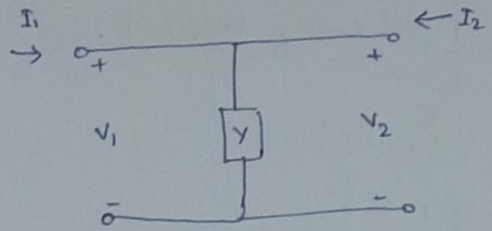
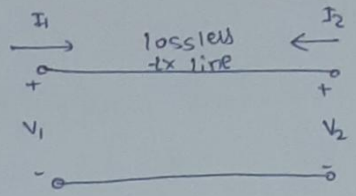
ABCD parameter for Shunt Admittance



$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}.$$

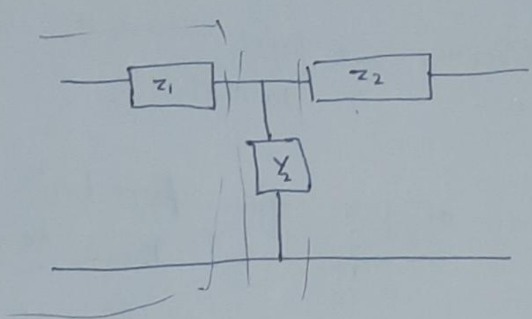
$$\begin{bmatrix} 1 & 0 \\ Y & 1 \end{bmatrix}$$

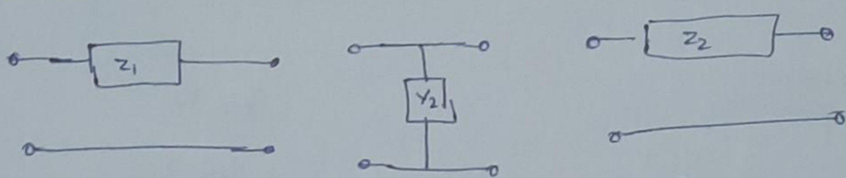


$$\begin{bmatrix} \cos\beta l & jZ_0 \sin\beta l \\ jY_0 \sin\beta l & \cos\beta l \end{bmatrix}.$$

A ×
B Ω
C ℧
D ×

e.g.

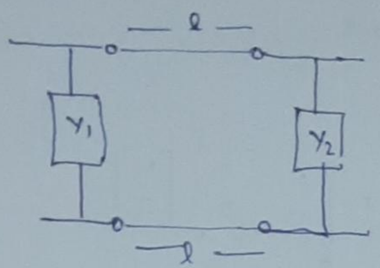




$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} A_1 & B_1 \\ C_1 & D_1 \end{bmatrix} \times \begin{bmatrix} A_2 & B_2 \\ C_2 & D_2 \end{bmatrix} \times \begin{bmatrix} A_3 & B_3 \\ C_3 & D_3 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & Z_1 \\ 0 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & 0 \\ Y_2 & 1 \end{bmatrix} \times \begin{bmatrix} 1 & Z_2 \\ 0 & 1 \end{bmatrix}$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 + Z_1 Y_2 & 2Z_1 + Z_1 Y_2 \\ Y_2 & 1 + Z_1 Y_2 \end{bmatrix}$$ — as $Z_1 = Z_2$



lossless tx wire

$$\begin{bmatrix} \cos\beta l & jZ_0 \sin\beta l \\ jY_0 \sin\beta l & \cos\beta l \end{bmatrix}.$$

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ Y_1 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ Y_2 & 1 \end{bmatrix}$$

$$= [$$

ABCD $\longrightarrow$ S-parameter.

