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UNIT-III

① Waveguide components AND Applications - I

3

Coupling Mechanisms :-

A resonant cavity favours a particular frequency that de on the dimensions of the cavity. Now there should be some opening through which the desired signal can be introduced. Now longer the o or the tigher the coupling, the greater will be the offset on the res frequency of the cavity.

There are 3 methods of coupling, those are

1) probe coupling
2) loop coupling
3) Aperture coupling

The first two are provide to couple coaxial lines to the difl types of cavities and the third is specially used to couple a waveg to a cavity.

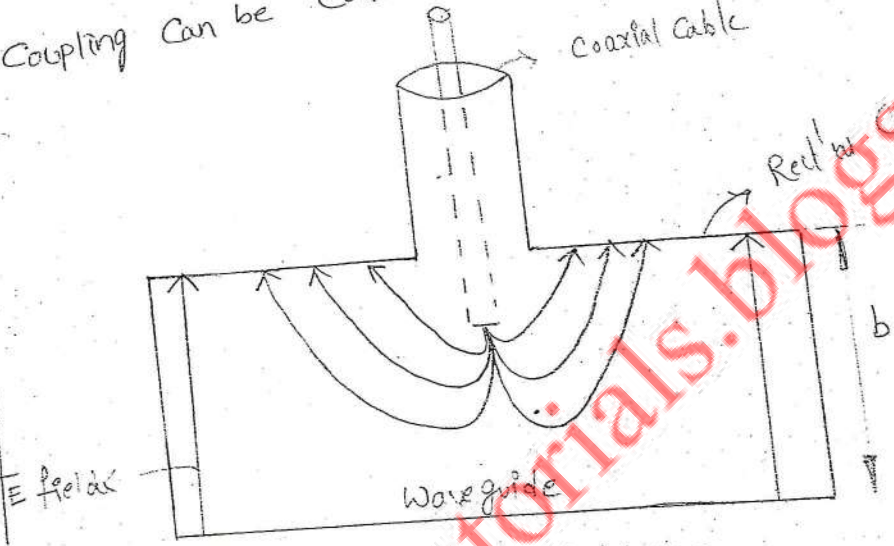
probe coupling :-

A coupling probe consists of an extended inner conductor of coaxial cable at the mid point of the wide walls. Here the higher order modes are also excited, because the E field in the vicinity the probe has components normal to the axis of the probe. This h order mode can be supressed by proper choice of waveguide

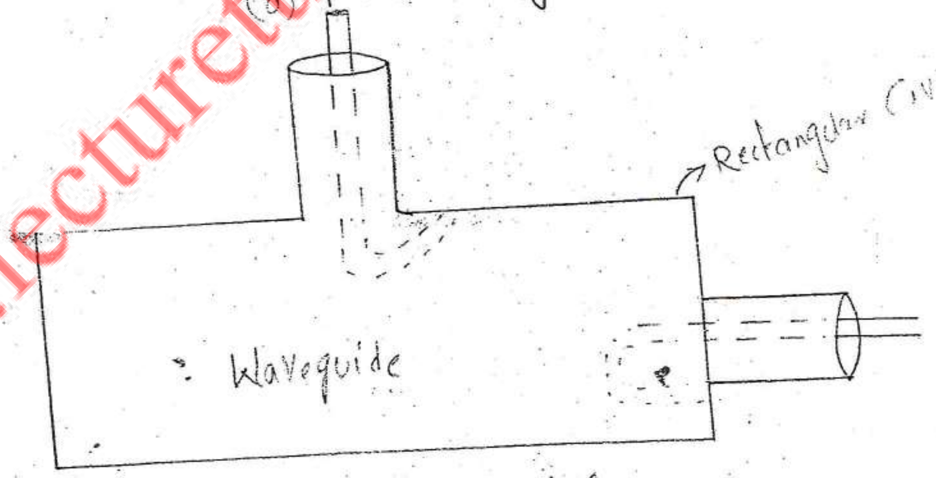
vicinity = S

Now to transfer maximum power ... the guide. This matching can be done by adjusting the length, position of probe. To match both magnitude, and phase two adjustments can be done one by using movable short in place of fixed one and by using stubs.

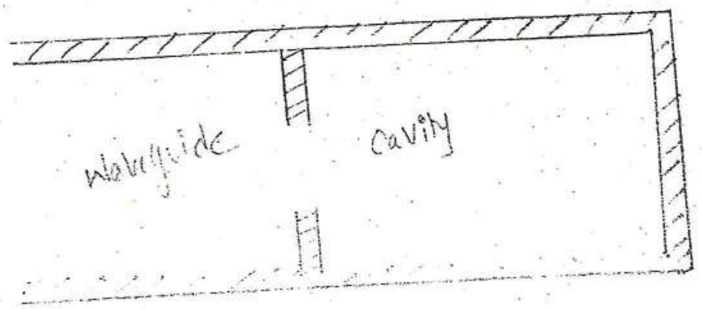
Coupling can be controlled by varying the amount of insertion.



(a) probe Coupling



(b) loop coupling



(c) aperture Coupling

(2) When loop is used to excite a cavity, it must be introduce away that lines of magnetic force of the desired cavity mode thread through it. Instead of one loop, two loops can be use excite the mode in more than one location. when the loop is par to magnetic lines of force it will not couple. the coaxial line of cavity i.e loop should be ⊥lar to the H field. Here coupling excitation can be controlled by rotating a loop.

Aperture Coupling :- Aperture which interrupt the flow of curr both in the waveguide and in the excited mode in the cavity. Mo than one set of iris can be used.

Re-entrant Cavity :-

In order to maintain resonance at operating frequency a for efficient energy transfer into the cavity resonator, the inductance and capacitance must be reduced. The reentrant cavity are specially designed to meet this requirments.

Reentrant cavity is one in which metalic boundar enter into the interior of cavity. one of the commonly us reentrant cavity is coaxial cavity. In this not only inductance and shel reduced but also resistance losses are reduced shielding enclosure prevents radiation loss.

Fig. Rectangular Cavity in Klystron and other Microwave Tubes.

(3) **Waveguide Irises :-** ← Waveguide Discontinuties (making & to provi(

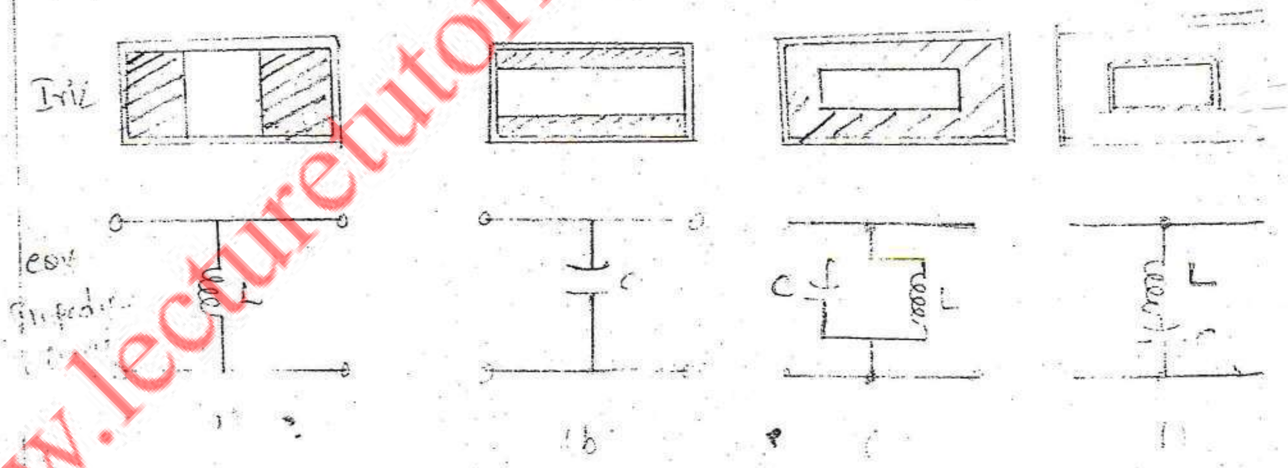
In any waveguide system, when there is a mismatch there will be reflections. In Tx'ion lines, in order to overcome this mismatch lumped impedances or stubs of required value are placed at pre-calculated points.

$\therefore Y = G + jB$, Y = admittance, G = conductance, B = susceptance

In waveguides also, some discontinuties (making or providing) are made use of for matching purposes.

Any susceptance appearing across the guide, causing mismatch (and production of standing waves) needs to be cancelled by introducing another susceptance of the same magnitude but of opsite nature.

Iris also called as windows, or apertures or diaphragms or obstacles).



Inductive Window :-

It allows a current to flow where none flowed before. The iris is placed in a position where the magnetic field is strong (or where electric field is relatively week). since the plane of polarisation of

E field is parallel to the plane of Iris, The current flow due to iris causes a magnetic field to be set up. Energy storage of magnetic field takes place and there is an increase in inductance at that point of waveguide.

Capacitive Iris :- In this, The potential which existed b/w the top and bottom walls of the waveguide now exists b/w surfaces which are closer and therefore the capacitance has increased at that point. the capacitive Iris is placed in a position where the E field is strong.

The inductive and capacitive irises if combined suitably the inductive and capacitive reactances introduced will be equal and the iris becomes a parallel resonant circuit. It acts like a Band pass filter, completely attenuated other modes. (only dominant mode passes).

The series resonant iris which is supported by a nonmetalic material and is Transparent to the flow of microwave energy.

(impedance $= \frac{1}{\text{admittance}}$

=

→ Susceptance is an expression of the ease with which Alternating current (AC) passes through a capacitance or inductance

$X_C \mid X_L$ =

$Y =$ $R \pm jX$

④ Posts and Tuning Screws :-

When a metalic cylindrical post is introduced into the broader side of waveguide, it produces the same effect as an iris in providing lumped reactance at that point. If the post extends only a short distance ($< \lambda g/4$) into the waveguide, it behaves capacitively, and this capacitive suscept increases with depth of penetration. When the depth is equal to $\lambda g/4$, the post behaves inductively and this inductance susceptance decreases when the post is moved further away from the centre of the waveguide. When the post is extended completely across the waveguide, the post becomes inductive.

