UNIT-III
WAVEGUIDE COMPONENTS

Waveguide Attenuators:

- Attenuator is an electronic device that reduces the power of the signal without effecting or reducing the waveform of the signal.
- A device used to control the amount of microwave power transferred from one point to another on a microwave transmission systems is called microwave attenuator.
- Microwave attenuators control the flow of microwave power either by reflecting it or absorbing it.
- Attenuators are commonly used for
  - ➢ Measuring power gain or loss in dB
  - ➢ Providing isolation between instruments
  - ➢ Reducing the power I/P to a particular stage to prevent overloading.

Attenuators can be classified as fixed or variable type

1. **Fixed Attenuators:**

- Fixed attenuators in circuits are used to lower voltage, dissipate power and to impedance matching.
- These are used where fixed amount of attenuation is to provided. If such a fixed attenuator absorbs all the energy entering into it, we call it as a waveguide terminator.
- This normally consists of a short section of waveguide with a tapered plug of absorbing material at the end.
- The tapering is done for providing a gradual transition from the wave guide medium to the absorbing medium thus reducing the reflection occurring at the media interface.

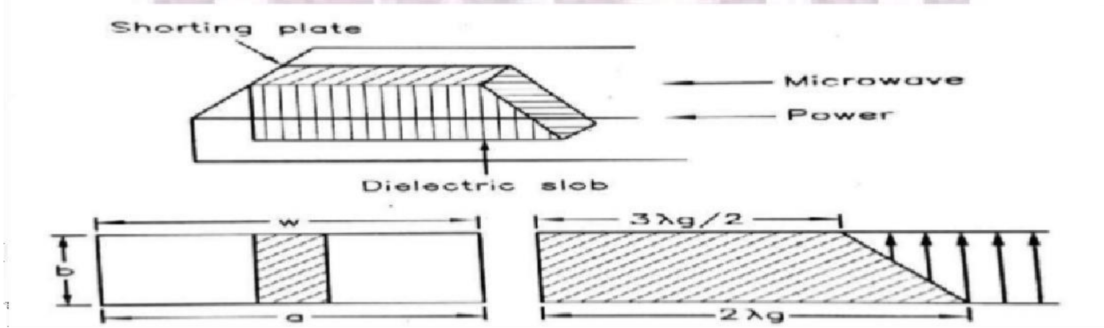


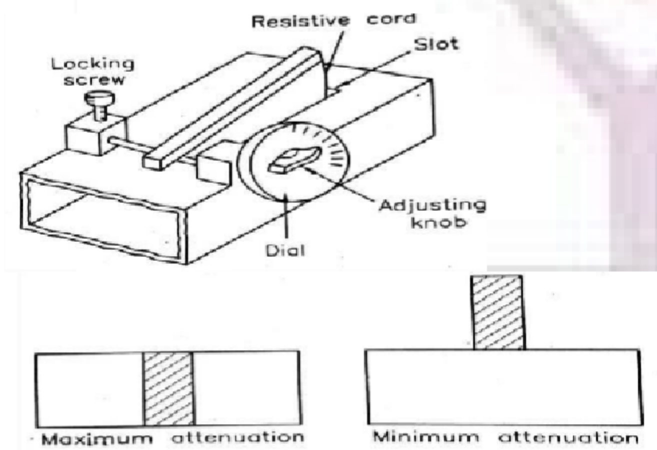
Figure shows fixed attenuator where a dielectric slab consisting of glass slab coated with aquadag or carbon film has been used as a plug.

2. **Variable Attenuators:**

- Variable attenuators provide continuous or step wise variable attenuation.
- For rectangular waveguides, these attenuators can be flap type or vane type.
- For circular waveguide rotary type is used.

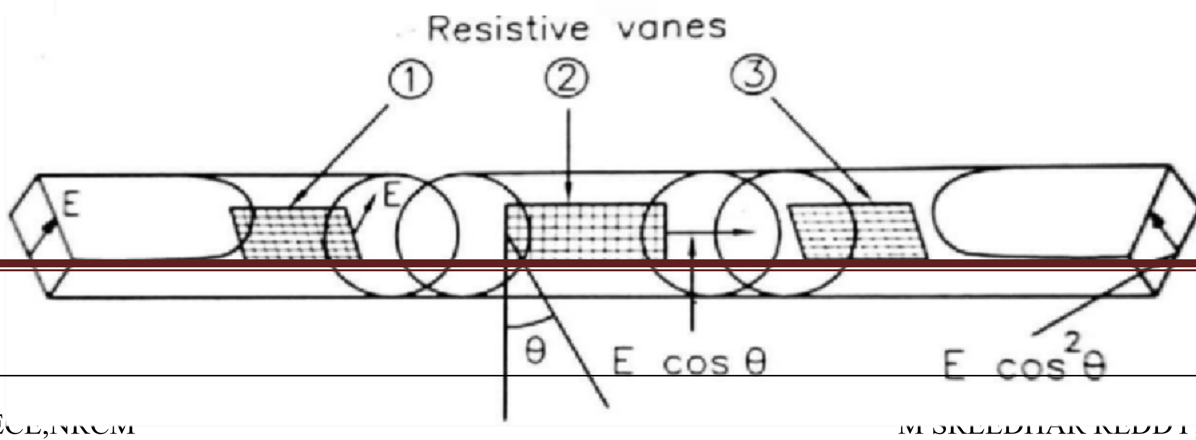
Resistive or Flap type Attenuators:

- Flap type attenuator consists of a resistive element or disc inserted into a longitudinal slot cut along the center of the wider dimension of the guide.
- Flap is mounted on the hinged arm allowing it to descent into the centre of waveguide.
- Degree of attenuation can be determined by depth of insertion of the flap.



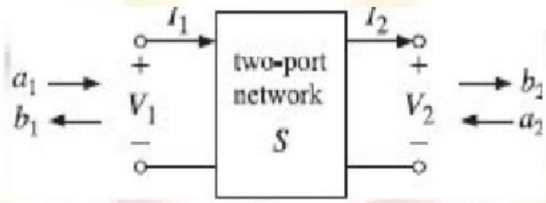
Rotatory vane Attenuator:

- A resistive rotary vane attenuator consists of three vanes.
- The central vane rotating type placed in the central section of a circular waveguide arrangement tapered at both ends.
- The other two vanes are rectangular sections.



SCATTERING PARAMETERS

- Linear two-port (and multi-port) networks are characterized by a number of equivalent circuit parameters, such as their transfer matrix, impedance matrix, admittance matrix, and scattering matrix. Fig. shows a typical two- port network.



- The transfer matrix, also known as the ABCD matrix, relates the voltage and current at port 1 to those at port 2, whereas the impedance matrix relates the two voltages V_1,V_2 to the two currents I_1, I_2.