S-parameter

S_{11} - reflection co-efficient at Port1

S_{22} - " " port2

S_{12} - measure of gain or loss from Port 1 to port 2

S_{21} - " " " Port 2 to Port1

for N-port Network

$$b_1 = S_{11} a_1 + S_{12} a_2 + \dots + S_{1N} a_N$$

$$b_2 = S_{21} a_1 + S_{22} a_2 + \dots + S_{2N} a_N$$

$$\vdots$$

$$b_N = S_{N1} a_1 + S_{N2} a_2 + \dots + S_{NN} a_N.$$

Properties

For Symmetrical Network: $[S] = [S]^T$

" loss-less network: $[S]\,[S^*]^T = 1$

1. Unitary Property : $\sum_{i=1}^{N} S_{ij} S_{ij}^{*} = \sum_{i=1}^{N} |S_{ij}|^2 = 1$;

for $j=1$ $\quad |S_{11}|^2 + |S_{21}|^2 + \cdots + |S_{N1}|^2 = 1.$

$$\left|\frac{b_1}{a_1}\right|^2 + \left|\frac{b_2}{a_1}\right|^2 + \cdots + \left|\frac{b_N}{a_1}\right|^2 = 1$$

$$\underbrace{|b_1|^2 + |b_2|^2 + \cdots + |b_N|^2}_{\text{Sum of outgoing power}} = \underbrace{|a_1|^2}_{\text{Input power}}$$

2) Orthogonal property :

$$\sum_{i=1}^{N} S_{ij} S_{ik}^{*} = 0 \qquad \text{where } j \neq k$$

for $j=1$ & $k=2$, $\quad S_{11} S_{12}^{*} + S_{21} S_{22}^{*} + \cdots + S_{N1} S_{N2}^{*} = 0.$

To check

Network reciprocal $\quad [S]^T = [S]$

" lossless $\quad$ - (unitary property)

Return loss at port 1 ?

$$RL = -20 \log(|S_{11}|).$$

Insertion loss and phase delay between port 2 and port 3

$$RL = -20 \log(|S_{23}|).$$

phase delay = - phase of S_{23}.

ABCD to S-parameter

Y - adding
Ø YOKAR
$Y \; 1/10$

$$S_{11} = \frac{A + B/Z_0 - CZ_0 - D}{A + B/Z_0 + CZ_0 + D}$$

$$S_{12} = \frac{2(AD - BC)}{A + B/Z_0 + CZ_0 + D}$$

$$S_{21} = \frac{2}{A + B/Z_0 + CZ_0 + D}$$

$$S_{22} = \frac{-A + B/Z_0 - CZ_0 + D}{A + B/Z_0 + CZ_0 + D.}$$

$$Z_{in} = Z + Z_0$$

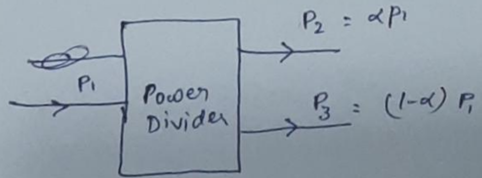
$$\Gamma_{in} = S_{11} = \frac{Z_{in} - Z_0}{Z_{in} + Z_0} = \frac{Z}{2Z_0 + Z}$$

6 $|S_{11}|^2 + |S_{21}|^2 = 1$ valid only if Z is lossless.

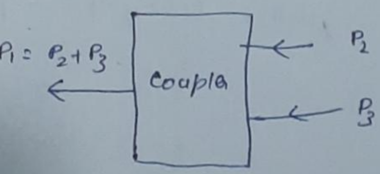
$$|S_{21}|^2 = 1 - |S_{11}|^2 = 1 - \left|\frac{Z}{2Z_0 + Z}\right|^2$$

$$S_{21} = \frac{2Z_0}{2Z_0 + Z}$$

Power Divider and Coupler



Power division
(1-Terminal)



Power combination
(2-Terminal)

A three port network cannot be lossless, reciprocal and matched at all ports.

or

It is not possible to construct a perfectly matched, lossless, reciprocal 3-port junction. Atleast one of the reflection coefficients must be different from zero in the reciprocal case,

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}.$$

Reciprocal $S = S^T$

$$\begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & 0 \end{bmatrix}$$

Unitary :-

R1: $|S_{12}|^2 + |S_{13}|^2 = 1$

R2: $|S_{12}|^2 + |S_{23}|^2 = 1$

R3: $|S_{13}|^2 + |S_{23}|^2 = 1.$

Orthogonal :-

$S_{13} \; S_{23}^* = 0$

$S_{12} \; S_{13}^* = 0$

$S_{23} \; S_{12}^* = 0.$

Assume $S_{13} = 0$

$S_{23} \neq 0$

$S_{12} \neq 0.$

Contradictory in unitary and orthogonal

Q. Check whether it is possible to design a lossless and reciprocal T - junction with two of its ports being matched while third is not matched.

