$\text{sinc}\,\theta = \frac{\sin\theta}{\theta}$

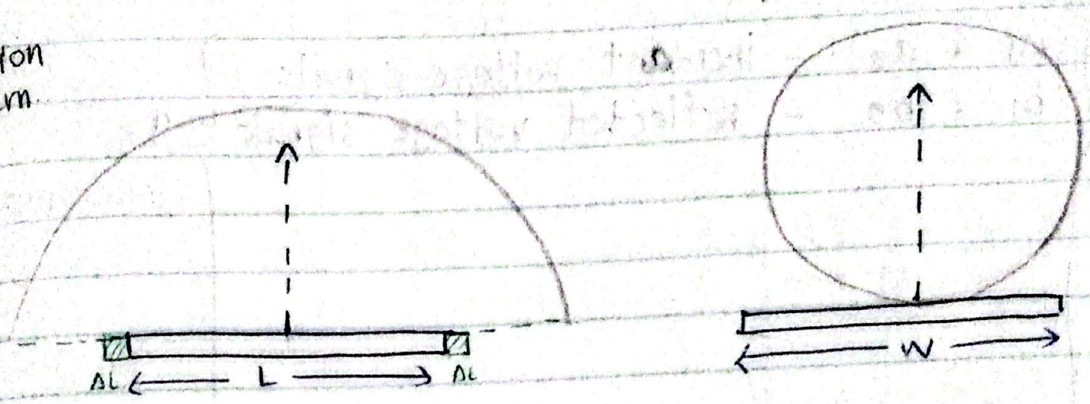
$$\boxed{Z_{IN} = \frac{90}{\varepsilon_r - 1}\left(\frac{\varepsilon_r L}{W}\right)^2}$$

$$Z_{IN} = \frac{90}{4.2-1}\left(\frac{4.2 \times 5.9}{8.6}\right)^2$$

$$= 28.125 \times 8.29$$

$$= \cancel{2.33}\ \ 233.15\ \Omega$$

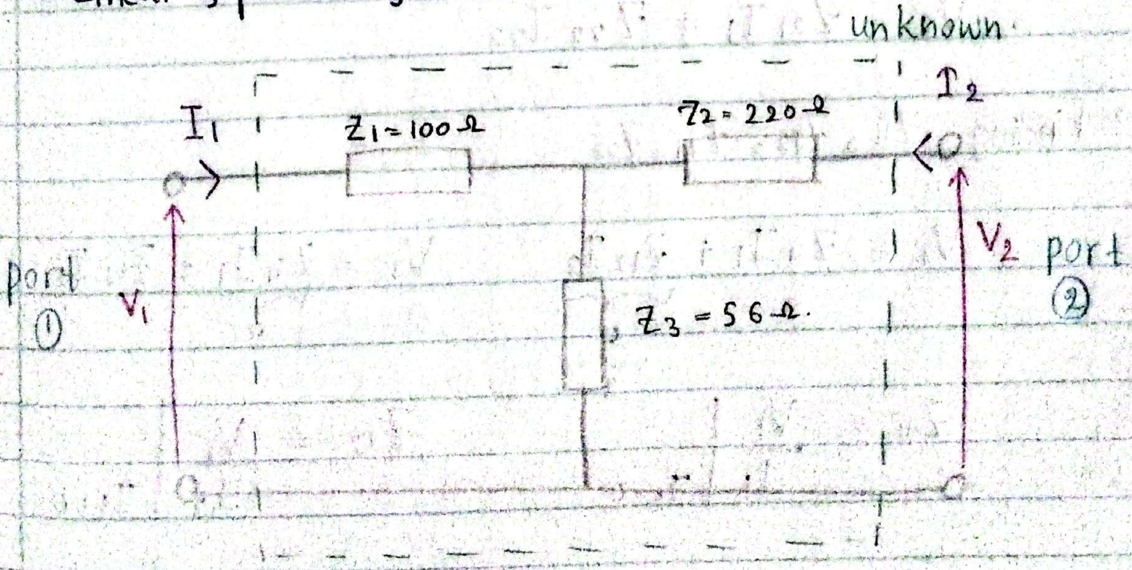
radiation pattern



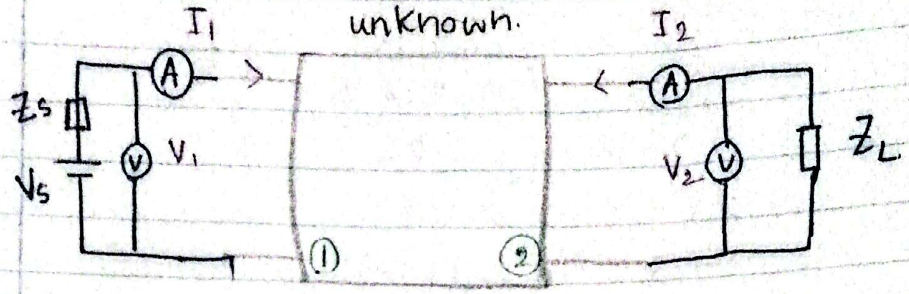
Two - Port Networks.

Method of analysis and representation of a circuit.

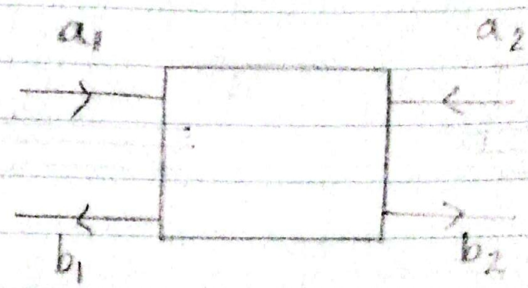
- Linear, passive, bilateral.



V_1, V_2 & I_1, I_2 measurable, 4 variables.



a_1 & a_2 - incident voltage signals.
b_1 & b_2 - reflected voltage signals
In microwave.



Two port network description.

$$V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$V_2 = Z_{21} I_1 + Z_{22} I_{22}$$

→ Finding $Z_{11}, Z_{12}, Z_{21}, Z_{22}$.

$$V_1 = Z_{11} I_1 + \underbrace{Z_{12} I_2}_{0} \qquad V_1 = \underbrace{Z_{11} I_1}_{0} + Z_{12} I_2$$

$$Z_{11} = \left.\frac{V_1}{I_1}\right|_{I_2=0} \qquad Z_{12} = \left.\frac{V_1}{I_2}\right|_{I_1=0}$$

$$= 156\ \Omega \qquad = 56\ \Omega$$

$$V_2 = \underbrace{Z_{21} I_1}_{0} + Z_{22} I_2 \qquad V_2 = Z_{21} I_1 + \underbrace{Z_{22} I_2}_{0}$$

$$Z_{22} = \frac{V_2}{I_2}\Bigg|_{I_1=0} \qquad Z_{21} = \frac{V_2}{I_1}\Bigg|_{I_2=0}$$

$$= 276\,\Omega \qquad = 56\,\Omega$$

$$V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$\frac{V_1}{I_1} = Z_{11} + Z_{12}\frac{I_2}{I_1}$$

