Unit 3 :- Passive Microwave Components

- Construction, working principle and scattering analysis of E-plane, H-plane and Magic Tee.

- Construction, working principle and scattering analysis of isolator, circulator, gyrator and directional coupler.

- Ferrite composition and Foraday's rotation principle.

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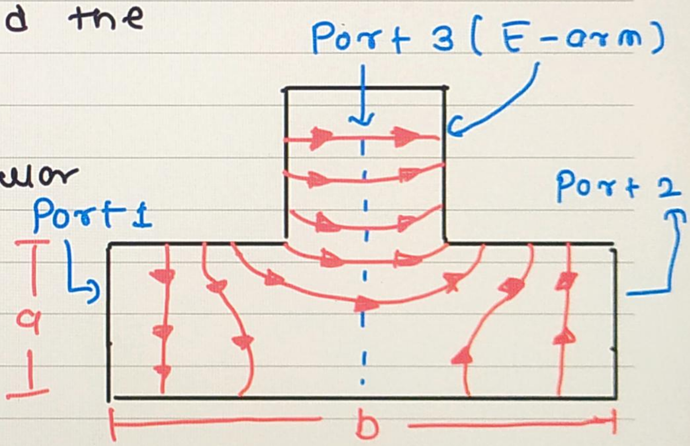
* E-plane Tee :-

- The arms represeneted by Port 1 and Port 2 are collinear arm. and the port 3 arm is E-arm.

- For construction, rectangular waveguide of appropriate dimensions according to frequency has to choose. Another waveguide of same dimensions has been plough together in perpendicular way.



(Fig. E-plane Tee)

- axis of E-arm is poralled to Electric field ⇒ E-plane Tee junction.

- **Function / Operation :-**

1. When input is given to E-arm (i.e. Port 3) :-

- when I/P is given to E-arm, Electric field will propagate through the secondary waveguide.

- Half of electric field will propogate through Port 1 and rest through Port 2. The Electric field of port-1 to port-2 is 180° out of phase.

- Thus signal is given to E-arm, E-plane Tee acts as Half Power Divider.

2. When I/P is given to either port of collinear arm :-

- Signal of same amplitude and 180° out of phase at Collinear arms ⟹ summation of signal at port 3.

- signal of same amplitude and same phase at collinear arms ⟹ No signal at Port 3

• Scattering Analysis :-

- The properties of E-plane Tee can be defined by the scattering matrix. $[S]_{3 \times 3}$

- As their as 3 ports, the S-matrix would be 3×3 matrix.

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

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$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \quad — (1)$$

- Scattering coefficients S_{13} and S_{23} are 180° out of phase of input.

$$\therefore \quad S_{13} = -S_{23}. \quad — (2)$$

- Port 3 is matched perfectly.

$$\therefore \quad S_{33} = 0. \quad — (3)$$

- From symmetric-matrix property,

$$S_{12} = S_{21}, \quad S_{31} = S_{13}, \quad S_{23} = S_{32} \quad — (4)$$

- From (2), (3) and (4), the eqn (1) becomes,

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix} \quad — (5)$$

- Now, we have four unknowns $S_{11}, S_{12}, S_{13}, S_{22}$.

- we have unitory property of S-matrix.

i.e.

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$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix} \begin{bmatrix} {}^*S_{11} & {}^*S_{12} & {}^*S_{13} \\ {}^*S_{12} & {}^*S_{22} & {}^*-S_{13} \\ {}^*S_{13} & {}^*-S_{13} & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

R_1C_1 : $S_{11} {}^*S_{11} + S_{12} {}^*S_{12} + S_{13} {}^*S_{13} = 1$

$$|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1 \quad - (6)$$

R_2C_2 : $S_{12} {}^*S_{12} + S_{22} {}^*S_{22} + S_{13} {}^*S_{13} = 1.$

$$|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \quad - (7)$$

R_3C_3 : $S_{13} {}^*S_{13} + S_{13} {}^*S_{13} = 1$

$$2|S_{13}|^2 = 1$$

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

R_3C_1 : $S_{13} {}^*S_{11} - {}^*S_{12} S_{13} = 0 \Rightarrow S_{11} = S_{12}$

- From (6) and (7), $S_{11} = S_{22}$

By calculating all the unknown scattering coefficients, we get the following S-Matrix for the E-plane Tee:

$$|S_{12}|^2 + |S_{22}|^2 + |S_{13}| = 1 \quad - (7)$$

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By calculating all the unknown scattering coefficients, we get the following S-Matrix for the E-plane Tee:

$$\boxed{[S] = \begin{bmatrix} 1/2 & 1/2 & 1/\sqrt{2} \\ 1/2 & 1/2 & -1/\sqrt{2} \\ \frac{1}{\sqrt{2}} & -1/\sqrt{2} & 0 \end{bmatrix}}$$

* Applications:-

1. Used as an isolator for the two devices which needs same signal and also needs to be isolated from each other.

2. Used as an Adder (By applying same amplitude and 180° out of phase signal at collinear arms)

3. Three devices placed at each port are completely isolated from each other.

* H-plane Tee:-

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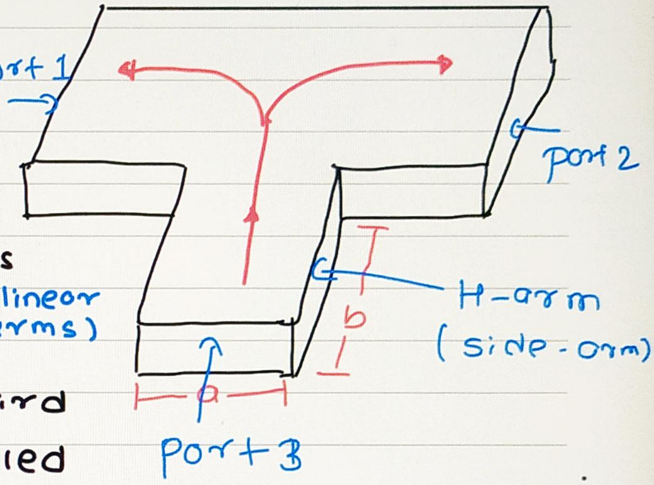
- H-plane Tee is formed by attaching a simple waveguide to the rectangular waveguide having two ports.



- The arms of rectangular waveguide makes two ports i.e. Port 1 and Port 2 (collinear arms)

- Simple waveguide makes third arm i.e. Port 3 also called as H-arm / side-arm.

- Axis of the side arm is parallel to the magnetic field, it is called E-plane Tee Junction.

* Function / operation :

1. When I/P is given to H-arm | Port 3 :

- When signal is given to H-arm, H-plane Tee acts as Half-Power Divider. In this equal amount of power gets divided into both ports and they are in phase to each other.

2. When I/P is given to either port of collinear arm / Port 1 or Port 2 :-

- signal of <u>same amplitude</u> and same <u>phase</u> is fed ⇒ <u>Summation of signal</u> at

- When signal is given to H-arm, H-plane Tee acts as Half-Power Divider. In this equal amount of power gets divided into both ports and they are in phase to each other.

2. When I/P is given to either port of collinear arm / port 1 or Port 2:-

- Signal of same amplitude and same phase is fed at collinear arm $\Rightarrow$ Summation of signal at side arm.

- Signal of same amplitude and 180° out of phase is fed at collinear arm $\Rightarrow$ No signal at side arm.

* Scattering Analysis :-

- The properties of H-plane Tee can be defined by scattering matrix.

- As their are 3 ports, 3 x 3 matrix is used to define.

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \quad \text{— (1)}$$

- From symmetric property,

$$|S_{21}| = |S_{12}|,\ |S_{31}| = |S_{13}|,\ |S_{32}| = |S_{23}| \quad \text{— (2)}$$

- Port 3 is perfectly matched.

$$\therefore |S_{33}| = 0. \quad \text{— (3)}$$

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- Scattering coefficients S_{13} and S_{23} are in phase.
  $\therefore |S_{13}| = |S_{23}|$ — (4)

- The S-matrix becomes,

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \quad — (5)$$

- Four unknown coefficient : $S_{11}, S_{12}, S_{13}, S_{22}$.

