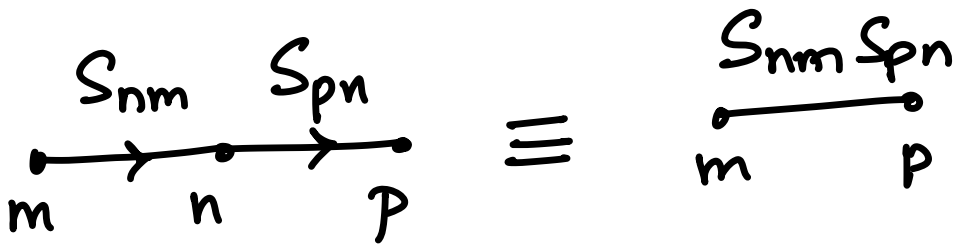
Branches: Gain (directed).



$$\Rightarrow b_j = S_{ji} a_i$$

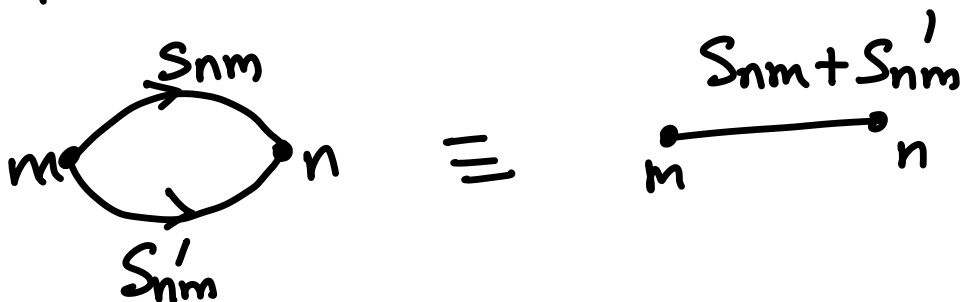
SFG Rules

#1

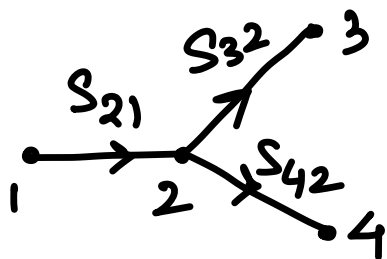


$$p = S_{pn} n = S_{pn} S_{nm} m$$