$$Z_{12} A_I = \frac{V_1}{I_1} - Z_{11}$$

$$\frac{-Z_{12} Z_{21}}{Z_{22} + Z_L} = \frac{V_1}{I_1} - Z_{11}$$

$$V_1 = Z_{11} I_1 - \left(\frac{Z_{12} Z_{21}}{Z_{22} + Z_L}\right) I_1$$

$$A_V = \frac{V_2}{V_1}$$

$$= \frac{Z_L(-I_2)}{Z_{11} I_1 - \left(\frac{Z_{12} Z_{21}}{Z_{22} + Z_L}\right) I_1}$$

$$= \frac{-Z_L A_I}{Z_{11} + Z_{12} A_I}$$

$$= \frac{-Z_L A_I}{Z_{11} + Z_{12} A_I}$$

$$= \frac{+Z_L Z_{21}}{Z_{11}(Z_{22} + Z_L) - Z_{12} Z_L}$$

$$V_2 = Z_{21} I_1 + Z_{22} I_2$$

$$\frac{V_2}{I_1} = Z_{21} + Z_{22}\frac{I_2}{I_A}$$

$$Z_{22} A_I = \frac{V_2}{I_1} - Z_{21}$$

$$V_2 = Z_L(-I_2)$$

$$Z_{22}\frac{I_2}{I_1} = -\frac{Z_L I_2}{I_1} - Z_{21}$$

$$\frac{I_2}{I_1}(Z_{22} + Z_L) = -Z_{21}.$$

$$\boxed{A_I = \frac{-Z_{21}}{Z_{22} + Z_L}}$$

$$Z_L = 1k\,\Omega$$

$$A_I = \frac{-56}{276 + 1000}$$

$$= \frac{-56}{1276}$$

$$= -0.044$$

$$\frac{V_2}{V_1} = \frac{Z_{21} I_1 + Z_{22} I_2}{Z_{11} I_1 + Z_{12} I_2}$$

$$= \frac{Z_{21} + Z_{22} A_I}{Z_{11} + Z_{12} A_I}$$

$$\boxed{A_V = \frac{Z_{22} Z_L}{Z_{11} Z_{22} - Z_{12} Z_{21} + Z_{11} Z_L}}$$

$$A_V = 0.281$$

$$A_S = \frac{V_2}{V_S}$$

$$V_S = Z_S I_1 + V_1$$

$$V_S - Z_S I_1 = V_1 = Z_{11} I_1 + Z_{12} I_2$$

$$V_S = (Z_{11} + Z_S) I_1 + Z_{12} I_2$$

$$A_S = \frac{V_2}{V_S}$$

$$= \frac{Z_{21} I_1 + Z_{22} I_2}{(Z_{11} + Z_S) I_1 + Z_{12} I_2}$$

$$= \frac{Z_{21} + Z_{22} A_I}{(Z_{11} + Z_S) + Z_{12} A_I}$$

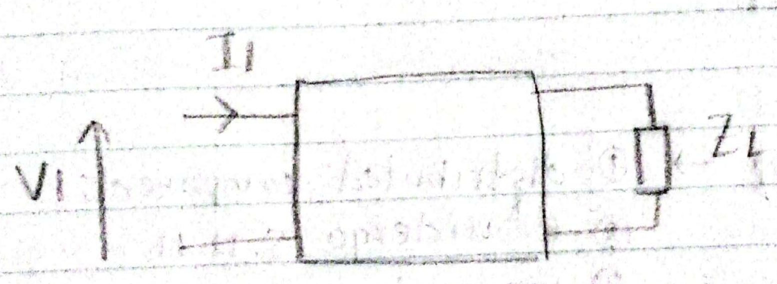
$$= \frac{Z_{21} + Z_{22}\left(\frac{-Z_{21}}{Z_{22} + Z_L}\right)}{(Z_{11} + Z_S) + Z_{12}\left(\frac{-Z_{21}}{Z_{22} + Z_L}\right)}$$

$$\cancel{A_s = \frac{Z_{21} Z_{22} + Z_{21} Z_L - Z_{22} Z_{21}}{Z_s Z_{11} Z_{22} + Z_s Z_L Z_{11} - Z_{21} Z_{12}}}$$

$$\boxed{A_s = \frac{Z_{21} Z_L}{(Z_{11} + Z_s)(Z_{22} + Z_L) - Z_{12} Z_{21}}}$$

$Z_s = 100\ \Omega$ $\quad Z_L = 1k\Omega$ $\quad A_V = 0.283$

$A_s = 0.173$



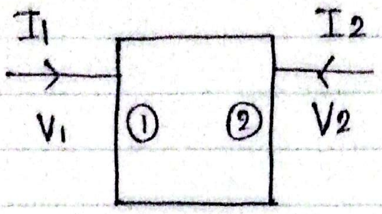
$$Z_{IN} = \frac{V_1}{I_1}$$

$0 < Z_L < \infty)$

Scatter Parameters / S-parameters

Two-port networks ← low frequency circuit theory

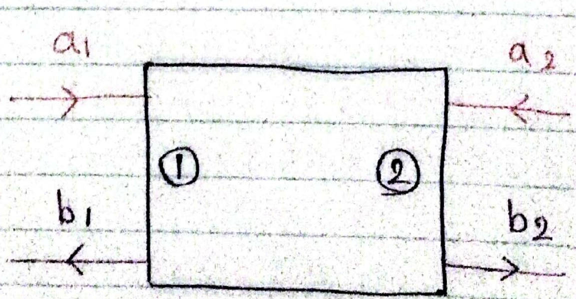
Scatter parameters ← same concept but adapted for high frequency use.



$$Z = \begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix}$$

High frequency → ① distributed components
② e^- undergo S.H.M
③ measuring power is convenient

at highfreq (i) VSWR
(ii) Network Analyser (better
we measure reflected power



a_1, a_2 incidant waves (Voltage waves)

b_1, b_2 are the reflected waves (voltage)

$A \equiv a$
$B \equiv b$

$$\boxed{\begin{aligned} V &= Ae^{\gamma z} + Be^{-\gamma z} \\ I &= \frac{A}{Z_0}e^{\gamma z} - \frac{B}{Z^0}e^{-\gamma z} \end{aligned}}$$ ← T.L.

$$b_1 = S_{11} a_1 + S_{12} a_2$$

$$b_2 = S_{21} a_1 + S_{22} a_2$$

$$S = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \longrightarrow \text{S - parameter matrix}$$

↓

description of the system

The scatter parameters are obtained as ratios when one port is matched ($a_1 = 0$ or $a_2 = 0$)

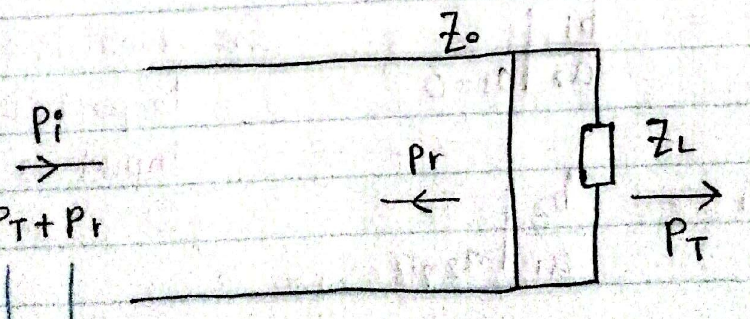
* Port reflection coefficients.