- From unitory property,

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \begin{bmatrix} {}^*S_{11} & {}^*S_{12} & {}^*S_{13} \\ {}^*S_{12} & {}^*S_{22} & {}^*S_{13} \\ {}^*S_{13} & {}^*S_{13} & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

- R_1C_1 : $S_{11}{}^*S_{11} + S_{12}{}^*S_{12} + S_{13}{}^*S_{13} = 1.$
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R_2C_2 : $S_{12}{}^*S_{12} + S_{22}{}^*S_{22} + S_{13}{}^*S_{13} = 1$
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$$\boxed{S_{13} = \frac{1}{\sqrt{2}}}$$

R_3C_1 : $S_{13}{}^*S_{11} + S_{13}{}^*S_{12} = 0$

R_3C_3 : $S_{13}^* S_{13} + S_{13}^* S_{13} = 1$

$$2|S_{13}|^2 = 1$$

$$\boxed{S_{13} = 1/\sqrt{2}}$$

R_3C_1 : $S_{13}^* S_{11} + S_{13}^* S_{12} = 0$

$$\boxed{S_{11} = -S_{12}.}$$

From (6) and (7), $\boxed{S_{11} = S_{22}.}$

After calculation, we get S-matrix as,

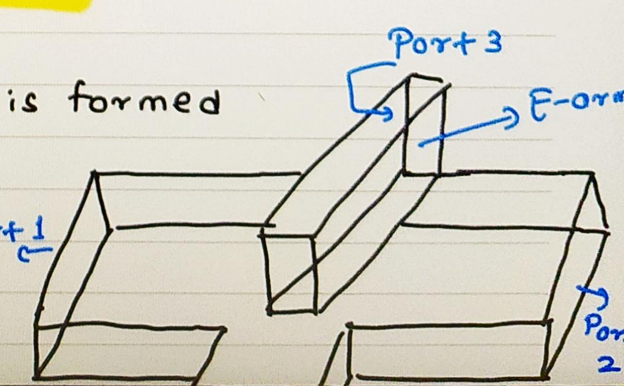
$$\boxed{[S] = \begin{bmatrix} 1/2 & -1/2 & \frac{1}{\sqrt{2}} \\ -1/2 & 1/2 & 1/\sqrt{2} \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 \end{bmatrix}}$$

* Applications :-

1. Used to couple two devices which requires same amount of power.
2. Can be used as adder. The signals appiled at collineor arms with some phose, summation will be obtained at H-arm.

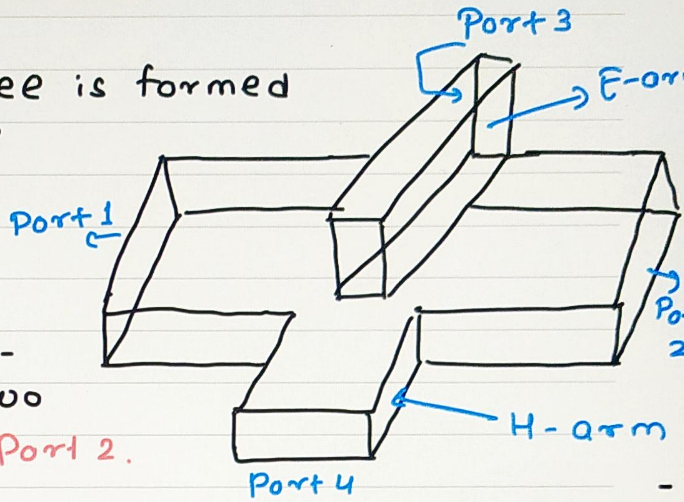
* E-H plane / Magic Tee :-

- The E-H plane / Magic Tee is formed by attaching two simple waveguide and one rectangular waveguide.



- The arms of the rectang-

* E-H plane / Magic Tee :-



- The E-H plane / Magic Tee is formed by attaching two simple waveguide and one rectangular waveguide.

- The arms of the rectangular waveguide makes two collinear arms i.e. Port 1, Port 2.

- One of the simple waveguide is parallel to the rectangular waveguide forms the H-arm and makes Port 4.

- Another waveguide which is perpendicular to the rectangular waveguide forms E-arm and makes Port 3.

