Chapter Waveguides

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- Limitation → cut off freq.
- waveguide act as HPF
- By selecting the dimension (conductor and dilectric), we can set the freq.
- By selecting the value of permitivity & permability → cut off freq.
- waveguide is the max's well equation with boundary condition.
- TEM mode is not possible bcoz we put the boundary either horizontally or vertically.
- when freq. is less → λ is ↑ses → size is ↑ses so that's not practically possible.
- Microstrip line → Small Power is involved
  Planer structure
- waveguide → Higher Power is involved.
- fundamental charc of waveguide and transmission lines are different.
- Classified
  - → Metal waveguides
  - → Diletric waveguides

Waveguide	Transmission Line
• TE or TM modes	• TEM and quasi-TEM mode.
• Operating freq > cut off freq.	• No cut off freq
• Metal waveguides tran. more power.	

Scanned by CamScanner

quasi-TEM mode

- Inplaner structure
- its not pure TEM mode
- fringing field – E and H fields are not $\perp^r$.

General wave char^{cs}:

$$\nabla \times E = -j\omega \mu H$$
$$\nabla \times H = j\omega \epsilon E$$

$K \rightarrow$ wave no.

$K = \omega\sqrt{\mu\epsilon}$

if lossy medium then $K \rightarrow$ complex
if lossless " " , $K \rightarrow$ real

$$E(x,y,z) = e(x,y)\, e^{-\gamma z}$$
$$H(x,y,z) = h(x,y)\, e^{-\gamma z}$$

$\hookrightarrow$ direction of Propagation

- $\frac{\partial}{\partial z}(e^{-\gamma z}) = \frac{\partial}{\partial z}(e^{-\beta z})$ when $\alpha = 0$

$$= -\beta z\, e^{-\beta z}$$

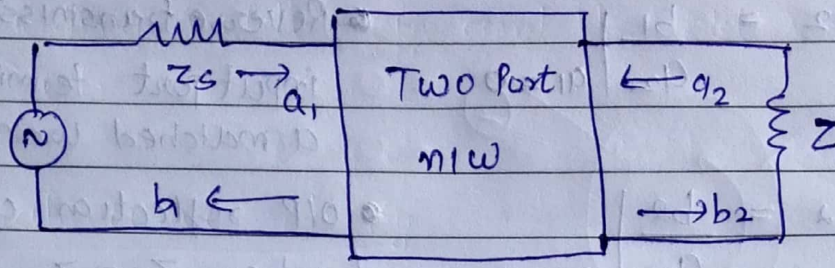
- $\frac{h}{K} = \frac{h}{\omega\sqrt{\mu\epsilon}} = \frac{h}{2\pi f\sqrt{\mu\epsilon}} = \frac{f_c}{f}$

$$f_c = \frac{h}{2\pi\sqrt{\mu\epsilon}}$$

S-parameter and Waveguide

Date: 31 Aug

S-parameter :



- S → Scattering Parameter
- S21 → transmission
  - ↑ ↳ input at port 1
  - output at port 2
- S11 → reflection
  - ↳ input at port 1
  - ↳ O/P at port 2
- A parameter set that relates to the travelling waves that are scattered or reflected
- Two port n/w → four parameters are there $S_{11}, S_{22}, S_{12}, S_{21}$
- We don't find relationship b/w current, Volt. → so using S-par.
- at lower freq. signal CRO used for observation
- at Higher freq, VNA (Vector n/w analyser) is used for the observation of Microwave and in VNA, S parameters are there bcoz through S parameter we can convert this into any diffr parameters.

- $b_1 = S_{11}\, a_1 + S_{12}\, a_2$

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

  linear eqn for two port n/w

$S_{11} = \frac{b_1}{a_1}\Big|_{a_2=0}$ • input reflection cofficient (when $Z_L = Z_0$ sets $a_2=0$)

$S_{12} = \frac{b_1}{a_2}\Big|_{a_1=0}$ • Reverse transmission (insertion) input port terminated in a matched load

$S_{22} = \frac{b_2}{a_2}\Big|_{a_1=0}$ • O/P reflection cofficient (when $Z_S = Z_0$ sets $V_S=0$)

$S_{21} = \frac{b_2}{a_1}\Big|_{a_2=0}$ • forward transmission (insertion) gain (O/P Port termination in a matched load)

• its possible when active elements is there for gain

- at lower freq., we can ignored the phase, but in the microwave, we can't so S-Parameter is used.

S-Parameter depends on :

- network is changed
- ~~char. impedence of the source~~
- freq. is changed
- load impedence is changed
- source impedence is changed

• S parameter is the property of the n/w under some conditions.