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

Here by making $a_2 = 0$ or $a_1 = 0$ we make the matching circuit.
no O C
no S C

reflection coefficient of port ②

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

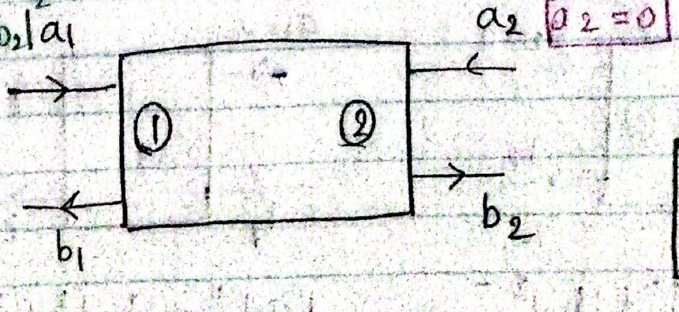


$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$P_i = P_T + P_r$

$$|a_1|^2 = |b_1|^2 + |b_2|^2$$

$$\rho = \left.\frac{b_1}{a_1}\right|_{a_2=0}$$



$$S_{11} = \rho$$

S_{11} is the reflection coefficient of port ①

$$|a_1|^2 = |b_2|^2 + |S_{11}|^2 |a_1|^2$$

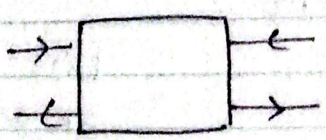
$$|b_2|^2 = |a_1|^2 - |S_{11}|^2 |a_1|^2$$

$$= (1 - |S_{11}|^2)|a_1|^2$$

$$\rho_1 = S_{11} = \frac{b_1}{a_1}\Big|_{a_2=0} \Rightarrow |S_{11}| = \left|\frac{b_1}{a_1}\right|$$

$$P_t = (1 - |\rho_1|^2) P_i$$

loseless system applied



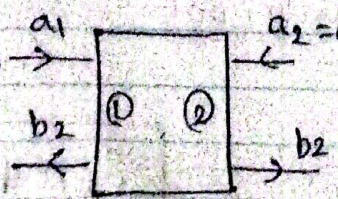
* port ~~reflection~~ transmission coefficients.

S_{21} - what is transmitted to port ② when an Input is given port ①

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

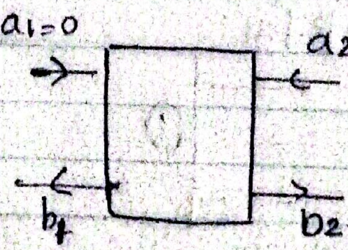
S_{12} - what is transmitted to port ① when an input is given port ②

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



$|a_1|^2 = |b_1|^2 + |b_2|^2$

lossless



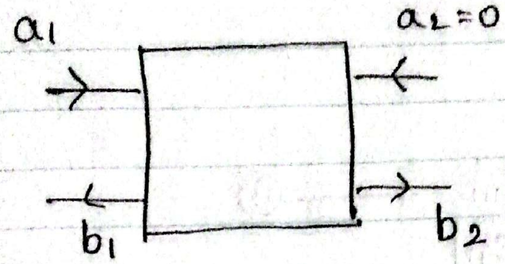
$|a_2|^2 = |b_2|^2 + |b_1|^2$

lossless

$$\frac{b_1}{a_1} = S_{11}$$

$$|S_{11}| = \frac{|b_1|^2}{|a_1|^2} \qquad |b_2|^2 = (1 - |S_{11}|^2)|a_1|^2$$

$$|b_1|^2 = (1 - |S_{22}|)^2 |a_2|^2$$



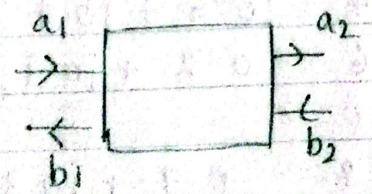
$$|a_1|^2 = |b_1|^2 + |b_2|^2$$

$$|b_2|^2 = (1 - |S_{11}|^2)|a_1|^2 \quad \text{— ①}$$

$$|b_2| = |S_{21}||a_1|$$

$$|S_{21}|^2|a_1|^2 = (1 - |S_{11}|^2)|a_1|^2$$

$$|S_{11}|^2 + |S_{21}|^2 = 1 \quad \leftarrow \text{N.W. is lossless.}$$



$$\longrightarrow \quad |S_{11}|^2 + |S_{21}|^2 = 1$$

lossless

→ Insertion loss in dB

$$IL = -20 \log_{10} |S_{21}|$$

→ Return loss in dB

$$RL = -20 \log_{10} |S_{11}|$$

→ VSWR

$$VSWR = \frac{1+|S_{11}|}{1-|S_{11}|} \quad \text{——} \; ①$$

$$VSWR = \frac{1+|S_{22}|}{1-|S_{22}|} \quad \text{——} \; ②.$$

Exercise

For the following two scatter matrices determine

$$A : \begin{pmatrix} 0.1 + j0.4 & 0.6 + j0.2 \\ 0.5 + j0.6 & 0.2 + j0.3 \end{pmatrix}$$

$$B : \begin{pmatrix} 0.1 + j0.2 & 0.7 + j0.3 \\ 0.6 + j0.7681146 & 0.2 + j0.6164414 \end{pmatrix}$$