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad \text{(transfer matrix)}$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ -I_2 \end{bmatrix} \quad \text{(impedance matrix)}$$

- Thus, the transfer and impedance matrices are the 2×2 matrices:
- The admittance matrix is simply the inverse of the impedance matrix, $Y = Z^{-1}$. The scattering matrix relates the outgoing waves b1, b2 to the incoming waves a1, a2 that are incident on the two-port:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}, \quad S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \quad \text{(scattering matrix)}$$

- The matrix elements S11, S12, S21, S22 are referred to as the scattering parameters or the S- parameters. The parameters S11, S22 have the meaning of reflection coefficients, and S21, S12, themeaning of transmission coefficients.

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad \text{(transfer matrix)}$$

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ -I_2 \end{bmatrix} \quad \text{(impedance matrix)}$$

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix}, \quad S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \quad \text{(scattering matrix)}$$

S- THE SCATTERING MATRIX

- The scattering matrix is defined as the relationship between the forward and backward moving waves. For a two-port network, like any other set of two-port parameters, the scattering matrix is a 2| matrix.

PROPERTIES OF SMATRIX:

In general the scattering parameters are complex quantities having the following Properties:

Property (1)

- When any Z port is perfectly matched to the junction, then there are no reflections from that S = 0. If all the ports are perfectly matched, then the leading diagonal II elements will all be zero.

Property (2)

- Symmetric Property of S-matrix: If a microwave junction satisfies reciprocity condition and if there are no active devices, then S parameters are equal to their corresponding transposes.

  i.e., $\mathbf{S_{ij}=S_{ji}}$

Property (3)

- Unitary property for a lossless junction - This property states that for any lossless network, the sum of the products of each term of anyone row or anyone column of the [SJ matrix with its complex conjugate is unity

Property (4)

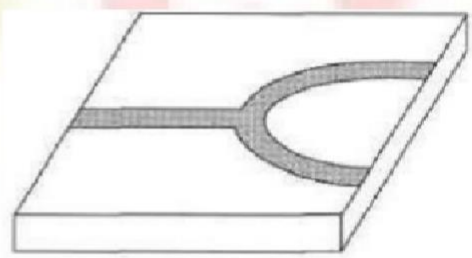
Phase - Shift Property:

- Complex S-parameters of a network are defined with respect to the positions of the port or reference planes. For a two-port network with unprimed reference planes 1and 2 as shown in figure 4.6, the S- parameters have definite values.

WAVEGUIDE MULTIPORT JUNCTIONS:

T-JUNCTION POWER DIVIDER USING WAVEGUIDE:

- The T-junction power divider is a 3-port network that can be constructed either from a transmission line or from the waveguide depending upon the frequency of operation.



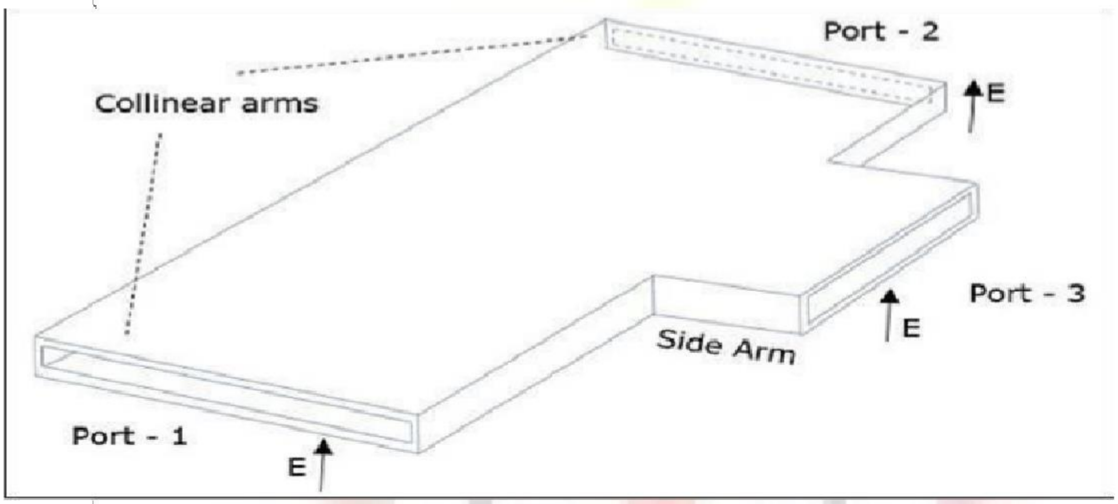
For very high frequency, power divider using waveguide is of 4 types

- H-Plane Tee
- E-Plane Tee
- E-H Plane Tee/Magic Tee
- Rat Race Tee

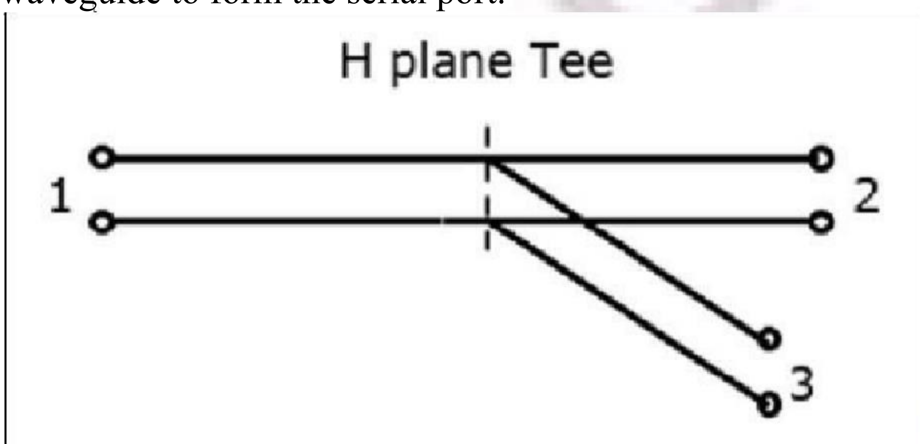
H-Plane Tee

An H-Plane Tee junction is designed by bestowing a simple waveguide to a rectangular waveguide which previously has two ports. The arms of rectangular waveguides make two ports called collinear ports i.e., Port1 and Port2, while the new one, Port3 is called as Side arm or H-arm. This H-plane Tee is also called as Shunt Tee.

As the axis of the side arm is similar to the magnetic field, this junction is called H- Plane Tee junction. This is also called as Current junction, as the magnetic field splits itself into arms. The cross-sectional details of H-plane tee can be agreed by the resulting figure.



The following figure shows the connection made by the sidearm to the bi-directional waveguide to form the serial port.



Properties of H-Plane Tee

The properties of H-Plane Tee can be defined by its $[S]_{3\times3}$matrix.