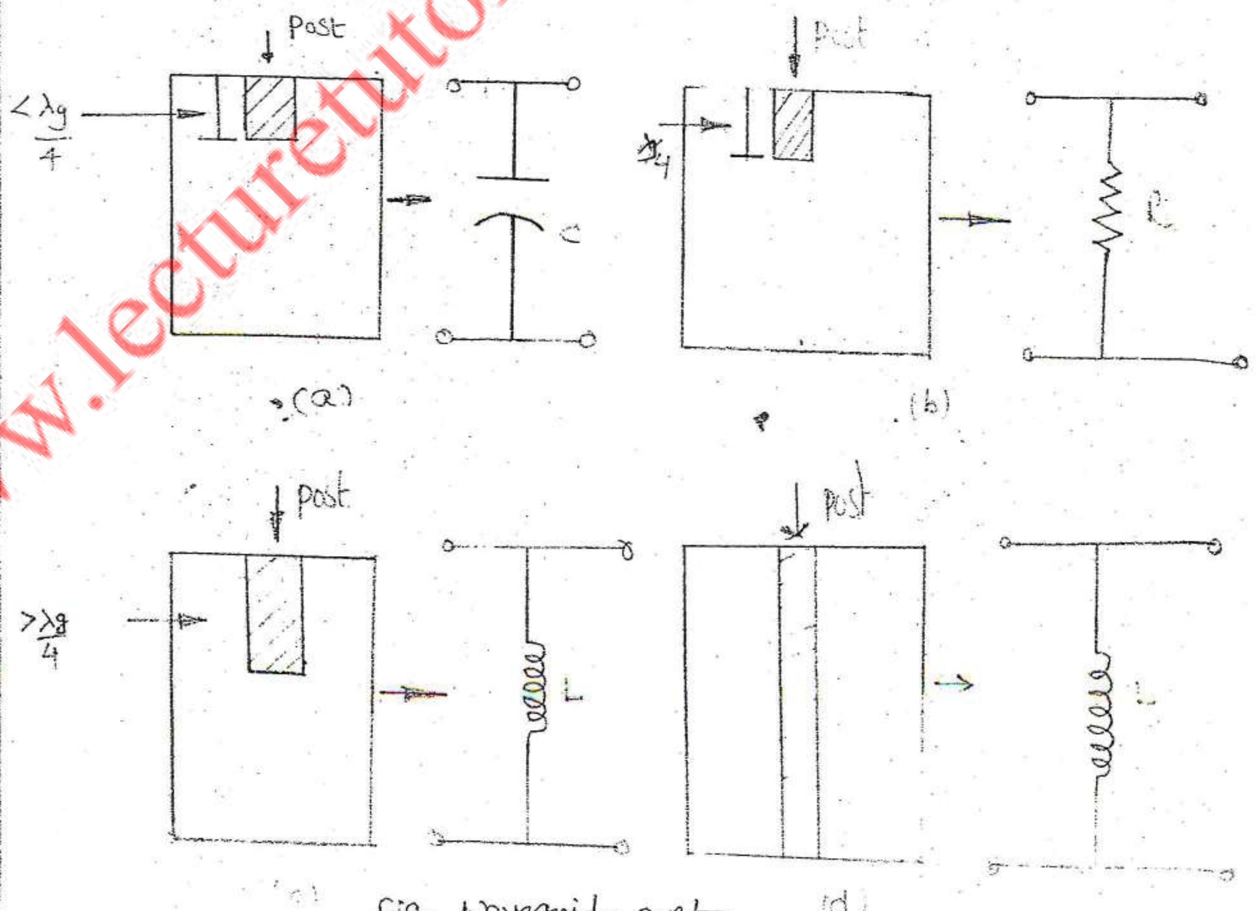
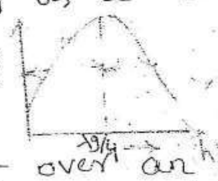
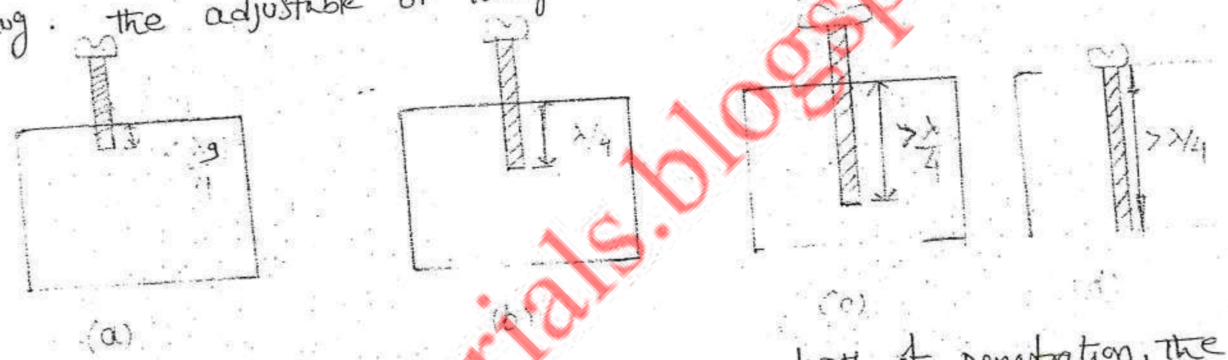


fig. waveguide posts

The amount of susceptance decreases as the diameter of the post is reduced. If the post is made is thicker, effective Q will be lowered and can acts as a band pass filter similar to an iris.

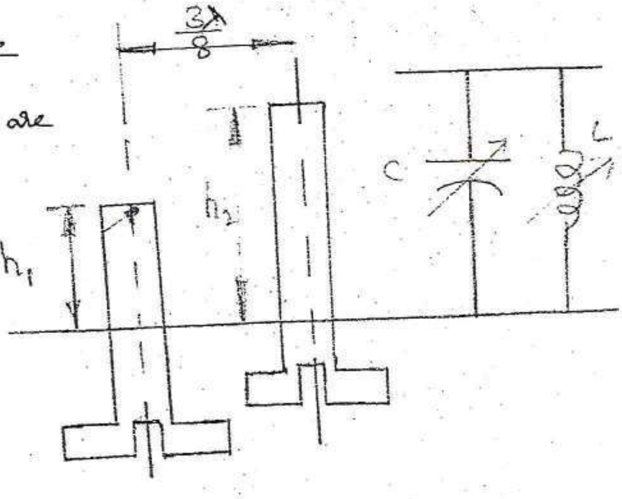


The Advantage of the post over an iris is that it is readily adjustable. An adjustable post is known as a screw or slug. the adjustable or tuning screws are shown below.



As in case of posts depending upon the depth of penetration, the tuning screw may introduce inductive or capacitance susceptance.

A combination of two screws $\frac{\lambda g}{4}$ apart can be used to match a waveguide to its load similar to use of two fixed stubs in a Tx'ion line. A very effective waveguide matcher can be realised when two tuning screws are placed in close proximity seperated by $3\lambda g/8$ as shown in fig. This is almost similar to the double stub matching in Transmission lines.



Waveguide Attenuators :-

* A device used to control the amount of microwave power transfe from one point to another on a microwave Transmission System is Called Microwave Attenuator.
* Microwave attenuator control the flow of microwave power either by reflecting it or absorbing it.

Attenuators are Commonly used for measuring power gain or loss in dBs, Attenuators Cabe classified as fixed or variable type.

1) **Fixed Attenuator :-** Fixed attenuator consist of a dissipative element called pad which is placed in a waveguide. The pad is placed in such a way that its plane is parallel to the E field, for This two thin metal rods are placed. The pad is Tapered for providing a gradual Transition from The waveguide medium to the absorbing medium of pad. This also reduces The reflections.

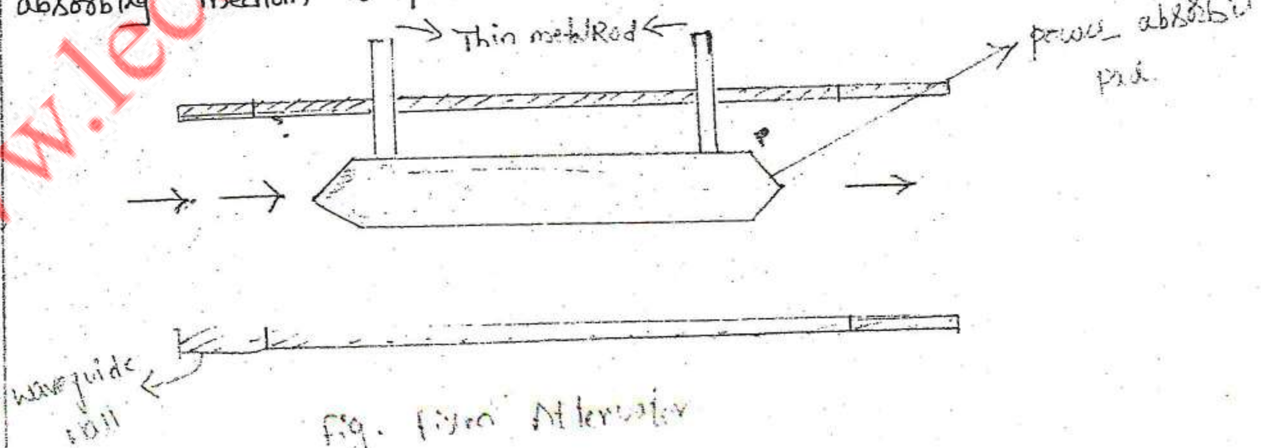


Fig. Fixed Attenuator

Fixed attenuators are used where fixed amount of attenuation is required.

The amount of power that a fixed attenuator can absorb depends on -

1) strength of dielectric field
2) Location of pad in waveguide
3) Area of pad
4) freqency of operation
5) pad material used for power absorption.

Attenuators
- fixed
- variable
  - flap, vane (Rect. wave guide)
  - rotary (Circular wave guide)

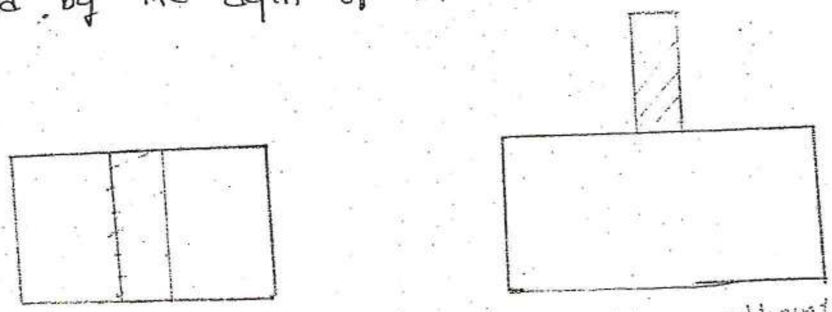
→ <u>Variable Attenuator</u> :- It provides continuous or step wise variable attenuation.

✓ For rectangular waveguide, these attenuators can be flap type or vane type.

✓ For circular waveguide, rotary type is used.

<u>Flap attenuator</u> :-

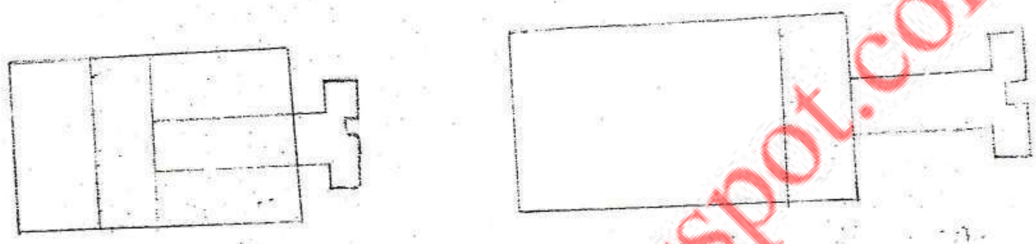
It consists of a resistive element inserted into a logitudinal slot cut along the centre of the wider dimension of the guide. The flap is mounted on the hinged arm allowing it to descend into the centre of the waveguide. (The degree of attenuation is determined by the depth of insertion of the flap).



(a) Maximum Attenuation   Minimum Attenuation

⑥ Vane type attenuator :-

It basically consists of a glass vane with a coating of aquadag or carbon similar to a fixed vane attenuator. If this vane used at the centre is made movable, it can be used as a variable attenuator.



(a) Maximum attenuator.

If this vane used at the centre is made movable, it can be used as a variable attenuator. ($\bar{E}$ lines are always concentrated at the centre of wave) the vane is tapered at both ends for matching the attenuator to the waveguide. An adequate match is obtained if the taper length is made equal to $\lambda g/2$.

Rotary vane attenuator :- It provides attenuation with an accuracy of $\pm 2.1\%$ of the indicated attenuation over the operating frequency ranges.

It consists of 3 vanes.

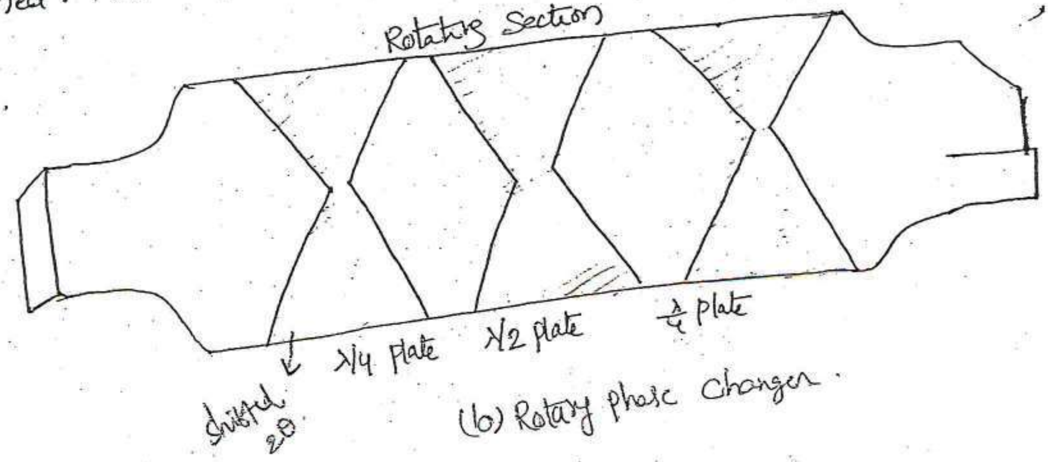
The central vane rotating type placed in the central section of a circular waveguide arrangement tapered at both ends. the other two vanes are in the rectangular sections.