T - 3 port

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

Assume $S_{11} = 0$, $S_{22} = 0$ [∵ Port 1 & 2 is matched

Reciprocal $[S] = [S]^T$

$$\begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{12} & 0 & S_{23} \\ S_{13} & S_{23} & S_{33} \end{bmatrix}$$

unitary.

R1: $|S_{12}|^2 + |S_{13}|^2 = 1$

R2: $|S_{12}|^2 + |S_{23}|^2 = 1$

R3: $|S_{13}|^2 + |S_{23}|^2 + |S_{33}|^2 = 1$

Orthogonal

Assume $S_{23} = 0$, $S_{13} = 0$

$C_1 C_2$ $\quad S_{13} S_{23}^* = 0$

$C_2 C_3$ $\quad S_{12}^* S_{13} + S_{23}^* S_{33} = 0$

$C_3 C_1$ $\quad S_{23}^* S_{12} + S_{33}^* S_{13} = 0$

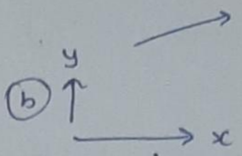
$S_{12} = 1$

$S_{33} = 1$

$$S = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

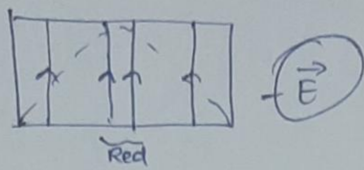
S- matrix of 3- port H-plane Tee

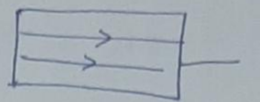
z - propagation



a - broadworld dirn.

TE_{10} - dominant mode





parallel w.r.to broadworld dirn.

- pratically dominant mode can propagate.

No. of modes can propagate - cut-off freq.

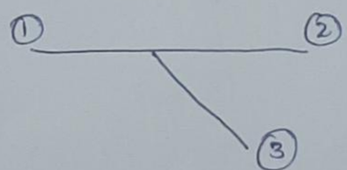
Transmission coefficient S_{12} S_{21}
cut-off freq (After 0 dB)
freq at which line cross

TE_{10}
E → ⊥r to 'a'
H → ∥' to 'a'

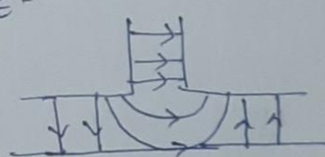
Side - arm ($\vec{H}$- direction)
$\vec{H}$-plane Tee

In the $\vec{E}$ direction
($\vec{E}$ -plane Tee).

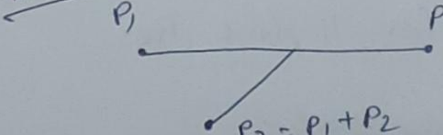
H - plane Tee



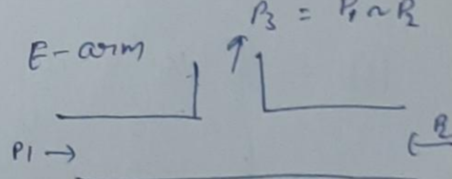
E - arm



H-arm



E-arm



H - plane Tee

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

- junction scattering coefficient S_{13} and S_{23} must be equal to the plane of symmetry

$$\therefore S_{13} = S_{23}$$

- From symmetry property, $S_{ij} = S_{ji}$

$$\therefore S_{12} = S_{21}, \quad S_{31} = S_{31} \quad S_{23} = S_{32} = S_{13}.$$

- considering port 3 is perfectly matched, reflection coefficient $S_{33} = 0$.