1. It is a 3×3 matrix as there are 3 possible inputs and 3 possible outputs.

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

2. Scattering coefficients S_{13} and S_{23} are equal here as the junction is symmetrical in plane

$$S_{ij} = S_{ji}$$

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

3. The port is perfectly matched to the junction.

$$S_{33} = 0$$

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \quad \text{........ Equation 2}$$

4. We can say that we have four unknowns, considering the symmetry property.

$$[S][S]* = [I]$$

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

From the Unitary property

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

$$|S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1 \quad \text{........ Equation 3}$$

$$R_2C_2 : |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \quad \text{......... Equation 4}$$

$$R_3C_3 : |S_{13}|^2 + |S_{13}|^2 = 1 \quad \text{......... Equation 5}$$

$$R_3C_1 : S_{13}S_{11}^* - S_{13}S_{12}^* = 0 \quad \text{......... Equation 6}$$

$$2|S_{13}|^2 = 1 \quad or \quad S_{13} = \frac{1}{\sqrt{2}} \quad \text{......... Equation 7}$$

$$|S_{11}|^2 = |S_{22}|^2$$

$$S_{11} = S_{22} \quad \text{......... Equation 8}$$

From the Equation 6,

$$S_{13}(S_{11}^* + S_{12}^*) = 0$$

$$S_{13} \neq 0, S_{11}^* + S_{12}^* = 0, \ or \ S_{11}^* = -S_{12}^*$$

$$S_{11} = -S_{12} \ or \ S_{12} = -S_{11} \quad \text{......... Equation 9}$$

$$|S_{11}|^2 + |S_{11}|^2 + \frac{1}{2} = 1 \quad or \quad 2|S_{11}|^2 = \frac{1}{2} \quad or \quad S_{11} = \frac{1}{2} \quad \text{..... Equation 10}$$

From equation 8 and 9,

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

We know that [b] = [s][a]

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & -\frac{1}{2} & \frac{1}{\sqrt{2}} \\ -\frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

This is the scattering matrix for H-Plane Tee, which explains its scattering properties.

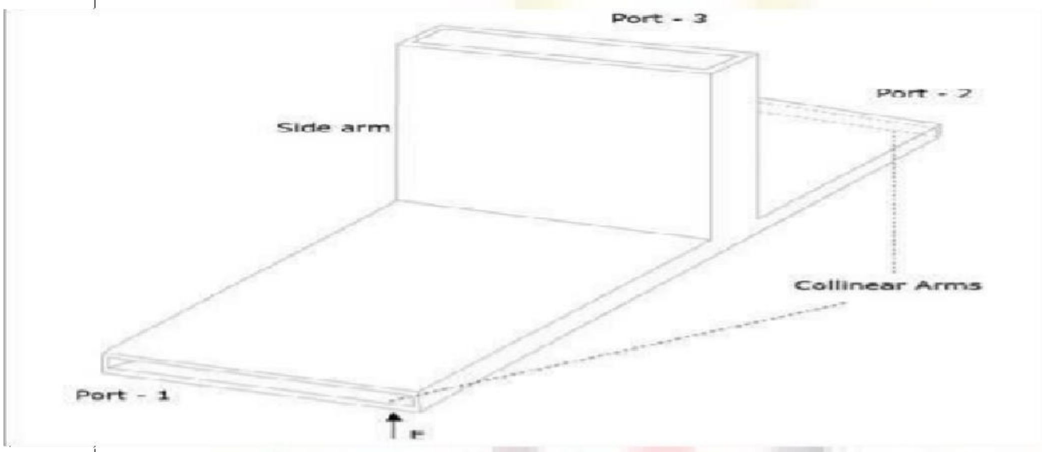
E-Plane Tee

An E-Plane Tee junction is formed by attaching a simple waveguide to the broader dimension of a rectangular waveguide, which already has two ports. The arms of rectangular waveguides make two ports called **collinear ports** i.e., Port1 and Port2, while the new one, Port3 is called as Side arm or **E-arm**. T his E- plane Tee is also called as **Series Tee**.

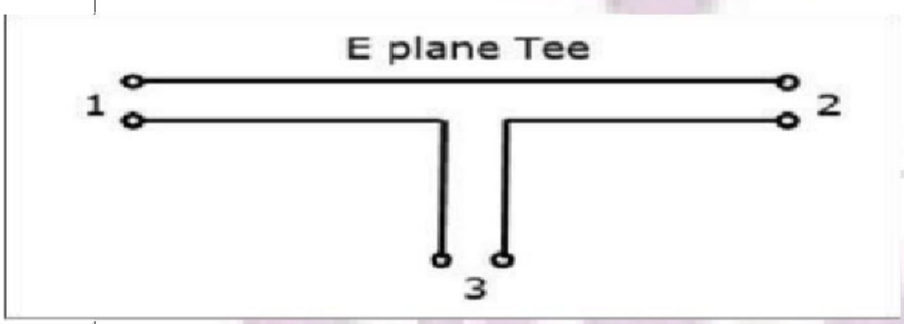
As the axis of the side arm is parallel to the electric field, this junction is called E- Plane Tee junction. This is also called as **Voltage** or **Series junction**. The ports 1 and 2 are 180° out of phase with each other. The cross-sectional details of E- plane tee can be understood by the following figure. An E-Plane Tee junction is designed by assigning a simple waveguide to the broader dimension of a rectangular waveguide, which previously has two ports. The arms of rectangular waveguides create two ports called collinear ports
i.e. Port1 and Port2, while the new one, Port3 is called as Side arm or E-arm. T his

E- plane Tee is also called as Series Tee.

As the axis of the side arm is similar to the electric field, this junction is called E- Plane Tee junction. This is also called as Voltage or Series junction. The ports 1 and 2 are 180° out of phase with each other. The cross-sectional details of E- plane tee can be assumed by the resulting figure.



The resulting figure displays the connection made by the sidearm to the bi-directional waveguide to form the parallel port.



Properties of E-Plane Tee

The properties of E-Plane Tee can be defined by its $[S]_{3x3}[S]_{3x3}$ matrix.

1. It is a 3×3 matrix as there are 3 possible inputs and 3 possible outputs.

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

2. Scattering coefficients S_{13} and S_{23} are out of phase by 180° with an input at port 3

$S_{23} = -S_{13}$ .... Equation 2

3. The port is perfectly matched to the junction.

$S_{33} = 0$ .... Equation 3

4. From the symmetric property,

$$S_{ij} = S_{ji}$$

$S_{12} = S_{21}$ $S_{23} = S_{32}$ $S_{13} = S_{31}$ .... Equation 4

Considering equations 3 & 4, the [S] matrix can be written as,

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix}$$ .... Equation 5

We can say that we have four unknowns, considering the symmetry property.