1) Whether the circuit is lossless
2) I.L. in dB
3) R.L in dB
4) VSWR

$$S = \begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix}$$

1) A

$$|S_{11}|^2 + |S_{21}|^2$$

$$= (0.1)^2 + (0.4)^2 + (0.5)^2 + (0.6)^2$$

$$= 0.01 + 0.16 + 0.25 + 0.36$$

$$= 0.78 \,//$$

B

$$|S_{11}|^2 + |S_{21}|^2$$

$$= (0.1)^2 + (0.2)^2 + (0.6)^2 + (0.7681146)^2$$

$$= 0.01 + 0.04 + 0.36 + 0.59$$

$$= 1 \,//$$

2) A $IL_A = -20 \log_{10}|S_{21}|$

$$= -20 \log_{10} 0.781$$

$$= 2.14\,dB \,//$$

$RL_A = -20 \log_{10} |S_{21}|$

$$= -20 \log_{10} 0.974$$

$$= 0.22\,dB \,//$$

3) $RL_A = -20 \log_{10} |S_{11}|$

$$= -20 \log_{10} \cancel{0.17}\, 0.41$$

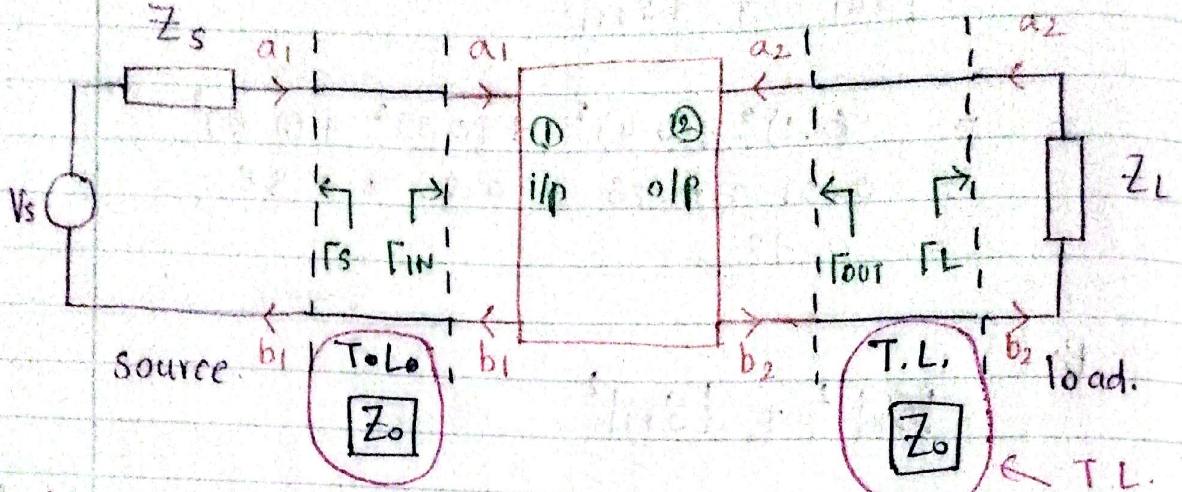
$$\cancel{= 15.39\,dB //} \quad = 7.74\,dB \,//$$

$RL_B = -20 \log_{10} |S_{11}|$

$$= -20 \log_{10} 0.22 \quad = 13.15\,dB \,//$$

4) VSWRA = 1.7 dB
VSWRB = 1.288 dB

Terminated Network



T.L. is the back bone of signal flow

Analysis
- in terms of the mismatch with respect to the T.L

Network
- passive
- Active i.e. an amplifier

① Identify the possible mismatches.
② Define a reflection coefficient for each mismatch.

now all $a_1, a_2, b_1, b_2 \neq 0$.

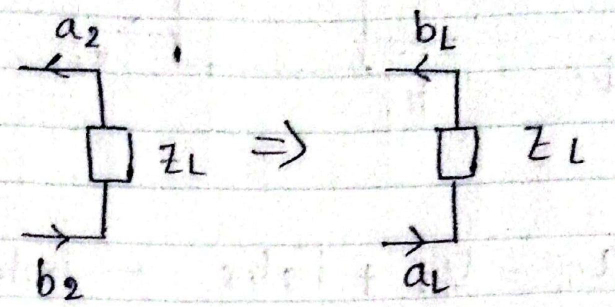
$$b_1 = S_{11} a_1 + S_{12} a_2 \quad — ①$$

$$a_2 = \Gamma_L b_2 \quad — ③$$

$$b_2 = S_{21} a_1 + S_{22} a_2 \quad — ②$$

$$\left.\begin{aligned} b_1 &= S_{11} a_1 + S_{12} \Gamma_L b_2 \\ b_2 &= S_{21} a_1 + S_{22} \Gamma_L b_2 \end{aligned}\right\} \quad b_2 = \frac{S_{21} a_1}{1 - S_{22}\Gamma_L}$$

$$b_1 = \left[S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L} \right] a_1$$



$b_L = \Gamma_L a_L$

$$a_L = b_2$$
$$b_L = a_2$$

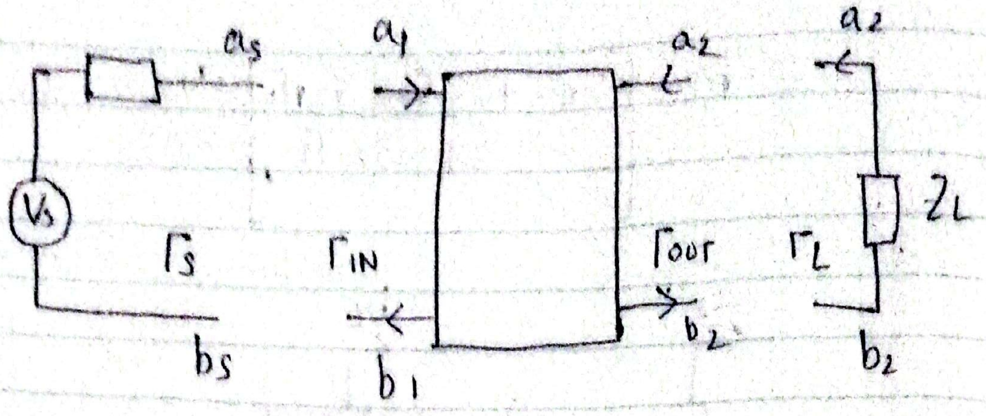
$\frac{b_1}{a_1} = \Gamma_{IN}$ $\qquad$ $\frac{b_1}{a_1} = S_{11}$ (if $a_2 = 0$)

$$\Gamma_{IN} - \frac{b_1}{a_1} = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22} \Gamma_L}.$$

if the load will perfectly match,

$\Gamma_L \neq 0$

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



$$a_s = V_s + \Gamma_s b_s \quad \leftarrow \text{isolated source.}$$

$$\Downarrow$$

connect to port ① $\quad a_1 = V_s + \Gamma_s b_1$

$$\frac{b_1}{a_1} = S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22}\Gamma_L}$$

$$a_1 = V_s + \Gamma_s \left(S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22}\Gamma_L} \right) a_1$$

$$V_s = \left[1 - \Gamma_s \left(S_{11} + \frac{S_{12} S_{21} \Gamma_L}{1 - S_{22}\Gamma_L} \right) \right] a_1$$

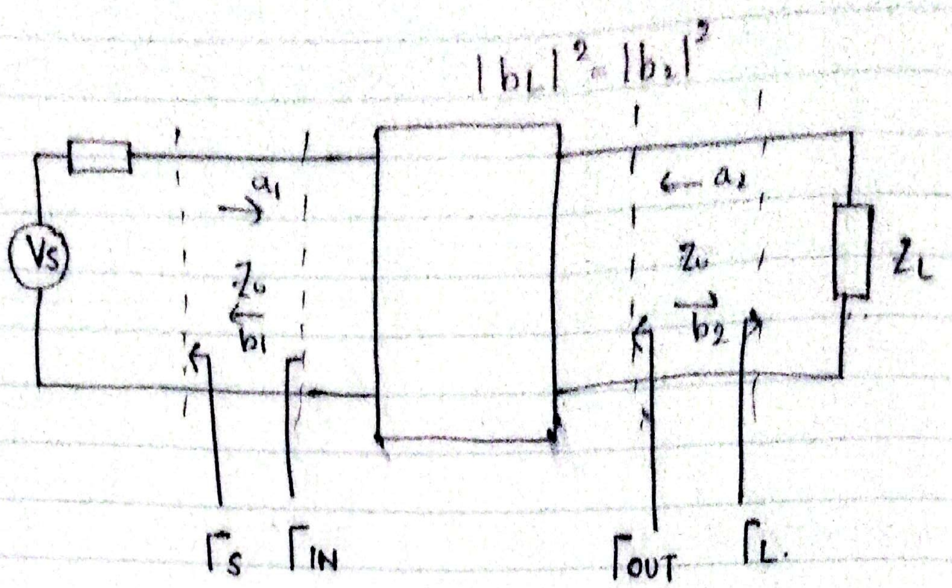
$$= \left[\frac{1 - S_{22}\Gamma_L - S_{11}\Gamma_s + S_{11} S_{22} \Gamma_s \Gamma_L \cancel{+} - S_{12} S_{21} \Gamma_L \Gamma_s}{1 - S_{22}\Gamma_L} \right] a_1$$