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix}.$$

lossless

unitary :-

R1 : $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1$ — a

$|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1$ — b

$|S_{13}|^2 + |S_{13}|^2 = 1$ — c

$$\Rightarrow S_{13} = 1/\sqrt{2}.$$

Apply ortho

$$[S] = \begin{bmatrix} 1/2 & -1/2 & 1/\sqrt{2} \\ -1/2 & 1/2 & 1/\sqrt{2} \\ 1/\sqrt{2} & \frac{1}{\sqrt{2}} & 0 \end{bmatrix}$$ — for H-plane Tee.

$[b] = [S][a]$

$$b_1 = \frac{a_1}{2} - \frac{a_2}{2} + \frac{a_3}{\sqrt{2}}$$

$$b_2 = -\frac{a_1}{2} + \frac{a_2}{2} + \frac{a_3}{\sqrt{2}}$$

$$b_3 = \frac{a_1}{\sqrt{2}} + \frac{a_2}{\sqrt{2}}$$

as port 3 is input i.e $a_3 \neq 0$

$a_1 = 0 \quad a_2 = 0$

$$b_1 = \frac{a_3}{\sqrt{2}}$$

$$b_2 = \frac{a_3}{\sqrt{2}}$$

$$b_3 = 0$$

Power gain $= 10 \log_{10}\left(\frac{P_1}{P_3}\right)$

$= 10 \log_{10}\left(\frac{P_1}{2P_1}\right)$

$= \underline{\underline{-3\,dB}}$.

- ~~Power coming~~ out.

Input Impedance

$$Z_A = R_A + jX_A$$

Reflection coefficient $\Gamma = \frac{Z_A - Z_0}{Z_A + Z_0}$

$$\boxed{VSWR = \frac{V_{max}}{V_{min}} = \frac{1 + |\Gamma|}{1 - |\Gamma|}}$$

Transmission line :-

R = series resistance per unit length, for both conductor in Ω/m.

L = " inductance " " " for both conductors in H/m

G = Shunt conductance per unit length in S/m

C = Shunt capacitance per unit length in F/m

For Sinusoidal Steady-state condition,

$$\frac{dV(z)}{dz} = -(R + j\omega L)\, I(z)$$

$$\frac{dI(z)}{dz} = -(G + j\omega C)\, V(z)$$

↓

wave propagation in Tx line,

$$\frac{d^2 V(z)}{dz^2} + \gamma^2 V(z) = 0$$

$$\frac{d^2 I(z)}{dz^2} - \gamma^2 I(z) = 0$$

$$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$$

complex propagation constant

$$V(z) = V_0^+ e^{-\gamma z} + V_0^- e^{\gamma z}$$

$$I(z) = I_0^+ e^{-\gamma z} + I_0^- e^{\gamma z}$$

$e^{-\gamma z}$ - wave propagating in $+z$ dir^n

$e^{\gamma z}$ - " " " $-z$ "

$$I(z) = \frac{\gamma}{R+j\omega L} \left(V_0^+ e^{-\gamma z} - V_0^- e^{\gamma z} \right)$$

$$Z_0 = \frac{R+j\omega L}{\gamma} = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$$

$$\frac{V_0^+}{I_0^+} e^{-\gamma z} = Z_0 = -\frac{V_0^-}{I_0^-} e^{\gamma z}$$

$$\lambda = \frac{2\pi}{\beta} \quad ; \quad v_p = \frac{\omega}{\beta} = \lambda f$$

phase velocity

(i) Lossless line

$R = 0, \; G = 0$

$$\boxed{\gamma = j\omega\sqrt{LC}}$$

$\alpha = 0$

$\beta = \omega\sqrt{LC}$

$[\gamma = \alpha + j\beta]$

$$\boxed{Z_0 = \frac{R+j\omega L}{\gamma} = \frac{j\omega L}{j\omega\sqrt{LC}} = \sqrt{\frac{L}{C}}}$$