For obtaining minimum reflections, The spacing b/w supporting rods and the taper of the slab must be properly choosen. When The slab is at The centre of the waveguide i.e where the $\bar{E}$ field is strong, its maximum effect is experienced. The electrical length of the section appears to increase as the slab is move towards The Centre of the guide since, The phase velocity in the Section of the guide is reduced by the dielectric, which is placed in the waveguide. $\boxed{v_p = \frac{\omega}{\beta}}$

Rotary phase changer :-

Its Construction is similar to that of rotary attenuator. Only difference is that the central resistive card is replaced by a half wave plate of dielectric material and two outer resistive cards are replaced by two quarter wave plate made of dielectric material.

Quarter wave plate Converts a linearly polarized TE_{11} mode into a circularly polarized mode which is shifted by an angle of 2θ. The second quarter wave plate converts the latter wave back to linear polarization. Rotating the half wave plate a maximum phase change of $180°$ can be obtained. The tapered end of the dielectric slab reduces reflection.



(b) Rotary phase changer.

Linear phase Changer :-

It is a rectangular waveguide consisting of three dielectric slabs in which the central slab is free to move longitudinally. Its movement is controlled by suitable drive mechanism. Each end of the dielectric slab is cut in a stepwise fashion as show below. To provide a broadband multisection quarter wave transformer to match the partially filled guide to the empty and completely filled guide.

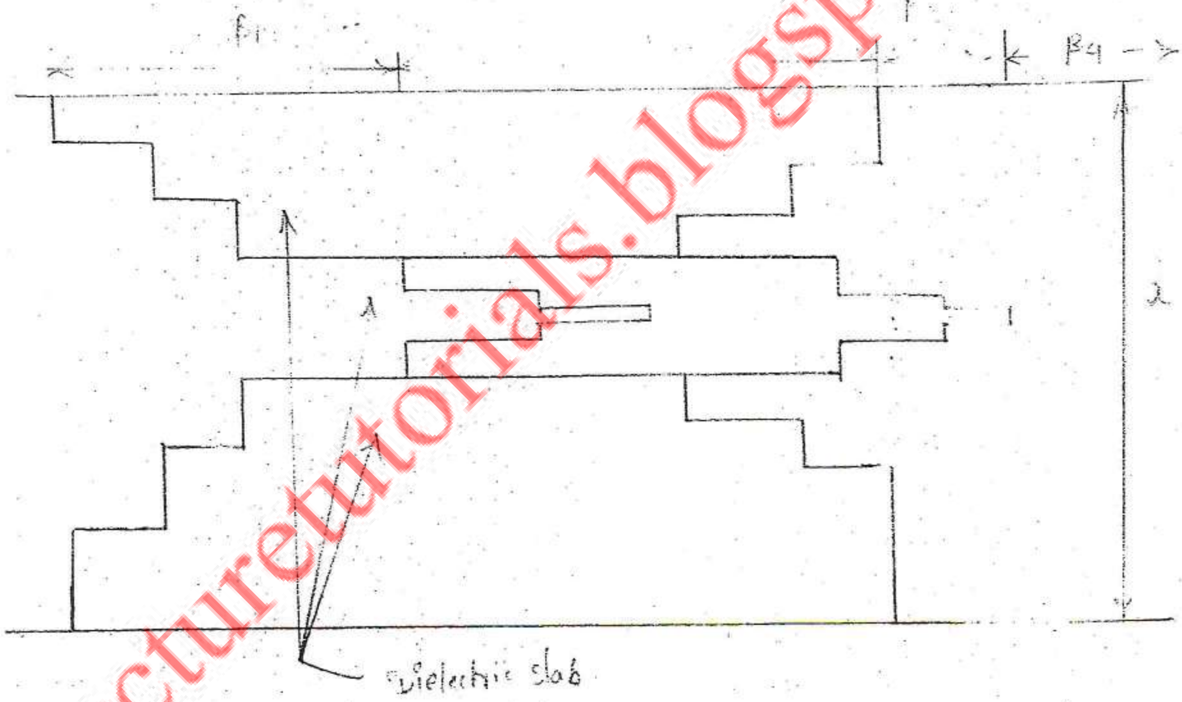


Fig: Linear phase changer (top view)

Here the relation b/w the propagation functions $\beta_1, \beta_2, \beta_3$ and β_4

$$\beta_1 + \beta_3 > \beta_2 + \beta_4$$

and overall phase change introduced.

$$\Delta\phi = \left[(\beta_1 + \beta_2) - (\beta_2 + \beta_4)\right] x$$

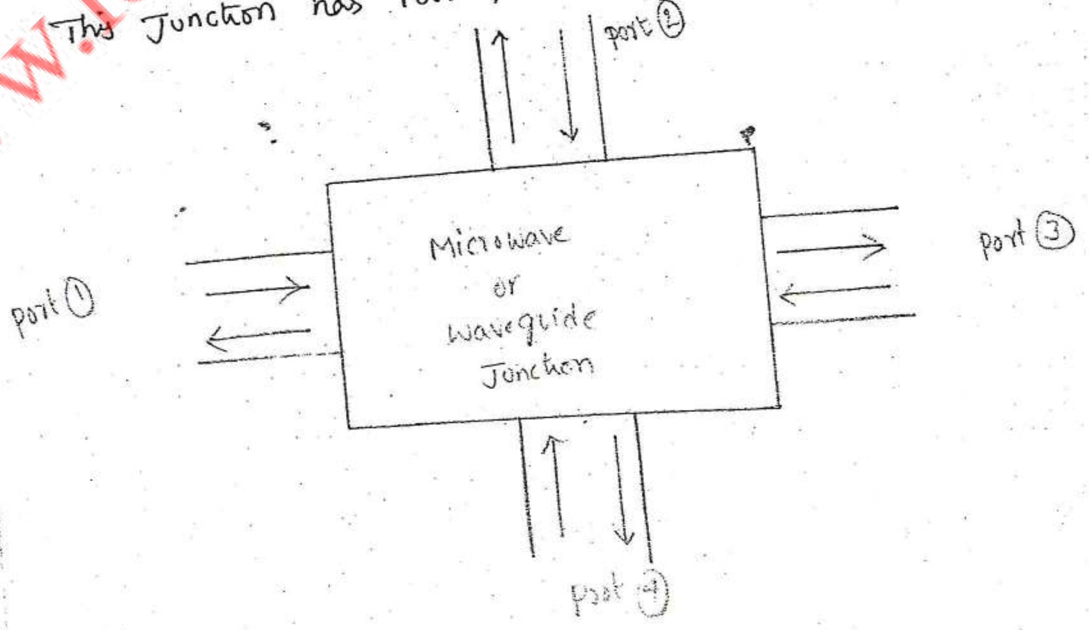
where x is displacement

Waveguide Multiport Junctions :-

Microwave systems normally consist of several microwave components including source and the load being connected to each other by waveguide or coaxial - cable or transmission line system. All these components must be built with low standing wave ratios, lower attenuation, lower insertion losses and other desirable characteristics to achieve the desired transmission of microwave signal.

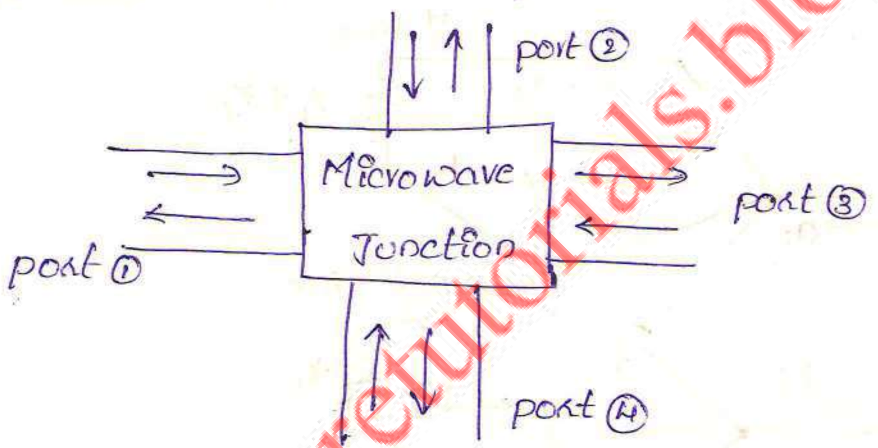
At a certain position in a waveguide system, many a times it becomes necessary to split all or part of the microwave energy into particular directions. This is achieved by waveguides or in general by coupler units that are combined to form microwave junctions. These same junction may be used to direct the energy as required. Alternatively, the same junction may be used to combine two or more signals. In general, a microwave junction is an interconnection of two or more microwave components.

This junction has four ports similar to low frequency two port N/w

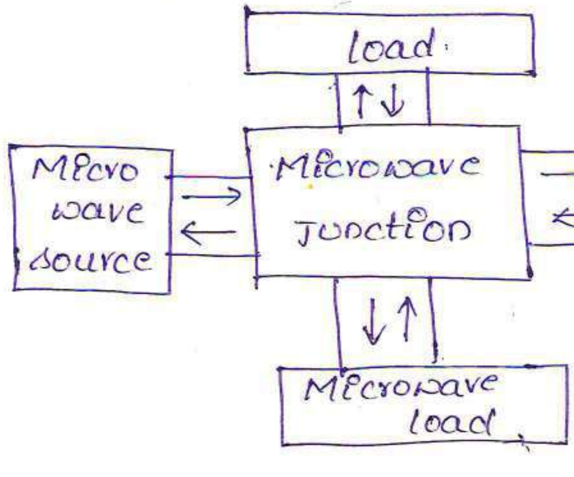


Microwave system consists of several microwave components including the source and the load being connected to each other by wave guide or coaxial transmission lines. All these components must be built with those standing wave ratios, lower attenuation and low instructions to achieve the desired transmission of micro wave. The components like rectangular wave guide and CWG, cavity resonators, wave guide, junctions, joints, corners, direction coupler, fertile devices, phase shifters and etc.

Microwave junction :- Microwave junction is an interconnection of two or more microwave components.



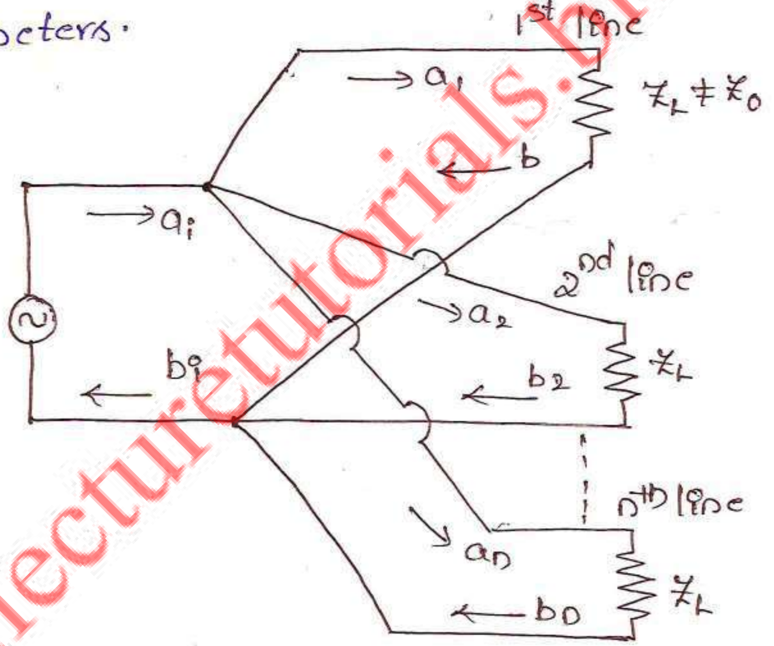
The junction has 4 ports, a microwave source at port 1 and microwave loads at ports 2, 3, 4. When i/p from microwave source is applied at port 1, a part of it comes out of port 2 another part out of port 3, some part out of port 4 and the remaining par may come out of port 1 itself due to mismatch between ports ① &



'S' parameters :- Generally two port networks described by their parameters such as Z, Y, h, ABCD. Here network parameters relate the total voltage and total current. In similar way, micro waves are associated with power instead of voltages and currents. Microwave junction can be defined by the parameters are called as S-parameters or scattering parameters which are represented in the form of a matrix. That matrix is called scattering matrix.