$$G_V = \frac{b_2}{V_s} = \frac{S_{21} a_1 + S_{22} a_2}{V_s}$$

Answer

$$G_V = \frac{S_{21}}{1 - S_{22}\Gamma_L - S_{11}\Gamma_s}$$

$$G_V = \frac{b_2}{V_s} = \frac{b_L}{V_s}.$$

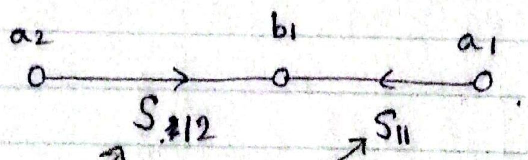


Basic signal flow model

o → node → variable

* o→— independent variable. [input] can change as we like

* o—← dependent [output]

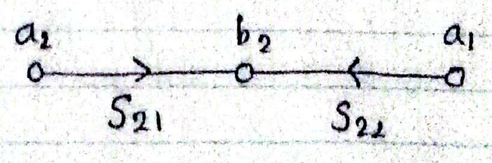


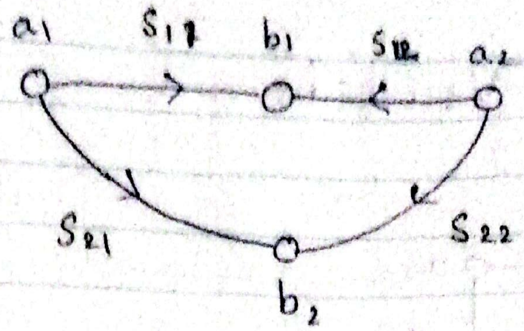
gain of the path

multiple edges entering node a sum

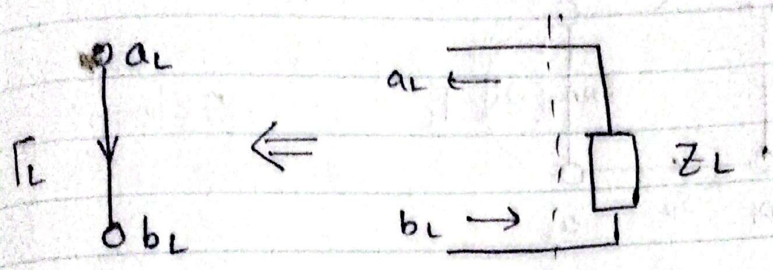
$$b_1 = S_{11} a_1 + S_{12} a_2$$

$$b_2 = S_{21} a_1 + S_{22} a_2$$

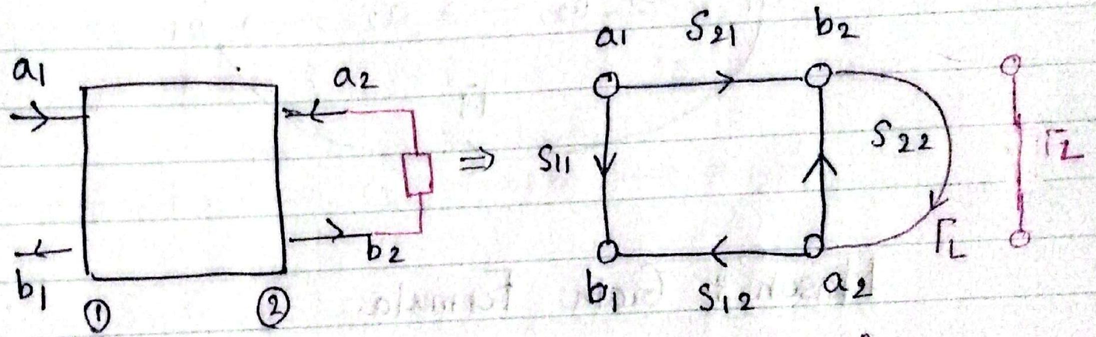




a - input / incidant
b - output / reflection.



$b_L = \Gamma_L a_L$



$b_2 = a_L$
$a_2 = a_L$

when we connect the node it creates a loop between a_2 and b_2.

Signal into the load → b_2
Signal out of the load = a_2

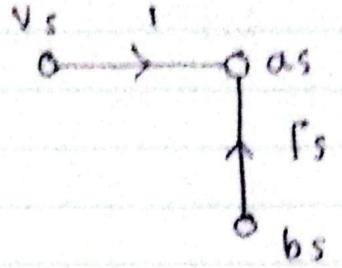
$$a_s = V_s + \Gamma_s b_s$$

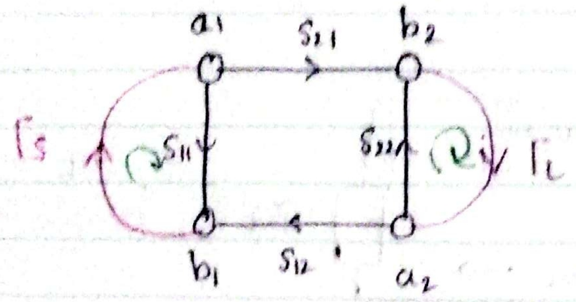
incidant signal

$a_s \equiv a_1$

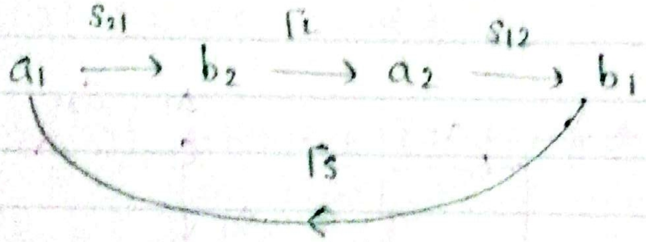
$b_s \equiv b_1$

reflect signal





3 loops



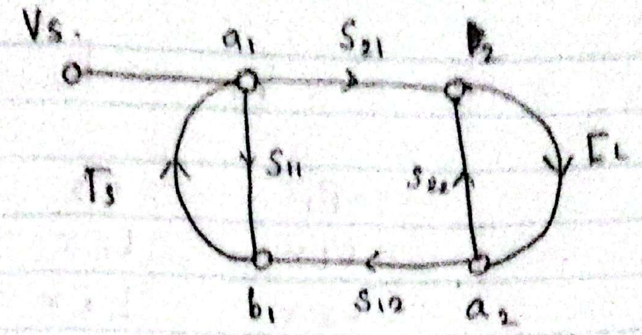
Mason's Gain Formula.

$$\boxed{G = \frac{\sum_i P_i \Delta_i}{\Delta}}$$

P_i → total gain of path i

Δ → determinant of the adjacency matrix of the graph

Δ_i → determinant of the adjacency matrix of the nodes of the path P_i



In the identified path it should not have repeated edges nodes.