$$V(z) = V_0^+ e^{-j\beta z} + V_0^- e^{j\beta z}$$

$$I(z) = \frac{V_0^+}{Z_0} e^{-j\beta z} - \frac{V_0^-}{Z_0} e^{j\beta z}$$

$$\boxed{\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{\omega\sqrt{LC}}} \quad ; \quad \boxed{v_p = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}}$$

phase velocity

$P_{avg} = \frac{1}{2} \frac{|V_0^+|^2}{Z_0} (1 - |\Gamma|^2)$. – Shows that average power flow is constant at any point on the line

$RL = -20 \log |\Gamma|$ dB.

$\Downarrow$

$\Gamma = 0$

$P_{avg} = P_{total}$

$= \frac{1}{2} \frac{|V_0^+|^2}{Z_0}$.

$$Z_{in} = \frac{V(-l)}{I(-l)} = \frac{V_0^+ (e^{j\beta l} + \Gamma e^{-j\beta l})}{V_0^+ (e^{j\beta l} - \Gamma e^{-j\beta l})}$$

$$= \frac{1 + \Gamma e^{-2j\beta l}}{1 - \Gamma e^{-2j\beta l}} Z_0.$$

$$Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan\beta l}{Z_0 + jZ_L \tan\beta l}$$

<u>lossless</u>

$Z_L = 0$

$Z_{in} = jZ_0 \tan\beta l$

<u>Smith Chart</u>

Voltage reflection coefficient, Γ

$\Gamma = |\Gamma| e^{j\theta}$

- Magnitude $|\Gamma|$ is plotted as radius from the centre of the chart
- 'θ' is measured counterclockwise from right-hand side of horizontal diameter.

$\bar{Z}_L = \frac{Z_L}{Z_0}$ – normalized Impedance.

$$\Gamma = \frac{\bar{z}_L - 1}{\bar{z}_L + 1} = |\Gamma| e^{j\theta}.$$

or,
$$\bar{z}_L = \frac{1 + |\Gamma| e^{j\theta}}{1 - |\Gamma| e^{j\theta}}.$$

$$r_L + j x_L = \frac{1 + \Gamma_r + j\Gamma_i}{(1 - \Gamma_r) - j\Gamma_i}$$

$$r_L = \frac{1 - \Gamma_r^2 - \Gamma_i^2}{(1-\Gamma_r)^2 + \Gamma_i^2} \quad (1) \quad ; \quad x_L = \frac{2\Gamma_i}{(1-\Gamma_r)^2 + \Gamma_i^2} \quad (2)$$

$$(\Gamma_r - 1)^2 + \left(\Gamma_i - \frac{1}{x_L}\right)^2 = \left(\frac{1}{x_L}\right)^2$$

<u>Smith chart 1.</u>

$Z_L = 40 + j70\,\Omega$ $\qquad$ $l = 0.3\lambda$

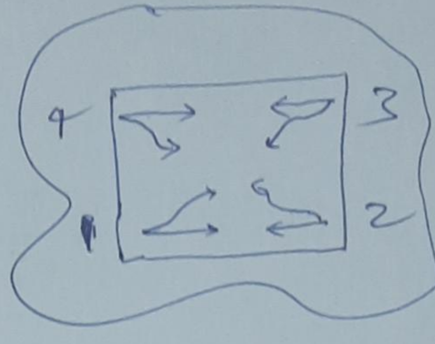
$Z_0 = 100\,\Omega$

$$\bar{z}_L = \frac{Z_L}{Z_0} = 0.4 + j0.7$$

Directional Coupler

- consists of two transmission line or waveguides coupled by fringing fields.

i/p	o/p	c/p	iso/p
1	2	3	4
2	1	4	3
3	4	1	2
4	3	2	1



Parameters

(a) Directivity (D)

$$\boxed{D = 10 \log \frac{P_3}{P_4} \text{ dB}}$$

→ Ratio of power coupled to the auxiliary arm to the power flowing in the uncoupled auxiliary arm

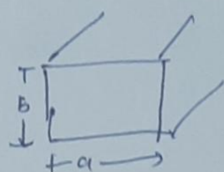
→ expressed in dB.