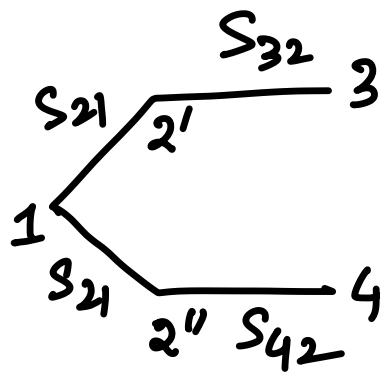
#2



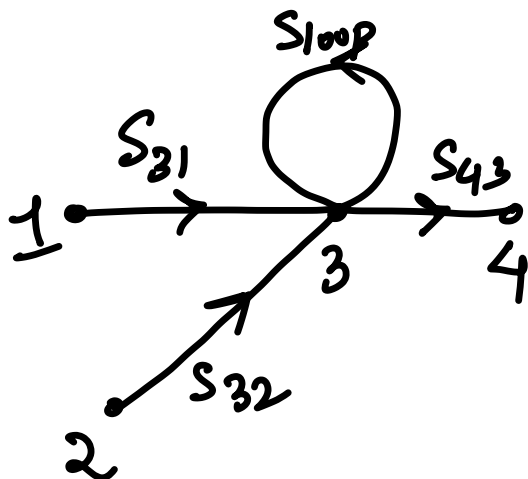
#3



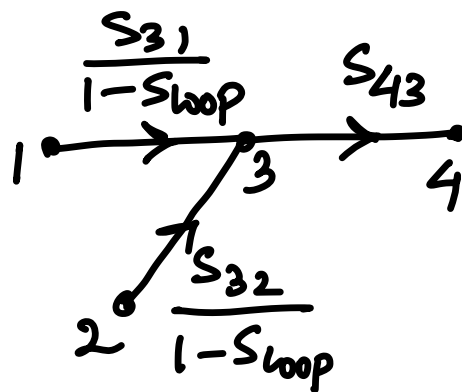
$\equiv$



#4



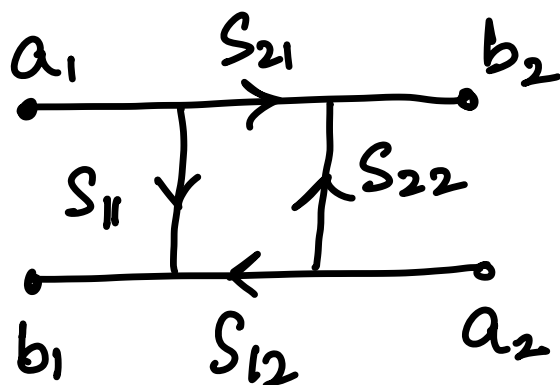
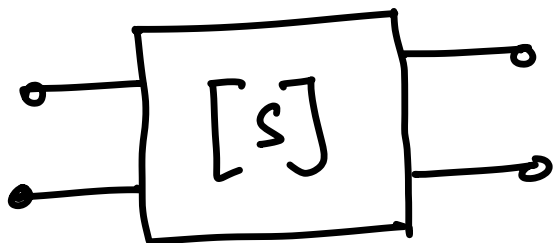
$\equiv$