1. Vs to b_2

P , $V_s \rightarrow a_1 \rightarrow b_2$

2. Vs to b_1

P_1, $V_s \rightarrow a_1 \rightarrow b_1$
P_2, $V_s \rightarrow a_1 \rightarrow b_2 \rightarrow a_2 \rightarrow b_2$

$L_1 = a_1 \xrightarrow{S_{21}} b_2 \xrightarrow{\Gamma_L} a_2 \xrightarrow{S_{12}} b_1 \xrightarrow{\Gamma_S} a_1$

$L_1(G) = S_{21}\Gamma_L S_{12}\Gamma_S$

$L_2 = a_1 \xrightarrow{S_{11}} b_1 \xrightarrow{\Gamma_S} a_1$

$L_2(G) = S_{11}\Gamma_S$

$L_3 = b_2 \xrightarrow{\Gamma_L} a_2 \xrightarrow{S_{22}} b_2$

$L_3(G) = \Gamma_L S_{22}$

$V_s \to b_2$ $\quad\quad\quad\quad$ $V_s \to b_1$

P	P_1	P_2
L_1 ✗	L_1 ✗	L_1 ✗
L_2 ✗	L_2 ✗	L_2 ✗
L_3 ✗	L_3 ✓	L_3 ✗

det of the entire signal flow graph

$$\Delta = 1 - \sum L(1) + \sum L(2) - \sum L(3) \ldots$$

$\Delta = 1 -$ sum of all loop gain $+$ sum of product of gains of non touching loops two at a time.

$$\Delta = 1 - (S_{11}\Gamma_s + S_{22}\Gamma_L + S_{12}S_{21}\Gamma_s\Gamma_L) + S_{11}S_{22}\Gamma_L\Gamma_s$$

$P(G) = S_{21}$

$P_1(G) = S_{11}$

$P_2(G) = S_{21}\Gamma_L S_{12}$

here only the sum of the gains of the non touching loop

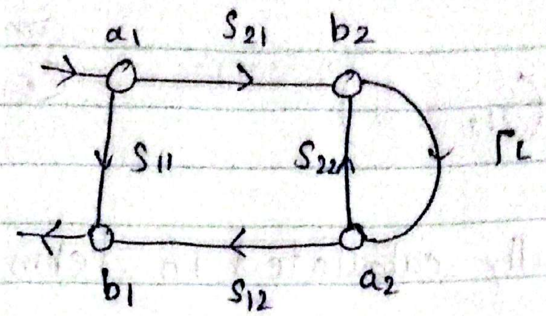
$P_1 \to L_1\ L_2$ touch, L_3 don't touch $\quad\quad$ $\Delta_1 = 1 - S_{22}\Delta_L$

$P_2 \to$ all touch. $\quad\quad$ $\Delta_2 = 1 - 0$

$$G = \frac{S_{11}\Delta_1 + S_{21}\Gamma_L S_{12}\Delta_2}{\Delta}$$

$$G = \frac{S_{11}(1 - S_{22}\Delta_L) + S_{12}\Gamma_L S_{21}}{\Delta}$$

Exercise.



① $\dfrac{b_1}{V_s}$

$\boxed{② \ \dfrac{b_1}{a_1}}$

③ $\dfrac{b_2}{a_2}$

$P_1 \quad a_1 \xrightarrow{S_{11}} b_1$

$P_2 \quad a_1 \xrightarrow{S_{21}} b_2 \xrightarrow{\overset{\Gamma_L}{S_{22}}} a_2 \xrightarrow{S_{12}} b_1$

$\underline{\Delta = 1 - \Delta}$

$\Delta = 1 - \Gamma_L S_{22}$

$\Delta_1 = 1 - S_{22}\Gamma_L$

$\Delta_2 = 1 - 0 = 1$

$\Gamma_{IN} = \dfrac{b_1}{a_1}$

$\Gamma_{OUT} = \dfrac{b_2}{a_2}$

$$G = \frac{b_1}{a_1} = \frac{S_{11}\Delta_1 + S_{21}S_{12}\Gamma_L\Delta_2}{\Delta}$$

$$= \frac{S_{11}(1 - S_{22}\Gamma_L) + S_{12}S_{21}\Gamma_L}{1 - S_{22}\Gamma_L}$$

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

Microwave Active Devices

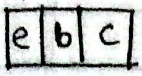
amplification (energy input)

* Typically are unilateral devices $(S_{12} \simeq 0)$

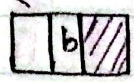
* Gains are typically calculated in terms of power.

$$\left|\frac{b_2}{V_s}\right|^2$$

* MW frequency active devices (npn)
  → Si Bipolar Junction Transistors up to 4GHz
  → GaAs Heterojunction BJTs

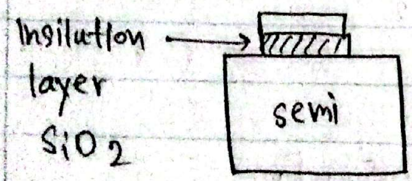


typical BJT

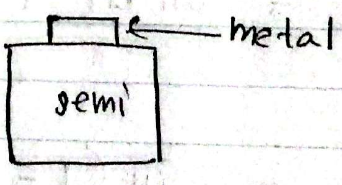


GaN - high power.

→ GaAs Metal Semiconductor Field Effect Transistors

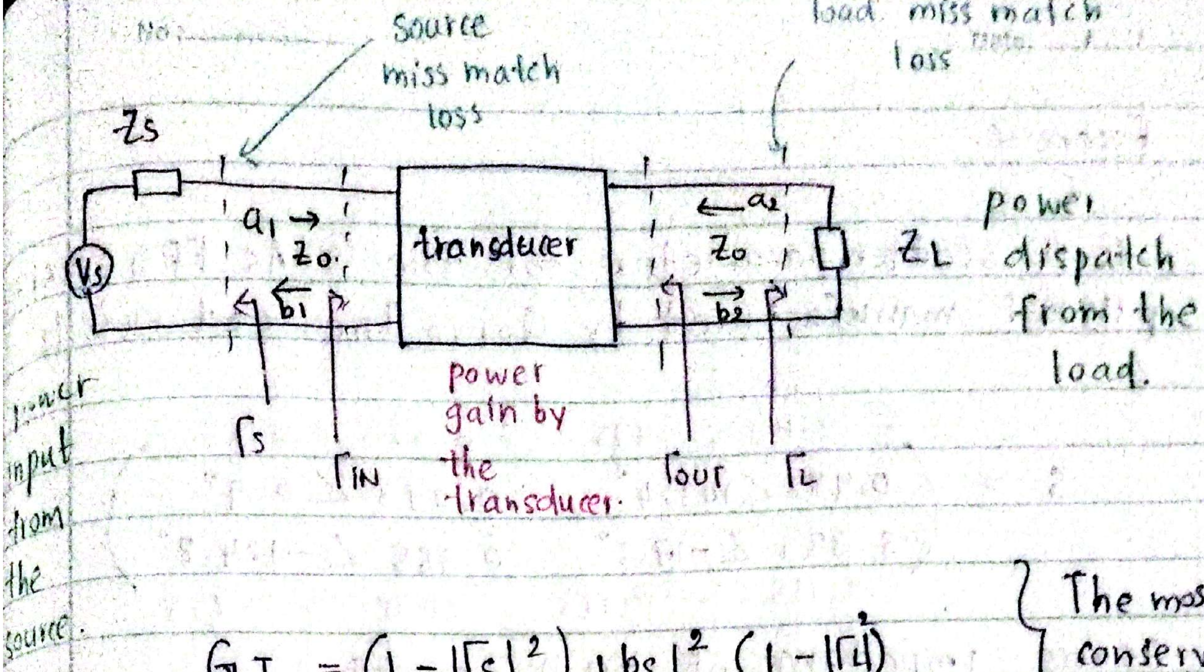


low frequency



MESFETS.