5. From the Unitary property

$$[S][S]* = [I]$$

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

Multiplying we get,

(Noting R as row and C as column)

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

$|S_{11}|^2 + |S_{11}|^2 + |S_{11}|^2 = 1$ .... Equation 6

$R_2C_2 : |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1$ .... Equation 7

$R_3C_3 : |S_{13}|^2 + |S_{13}|^2 = 1$ .... Equation 8

$R_3C_1 : S_{13}S^*_{11} - S_{13}S^*_{12} = 1$ .... Equation 9

Equating the equations 6 & 7, we get

$$S_{11} = S_{22} \quad \text{......... Equation 10}$$

From Equation 8,

$$2|S_{13}|^2 \quad or \quad S_{13} = \frac{1}{\sqrt{2}} \quad \text{......... Equation 11}$$

From Equation 9,

$$S_{13}(S_{11}^* - S_{12}^*)$$

$$\text{Or } S_{11} = S_{12} = S_{22} \quad \text{......... Equation 12}$$

Using the equations 10, 11, and 12 in the

equation 6, we get,

$$|S_{11}|^2 + |S_{11}|^2 + \frac{1}{2} = 1$$

$$2|S_{11}|^2 = \frac{1}{2}$$

$$\text{Or } S_{11} = \frac{1}{2} \quad \text{......... Equation 13}$$

Substituting the values from the above equations in [S][S]

matrix, We get,

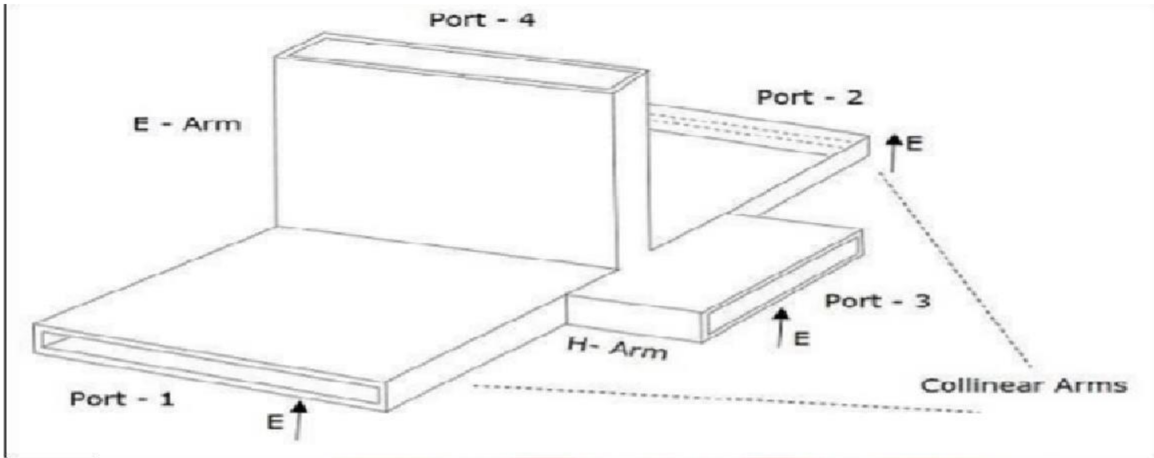
$$[S] = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{\sqrt{2}} \\ \frac{1}{2} & -\frac{1}{\sqrt{2}} & 0 \end{bmatrix}$$

We know that [b]= [S][a]

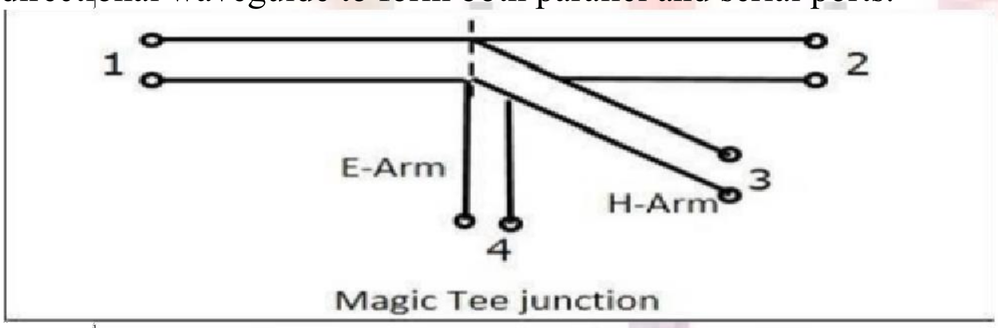
$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ \frac{1}{2} & \frac{1}{2} & -\frac{1}{\sqrt{2}} \\ \frac{1}{2} & -\frac{1}{\sqrt{2}} & 0 \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$$

This is the scattering matrix for E-Plane Tee, which explains its scattering properties.

E-H-Plane



The resulting figure shows the assembly made by the side arms to the bi-directional waveguide to form both parallel and serial ports.



Characteristics of E-H Plane Tee

- If a signal of equal phase and magnitude is sent to port 1 and port 2, then the output at port 4 is zero and the output at port 3 will be the additive of both the ports 1 and 2.
- If a signal is sent to port 4, (E-arm) then the power is divided between port 1 and 2 equally but in opposite phase, while there would be no output at port 3. Hence, $S_{34} = 0$.
- If a signal is fed at port 3, then the power is divided between port 1 and 2 equally, while there would be no output at port 4. Hence, $S_{43} = 0$.
- If a signal is fed at one of the collinear ports, then there appears no output at the other collinear port, as the E-arm produces a phase delay and the H-arm produces a phase advance. So, $S_{12} = S_{21} = 0$.

Properties of E-H Plane Tee

The properties of E-H Plane Tee can be defined by its $[S]_{4\times4}$matrix.

1. It is a 4×4 matrix as there are 4 possible inputs and 4 possible outputs.

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} \quad \text{........ Equation 1}$$

2. As it has H-Plane Tee section As it has H-Plane Tee section

$$S_{23} = S_{13} \quad \text{........ Equation 2}$$

3. As it has E-Plane Tee section

$$S_{24} = -S_{14} \quad \text{........ Equation 3}$$

4. The E-Arm port and H-Arm port are so isolated that the other won't deliver an output, if an input is applied at one of them. Hence, this can be noted as

$$S_{34} = S_{43} = 0 \quad \text{........ Equation 4}$$

5. From the symmetry property, we have

$$S_{ij} = S_{ji}$$

$$S_{12} = S_{21}, S_{13} = S_{31}, S_{14} = S_{41}$$

$$S_{23} = S_{32}, S_{24} = S_{42}, S_{34} = S_{43} \quad \text{........ Equation 5}$$

6. If the ports 3 and 4 are perfectly matched to the junction, then

$$S_{33} = S_{44} = 0 \quad \text{........ Equation 6}$$

Substituting all the above equations in equation 1, to obtain the [S][S] matrix,

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & S_{13} & -S_{14} \\ S_{13} & S_{13} & 0 & 0 \\ S_{14} & -S_{14} & 0 & 0 \end{bmatrix} \quad \text{........ Equation 7}$$

7. From Unitary property, [S][S]*=[I]

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

$R_1C_1 : |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1 + |S_{14}|^2 = 1$ .... Equation 8

$R_2C_2 : |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 + |S_{14}|^2 = 1$ .... Equation 9

$R_3C_3 : |S_{13}|^2 + |S_{13}|^2 = 1$ .... Equation 10

$R_4C_4 : |S_{14}|^2 + |S_{14}|^2 = 1$ .... Equation 11

From the equations 10 and 11, we get

$S_{13} = \frac{1}{\sqrt{2}}$ .... Equation 12

$S_{14} = \frac{1}{\sqrt{2}}$ .... Equation 13

Comparing the equations 8 and 9, we have

$S_{11} = S_{22}$ .... Equation 14

Using these values from the equations 12 and 13, we get

$$|S_{11}|^2 + |S_{12}|^2 + \frac{1}{2} + \frac{1}{2} = 1$$

$$|S_{11}|^2 + |S_{12}|^2 = 0$$

$S_{11} = S_{22} = 0$ .... Equation 15

From equation 9, we get

$S_{22} = 0$ ....**Equation 16**

Now we understand that ports 1 and 2 are perfectly matched to the junction. As this is a 4 port junction, whenever two ports are perfectly matched, the other two ports are also perfectly matched to the junction.