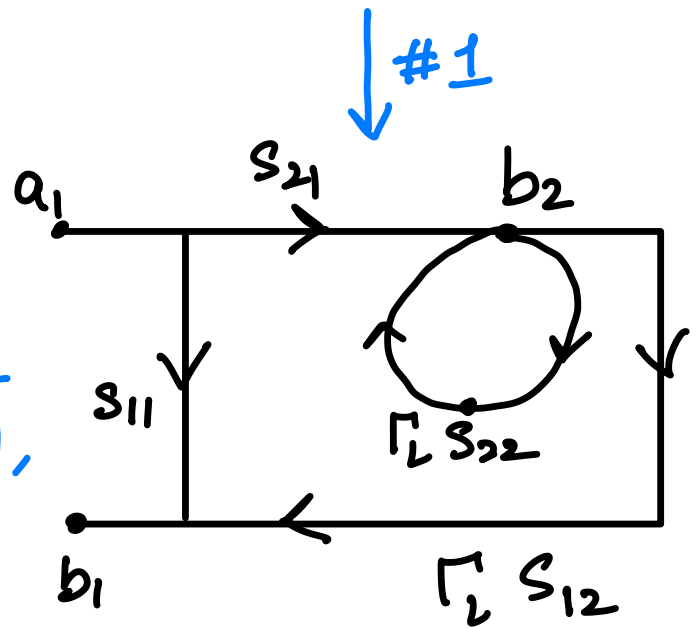
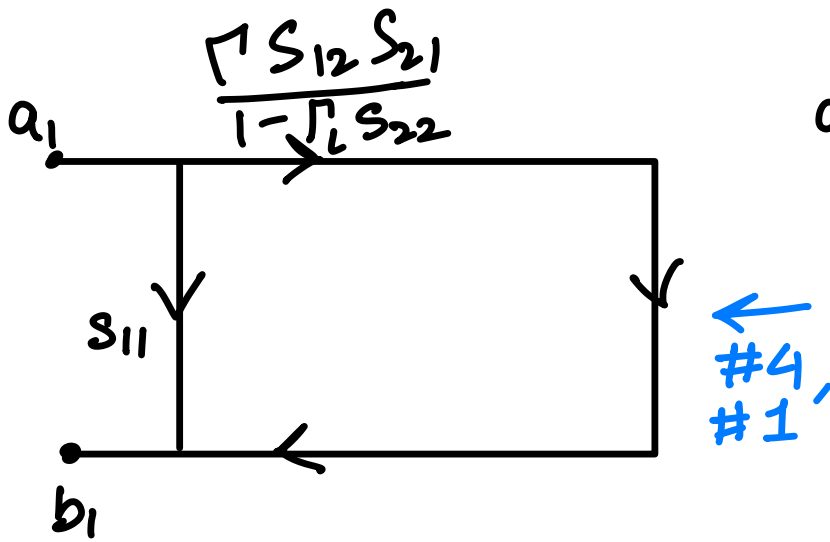
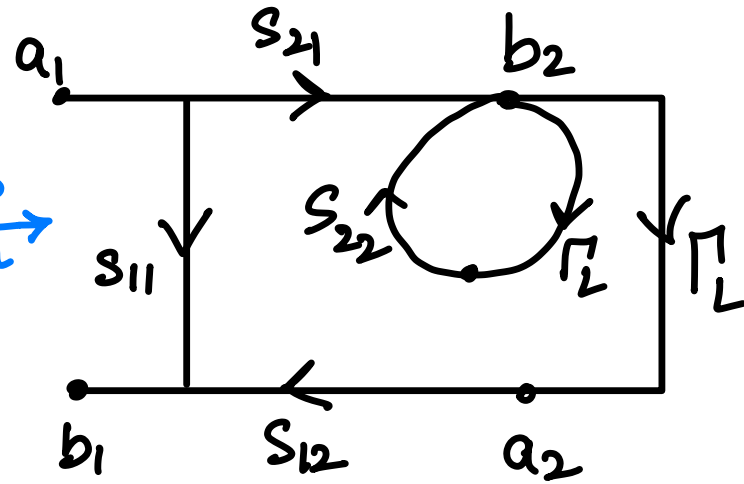
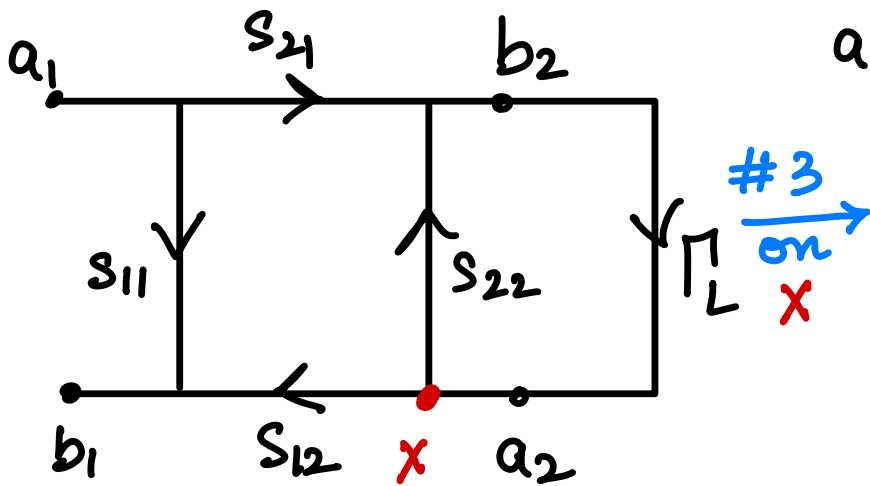
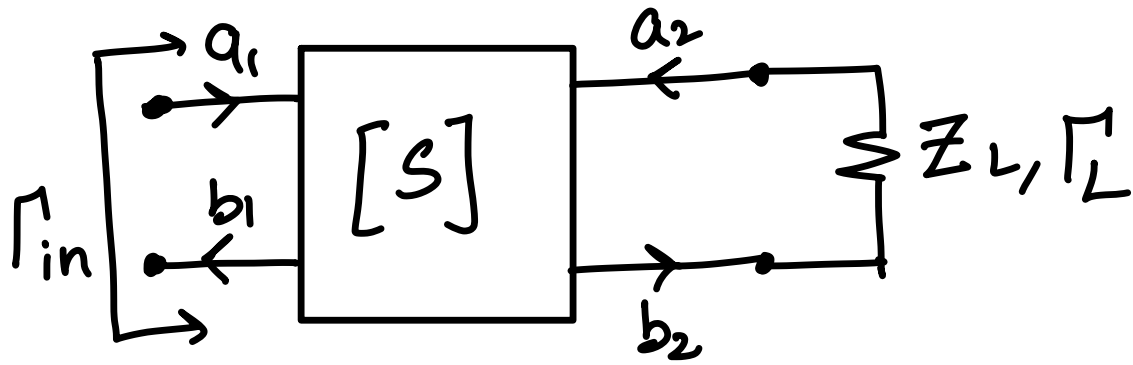
$$a_3 = S_{31} a_1 + S_{32} a_2 + S_{loop} a_3$$