* Function / Operation :

1. When I/P is applied to collinear arms i.e. Port 1 and Port 2 :

- Signals with same amplitude and same phase at Port 1 and Port 2 ⇒ No signal at E-arm ⇒ Summation of signal at H-arm

- Signals with same amplitude and 180° out of phase at Port 1 and ⇒ Summation of signal at E-arm ⇒ No signal at H-arm.

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1. When I/P is applied to collinear arms i.e. Port 1 and Port 2

- Signals with same amplitude and same phase at Port 1 and Port 2 ⇒ No signal at E-arm ⇒ Summation of signal at H-arm

- Signals with same amplitude and 180° out of phase at Port 1 and Port 2 ⇒ summation of signal at E-arm ⇒ No signal at H-arm.

2. When I/P is applied at E-ARM :

- I/P applied to E-arm ⇒ signal with same amplitude and out of phase appears at PORT-1 and PORT-2. ⇒ No signal at H-ARM.

3. When I/P applied to H-ARM :

- I/P applied to H-arm ⇒ Signal with same amplitude and same phase appears at PORT-1 and PORT-2 ⇒ No signal at E-ARM.

* Scattering Analysis :

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- The properties of E-H plane Tee can be defined by its scattering matrix.

- Due to four ports, the S-Matrix is of 4×4 matrix.

- S-matrix is as follows:-

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

- Due to H-plane Tee section,
$$|S_{24}| = |S_{14}|$$

- Due to E-plane Tee section, $|S_{23}| = -|S_{13}|$

- As E-arm and H-arm are isolated from each other, $|S_{34}| = |S_{43}| = 0$.

- Due to symmetry property
$$|S_{12}| = |S_{21}|, \ |S_{13}| = |S_{31}|, \ |S_{14}| = |S_{41}|$$
$$|S_{23}| = |S_{32}|, \ |S_{34}| = |S_{43}|, \ |S_{24}| = |S_{42}|$$

- As ports 3, 4 are perfectly matched.
$$|S_{33}| = |S_{44}| = 0$$

- Now S-matrix is,

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & -S_{13} & S_{14} \end{bmatrix}$$

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- Now, unitary property:

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & -S_{13} & S_{14} \\ S_{13} & -S_{13} & 0 & 0 \\ S_{14} & S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} {}^*S_{11} & {}^*S_{12} & {}^*S_{13} & {}^*S_{14} \\ {}^*S_{12} & {}^*S_{22} & {}^*-S_{13} & {}^*S_{14} \\ {}^*S_{13} & {}^*-S_{13} & 0 & 0 \\ {}^*S_{14} & {}^*S_{14} & 0 & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

R_1C_1 : $|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1$

R_2C_2 : $|S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1$.

R_3C_3 : $|S_{13}|^2 + |S_{13}|^2 = 1 \Rightarrow |S_{13}| = 1/\sqrt{2}$

R_4C_4 : $|S_{14}| = 1/\sqrt{2}$

* Isolator :-

- Isolator is mainly used to isolate particular component in macrowave system.
- 2-port device in which signal propagates only in one direction.
- non-reciprocal device.
- Ideal isolator prevents propagation in one direction completely.

* Working:

1. When signal enters from Port - 1 :

- When signal enters at port 1, the signal is parallel to resistive vane. It does not absorb signal.
- The signal passes to ferrite rod which shifts it by 45° degrees.
- This shifted signal is obtained at Port - 2.

2. When signal enters from Port - 2 :

- When signal enters from port 2, it is parallel to resistive vane.
- This signal enters ferrite rod, it does not provide phase shift of 45° as it is entered from opposite direction.
- Thus signal becomes perpendicular to resistive vane, which completely absorbs the signal. No signal will reach port - 1. Signal gets isolated.

* Applications :

1. High voltage devices such as transformers.

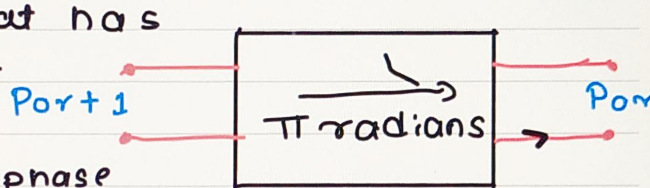
vane, which completely absorbs the signal. No signal will reach port-1. Signal gets isolated.