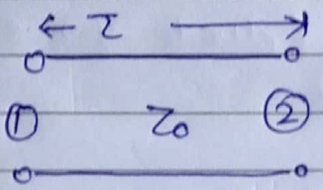
properties of S-matrix :

- [S] is always square matrix
- symmetric matrix $S_{ij} = S_{ji}$
- Unitary matrix $= [S].[S]^* = [I]$

• $\sum_{i=1}^{n} S_{ik} S_{ij}^{*} = 0$; $k \neq j$

Examples of s-parameters :

(i)



Transmission line

• all the ports are properly terminated

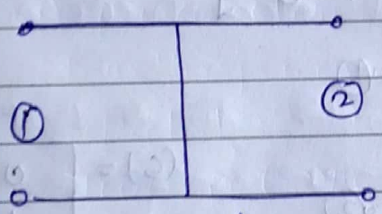
$$[S] = \begin{bmatrix} 0 & e^{-j\omega l} \\ e^{-j\omega l} & 0 \end{bmatrix}$$

represent the loss in the signal

• when reflection is not there.

∴ $\gamma = \alpha + j\beta \rightarrow$ propagation
α: attenuation $= 0$
from the transmission line

(ii)



Short

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

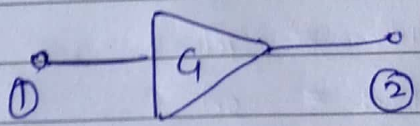
• transmission parameter are zero

• Short ckt → Phase shifted by 180°

• Here full reflection

(iv) open ckt: $[S] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ same phase

(iii)



Amplifier

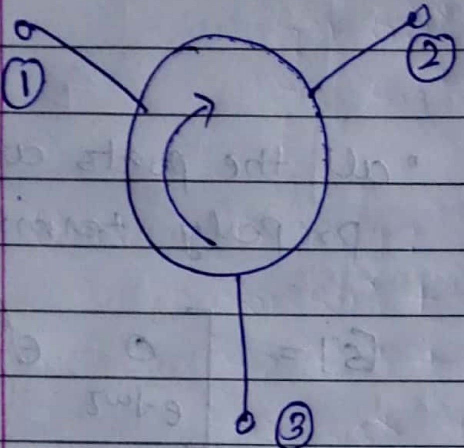
$$[S] = \begin{bmatrix} 0 & 0 \\ G & 0 \end{bmatrix}$$

• Unidirectional

for 3dB attenuator

$$[S] = \begin{bmatrix} 0 & 3 \\ 3 & 0 \end{bmatrix}$$

ex: (v)

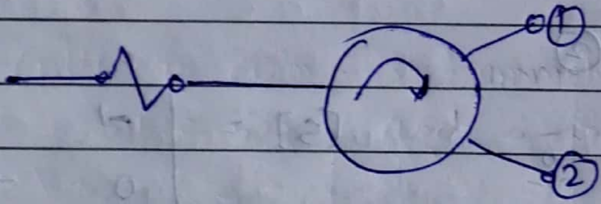


"Circulator"

all the three ports are properly matched

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

(vi)



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

"isolator"

[w/o any insertion loss, Unidirectional]

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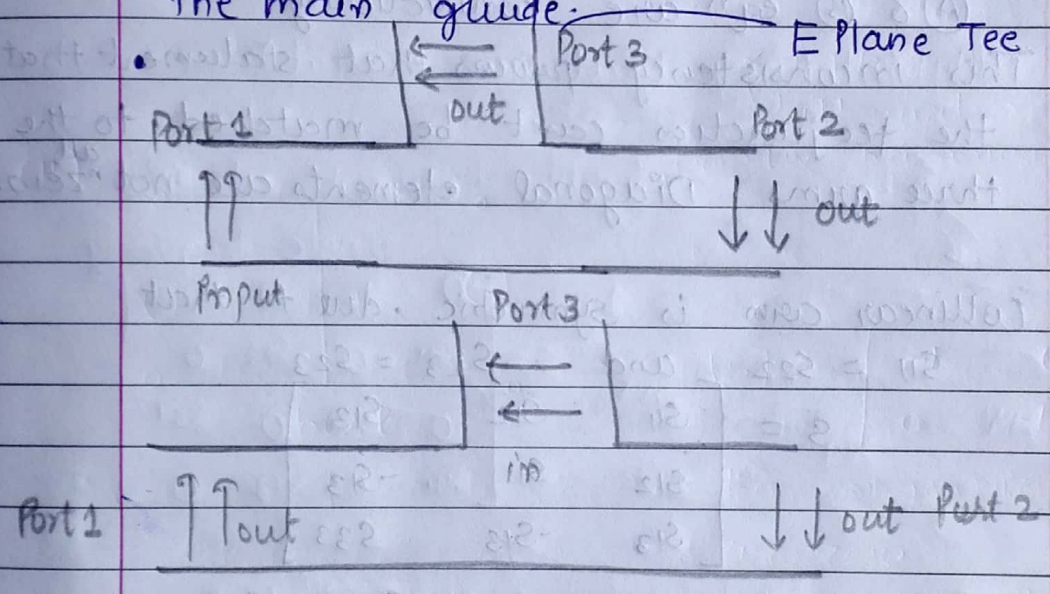
Microwave Hybrid circuits:

- Waveguide Tees (H-Plane, E-Plane, Magic, Ring Hybrid)
- Directional coupler
- Circulator
- Isolator

Wave guide Tees:

(i) E-Plane Tee:

- axis of side arm is parallel to E field of the main guide.
-



- To avoid the reflection, matching of impedence is compulsary.
- divider, out of phase
- S-matrix of matched E-Plane Tee $= \begin{bmatrix} 0 & S_{12} & S_{13} \\ S_{21} & 0 & S_{23} \\ S_{31} & S_{32} & 0 \end{bmatrix}$

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

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

S_{23}

zero property:

$$S_{11} S_{12}^* + S_{21} S_{22}^* + S_{31} S_{32}^* = 0$$

hence

$$S_{31} S_{32}^* = 0$$

$$S_{13} S_{23}^* = 0 \quad \text{(due to sym property)} \quad \text{(A)}$$

Unitary Property:

$$S_{21} S_{21}^* + S_{31} S_{31}^* = 1 \quad \text{(in one column)}$$

$$S_{12} S_{12}^* + S_{32} S_{32}^* = 1$$

$$S_{13} S_{13}^* + S_{23} S_{23}^* = 1 \longrightarrow \text{(B)}$$

(A) & (B) eq^n are contradictory
This inconsistency proves that statement that the tee junction can't be matched to the three arms. Diagonal elements are not all zero.

- Collinear arm is symmetric, due to that

$S_{11} = S_{22}$ and $S_{13} = S_{23}$

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{11} & -S_{13} \\ S_{13} & -S_{13} & S_{33} \end{bmatrix}$$

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

(ii) **H-Plane Tee:**

- axis of the side arm is parallel to H field of the main guide.
- it can be used as combiner.
- in phase

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

- if we gives the i/P to Port 3, we get the power split into Port 1 and Port in Phase and same magnitude.

(iii) Magic Tee :

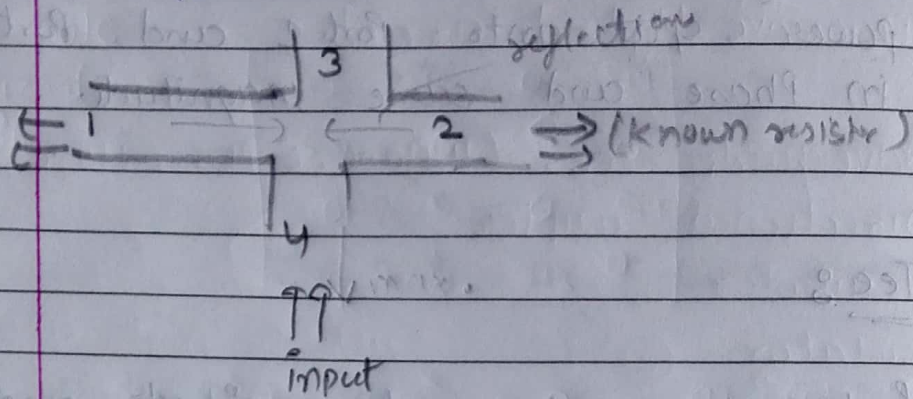
- If two waves of equal magnitude and same phase are fed into Port 1 and Port 2, the O/P will be zero at Port 3 and additive at Port 4.
- Port 4 (H) and Port 3 (E)

$$S = \begin{bmatrix} 0 & 0 & S_{13} & S_{14} \\ 0 & 0 & S_{23} & S_{24} \\ S_{31} & S_{32} & 0 & 0 \\ S_{41} & S_{42} & 0 & 0 \end{bmatrix}$$

- combination of E-Plane and H-Plane Tee.
- when I/P at Port 1 and its equally divided into Port 3 and Port 4.
- Application:
  - ↳ Mixing (i/P 1 & 2 and o/P at 4)
  - ↳ Duplexing (used in Radar)
    - when we Tx the signal it connected to Tx and when we Rx " it " " to Rx. → antennas
    - decoupled b/w Tx and Rx
    - so that's done in Magic tee as E and H are decoupled.