$$\Rightarrow a_3 = \frac{S_{31}}{1 - S_{loop}} a_1 + \frac{S_{32}}{1 - S_{loop}} a_2$$

Example



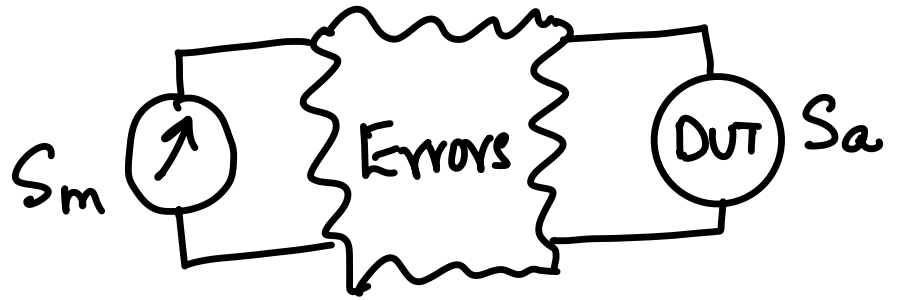
Example



#2

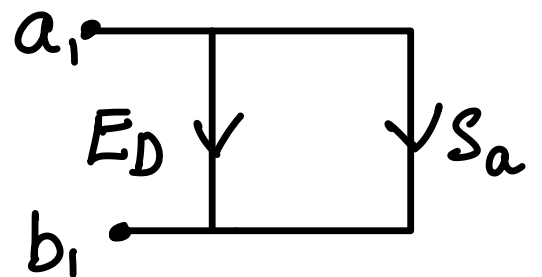
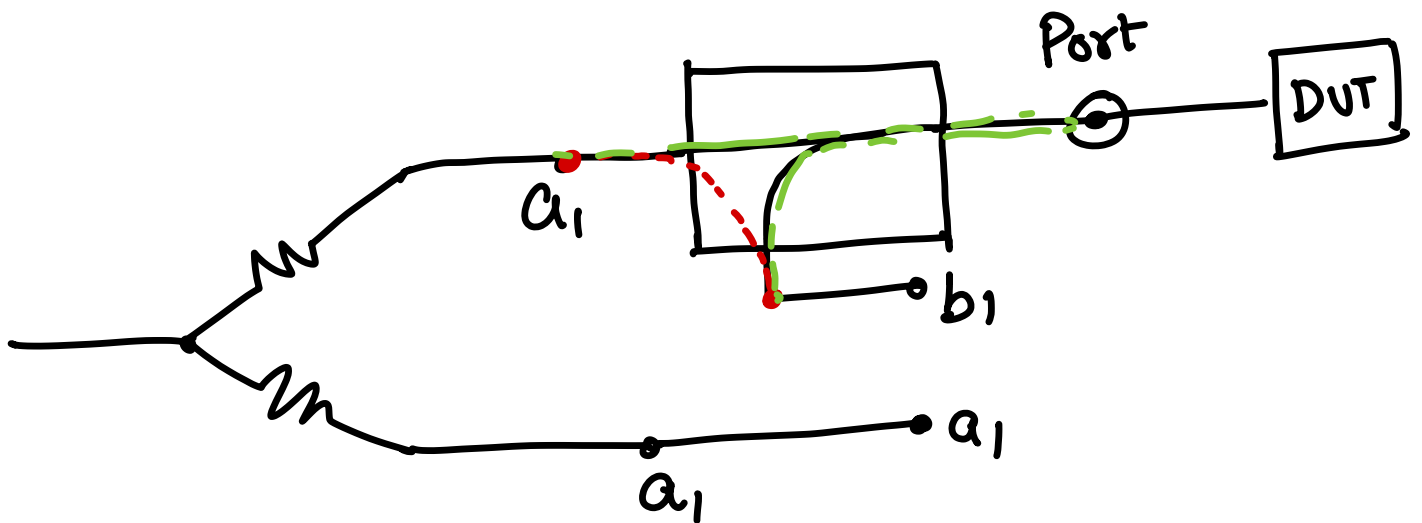
$$\Rightarrow \Gamma_{in} = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - \Gamma_L S_{22}}$$

Error Model (VNA).

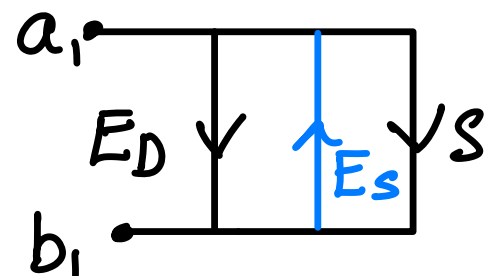
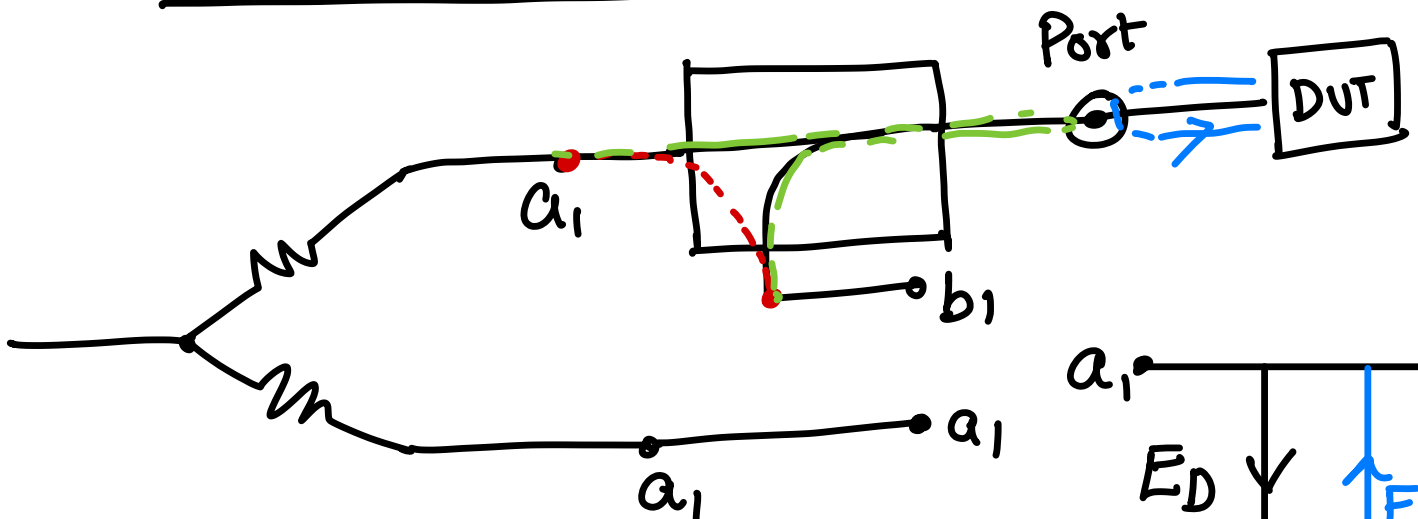