WR 37

a = 7.3 inch

Last two digit represent WR 90 dimension of waveguide

a = 0.9 inch



a = 2b TE10 is dominant mode.

Coupling factor:-

$$C_{dB} = 10 \log_{10} \frac{i/p}{c/p}$$

i/p → Input power

c/p → coupled power

$$\boxed{C_{dB} = 10 \log_{10} P_1/P_3}$$

ratio of power entering at the input to the power coupled at the output in auxiliary arm.

Insertion loss :-

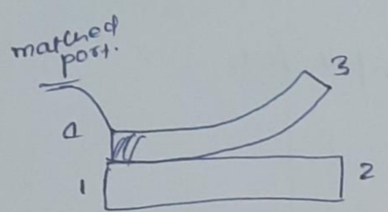
loss arises due to insertion of component over a line. It specifies the total output power from all ports relative to the input power.

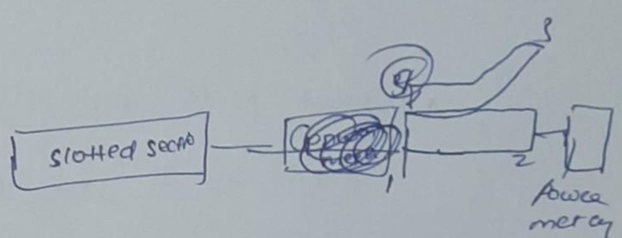
$$IL = 10 \log \frac{P_2 + P_3 + P_4}{P_1} \text{ dB.}$$

Isolation

Another way of specifying directivity and it is equal to the sum of directivity and coupling

$$\text{Isolation} = 10 \log \frac{P_1}{P_4} \text{ dB.}$$





If we are measuring power at port 2, all the other port should be shorted.

S-matrix

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}$$

It is possible to match all ports as it is not case in power divider.

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{21} & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & S_{34} \\ S_{41} & S_{42} & S_{43} & 0 \end{bmatrix}$$

reciprocal $= [S] = [S]^T$

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & S_{14} \\ S_{12} & 0 & S_{23} & S_{24} \\ S_{13} & S_{23} & 0 & S_{34} \\ S_{14} & S_{24} & S_{34} & 0 \end{bmatrix}$$

no power flow from port 1 to port 4

S_{41} Input = 1

Out

Adjacent ports are isolated from input port,

$S_{14} = S_{23} = S_{32} = S_{41} = 0.$

$$[S] = \begin{bmatrix} 0 & S_{12} & S_{13} & 0 \\ S_{12} & 0 & 0 & S_{24} \\ S_{13} & 0 & 0 & S_{34} \\ 0 & S_{24} & S_{34} & 0 \end{bmatrix}$$

Apply unitary and orthogonal property.

$$[S] = \begin{bmatrix} 0 & P & j2 & 0 \\ P & 0 & 0 & j2 \\ jQ & 0 & 0 & P \\ 0 & j2 & P & 0 \end{bmatrix}.$$

Bathe hole (Single hole)

Q. The input power = 1mV

$C = 15\,dB$

$D = 30\,dB.$

Calculate the power at all port.

$$15 = 10 \log_{10} \frac{10^{-3}}{P_4}.$$

$$\cancel{15} = \cancel{30}\,2 \log_{10} P_4$$

$$0.5 = \log_{10} P_3$$

$$P_3 = (10)^{0.5}$$

$$= 3.16\ W$$

$$4P_{dBm} = 10 \log_{10} \frac{P}{1mW}.$$

Q. $$[S] = \begin{bmatrix} 0.2 \angle 0^\circ & 0.6 \angle 90^\circ \\ 0.6 \angle 90^\circ & 0.1 \angle 0^\circ \end{bmatrix}$$