→ It is a square matrix which gives all the combinations of power relationships between various i/p and o/p ports of the microwave junctions.

→ The elements of this matrix is called as standing coefficients or S-parameters.



To obtain the relation between this scattering matrix and the input, output powers at different ports consider the junction of 'n' number of transmission lines.

<u>Case i)</u> :- Let the 1st line be terminated in an impedance other than the characteristic impedance ($Z_L \neq Z_0$) and all the remaining lines in an impedance = Z_0 i.e. $Z_L = Z_0$.

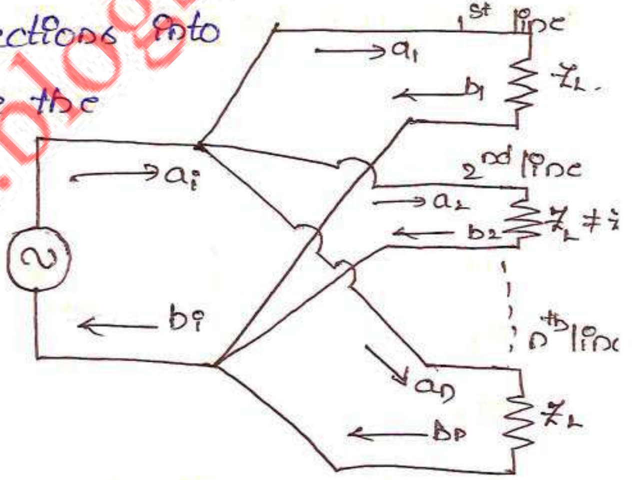
If a_i be the incident wave at the junction due to a source at the i^{th} line then it divides itself among $(n-1)$ no. of lines as $a_1, a_2 \ldots \ldots a_n$. There will be no reflection from 2^{nd} to n^{th} line and the incident waves are absorbed since their impedances are equal to characteristic impedance but there is no mismatch at the first line and hence there will be reflected wave b_1 going back into the junction

$$b_1 = (\text{reflection coefficient})\, a_1$$
$$= S_{i_1} a_1$$

where S_{i_1} – reflection coefficient of 1^{st} line.

i – Source connected to i^{th} line.

<u>Case (2)</u> :- Let all the $(n-1)$ lines be terminated in an impedance other than Z_0, then there will be reflections into the junction from every line and hence the total contribution to the outward travelling wave in the i^{th} line is given by



$$b_i = a_1 S_{i1} + a_2 S_{i2} + \ldots\ldots + S_{in} a_n$$

where $i = 1, 2, 3 \ldots\ldots n$

$$b_1 = S_{11} a_1 + S_{12} a_2 + S_{13} a_3 + \ldots\ldots + S_{1n} a_n$$
$$b_2 = S_{21} a_1 + S_{22} a_2 + S_{23} a_3 + \ldots\ldots + S_{2n} a_n$$
$$\vdots$$
$$b_n = S_{n1} a_1 + S_{n2} a_2 + S_{n3} a_3 + \ldots\ldots + S_{nn} a_n.$$

In matrix form,

$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} & \ldots & S_{1n} \\ S_{21} & S_{22} & S_{23} & \ldots & S_{2n} \\ \vdots & \vdots & \vdots & & \vdots \\ S_{n1} & S_{n2} & S_{n3} & & S_{nn} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix}$$

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

* Properties of S matrix:-

1. [S] is always a square matrix of order $n \times n$.

2. [S] is a unitary matrix $[S][S]^* = [I]$.

3. [S] is a symmetric matrix.

4. The sum of the products of each term of any row or column multiplied by the complex conjugate of the corresponding matrix of any other row or column is zero.

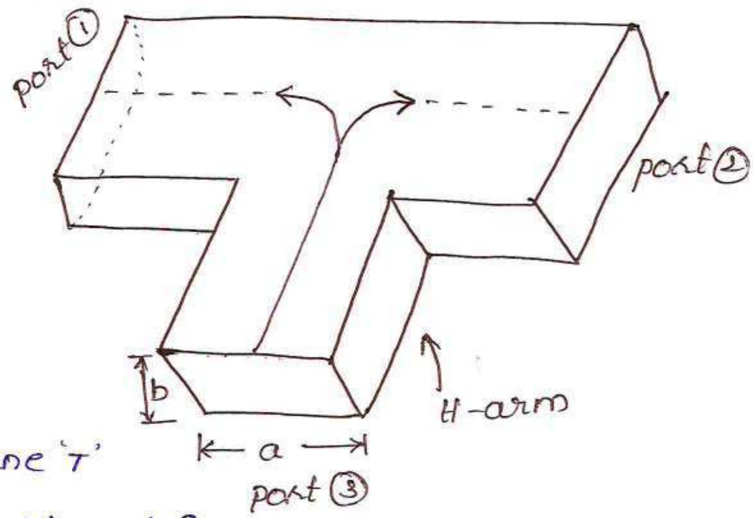
$$\sum_{i=1}^{n} S_{ik} \quad S_{ij}^* = 0$$

But k, J are not equal.

* Microwave Tee junction:- The Tee junction is an intersection of 3 waveguides in the form of english alphabet 'T'. There are several types of Tee junction.

i) H-plane Tee junction
ii) E-plane Tee junction
iii) E-H plane Tee junction
iv) Ratrace junction

i) H-plane Tee junction:- A H-plane Tee junction is formed by cutting a rectangular slot along the width of a main wave guide and attaching another wave guide. The side arm is called as H-arm.



The properties of a H-plane 'T' can be completely defined by its 'S' matrix. The order of scattering matrix is 3x3 since there are '3' possible inputs and '3' possible outputs.

i) Because of planed symmetry of the junction scattering coefficients S_{13} and S_{23} must be equal i.e. $S_{13} = S_{23}$

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

ii) From the symmetric property of 's' matrix,

$$S_{ij} = S_{ji} \Rightarrow S_{12} = S_{21},\ S_{13} = S_{31},\ S_{23} = S_{32}$$

iii) Since port ③ is perfectly matched in the junction whith this properties, 's' matrix becomes

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

iv) From the unitary matrix property

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

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

Multiply R_1 & $C_1 \Rightarrow |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1 \longrightarrow ①$

R_2 & $C_2 \Rightarrow |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \longrightarrow ②$

R_3 & $C_3 \Rightarrow |S_{13}|^2 + |S_{13}|^2 = 1 \longrightarrow ③$

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

R_3 & $C_1 \Rightarrow |S_{13}||S_{11}^*| + |S_{13}||S_{12}^*| = 0$

from Eq ① and ②

$$S_{11} = S_{22}$$

Eq ③ $R_3 C_1 \Rightarrow S_{13}(S_{11}^* + S_{12}^*) = 0$

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

$$S_{11}^* = -S_{12}^* \ \text{(or)}\ S_{11} = -S_{12}$$

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

$$2|S_{11}|^2 = 1/2$$

$$|S_{11}|^2 = 1/4 \Rightarrow |S_{11}| = 1/2$$

$$|S_{22}| = 1/2$$

$$S_{12} = -1/2$$

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

we know that $[b] = [S][a]$

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

$$b_1 = 1/2\, a_1 + -1/2\, a_2 + 1/\sqrt{2}\, a_3$$

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

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

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

<u>case (i)</u> :- Input is given at port ③ and no inputs at ports ① & ②

i.e. $a_3 \neq 0$, a_1 and a_2 are zero

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

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

$$b_3 = 0$$

Let P_3 be the power input at port ③ then this power divides equally b/w port ① and port ②. The amount of power coming out of port ① and port ② due to input at port ③ will be equal to, $10 \log P_1/P_3 = 10 \log P_1/2P_1 = -3\,dB$

Hence, the H-plane Tee is called 3dB splitter.

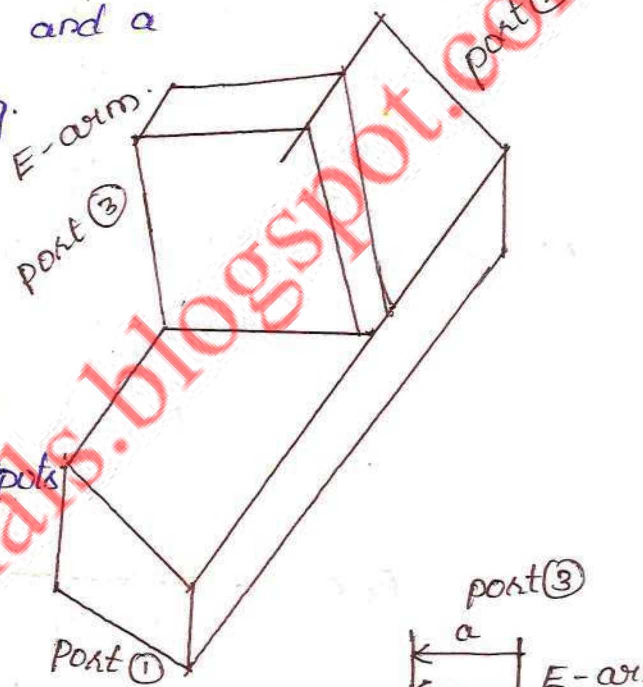
Case (2) :- let $a_1 = a_2 = a$, $a_3 = 0$

$$\Rightarrow b_1 = a/2 - a/2 = 0$$

$$b_2 = -a/2 + a/2 = 0$$

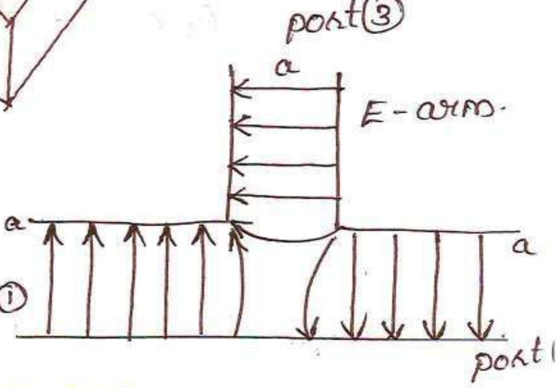
$$b_3 = a\left(1/\sqrt{2} + 1/\sqrt{2}\right) = \sqrt{2}a.$$

* E-plane Tee junction :- A Rectangular slot is cut along border dimension of a long wave guide and a side arm is attached as in fig.



Port ① and port ② are collinear arms and port ③ is E-arm.

When TE_{10} mode is made to propagate into port ③. The two outputs at port ① and port ② will have a phase shift of 180°.



The Scattering matrix of E-plane Tee described its properties and derived as follows.