Sources of Error

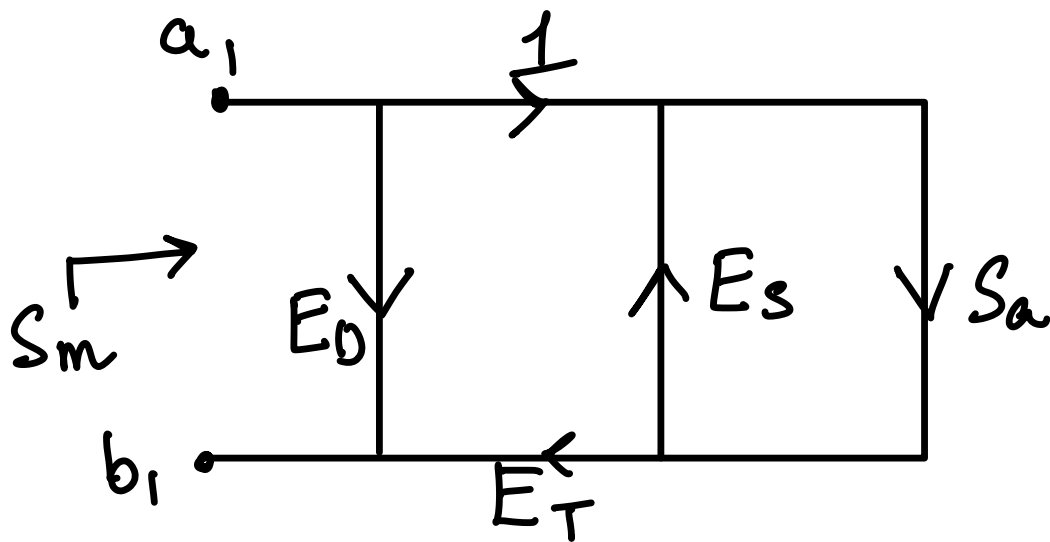
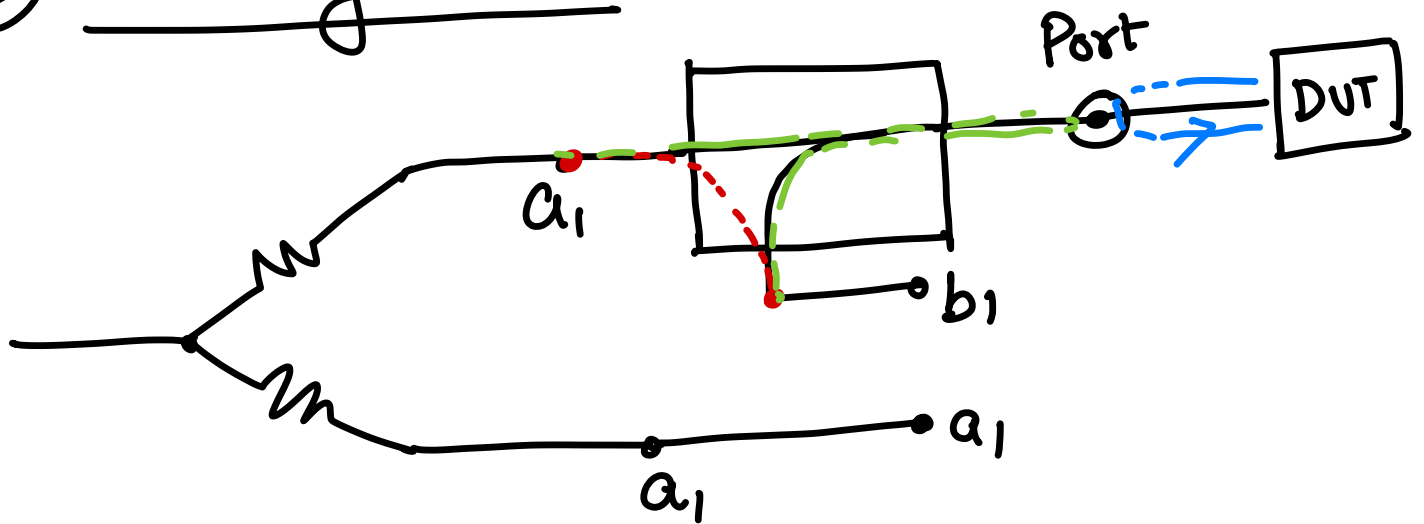
1) Directivity Error