The junction where all the four ports are perfectly matched is called as Magic Tee Junction.

By substituting the equations from 12 to 16, in the [S][S] matrix of equation 7, we obtain the scattering matrix of Magic Tee as

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

We already know that, [b] = [S][a] Rewriting the above, we get

$$\begin{vmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{vmatrix} = \begin{bmatrix} 0 & 0 & \frac{1}{2} & \frac{1}{\sqrt{2}} \\ 0 & 0 & \frac{1}{2} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & 0 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} & 0 & 0 \end{bmatrix} \begin{vmatrix} a_1 \\ a_2 \\ a_3 \\ a_4 \end{vmatrix}$$

Applications of E-H Plane Tee

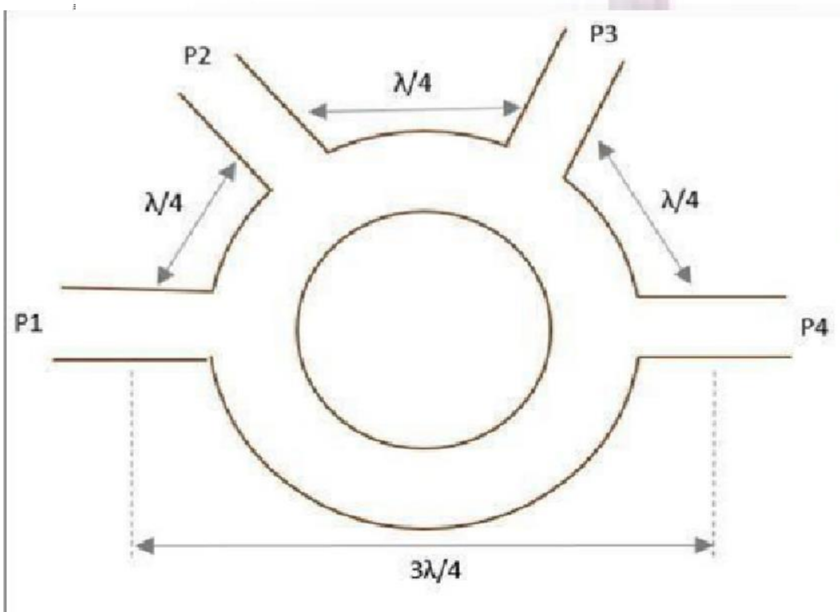
Some of the greatest mutual applications of E-H Plane Tee are as follows :

- E-H Plane junction is used to amount the impedance − A null detector is linked to E- Arm port while the Microwave source is linked to H-Arm port. The collinear ports composed with these ports make a bridge and the impedance measurement is done by balancing the bridge.

- E-H Plane Tee is used as a duplexer − A duplexer is a circuit which mechanisms as both the transmitter and the receiver, by means of a single antenna for both drives. Port 1 and 2 are used as receiver and transmitter where they are inaccessible and hence will not interfere. Antenna is connected to E-Arm port. A matched load is connected to H- Arm port, which provides no reflections. Currently, there exists transmission or reception without any problem.
- E-H Plane Tee is used as a mixer − E-Arm port is connected with antenna and the H- Arm port is connected with local oscillator. Port 2 has a matched load which has no

reflections and port 1 has the mixer circuit, which gets half of the signal power and half of the oscillator power to produce IF frequency.

- In addition to the above applications, an E-H Plane Tee junction is also used as Microwave bridge, Microwave discriminator, etc.
- If we need to association two signals with no phase modification and to avoid the signals with a path difference then we need microwave device. A usual three-port Tee junction is taken and a fourth port is added to it, to make it a ratrace junction. All of these ports are linked in angular ring forms at equal intervals using series or parallel junctions.
- The mean circumference of total race is 1.5λ and each of the four ports is detached by a distance of λ/4. The resulting figure shows the image of a Rat-race junction.



Rat-race Coupler

Let us study a few cases to appreciate the operation of a Rat-race junction.

Case 1

If the input power is applied at port 1, it gets similarly split into two ports, but in clockwise direction for port 2 and anti-clockwise direction for port 4. Port 3 has unconditionally no output.The reason being, at ports 2 and 4, the powers combine in phase, whereas at port 3, cancellation occurs due to λ/2 path difference.

Case 2

If the input power is applied at port 3, the power gets similarly separated between port 2 and port 4. But there will be no output at port 1.

Case 3

If two unequal signals are applied at port 1 itself, then the output will be relative to the sum of the two input signals, which is separated between port 2 and 4. Now at port 3, the differential output appears.

The Scattering Matrix for Rat-race junction is represented as

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

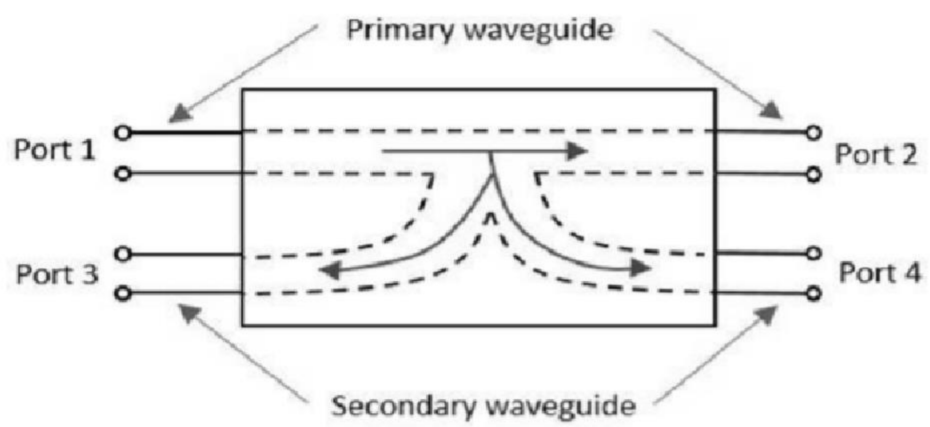
Applications:

Rat-race junction is used for uniting two signals and separating a signal into two halves.

Directional coupler

- A Directional coupler is a device that trials a minor amount of Microwave power for measurement tenacities. The power measurements comprise incident power, reflected power, VSWR values, etc.

- Directional Coupler is a 4-port waveguide junction comprising of a primary main waveguide and a secondary supporting waveguide. The resulting figure shows the image of a directional coupler.