(i) where [S] is a square matrix of order 3x3

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

(ii) Since outputs at port ① and port ② are out of phase by 180° with an input at port ③

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

(iii) If port ③ is perfectly matched then $S_{33} = 0$

(iv) From the symmetric matrix of [S] matrix, i.e. $S_{ij} = S_{ji}$.

i.e. $S_{13} = S_{31}$, $S_{23} = S_{32} = -S_{13}$ and $S_{12} = S_{21}$.

v) Hence the [S] matrix is

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

vi) From the unitary property $[S][S]^* = [I]$

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

Multiply $R_1C_1 \Rightarrow |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 = 1 \rightarrow (1)$

$R_2C_2 \Rightarrow |S_{12}|^2 + |S_{22}|^2 + |S_{13}|^2 = 1 \rightarrow (2)$

$R_3C_3 \Rightarrow |S_{13}|^2 + |S_{13}|^2 = 1 \rightarrow (3)$

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

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

$\Rightarrow S_{13}[S_{11}^* - S_{12}^*] = 0$

$S_{11} = S_{12} \rightarrow (4)$

from equation (1) and (2)

$S_{11} = S_{22}$

from eq. (3) $2|S_{13}|^2 = 1$

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

from Eq. (4) $\Rightarrow S_{13}(S_{11}^* - S_{12}^*) = 0$

$S_{11}^* - S_{12}^* = 0$

$S_{11}^* = S_{12}^*$ or $S_{11} = S_{12}$

from Eq. (1) $\Rightarrow |S_{11}|^2 + |S_{11}|^2 + 1/2 = 1$

$S_{11} = 1/2 \Rightarrow S_{22} = 1/2$, $S_{13} = 1/\sqrt{2}$

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

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

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

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

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

$$b_3 = a_1/\sqrt{2} - a_2/\sqrt{2}$$

Case (i) :- a_1 and $a_2 = 0$, $a_3 \neq 0$

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

$$b_2 = -a_3/\sqrt{2}$$

$$b_3 = 0.$$

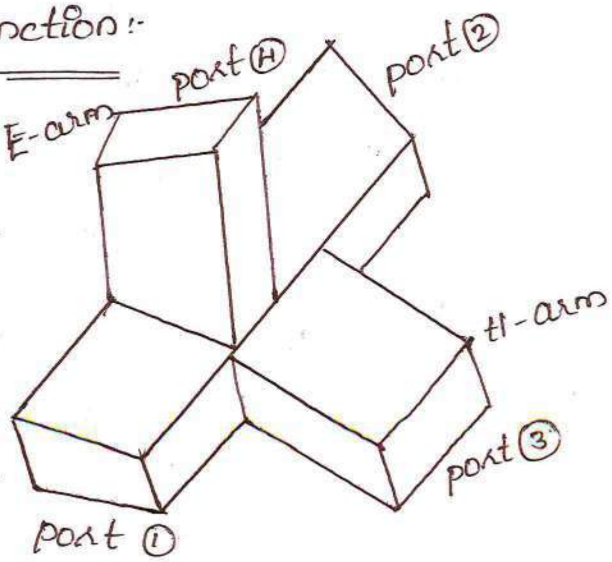
Case (ii) :- $a_1 = a_2 = a$, $a_3 = 0$

$$b_1 = a/2 + a/2 = a.$$

$$b_2 = a/2 + a/2 = a.$$

$$b_3 = a/\sqrt{2} - a/\sqrt{2} = 0.$$

* E-H plane (or) Hybrid (or) Magic Tee junction:-



Here rectangle plane are cut both along the width and breadth of a long wave guide and side arms are attached as shown in fig.

port (1) and port (2) are collinear arms. port (3) is the H-arm and port (H) is the E-arm. This port (H) is hybrid Tee junction combine

'3' power dividing properties of both H-plane Tee and E-plane Tee.

The properties of EH plane T and its scattered matrix can be obtained as follows:

$[S]$ is a square matrix of order 4×4.

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

because of H-plane Tee property, $S_{13} = S_{23}$

because of E-plane Tee property, $S_{14} = -S_{24}$.

by using symmetric property, $S_{ij} = S_{ji}$

$\Rightarrow$ $S_{12} = S_{21}$, $S_{13} = S_{31}$, $S_{41} = S_{14}$, $S_{34} = S_{43}$, $S_{23} = S_{32}$, $S_{24} = S_{42}$.

if port ③ and ④ are perfectly matched, then $S_{33} = S_{44} = 0$

By substituting the above properties in $[S]$ matrix

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

Because of geometry of the junction at port ③ an input is applied, no output at port ④. since they are isolated ports and viceversa $S_{34} = S_{43} = 0$

from $[S][S]^* = [I]$

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

Multiplying. $R_1C_1 \Rightarrow |S_{11}|^2 + |S_{12}|^2 + |S_{13}|^2 + |S_{14}|^2 = 1 \rightarrow ①$

$R_2C_2 \Rightarrow |S_{12}|^2 + |S_{22}|^2 + |S_{23}|^2 + |S_{24}|^2 = 1 \rightarrow (2)$

$R_3C_3 \Rightarrow |S_{13}|^2 + |S_{23}|^2 = 1 \rightarrow (3)$

$R_4C_4 \Rightarrow |S_{14}|^2 + |S_{14}|^2 = 1 \rightarrow (4)$

from Eq. (3), $S_{13} = 1/\sqrt{2} \rightarrow (5)$

from Eq. (4), $S_{14} = 1/\sqrt{2} \rightarrow (6)$

By comparing Eq (1) and (2), $S_{11} = S_{22}$

Substituting the above values in eq. (1)

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

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

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

$$|S_{11}| = 0 = |S_{12}|.$$

from Eq (2), $S_{22} = 0$.

This means ports (1) and (2) are also perfectly matched to the junction. Hence in any port (4) junction if any 2 ports are perfectly matched to the junction. Then the remaining two ports are automatically matched to the junction. Such a junction where it all ports are perfectly matched through the junction is called Magic Tee junction.

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

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

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

$b_1 = a_3/\sqrt{2} + a_H/\sqrt{2}$

$b_2 = a_3/\sqrt{2} - a_H/\sqrt{2}$

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

$b_H = a_1/\sqrt{2} - a_2/\sqrt{2}$

Case (i):- Input is applied at port ③, $a_3 \neq 0$, $a_1 = a_2 = a_H = 0$.

$\Rightarrow b_1 = a_3/\sqrt{2}, b_3 = 0$

$b_2 = a_3/\sqrt{2}, b_H = 0.$

Case (ii):- $a_H \neq 0, a_1 = a_2 = a_3 = 0$

$b_1 = a_H/\sqrt{2}, b_3 = 0$

$b_2 = -a_H/\sqrt{2}, b_H = 0.$

Case (iii):- $a_1 \neq 0, a_2 = a_3 = a_H = 0$

$b_3 = a_1/\sqrt{2}, b_1 = 0, b_2 = 0$

$b_H = a_1/\sqrt{2}.$

When power is fed into port ① nothing comes out of port ②. Hence, port ① and ② are called isolated ports. Similarly an input at port ② cannot come out at port ①. Similarly E and H ports are isolated ports.

Case (iv):- $a_3 = a_H = a, a_1 = a_2 = 0.$

$b_1 = \sqrt{2}a$

$b_2 = 0, b_3 = b_H = 0.$ This is additive property.

Case (v):- $a_1 = a_2 = a, a_3 = a_H = 0$

$b_3 = \sqrt{2}a, b_H = b_1 = b_2 = 0.$

* Applications of Magic Tee:-

1. Measurement of impedance:- A magic Tee has been used in the form of a bridge. Microwave source is connected in arm-3 and null detector in port ④. The unknown impedance is connected

in arm-2 and a standard variable known impedance in arm ①. Using the properties of magic-Tee the power from microwave source gets divided equally between arms ① and ② is $a_3/\sqrt{2}$. The impedances are not equal to the characteristics impedance. Hence, there will be reflections from port ① & ② are ρ_1 and ρ_2 and powers $\rho_1 a_3/\sqrt{2}$ and $\rho_2 a_3/\sqrt{2}$. Enter the magic Tee junction from port ① and port ②. The resultant is taken into port ④ i.e: the null detectors can be calculated as

$$\frac{1}{\sqrt{2}}\left[\frac{1}{\sqrt{2}}\cdot \rho_1 a_3\right] - \frac{1}{\sqrt{2}}\left[\rho_2 a_3/\sqrt{2}\right] = \frac{1}{2} a_3(\rho_1 - \rho_2)$$

For perfect balancing of the bridge, the above equation is equal to '0'

$$\frac{1}{2} a_3(\rho_1 - \rho_2) = 0 \quad , a_3 \neq 0$$

$$\rho_1 - \rho_2 = 0$$

$$\rho_1 = \rho_2$$

$$\frac{Z_1 - Z_L}{Z_1 + Z_L} = \frac{Z_2 - Z_L}{Z_2 + Z_L}$$

$$Z_1 = Z_2$$

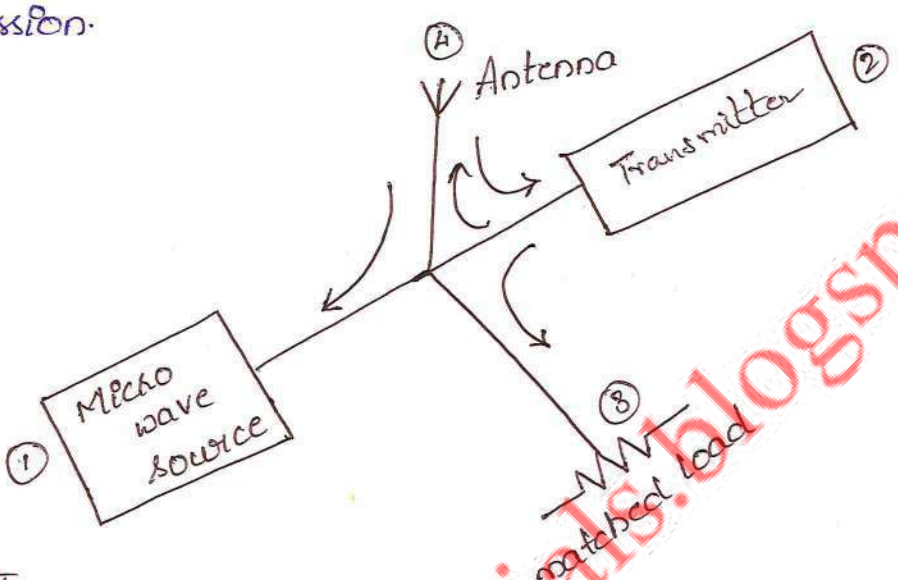
$$R_1 + jX_1 = R_2 + jX_2.$$

$$R_1 = R_2 \ \& \ X_1 = X_2$$

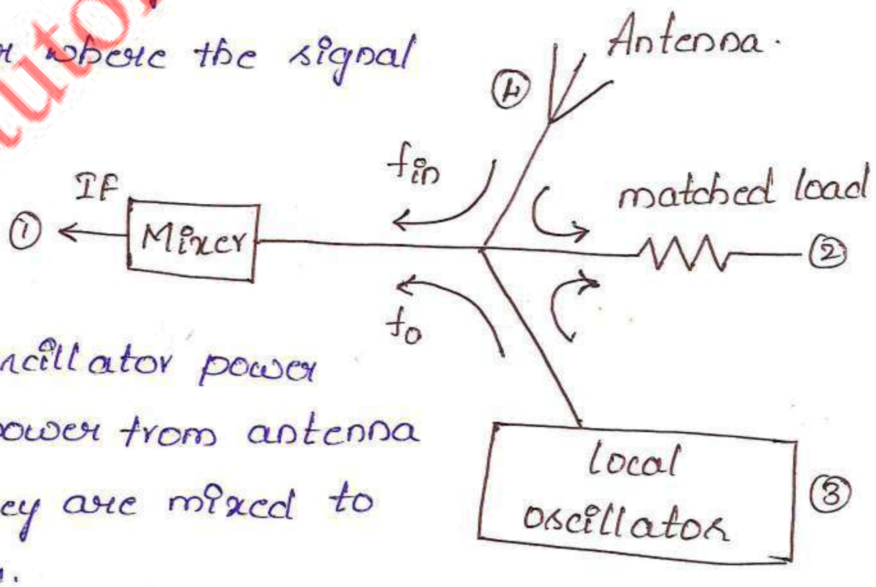
Thus, the unknown impedance can be measured by adjusting the standard variable impedance till the bridge is balanced and both impedances becomes equal.