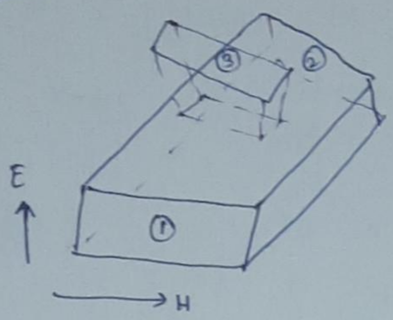
(a) Prove that the network is reciprocal but not lossley

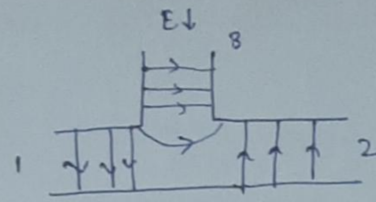
(b) Find the return loss at Port 1 when Port-2 is Short circuited.

$$(S) = \begin{bmatrix} 0.2 & +j\,0.6 \\ j0.6 & 0.1 \end{bmatrix}$$

$$RL = -20\log \lfloor 1$$

$\vec{E}$-arm





$S_{13} = -S_{23}$ [out of phase].

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}.$$

port -3 → Input

- port 3 is matched the

$S_{33} = 0$.

① port 1 & 2 are out of phase

$S_{13} = -S_{23}$

② Summetry property

$S_{12} = S_{21}$, $S_{13} = S_{31}$, $S_{23} = S_{32}$

Apply unitar

$$(S) = \begin{bmatrix} 1/2 & 1/2 & 1/\sqrt{2} \\ 1/2 & 1/2 & -1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix}$$

$(b) = [S]\,[a]$:

$b_1 = \frac{1}{2}a_1 + \frac{1}{2}a_2 + \frac{1}{\sqrt{2}}a_3$

$b_2 = \frac{1}{2}a_1 + \frac{1}{2}a_2 - \frac{1}{\sqrt{2}}a_3$

$b_3 = \frac{1}{\sqrt{2}}a_1 - \frac{1}{\sqrt{2}}a_2$

if $a_1 = a_2 = 0$ & $a_3 \neq 0$

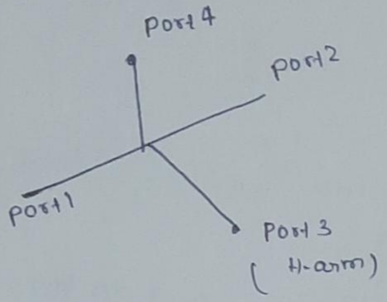
then, $b_1 = \frac{1}{\sqrt{2}}a_3$ & $b_2 = -\frac{1}{\sqrt{2}}a_3$.

Output power at port 2 & port 1 is ½ power at port 3.

→ an i/p power in port 3 divides equally between port 1 & 2 but 180° out of phase with each other.

Thus, E-plane Tee acts as a 3dB splitter.

<u>Microwave Hybrid circuit :-</u> / magic Tee (Both $\vec{E}$ and $\vec{H}$ arm.



For H-plane Tee
$S_{43} = 0$ — no output

$S_{23} = S_{13}$, $S_{33} = 0$
↳ It should matched

for E-plane Tee

$S_{34} = 0$ — Isolated

$S_{14} = -S_{24}$, $S_{44} = 0$
It should be matched

~~cST~~ ~~port~~

i(3) - input at port 3.
O_{13}
O_{23}
O_{43}

$$(S) = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix}.$$

Co-axial Cable

$$C = \frac{2\pi\epsilon_0\epsilon_r}{\ln D/d} \quad (F/m)$$

d - inner diameter
D - outer - diameter.

$$L = 0.2 \ln\frac{D}{d} \quad (\mu H/m)$$

$$Z_0 = \sqrt{L/C} \quad , \quad Z_0 = \frac{60}{\sqrt{\epsilon_r}} \ln\frac{D}{d} \quad (\Omega/m)$$

Attenuation

dB/100m

1.5m
4 feet

2dB/100m

100m ———— 2dB loss

1 ———— $2/100$

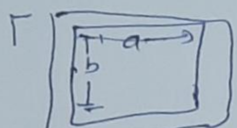
1.5 ———— $\frac{1.5 \times 2}{100} = 0.03$ dB loss.