2) Source Mismatch



3) Tracking Error



3-TERM
MODEL

$$S_m = E_0 + \frac{E_T S_a}{1 - E_S S_a}$$

$$S_a = \frac{S_m - E_0}{E_S (S_m - E_0) + E_T}$$

Calibration Standards (SOL)

$$\text{Short} : S_a^s = -1$$

$$\text{Open} : S_a^o = 1$$

$$\text{Load} : S_a^l = 0$$

$$E_D = S_m^l$$

$$S_m^s = E_D - \frac{E_T}{1+E_s}$$

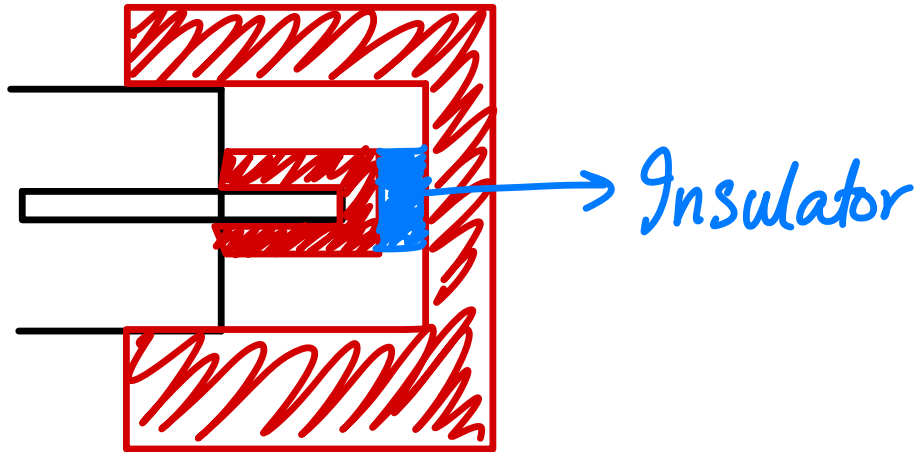
$$S_m^o = E_D + \frac{E_T}{1-E_s}$$

$$E_D = S_m^l$$

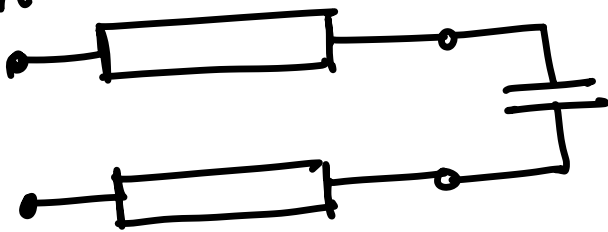
$$E_s = \frac{S_m^s + S_m^o - 2S_m^l}{S_m^o - S_m^s}$$

$$E_T = \frac{2(S_m^s - S_m^l)(S_m^o - S_m^l)}{S_m^s - S_m^o}$$

Calibration Standards (Practice)