* Applications :

1. High voltage devices such as transformers.
2. When a fault occurs in substation, then isolator cuts out a portion of substation.

* Gyrator :-

- Two port device that has a relative phase shift of 180° in forward direction and 0 zero phase shift in reverse direction.



(Fig. gyrator)

- The symbol for gyrator is shown in Fig.

- When signal is transmitted from port 1 to port 2 it offers a phase shift of 180° and when signal if fed to port 2 it offers 0° phase shift to the signal.

(Fig. gyrator)

- Known as differential phase shift device.

* Circulator :

- A circulator is a three or four port device, in which a microwave or radio frequency signal entering any port is transmitted to next port in rotation only.

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- A circulator is a three or four port device, in which a microwave or radio frequency signal entering any port is transmitted to next port in rotation only.

- It has a peculiar property that each terminal is connected only to next clockwise terminal.

- E.g :- 1. Input at Port 1 ⇒ Output at Port 2.
  Input at Port 2 ⇒ Output at Port 3.

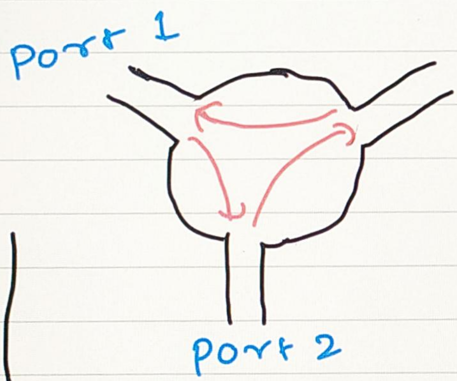

fig. 3-port Circulator

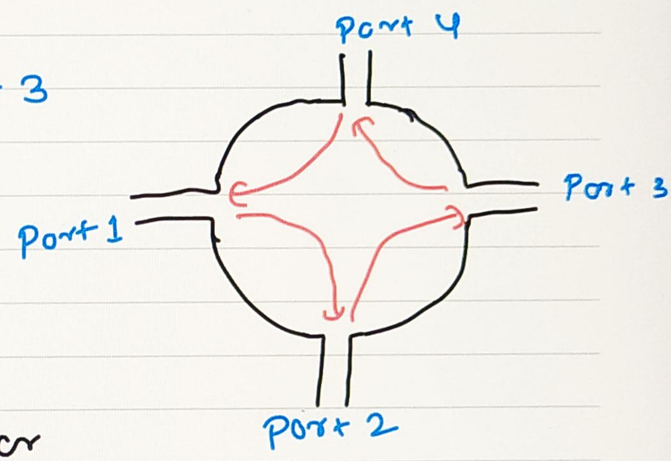

Fig. 4-port circulator

$$S = \begin{bmatrix} 0 & 0 & S_{13} \\ S_{21} & 0 & 0 \\ 0 & S_{32} & 0 \end{bmatrix}$$

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

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

* Working of 4-port Circulator:

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- Power entering Port 1 travels along the magnetized ferrite. The direction of the E-field vector gets rotated by 45°. Therefore, the power entered at Port 1 appears at Port 2.

- The power cannot be coupled to Port 4 because Port 2 and Port 4 are 90° out of phase.

* Applications:

1. Duplexer
2. Radar system
3. Isolator
4. Reflection Amplifer.
5. Amplifier Systems
6. Antenna transmitting and Receiving

* Directional Coupler:

- A directional coupler is a 4-port waveguide junction consisting of primary main waveguide and secondary auxiliary waveguide.

- It is used to couple the microwave power which may be unidirectional / bidirectional.