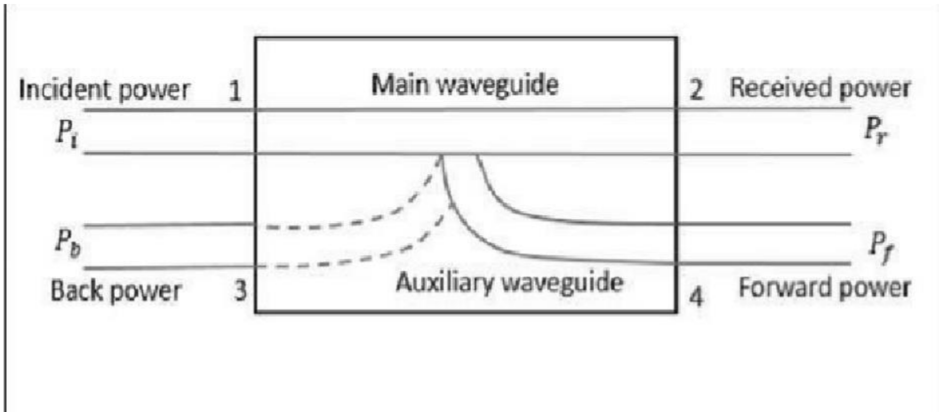
Directional Coupler

- Directional coupler is used to couple the Microwave power which may be unidirectional or bi-directional.

Properties of Directional Couplers:

The properties of an ideal directional coupler are as follows.

- ll the finishes are matched to the ports.
- When the power travels from Port 1 to Port 2, some portion of it gets coupled to Port 4 but not to Port 3.
- As it is also a bi-directional coupler, when the power travels from Port 2 to Port 1, some portion of it gets coupled to Port 3 but not to Port 4.
- If the power is incident through Port 3, a portion of it is coupled to Port 2, but not to Port 1.
- If the power is incident through Port 4, a portion of it is coupled to Port 1, but not to Port 2.
- Port 1 and 3 are decoupled as are Port 2 and Port 4.
- Preferably, the output of Port 3 should be zero. Though, almost, a small amount of power called back power is practical at Port 3. The resulting figure specifies the power flow in a directional coupler.



Directional Coupler indicating powers

Where

- P_i = Incident power at Port 1
- P_r = Received power at Port 2
- P_f= Forward coupled power at Port 4
- P_b = Back power at Port 3

Resulting are the parameters used to define the performance of a directional coupler.

Coupling Factor (C)

The Coupling factor of a directional coupler is the ratio of incident power to the forward power, measured in dB.

$$C = 10\, log_{10} \frac{P_i}{P_f} dB$$

Directivity (D)

The Directivity of a directional coupler is the ratio of forward power to the back power, measured in dB.

$$D = 10\, log_{10} \frac{P_f}{P_b} dB$$

Isolation

It defines the directive properties of a directional coupler. It is the ratio of incident power to the back power, measured in dB.

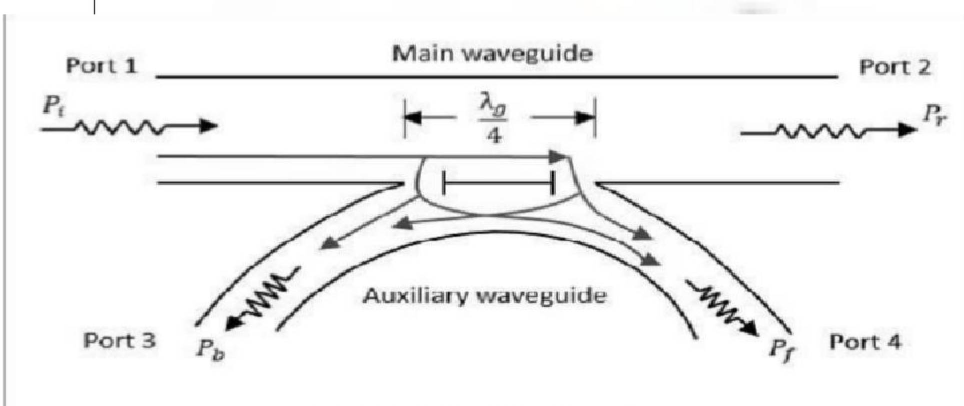
$$I = 10\, log_{10} \frac{P_i}{P_b} dB$$

Isolation in dB = Coupling factor +

Directivity

Two-Hole Directional Coupler

This is a directional coupler with same main and auxiliary waveguides, but with two small holes that are common between them. These holes are λg/4 distance apart where λg is the guide wavelength. The following figure shows the image of a two-hole directional coupler.



Two-hole directional coupler

A two-hole directional coupler is planned to see the ideal condition of directional coupler, which is to evade back power. Some of the power while travelling between Port 1 and Port 2, escapes through the holes 1 and 2.

The greatness of the power depends upon the dimensions of the holes. This leakage power at both the holes are in phase at hole 2, adding up the power causal to the forward power Pf. Though, it is out of phase at hole 1, stopping each other and stopping the back power to occur. Therefore, the directivity of a directional coupler improves. The general S matrix of a directional coupler is,

$$S = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{21} & S_{22} & S_{23} & S_{24} \\ S_{31} & S_{32} & S_{33} & S_{34} \\ S_{41} & S_{42} & S_{43} & S_{44} \end{bmatrix} ------(1)$$

1. Since all ports in a directional coupler are matched.

$S_{11} = S_{22} = S_{33} = S_{44} = 0$------------------ (2)

2. Since there is no coupling between ports 1 & 3 and ports

2 & 4 $S_{13} = S_{31} = S_{24} = S_{42} = 0$ ----- (3)

Apply equation (2) & (3) in (1)

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

3. By unitary property, [S][S]* = I

$$\begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{23} & 0 \\ 0 & S_{23} & 0 & S_{34} \\ S_{14} & 0 & S_{34} & 0 \end{bmatrix} \begin{bmatrix} 0 & S_{12}^* & 0 & S_{14}^* \\ S_{12}^* & 0 & S_{23}^* & 0 \\ 0 & S_{23}^* & 0 & S_{34}^* \\ S_{14}^* & 0 & S_{34}^* & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 \Rightarrow |S_{12}|^2 + |S_{14}|^2 = 1$------------- (4)
$R_2C_2 \Rightarrow |S_{12}|^2 + |S_{23}|^2 = 1$------------- (5)
$R_3C_3 \Rightarrow |S_{23}|^2 + |S_{34}|^2 = 1$------------- (6)
$R_1C_3 \Rightarrow S_{12} S_{23}^* + S_{14} S_{34}^* = 0$------------ (7)

Comparing equations (4) and (5)

$|S_{12}|^2 + |S_{14}|^2 =$
$|S_{12}|^2 + |S_{23}|^2$ S_{14}
$= S_{23}$ ------------------------------------(8)

Comparing equations (5) and (6)

$|S_{12}|^2 + |S_{23}|^2 =$
$|S_{34}|^2 + |S_{23}|^2$ S_{12}
$= S_{34}$ ------------------------------------(9)

Let, S_{12} be real and positive,
i.e, $S_{12} = S_{34} = p$---------------- (10)

applying equation (10) in (7)