2. Magic Tee as a Duplexer :- The transmitter and receiver are connected in ports ② and ① respectively, antenna in the E-arm or port ④ and port ③ of magic Tee is terminated in a matched load as shown in fig.. During the transmission, half the power

reaches the antenna from where it is radiated into space. Other half reaches the matched load where it is absorbed without reflections. No transmitter power reaches the receiver since port ① and ② are isolated ports in a magic Tee. During reception, half of the received power goes to the receiver and the other half to the transmitter are isolated during reception as well as during transmission.



3. Magic Tee as a Mixer :- A Magic Tee can also be used in microwave receivers as a mixer where the signal and local oscillator are fed into the E and H arms as shown in fig.

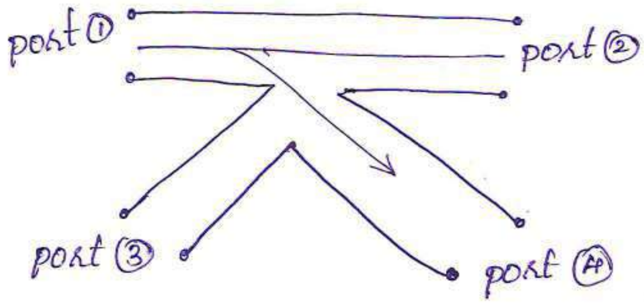


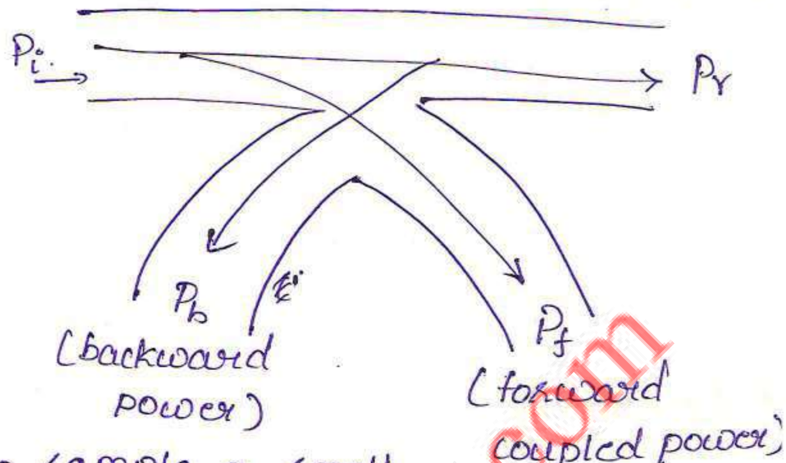
Half of the local oscillator power and half of the received power from antenna goes to the mixer where they are mixed to generate the IF frequency.

$$IF = f_{in} - f_o$$

Magic Tee has many other applications such as a microwave discriminator, microwave bridge etc.

* Directional Coupler:-





Directional couplers can sample a small amount of microwave power for measurement purpose. They can be designed to measure incident and reflected power and SWR values. They can be unidirectional for measuring incident power and can be bidirectional for measuring both incident and received powers. The directional coupler is a 4 port wave guide junction consisting of primary main wave guide and secondary auxilar wave guide as shown in fig.

1. With matched termination at all the ports. the properties of ideal directional coupler can be summarized as follows:-
2. A portion of power travelling from port ① to port ② is coupled to port ④ but not port ③
3. A portion of power incident on ③rd port is coupled to port ② but not to port ① and a portion of power incident on port ④ is coupled to port ① but not to port ②.

Ideally, no power should come out of port ③

The performance of a directional coupler is usually defined in terms of parameters which are defined as

$$\text{coupling factor} = 10 \log P_i/P_f$$

$$\text{Directivity} = 10 \log P_f/P_b$$

Isolation $= 10\log P_i/P_b$

* <u>Coupling factor</u>:- It is defined as the ratio of incident power (P_i) to the forward coupled power (P_f)

$$C = 10\log_{10} P_i/P_f$$

The coupling factor is a measure of how much of the incident power is being sampled.

* <u>Directivity</u>:- It is defined as the ratio of forward power to backward power.

$$D = 10\log_{10} P_f/P_b$$

Directivity is the measure of how well the directional coupler distinguish b/w the forward and reverse travelling power.

* <u>Isolation</u>:- It is defined as the ratio of incident power to the backward power.

$$I = 10\log_{10} P_i/P_b$$

It describes the directional propagation of directional coupler. For a typical directional coupler,

$$C = 20\,dB$$
$$D = 60\,dB$$

$C = 20$

$10\log_{10} P_i/P_f = 20$

$P_i/P_f = 10^2$

$D = 60$

$10\log_{10} P_f/P_b = 60$

$P_f/P_b = 10^6$

$P_i/P_b = 10^8$

$$\boxed{P_b = \frac{P_i}{10^8}}$$

Since P_b is very small. Hence the power coming out of port (3) can be neglected.

S-matrix of directional Coupler:- This is a square matrix of order 4×4

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

In a directional coupler, all the 4-~~poles~~ Ports are perfectly matched to the junction $S_{11} = S_{22} = S_{33} = S_{44} = 0$.

From Symmetric property, $S_{ij} = S_{ji}$

$S_{12} = S_{21}$, $S_{13} = S_{31}$, $S_{32} = S_{23}$, $S_{24} = S_{42}$, $S_{34} = S_{43}$, $S_{14} = S_{41}$.

Ideally back power is '0' so there is no coupling between port ① and ③

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

Similarly, there is no coupling between ports ② and ④.

$$S_{24} = S_{42} = 0$$

Now,

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

From the unitary matrix, $[S][S]^* = [I]$

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

$$R_1C_1 \rightarrow |S_{12}|^2 + |S_{14}|^2 = 1 \rightarrow ①$$

$$R_2C_2 \rightarrow |S_{12}|^2 + |S_{23}|^2 = 1 \rightarrow ②$$

$$R_3C_3 \rightarrow |S_{23}|^2 + |S_{34}|^2 = 1 \rightarrow ③$$

$$R_1C_3 \rightarrow S_{12}S_{23}^* + S_{14}S_{34}^* = 0 \rightarrow ④$$

from Eq ① and ②

$$S_{14} = S_{23}$$

from Eq. ② and ③

$$S_{12} = S_{34}.$$

Let $S_{12} = P = S_{34} = S_{34}^*$

$$\Rightarrow P \cdot S_{23}^* + S_{14} P = 0$$

$$P[S_{23}^* + S_{14}] = 0$$

$$P \neq 0 \Rightarrow S_{23}^* + S_{14} = 0$$

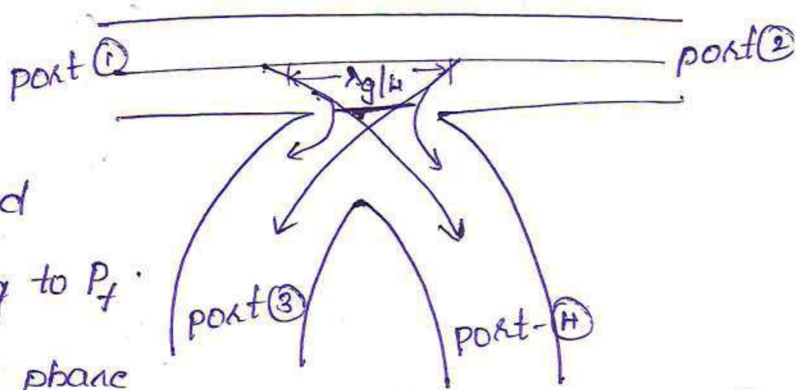
$$S_{23}^* + S_{23} = 0$$

let $S_{23} = jq \Rightarrow S_{23}^* = -jq$

$$[S] = \begin{bmatrix} 0 & P & 0 & jq \\ P & 0 & jq & 0 \\ 0 & jq & 0 & P \\ jq & 0 & P & 0 \end{bmatrix} \quad \text{where } P^2 + q^2 = 1$$

* Two-hole directional coupler:- The principle of operation of a two-hole directional coupler is shown in fig. It consists of two guides the main and the auxiliary with two tiny holes common between them as shown. The two holes are at a distance of $\lambda g/4$ and λg is the guide wavelength.

The two leakages out of holes ① and ② both in phase at the position of 2^{nd} hole and hence they add up contributing to P_f.



But the two leakages are out of phase of 180° at the position of the 1^{st} hole and therefore they cancel each other making $P_b = 0$ (ideally). The magnitude of the power coming out of 2 holes depends upon the dimension of the two holes. Since, the distance between holes is $\lambda g/4$, P_b is made '0'. The number of holes can be one or more than two. The degree of coupling is determined by size and location of the holes in the waveguide walls

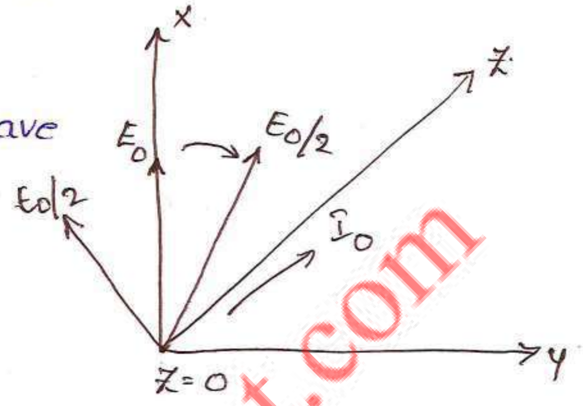
Although a high degree of directivity can be acheived at a fixed frequency, it is quite difficult over a band of frequencies. In this connection, it should be realized that frequency determines the seperation of the two holes as a fraction of wavelength.

* **Ferrite Devices** :- Ferrites are non-metallic materials with resistivities nearly 10^{14} times greater than metals with dielectric constant around 10-15 and relative permeability is of the order 1000. They are oxide based ~~components~~ compounds having general composition of the form MeO, Fe_2O_3 i.e; a mixture of metallic oxide and Ferric oxide where MeO represents any divalent metallic oxide such as MnO, ZnO, CdO, NiO. They are obtained by firing powered oxides of materials at 1100°c or more and pressing them into different shapes. This process gives them characteristic of ceramic insulators so that they can be used at microwave frequencies.

Ferrites have non-reciprocal property which is useful at microwave frequencies. When two circularly polarized waves one rotating clockwise and another anti-clockwise are made to propagate through ferrites.

* **Faraday Rotation** :- Consider an infinite lossless medium a static

field B_0 is applied along z-direction. ~~A plane TEM wave~~ i.e. ~~linearly polarized along z-direction~~ A plane TEM wave i.e. linearly polarized along x-axis is made to propagate through the ferrite in the z-direction.



The plane of polarization of this wave will rotate with a distance. The phenomenon is known as Faraday rotation.

Any linearly polarized wave can be regarded as the vector sum of the two counter rotating circularly polarized waves.

Angle of rotation, $\theta = l/2 \left(\beta^{+} \sim \beta^{-} \right)$

where l - length of the ferrite rod

β^{+} - phase shift of right circularly polarized wave.

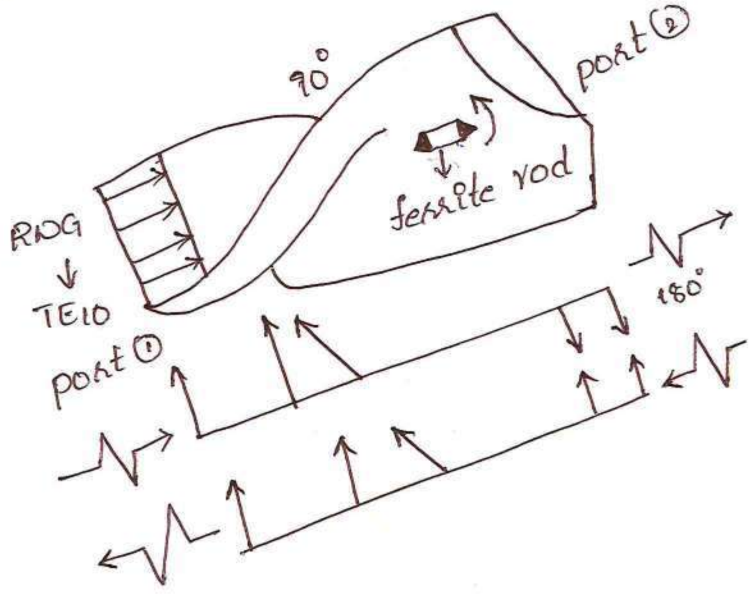
β^{-} - phase shift of left circularly polarized wave.