- It samples small amount of power for

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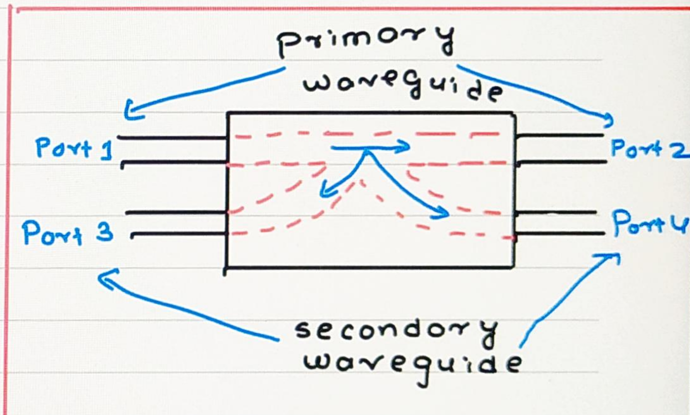
- A directional coupler is a 4-port waveguide junction consisting of primary main waveguide and secondary auxiliary waveguide.

- It is used to couple the microwave power which may be unidirectional / bidirectional.

- It samples small amount of power for measurement purpose. Measurement includes includes incident power, reflected power, etc.

• Properties :-



- All the terminations are matched to the ports.

- When power travels from Port 1 to Port 2, some portion of it's get coupled to Port 4 but not port 3.

Port 1 to Port 2 ⟹ Coupled to Port 4 ⟹ Not coupled to Port 3.

- when power travels from Port 2 to Port 1, some portion couples with Port 3 but not Port 4.

Port 2 to Port 1 ⟹ couples with Port 3 ⟹ Don't couples with Port 4.

to Port 4 but not port 3.

Port 1 to Port 2 ⟹ Coupled to Port 4 ⟹ Not coupled to Port 3.

- when power travels from Port 2 to Port 1, some portion couples with Port 3 but not Port 4.

Port 2 to Port 1 ⟹ couples with Port 3 ⟹ Don't couples with Port 4.

- when power is incident at Port 3, a portion is coupled to Port 2.

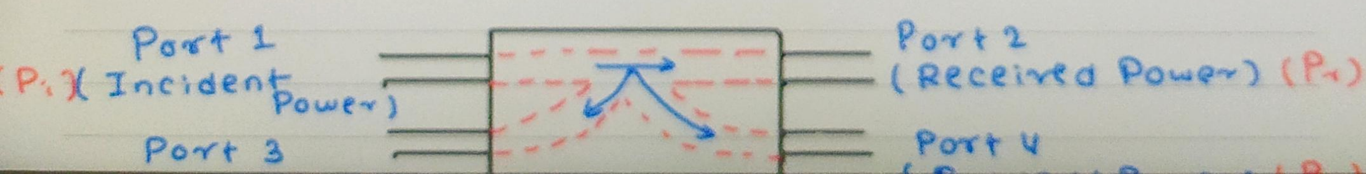
Power at Port 3 ⟹ couples with Port 2 ⟹ Don't couple with Port 1

- when power is incident at Port 4, a portion get's coupled with Port 1.

Power at Port 4 ⟹ couples with Port 1 ⟹ Don't couple with Port 2

- Port 3 and Port 1, Port 2 and Port 4 are decoupled.

*. Parameters :



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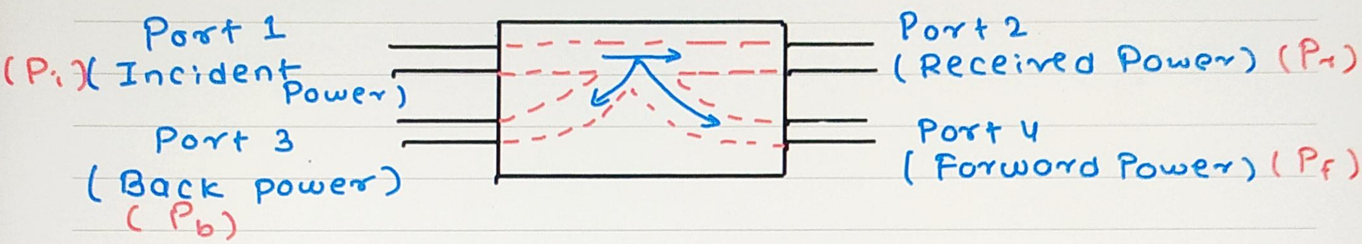


- Ideally , the power at Port 3 should be zero. But practically there is some amount of power called back power.