Lab exam

$a = 22$
$b = 10$

thickness 1mm

→ frequency = ?



Material ' ✓ ' (provided).

formulae for f_c (cut-off freq)

$b \sim a/2$ (TE_{10} is dominant mode).

$f_c \Big|_{TE_{10}} = 7\,GHz$ 5 to 10

- study dominant no { mode - 1 only }.

cut-off freq — S_{12} or S_{21} [S-parameter

0-dB crossing frequency.

S_{12} (1)
mode number.

Q2.

Two modes {upper freq - high}.

↳ ~~two~~ S_{12} (1) S_{12}(2)
S_{21} (1) S_{21} (2)

Q3.

→ Identify the modes

$\vec{E}$

Propagating and non-propagating dominant mode

↳ $\vec{E}$ pattern ✓ with transmission (coeffic) (S-parmat)

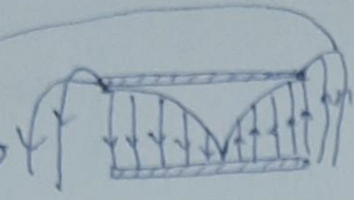
better.

Background → Normal ✓

Microstrip Line

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 10\frac{d}{w}}}\right)$$

fringing lines

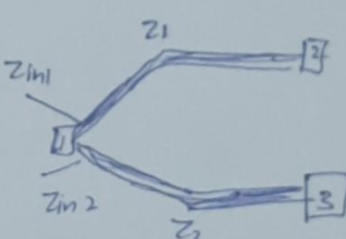


$$Z_0 = \begin{cases} \dfrac{60}{\sqrt{\epsilon_e}} \ln\left(\dfrac{8d}{w} + \dfrac{w}{4d}\right) & ; \text{ for } \dfrac{w}{d} \le 1 \\[2ex] \dfrac{120\pi}{\sqrt{\epsilon_e}\left[w/d + 1.393 + 0.667 \ln\left(w/d + 1.444\right)\right]} & ; \text{ for } \dfrac{w}{d} \ge 1 \end{cases}$$

planar Transmission lines

planar power divider

2-way equal power divider



I/P port should be matched

$S_{11} = 0$

$Z_{in1} = 100$

$Z_{in2} = 100$

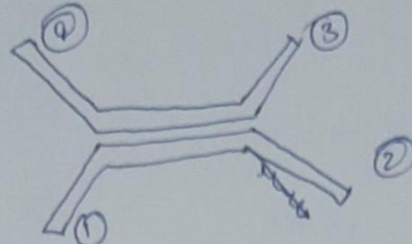
$$Z_{in_1} = \frac{|Z_1|^2}{Z_L}$$

$$|Z_1|^2 = Z_{in_1} \cdot Z_L$$

For equal power division and loss-less network,

$$S_{21} = S_{31} = \frac{-j}{\sqrt{2}} = S_{12} = S_{13}.$$

Coupled line Directional Coupler (CLDC)



1 - input port

2 - Directly coupled port or Through port

---

1 Transmission line

Zin

SWR

Γ

$$S = \frac{1+|\Gamma|}{1-|\Gamma|}$$

(Sadiku Example)

Smith chart

Fundamental formula

equation

- plot of current / voltage (graph) } p.
- draw voltage profile and current profile for short and open circuit. {plot if ~~R~~ is given}

Zin - for short & open ckt. } conductive or Inductive.

2 Application Sadiku

1 calculate Unknown Impedance (Smith Chart).

By

2 Quater-wave transformer (Design)

& Diagram