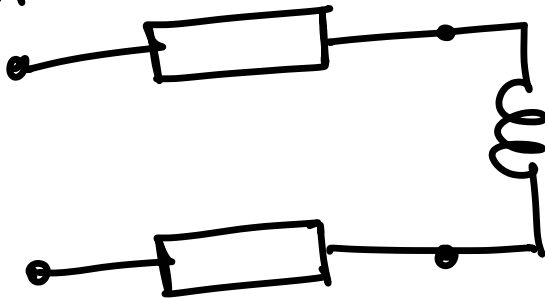


open

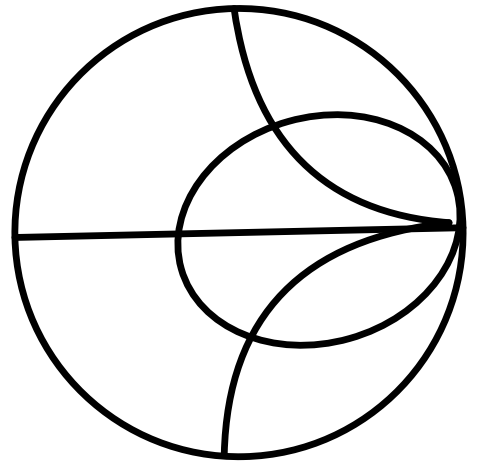


$$C(f) = C_0 + C_1 f + C_2 f^2 + C_3 f^3$$

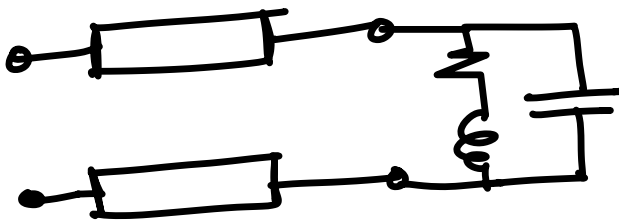
short



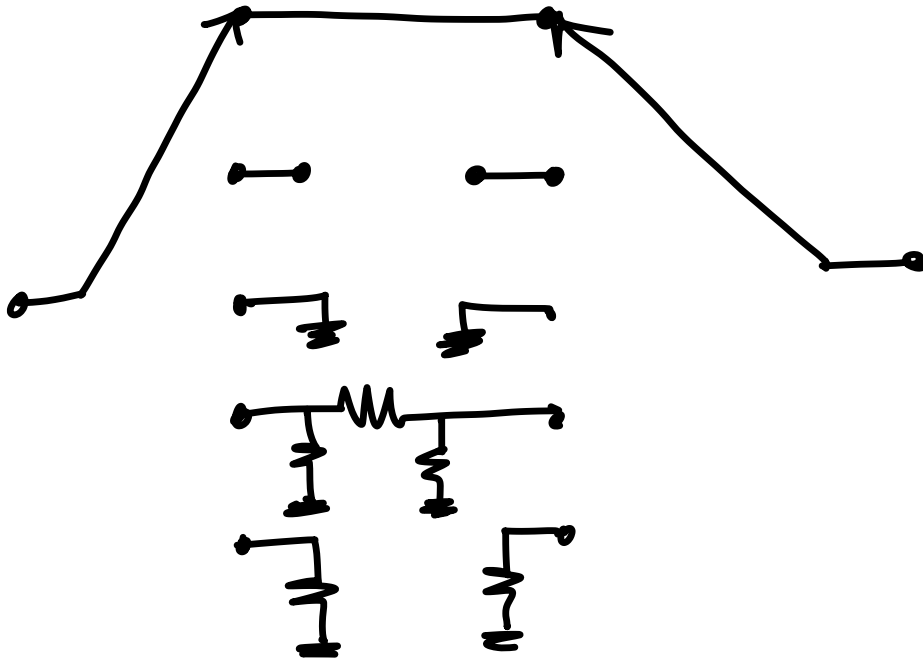
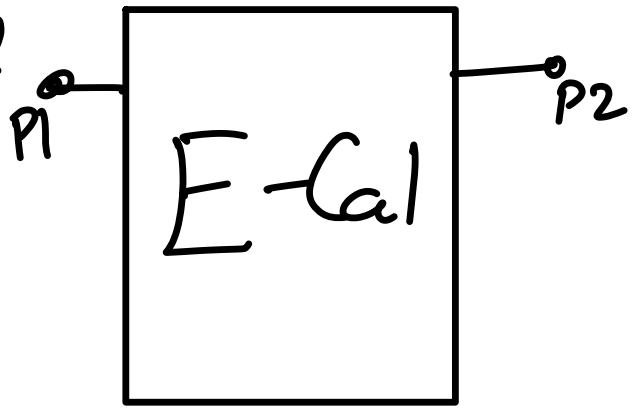
$$L(f)$$