→ GaAs High Electron Mobility Devices.



$$G_T = \underbrace{(1 - |\Gamma_S|^2)}_{\text{source missmatch}} \underbrace{\left|\frac{b_S}{V_S}\right|^2}_{\text{gain trans.}} \underbrace{(1 - |\Gamma_L|^2)}_{\text{load missmatch}}$$

The most conservative power gain of a MW circuit is the transducer power gain given by.

~~$G_T = 1|\Gamma_S|^2)$~~

$$G_T = \frac{(1 - |\Gamma_S|^2)\,|S_{21}|^2\,(1 - |\Gamma_L|^2)}{\left(\left|(1 - S_{11}\Gamma_S)(1 - S_{22}\Gamma_L) - S_{12}S_{21}\Gamma_L\Gamma_S\right|^2\right)}$$

$\Gamma_S = 0 \quad \Gamma_L = 0 \Big\} \; G_T = |S_{21}|^2$ maximum possible gain

$S_{12} \approx 0 \leftarrow$ unilateral approximation

$$G_T \approx G_{UT} = \frac{(1 - |\Gamma_S|^2)\,|S_{21}|^2\,(1 - |\Gamma_L|^2)}{\left(|(1 - S_{11}\Gamma_S)(1 - S_{22}\Gamma_L)|^2\right)}$$

Exercise.

$50\ \Omega$ scatter parameter for the GaAs FPD6836P... pHEMT manufactured by Qorvo, Inc. at 10 GHz

$$S = \begin{pmatrix} \overset{(-0.113,\ 0.475)}{0.488\angle 103.4^\circ} & \overset{(0.073,\ 0.001)}{0.073\angle 0.9^\circ} \\ \underset{3.188 \quad -0.993}{3.339\angle -17.3^\circ} & \underset{-1.915 \quad -2.755}{0.355\angle -124.8^\circ} \end{pmatrix}$$

source impedance of $40\ \Omega$ — Γ_S
load " " $60\ \Omega$ — Γ_L

① The transducer power gain
② The unilateral transducer power gain

$$\Gamma_S = \frac{50-40}{50+40} = \frac{1}{9}$$

$$\Gamma_L = \frac{60-50}{60+50} = \frac{1}{11}$$

① $S_{12} \neq 0$

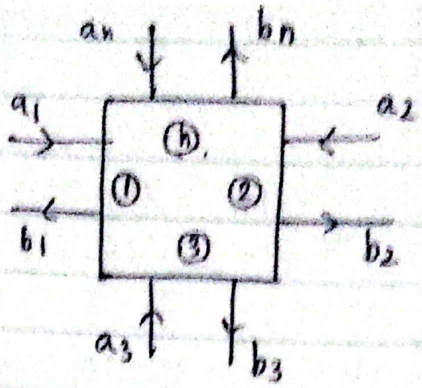
$$G_T = \frac{(1-|\Gamma_S|^2)\,|S_{21}|^2\,(1-|\Gamma_L|^2)}{|(1-S_{11}\Gamma_S)(1-S_{22}\Gamma_L) - S_{12}S_{21}\Gamma_L\Gamma_S|^2}$$

$=$

Date: 04/07/2025

N-Port Devices

+ MW device which have more than two ports



reflection for each port

S_{ij} - Tx coefficient from port j to port i

$$\begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_N \end{pmatrix} = \begin{pmatrix} S_{11} & S_{12} & \cdots & S_{1N} \\ S_{21} & S_{22} & \cdots & S_{2N} \\ \vdots & \vdots & & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{NN} \end{pmatrix} \begin{pmatrix} a_1 \\ a_2 \\ \vdots \\ a_N \end{pmatrix}$$

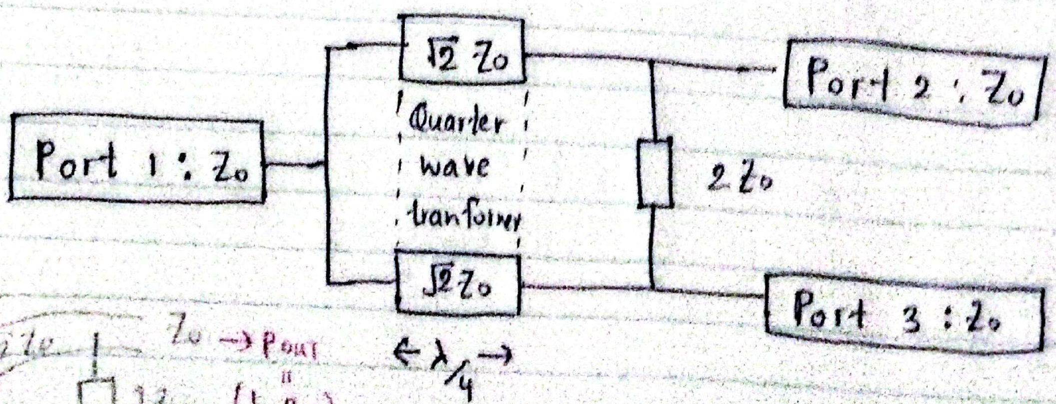
Tx coefficient.