Date: 5 Sep

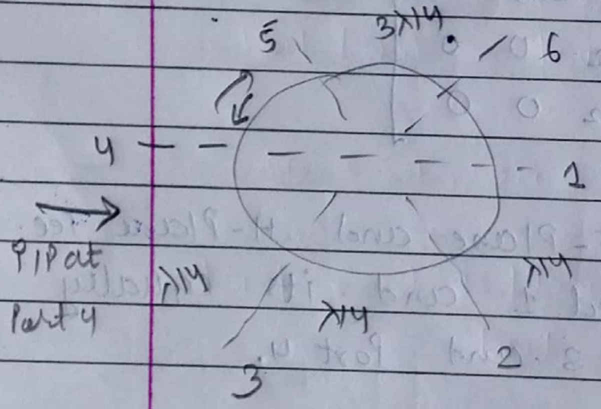
↳ impedence measurements



By changing the known impedence so that at port 3 O/P = 0

↳ Radar transmitters

(PU) Hybrid Ring (Rat-Race circuit)



- works at only single frequency

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

I/P at Port 4, and checks O/P at 3

anticlock wise $= \lambda/4$

clock wise $= 3\lambda/4 + \lambda/4 + \lambda/4 = 5\lambda/4$

are in phase

I/P at Port 4 and checks O/P at 2

anti clock wise $= \lambda/2$

clock wise $= \lambda$

are out of Phase } - so not getting the O/P @ 2

- 8 to 10 GHz → isolator and circulator will work properly

Date: 5 | Sep - 2017

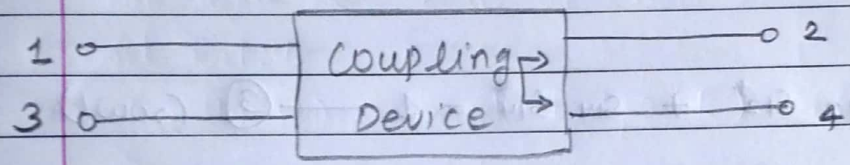
Waveguide corners, Bends and Twists :

used to change the direction of the guide through an arbitr angle.

$$L = (2n+1)\frac{\lambda}{4}$$

used to change the direction of the guide through an arbitary angle.

Directional coupler :



- Holes present in the wall which is present common to both waveguide joint, helps in coupling of power.
- when all ports are terminated in their char^c impedence, there is free transmission of Power b/w port 1 and Port 2.
- 3 dB coupling → Power is splitted b/w 2 and 4.

- insertion loss
  coupling factor = $10 \log_{10} (P_1/P_4)$
  Directivity = $10 \log (P_4/P_3)$
  desired direction → P_4
  undesired " → P_3

{ The degree of coupling b/w 1 & 4 and 2 & 3 depends on structure of coupling mechanism.
coupling depends on the mechanism.

- Types :
  (a) Two hole directional coupler
  (b) four hole
  (c) Reverse coupling

(d) Bethe-hole directional coupler

⇒ Two hole Directional coupler

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{21} & 0 & S_{23} & 0 \\ 0 & S_{32} & 0 & S_{34} \\ S_{41} & 0 & S_{43} & 0 \end{bmatrix}$$

applying zero property

$$S_{12} S_{14}^* + S_{32} S_{34}^* = 0 \quad \text{— ① (col 2, 4)}$$

$$S_{21} S_{23}^* + S_{41} S_{43}^* = 0 \quad \text{— ② (col 1, 3)}$$

Unitary property

$$S_{12} S_{12}^* + S_{14} S_{14}^* = 1 \quad \text{— ③ (row 1)}$$

① & ②

$$|S_{12}|\,|S_{14}| = |S_{32}|\,|S_{34}|$$

$$|S_{21}|\,|S_{23}| = |S_{41}|\,|S_{43}|$$

$S_{12} = S_{21}$, $S_{14} = S_{41}$, $S_{32} = S_{23}$ → symmetric

$$|S_{12}| = \frac{|S_{32}|\,|S_{34}|}{|S_{14}|} \quad \text{— (A)}$$

$$|S_{21}| = \frac{|S_{41}|\,|S_{43}|}{|S_{23}|} \quad \text{— (B)}$$

(A) = (B)

$$\frac{|S_{32}|\,\cancel{|S_{34}|}}{|S_{14}|} = \frac{|S_{14}|\,\cancel{|S_{34}|}}{|S_{32}|}$$

$$\Rightarrow |S_{23}| = |S_{41}|$$

$$\Rightarrow |S_{12}| = |S_{34}|$$

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

- directional coupler are reciprocal.

Circulator and isolator :

- Non-reciprocal components
- Ferrite → non-metallic magnetic material
- property → Faraday rotation in the Ferrite material.
- isolator two port device

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

- circulator's Applications: Radar
  (When we transmit the power to Tx , not to Rx
  received signal from antenna to Rx not to Tx)

Cavity Resonator :

- used for the measure the microwave frequency
- size of cavity is ~~the~~ multiple of the $\lambda/2$
- incident and reflected wave are must be in phase → resonance
- cavity meter is in series → all the energy is absorb by the cavity