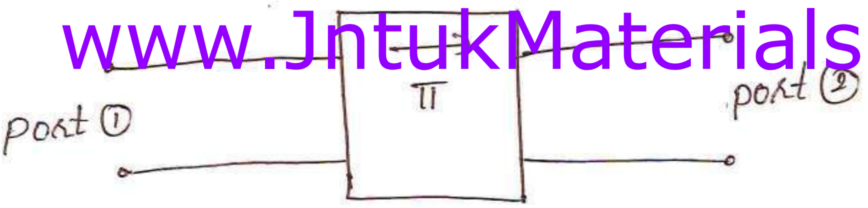
* **Microwave Devices which make use of Faraday rotation:**

There are 3 important devices which make use of faraday rotation.
1. Gyrator
2. Isolator
3. Circulator.

1. **Gyrator:-**

It is a two-port device that has a relative phase difference of 180° for transmission from port I to port-II.





Construction :- It consists of a piece 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 tappered at both ends is located inside the circular waveguide supported by polyfoam and the waveguide is surrounded by permanent magnet which generates dc magnetic field for proper operation of ferrite. To the input end a 90° twisted rectangular waveguide is connected as shown. The ferrite rod is tapered at both ends to reduce the attenuation and also for smooth rotation of the polarized wave.

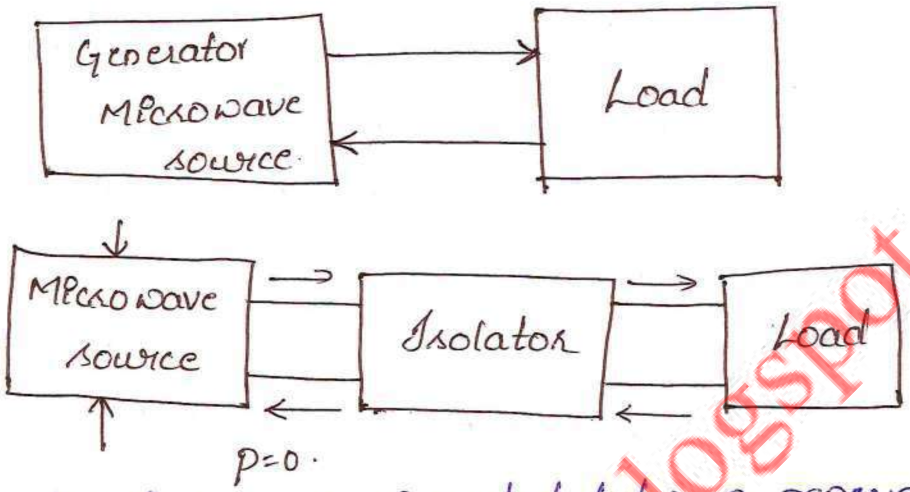
Operation :- when the wave enters port ① its plane of polarization rotates by 90° because of the twist in the waveguide. It again undergoes Faraday rotation through 90° because of ferrite rod and the wave which comes out of port ② will have a phase shift of 180° compared to the wave entering port ①.

But when the same wave enters port ②, it undergoes faraday rotation through 90° in the same anticlockwise direction. Because of the twist, this wave gets rotated back by 90° comes out of port ① with 0° phaseshift. Hence a wave at port ① undergoes a phase shift of π radians but a wave fed from port ② does not change its phase in a gyrator.

2. Isolator :- An Isolator is a two-port device which provides very small attenuation for transmission from port ① to port ② but provides maximum attenuation for transmission from port ② to port ①. In most microwave generators the output will be fluctuate with chan-

ges in load impedance. This is due to mismatch of generator output to the load resulting in reflected waveform.

But these reflected waves should not be allowed to reach the microwave generator which will cause amplitude and frequency instability of microwave generator.

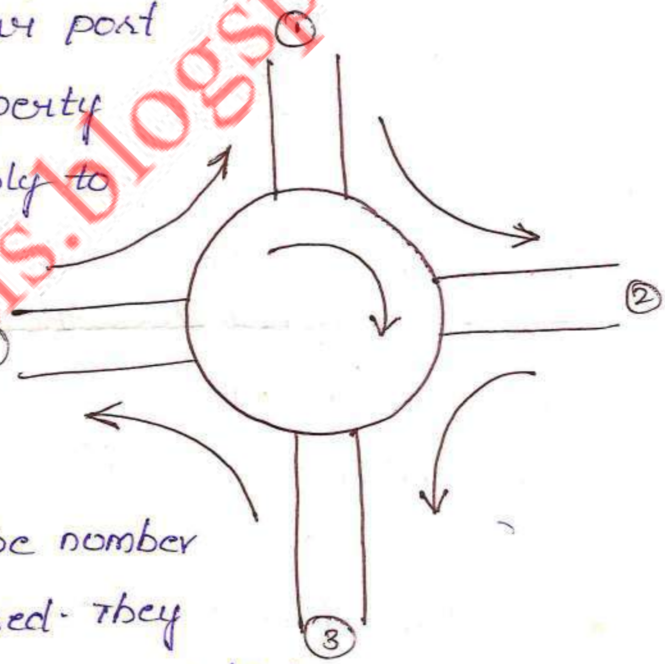


When the isolator is inserted between generator and load the generator is coupled to the load with attenuation and reflections if any from the load side are completely absorbed by the isolator without affecting the generator output.

Construction:- The construction of isolator is similar to gyrator except that an isolator makes use of 45° twisted rectangular waveguide and 45° faraday rotation ferrite rod. A resistive card is placed along the larger dimensions of the rectangular waveguide. So, it absorbs any wave whose plane of polarization is parellel to the plane of resistive card. The resistive card does not absorb any wave whose plane of polarization is perpendicular to its own plane.

Operation:- A TE_{10} wave passing from port ① through the resistive ~~loss~~ card and is not attenuated. After coming out of the card the wave gets shifted by 45° because of the anti-clock wise twist and then by another 45° in clockwise direction because of the ferrite rod. And hence comes out of port ② with out any attenuation. TE_{10} wave fed from port ② just pass from the resistive card since the plane of polarization of the wave is perpendicular to the resistive card. Then, the wave is shifted by 45° due to the ferrite rod in clockwise direction and further the wave rotated by 45° in clockwise direction due to the twist in the waveguide. Now the plane of polarization will be parellel to the resistive card and hence it is absorbed by the resistive card and the output at port-I will be zero. This power is dissipated in the card as heat.

3. <u>Circulator</u> :- A circulator is a four port 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 ④ and ② is connected to port ③ etc. Although there is no restriction on the number of ports, four ports are commonly used. They are useful in parametric amplifiers, tunnel diode amplifiers and duplexer in radars.

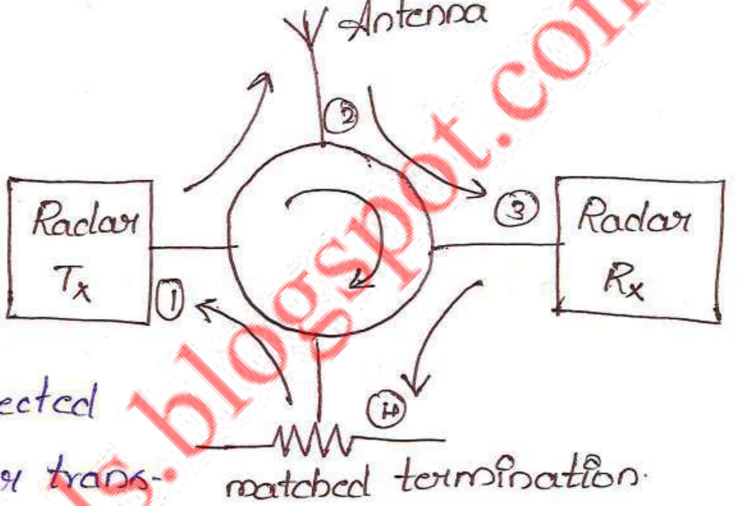


<u>Construction</u>:- A four port faraday rotation circulator is shown. The power entering port ① is TE_{10} mode and is converted to TE_{11} mode because of gradual rectangular to circular transmission. This power passes port ③ unaffected since the electric field is not significantly cut and is rotated through 45° due to ferrite, passes port ④ unaffected and finally emerges out of port ②. Power from port ② will have plane of polarization already tilted by 45° with respect to port ①.

This power passes port ② unaffected because again the electric field is not significantly cut. The wave gets rotated by another 45° due to ferrite rod in clockwise direction. This power whose plane of polarization is tilted through 90° finds port ③ suitably aligned and emerges out of it. Similarly port ③ is coupled to port ④ and port ④ to port ①.

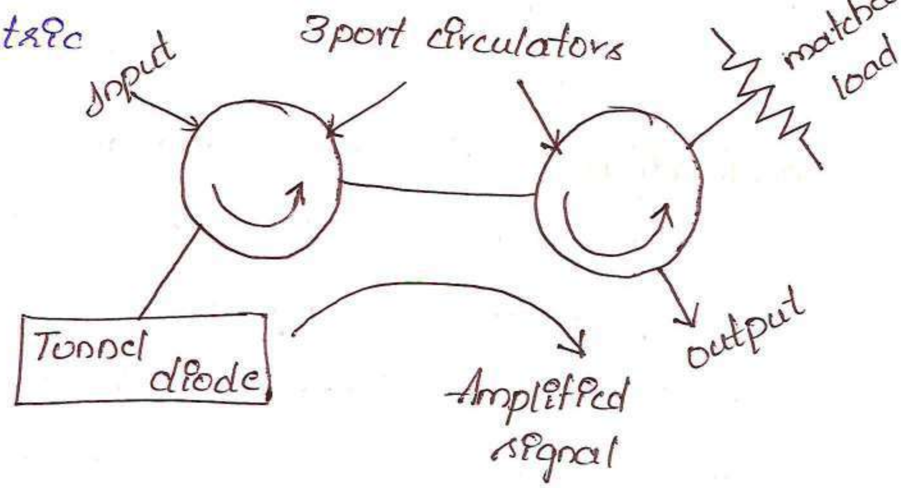
Applications of circulator :-

1. A circulator can be used as a duplexer for a radar antenna system.



Transmitter feeds the antenna while the received energy is directed to the receiver. The powerfull radar transmitter is isolated from the sensitive receiver and also the same antenna can be used for both transmission and reception. This is the duplexer action performed by a circulator.

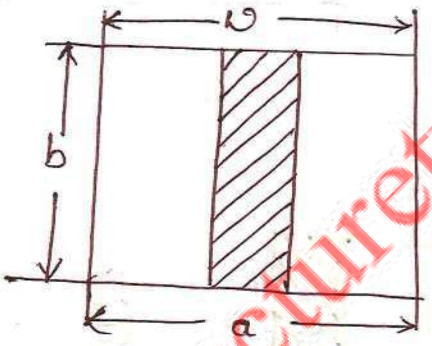
2. we have three port circulators, stripline circulators that have many applications. Two three port circulators can be used in tunnel diode or parametric amplifier.