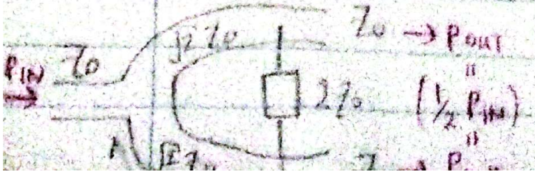
i - o/p ~~th~~ j - i/p

$i \neq j$

$S_{ij} \neq S_{ji}$

Winkinson Power Divider

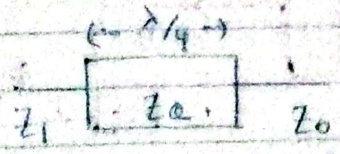




Scatter matrix

$$S = \frac{-j}{\sqrt{2}} \begin{pmatrix} 0 & 1 & 1 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix}$$

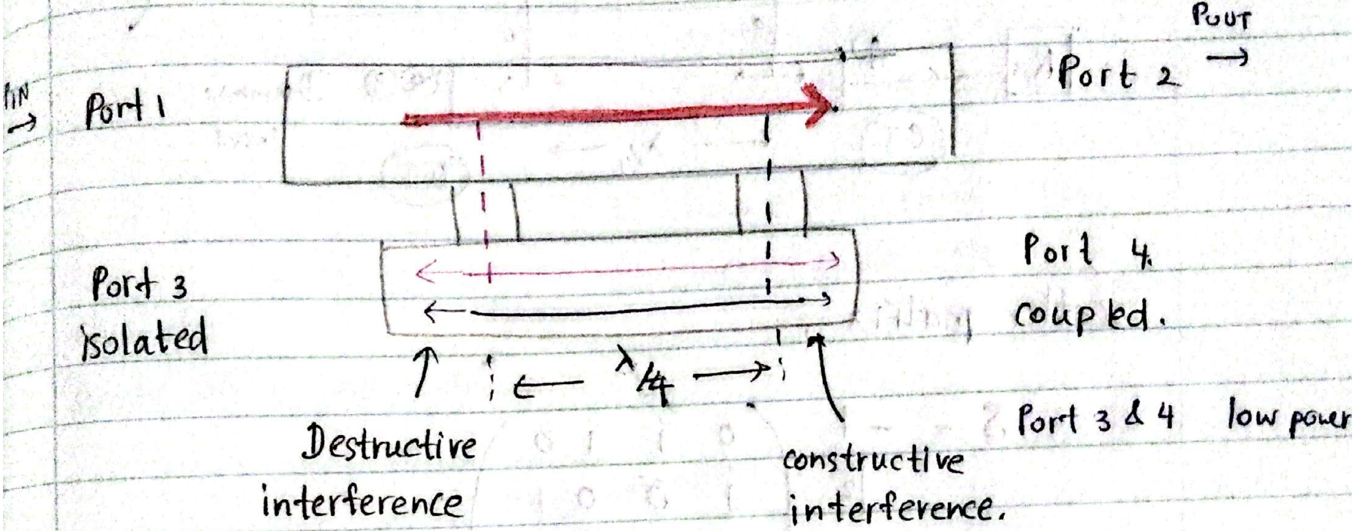
Quarter Wave Tranformer



$$Z_1 Z_0 = (Z_a)^2$$

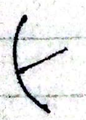
Directional couplers.

Port 1 & 2 high power



Isolation of high power and low power sections

ex: radar systems


common antenna.

Tx – many kW or even MWatts

Rx – μW, nW, pW

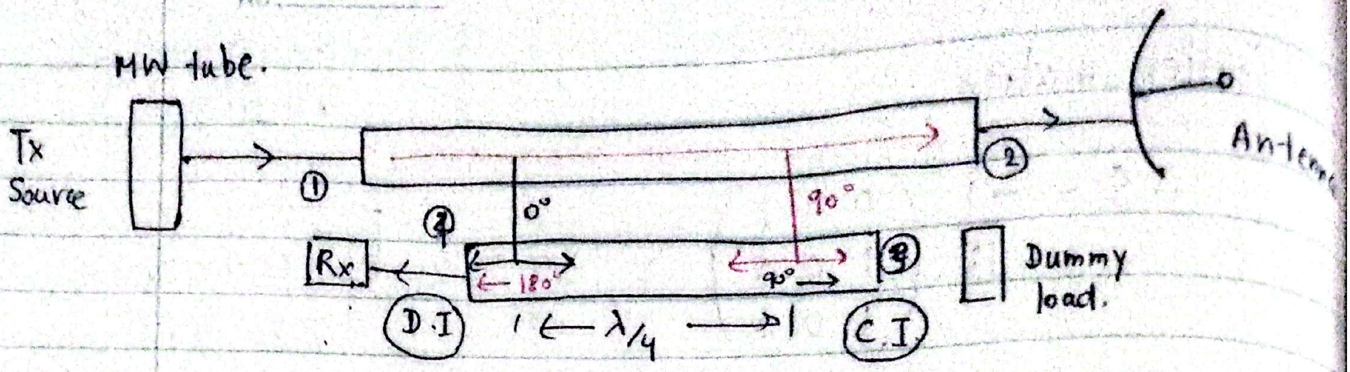
10^{-6}

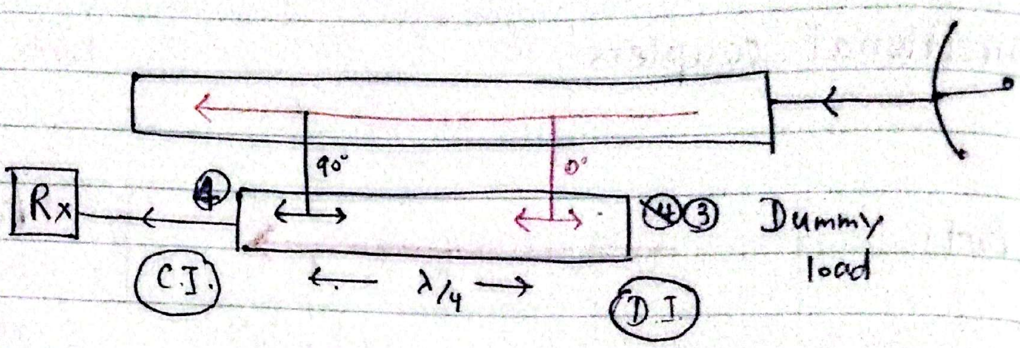
10^{-9}

10^{-12}

–sensitive

* Phase difference happen





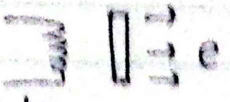
Scatter matrix,

$$S = \frac{-1}{\sqrt{2}} \begin{pmatrix} 0 & j & 1 & 0 \\ j & 0 & 0 & 1 \\ 1 & 0 & 0 & j \\ 0 & 1 & j & 0 \end{pmatrix}$$

Microwave Tubes

microwave tubes ⟶ oscillators magnetron + MW oven
└⟶ amplifiers

- MW tubes are vaccum tubes.
- Use thermionic emission

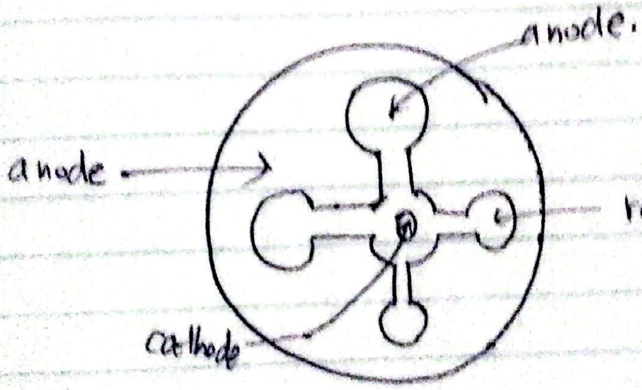


heater

1. large E field for accelarating e^n (provides the amplification).

2. large H field for focus / guide the e^n

schematic
Anode of a magnetron.



Schematic of a Klystron - Amplifier.

→ low power input & high power output.
→ two resonant cavities.
→ amplification by a modulated e^n beam
→ klystron have a very small bandwidth.