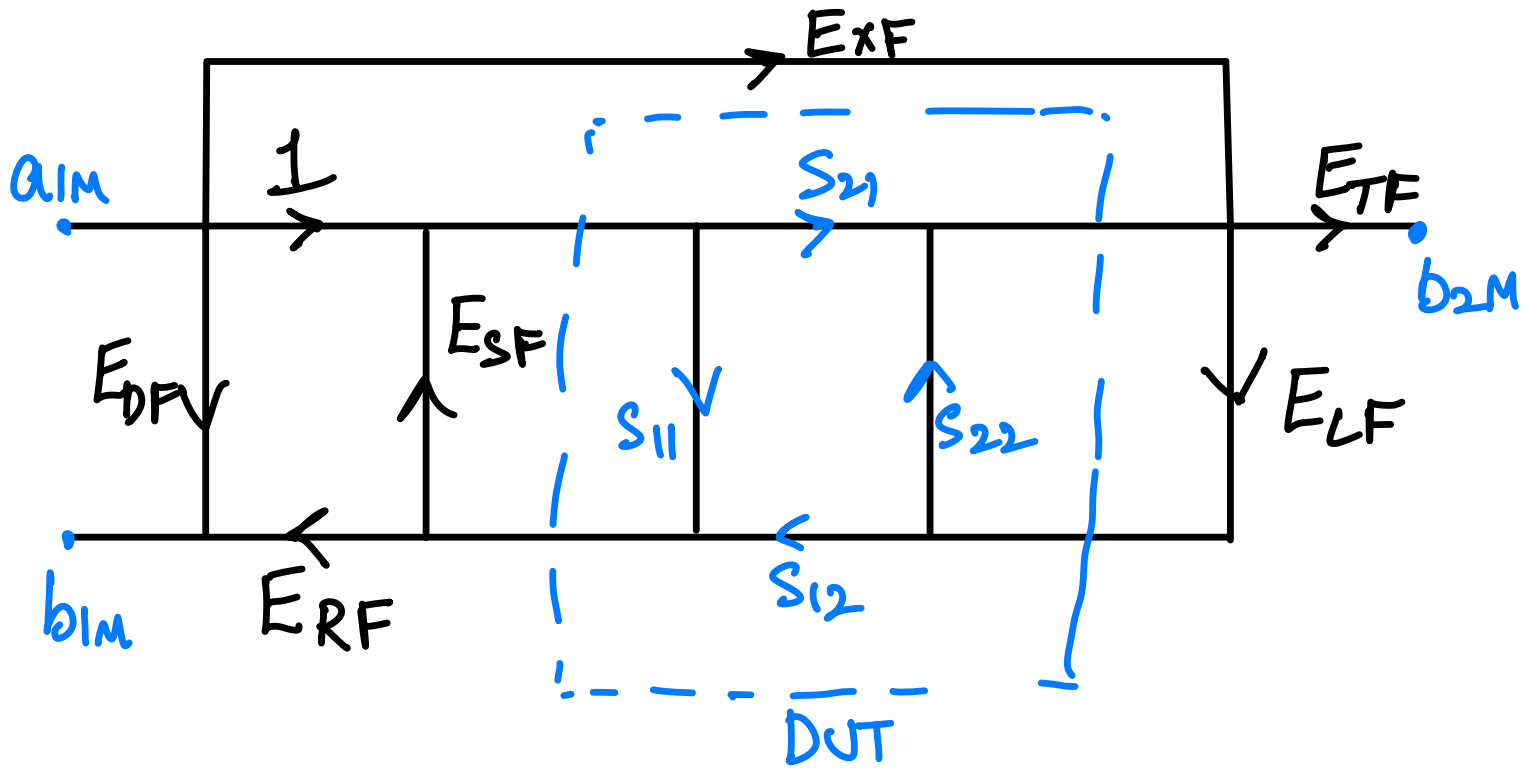
load



Electronic - Calibration



Standard 2-port VNA uses a



$$S_{11M} = \frac{b_{1M}}{a_{1M}}$$

$$= E_{DF} + \frac{E_{RF} \left(S_{11A} + \frac{S_{21A} E_{LF} S_{12A}}{1 - S_{22A} E_{LF}} \right)}{\left[1 - E_{SF} \left(S_{11A} + \frac{S_{21A} E_{LF} S_{12A}}{1 - S_{22A} E_{LF}} \right) \right]}$$

$$S_{21M} = \frac{b_{2M}}{a_{1M}}$$

$$= E_{XF} + \frac{S_{21A} E_{TF}}{(1 - S_{11A} E_{SF})(1 - S_{22A} E_{LF}) - E_{SF} S_{21A} S_{12A} E_{LF}}$$

SOLT (Short, Open, Load, Thru).

Port 1 $\rightarrow$ 3

Port 2 $\rightarrow$ 3

Thru $\rightarrow$ 4