Therefore, $p\ S_{23}^*$
$+ S_{14}\ p = 0$ $p\ [S_{23}^*$
$+ S_{14}] = 0$
$p\ [S_{23}^* +$
$S_{23}] = 0$
$S_{23}^* + S_{23}$
$= 0$

To satisfy the above condition, S_{23} should be a

complex value. Let $S_{23} = jq$

Therefore, the S matrix of directional coupler is,

$$S = \begin{bmatrix} 0 & p & 0 & jq \\ p & 0 & jq & 0 \\ 0 & jq & 0 & p \\ jq & 0 & p & 0 \end{bmatrix}$$

Ferrite components:

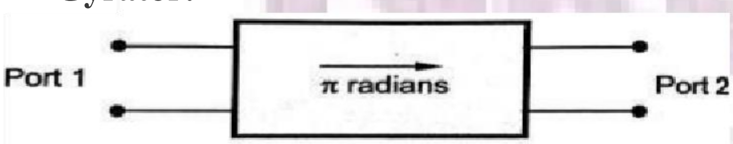
Introduction to ferrites:

A ferrite is a nonmetallic material (though often an iron oxide compound) which is an insulator, but with magnetic properties similar to those of ferrous metals. Among the more common ferrites are manganese ferrite ($MnFe_2O_3$), zinc ferrite ($ZnFe_2O_3$) and associated ferromagnetic oxides such as yttrium-iron- garnet [$Y_3Fe_2(FeO_4)_3$], or YIG for short. (Gamets are vitreous mineral substances of various colors and composition, several of them being quite valuable as gems.) Since all these materials are insulators, electromagnetic waves can propagate in them. Because the ferrites have strong magnetic

properties, external magnetic fields can be applied to them with several interesting results, including the Faraday rotation mentioned in connection with wave propagation.

When electromagnetic waves travel through a ferrite, they produce an RF magnetic field in the material, at right angles to the direction of propagation if the mode of propagation is correctly chosen. If an axial magnetic field from a permanent magnet is applied as well, a complex interaction takes place in the ferrite. The situation may be somewhat simplified if weak and strong interactions are considered separately.

Gyrator:



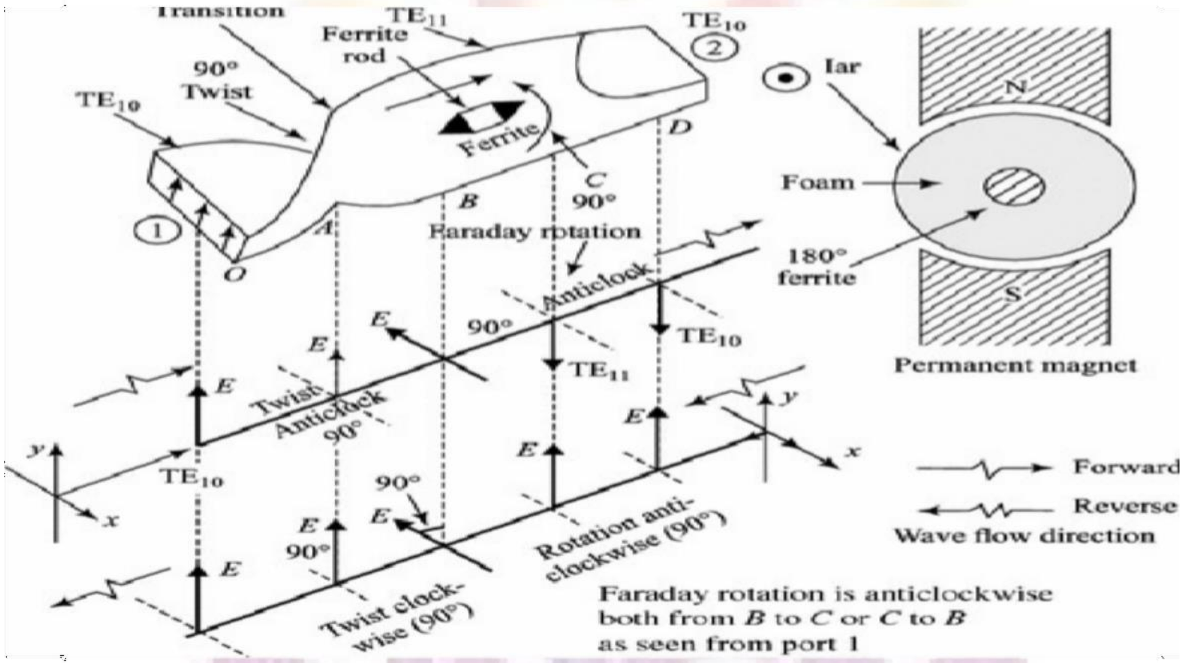
- Gyrator is two port device that has the relative phase difference of 180° for transmission from port 1 to port 2 and "no phase shift" for transmission from port 2 to port 1.

Construction:

- It consists of a piece of circular waveguide carrying the dominant TE_{11} mode with transitions to a standard rectangular waveguide with dominant mode TE_{10} at both ends.
- A thin circular ferrite rod tapered at both ends is located inside the circular waveguide supported by a polyfoam.
- The waveguide is surrounded by a permanent magnet which generates dc magnetic field for proper operation of ferrite.
- To the input end a 90° twisted rectangular waveguide is connected.
- The ferrite rod is tapered at both ends to reduce the attenuation and also for smooth rotation of polarized wave.

Operation

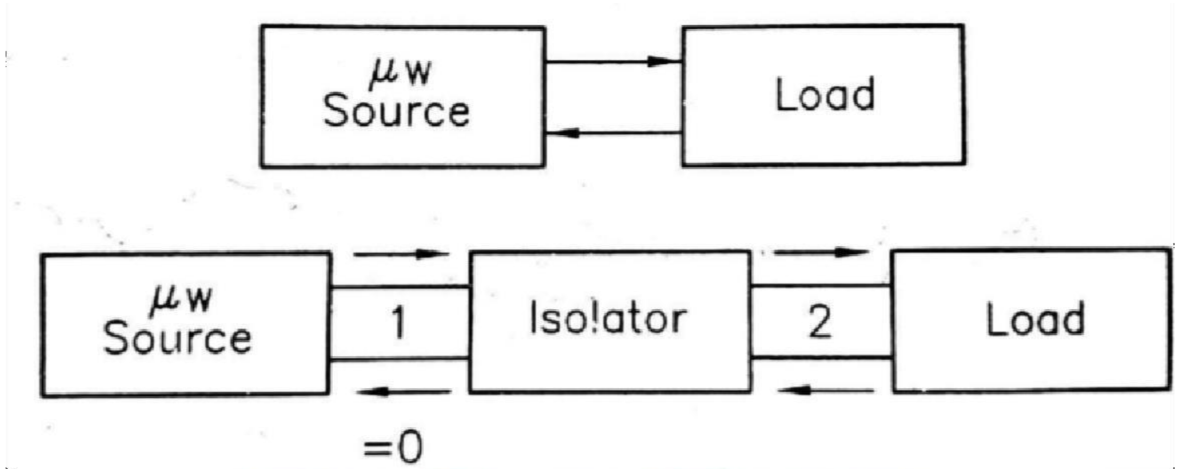
- When a wave enters port 1 its plane of polarization rotates by 90º because of the twist in the waveguide.
- It again undergoes faraday rotation through 90º because of the ferrite rod and the wave which comes out of port 2 will have a phase shift of 180º compared to the wave entering at port 1.
- When the same wave enters at port 2, it undergoes faraday rotation through 90º in the same direction.
- Because of the twist this wave gets rotated back by 90º comes out of port 1 with 0º phase shift.