1. Coupling Factor(C) : Ratio of incident power to forword Power.

$$\boxed{C = 10 \log_{10}\left(\frac{P_i}{P_f}\right) \text{ dB}}$$

2. Directivity (D) : Ratio of forword power to back power

$$\boxed{D = 10 \log_{10}\left(\frac{P_f}{P_b}\right) \text{ dB}}$$

3. Isolation (I) : Ratio of incident power to back power.

$$\boxed{I = 10 \log_{10}\left(\frac{P_i}{P_b}\right) \text{ dB}}$$

$$I = \underbrace{C}_{\text{Coupling}} + \underbrace{D}_{\text{Directivity}}$$

* S- Matrix for Ideal Directional Coupler :

* S-Matrix for Ideal Directional Coupler :

- S-matrix for ideal dc is given by:

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

- In dc, all four ports are perfectly matched.

$\therefore$ $S_{11} = S_{22} = S_{33} = S_{44} = 0.$

- From symmetric property.

$\therefore$ $S_{23} = S_{32}$, $S_{13} = S_{31}$, $S_{24} = S_{42}$

$S_{34} = S_{43}$, $S_{41} = S_{14}$, $S_{12} = S_{21}$

- Port 3 and Port 1, Port 2 and Port 4 are decoupled.

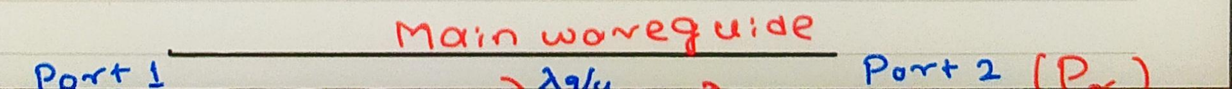
$\therefore$ $S_{13} = S_{31} = 0.$

$\therefore$ $S_{24} = S_{42} = 0.$

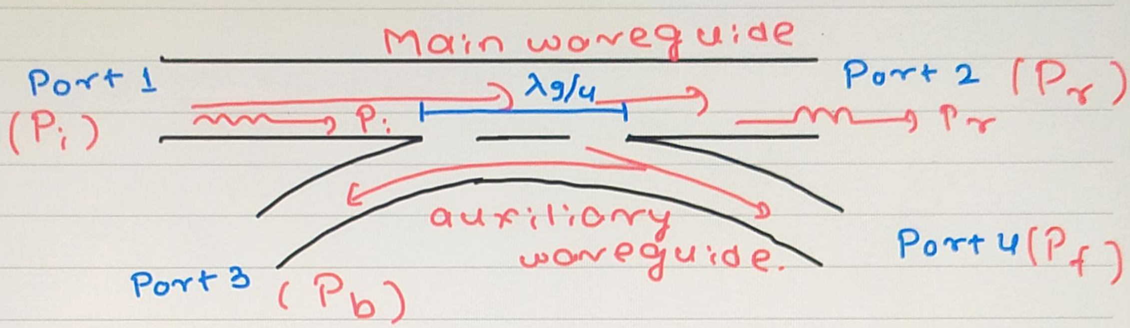
- S-Matrix becomes

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

* Two-Hole Directional Coupler:



* Two-Hole Directional Coupler:



- The two-hole directional coupler have same main waveguide and auxiliary waveguide with two small holes between them. These holes are $\lambda g/4$ apart from each other where λg is guide wavelength.

- When signal travels from port 1 towards Port 2, some of the power escapes through hole 1 and hole 2.

- Hole 1 ⇒ out of phase of signal ⇒ cancelling each other and prevent back power occur.

  Hole 2 ⇒ In phase of signal ⇒ Adding up to forward power.

- Directivity of DC improves.

* Applications:

1. Used to measure incident and reflected power along with VSWR values.
2. Used for purpose of unidirectional wave

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1. Used to measure incident and reflected power along with VSWR values.
2. Used for purpose of unidirectional wave launching.

* Faraday's rotation Principle:

- Faraday's rotation is a fundamental phenomenon related to the polarization of electromagnetic wave in magnetic field discovered by M. Faraday in 1845.

- When an electromagnetic wave passes through ferrites, plane of polarisation is rotated by an θ in proportion to magnetic field 'B' and thickness 'd'.

- The relation is given as:

$$\theta_F = V \, B d$$

Verdet constant.