Isolators:

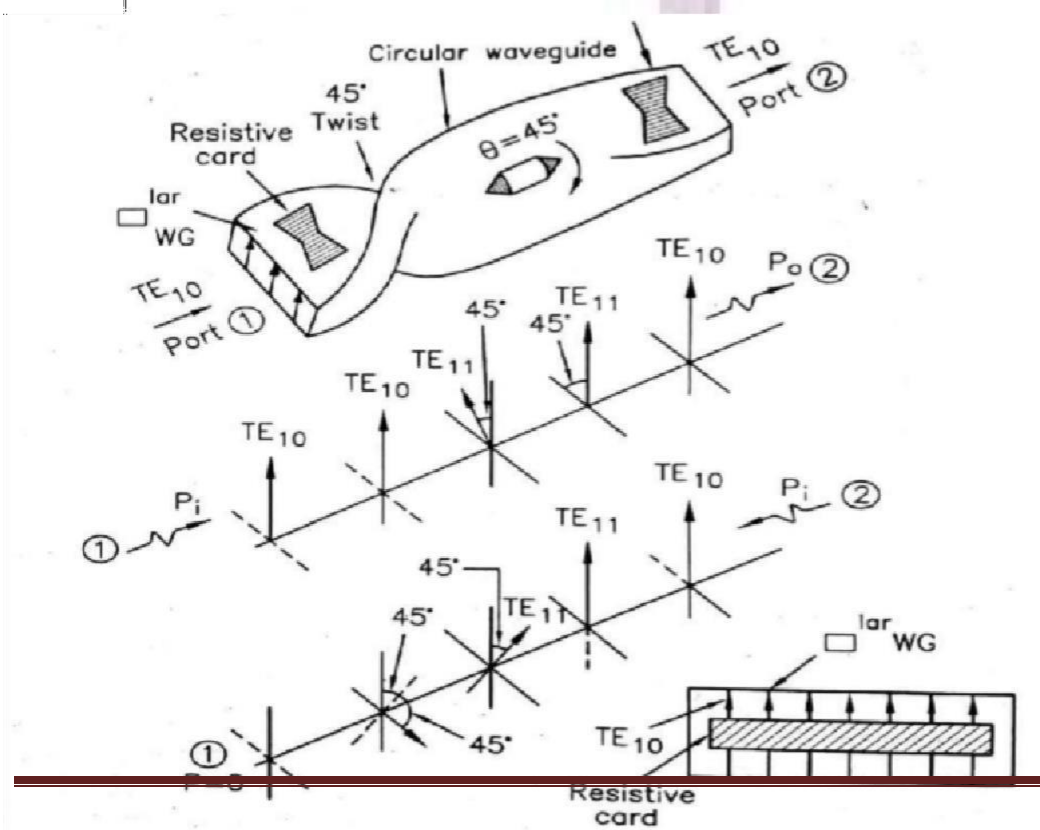
- An isolator is a 2-port device which provides a very small amount of attenuation for transmission from port 1 to port 2 but provides maximum attenuation for transmission from port 2 to port 1.
- This requirement is very much desirable when we want to match a source with a variable load.
- In most microwave generators, the output amplitude and frequency tend to fluctuate very significantly with changes in load impedance.
- Due to mismatch of generator output to the load resulting in reflected wave from load.
- These reflection will cause amplitude and frequency instabilities of the microwave generator.
- When the isolator is inserted between generator and load, the generator is coupled to the load with zero attenuation and if any reflection from the load is completely absorbed by

the isolator without affecting the generator output.



Construction

- Isolator makes use of 45º twisted rectangular waveguide and 45º faraday rotation ferrite rod.
- A resistive card is placed along the larger dimension of the rectangular waveguide, so as to absorb any wave whose plane of polarization is parallel to the plane of resistive card.
- The resistive card does not absorb any wave whose plane of polarization is perpendicular to the plane of its own.



- Then the wave gets rotated by 45º in clockwise direction due to ferrite rod and rotated by another 45º due to the twist in the waveguide.
- Now the plane of polarization of the wave is parallel with the plane of resistive card and hence the wave will be completely absorbed by the resistive card and the output at port 1 will be zero.
- This power is dissipated in the card as a heat.
- In practice 20 to 30 dB isolation is obtained for transmission from port 2 to port 1.

- A circulator is a four port microwave device which has a peculiar property that each terminal is connected only to the next clockwise terminal i.e., port 1 is connected to port 2 only and not to port 3 and port 4.
- Although there is no restriction on the number of ports, four ports are most commonly used.

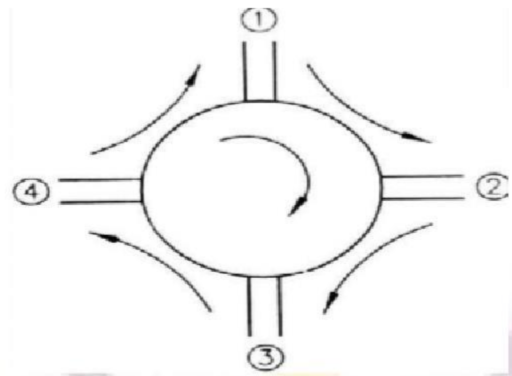
Operation

- The power entering port 1 is TE_{10} mode and is converted to TE_{11} mode because of gradual rectangular to circular transition.
- This power passes port 3 unaffected since the electric filed is not significantly cut and is rotated through 45°due to the ferrite, passes port 4 unaffected for the same reason and finally emerges out of port 2.
- Power from port 2 will have plane of polarization already titled by 45° with respect to port 1.

Circulator:

Operation

- A TE_{10} wave passing from port 1 through the resistive card and is not attenuated.
- After coming out of the card, the wave gets shifted by 45° because of the twist in anticlockwise direction and then by another 45° in clockwise direction because of the ferrite rod and hence coming out of port 2 with the same polarization as at port 1 without any attenuation.
- But a TE_{10} wave fed from port 2 gets a pass from the resistive card placed near at port 2 because plane of polarization of the wave is perpendicular to the plane of the resistive card.



- **This power passes port 4 unaffected and gets rotated by 45° due to ferrite rod in the clockwise direction. And now totally plane of polarization is tilted through 90° finds port 3 suitably aligned and emerges out of it.**
- **Similarly port 3 in coupled only to port 4 and port 4 to port 1.**