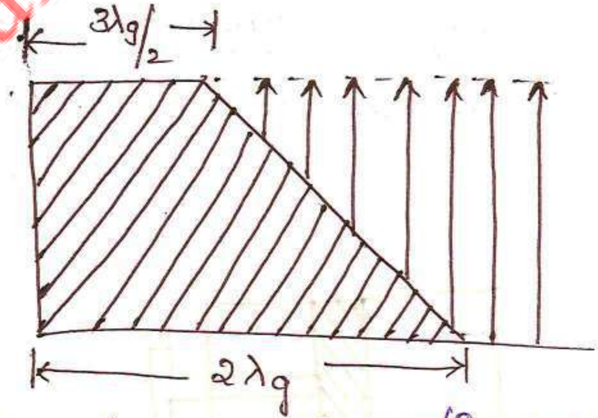


3. Circulators can be used as low power devices as they can handle low powers only.

* **Microwave Attenuators:** Attenuators are commonly used for measuring power gain or loss in dB's, for providing isolation between instruments, for reducing the power input at a particular stage to prevent overloading and also for providing the signal generators with a means of calibrating their outputs accurately so that precise measurement could be made.

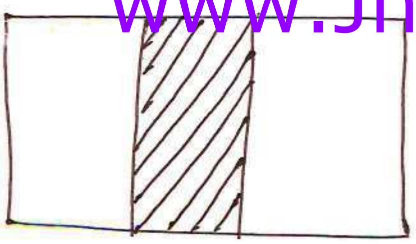
Fixed attenuators:- They are used where fixed amount of attenuation is to be provided. If such a fixed attenuator absorbs all the energy entering into it, we call it as a waveguide terminator. This normally consists of a short section of a waveguide with a tapered plug of absorbing material at the end. The tapering is done for providing a gradual transition from the waveguide medium to the absorbing medium thus reducing the reflection occuring at a media interface.



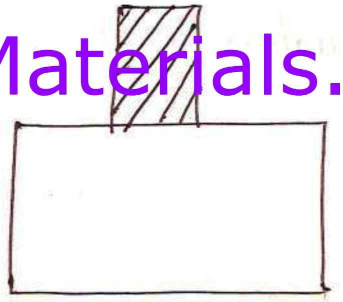


Variable attenuators:- Variable attenuators provide continuous or step size variable attenuation. For rectangular waveguides, these attenuators can be flap type or Vane type. For circular waveguides rotary type is used.

Flap type attenuator:- It consists of a resistive element or disc inserted into longitudinal slot cut along the centre of the wider dimension of the guide. The flap is mounted on a hinged arm allowing it to descend into the centre of the waveguide. The degree of attenuation is determined by the depth of insertion of the flap.

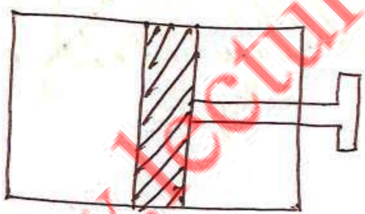


Maximum attenuation

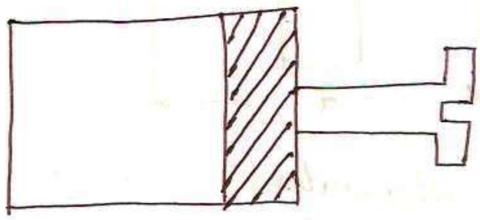


Minimum attenuation.

Vane type attenuators: This basically consists of a glass vane with a coating of aquadog or carbon similar to a fixed vane attenuator. If the vane used at the centre is made movable, where it provides attenuation can be used as variable attenuator. The vane positioned at the centre of the waveguide can be moved laterally from the centre, where it provides attenuation to the edges where the attenuation is considerably reduced since the electric field lines are concentrated at the centre of the waveguide. The vane is tapered at both the ends to match the attenuator to the waveguide and tapered length must be equal to $\lambda g/2$. The amount of attenuation is frequency sensitive and also has to be calibrated against a precision attenuator.



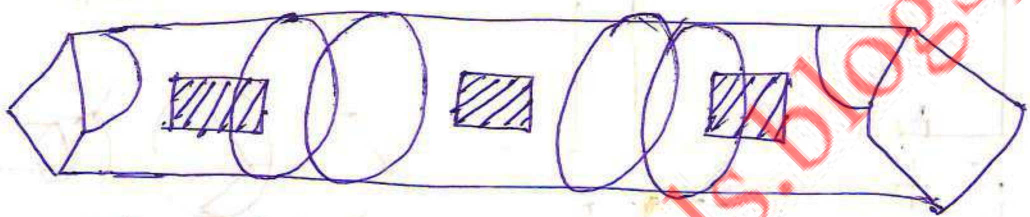
Maximum altenation



Minimum altenation.

Rotary type attenuator:- A resistive rotary ~~vales~~ Vane attenuator provides precision attenuation with an accuracy of ±2.1% of indicated attenuation over the operating frequency range. It consists of 3 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 in the rectangular sections. When all the three vanes are alligned their planes are at 90° to the direction of electric field.

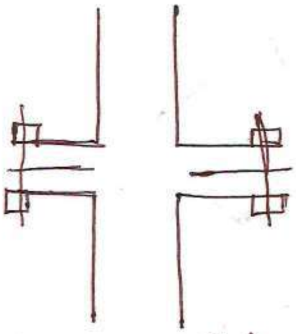
Hence there is no attenuation. Vane 1 prevents any horizontal polarization and hence electric field at the output of vane 1 is vertically polarized. The centre vane 2 is rotating type and if it has rotated by an angle θ. the $E\sin\theta$ component is attenuated and $E\cos\theta$ component is present at the output of vane 2 and the final output of the attenuator becomes $E\cos^2\theta$. which has the same polarization as the input wave. The attenuation due to this rotary vane attenuator is then equal to $20\log\cos^2\theta = 40\log\cos\theta$ that is independent of frequency and its precise.



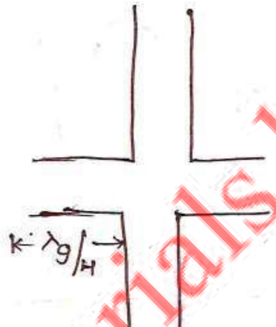
* <u>Waveguide joints</u>:- It is not possible to build a wave guide system in one piece and may require several sections connected by joints. These are the waveguide joints and must be constructed in such a way that a good connection is made between any two sections of the waveguide without affecting the E and H patterns. Irregularities in a joint cause reflection effects, create standing waves and increase the attenuation.

There are several types of waveguide joints. Some of them are semipermanent butt joints, a bolted flange consists of two section bolted together with a gasket to exclude moisture. For perfect mechanical alignment, it should be ensured that there are no bends or discontinuities and the ends of the waveguides and flanges must have mirror smooth finish to avoid the reflection effects.

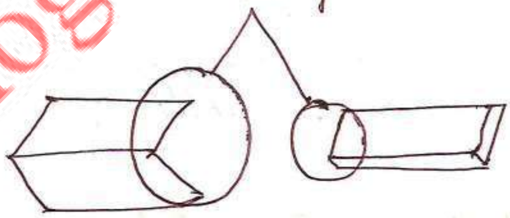
The choke joint is superior to butt joint and is very widely used. It consists of flanges that are connected to the waveguide at its center. The right side flange is flat and left one is slotted, $\lambda g/4$ deep from the inner surface of the waveguide. This is positioned at a distance of $\lambda g/4$ from the point where flanges are joined. Due to the $\lambda g/2$ length taken together, a short ckt. is created at the place where the walls are joined together resulting in an electrical short. Mechanically they are seperated by as much as one tenth of a wavelength and the area can be sealed with a rubber gasket for avoiding moisture.



Bolted joint.



$\lambda g/4$ flange joint.



choke joint

Problems

① A 20mW Signal is fed into the series arm (E-arm) of a lossless magic Tee Junction. Calculate the power delivered through each port when other ports are terminated in matched load?

Sol: Given,

Power applied at the series arm, $a_4 = 20\,mW$ (i.e at Port 4)

$b_1 = ?$

$b_2 = ?$

$b_3 = ?$

Then it behaves as a E-plane Tee

$\therefore \; a_1 = a_2 = a_3 = 0$

then, $b_1 = \frac{a_4}{\sqrt{2}} = \frac{20\,mW}{\sqrt{2}} = 14.142\,mW$

$b_2 = -\frac{a_4}{\sqrt{2}} = -14.142\,mW$

and power obtained at port (3) i.e at shunt arm is zero.

$\therefore \; b_3 = 0$

② A 20 dB directional Coupler is found to give 3dBm in output power through coupled port. If the isolation is specified as 55dB find the power available at the isolated port?

Sol: Given,

Coupling factor (C) = 20 dB

Power through Coupling Port $P_f = 3\,dBm$

Isolation, $I = 55\,dB$

Power available at isolated port $P_b = ?$

We know that,

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

$$= 10 \log_{10}\left(\frac{P_f}{P_i}\right) + 10 \log\left(\frac{P_i}{P_b}\right)$$

$$= 10 \log_{10}\left(\frac{P_i}{P_b}\right) - 10 \log\left(\frac{P_i}{P_f}\right)$$

$$D = I - C \implies \boxed{I = C + D}$$

$$10 \log_{10} \frac{P_f}{P_b} = 55 - 20 = 35$$

$$\implies \frac{P_f}{P_b} = 10^{3.5} \implies P_b = \frac{P_f}{10^{3.5}}$$

$$P_b = 9.4 \times 10^{-4} \text{ dBm}$$

(3) A directional coupler has the scattering matrix given below Find the directivity, coupling factor and isolation?

Sol:

$$[S] = \begin{bmatrix} 0.05\angle 30 & 0.96\angle 0 & 0.1\angle 90 & 0.05\angle 90 \\ 0.96\angle 0 & 0.05\angle 30 & 0.05\angle 90 & 0.1\angle 90 \\ 0.1\angle 90 & 0.05\angle 90 & 0.04\angle 30 & 0.96\angle 0 \\ 0.05\angle 90 & 0.1\angle 90 & 0.96\angle 0 & 0.05\angle 30 \end{bmatrix}$$

$$\text{Coupling factor (C)} = 10 \log \frac{P_1}{P_3}$$

$$C = -20 \log |S_{13}| = -20 \log 0.1 = 20 \text{ dB}$$

$$\text{Directivity (D)} = 10 \log \frac{P_3}{P_4} = -20 \log \frac{|S_{13}|}{|S_{14}|}$$

$$D = -20 \log \frac{0.1}{0.05} = -6.02 \text{ dB}$$

$$I = C + D = 13.98 \text{ dB}$$

(4) A Matched Isolator has insertion loss of 0.5 dB and isolation of 25 dB. Find the S-Matrix?

Sol: Given that,

Insertion loss = 0.5 dB

$$\Rightarrow -20 \log |S_{21}| = 0.5$$

$$\Rightarrow S_{21} = 10^{\frac{-0.5}{20}} \Rightarrow \boxed{S_{21} = 0.944}$$

Isolation = 25 dB

$$\Rightarrow -20 \log |S_{12}| = 25 \Rightarrow S_{12} = 10^{-25/20}$$

$$\Rightarrow \boxed{S_{12} = 0.0562}$$

If the Isolator is perfectly matched $S_{11} = S_{22} = 0$

$$\therefore \text{S-Matrix } [S] = \begin{bmatrix} 0 & 0.0562 \\ 0.944 & 0 \end{bmatrix}$$

(5) In an H-plane Tee Junction, 20mW power is ~~delivered~~ applied to port (3) i.e is perfectly matched to the junction. Calculate the power delivered to the load 60 Ω and 75 Ω connected to ports (1) and port (2), if the characteristic impedance of the line is 50 Ω?

Sol: The [S] for H-plane Tee with port (3) matched to the junction

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

(6) Power at port ③ gets equally divided into ports ① and port ②

i.e 20 mW power at port ③ delivers 10 mW at ports ① and ②.

i.e $b_1 = b_2 = 10\,mW$

∴ Power reflected from port ① and port ② are

$$\frac{1}{2}[\rho_1 b_1]^2 \text{ and } \frac{1}{2}[\rho_2 b_2]^2 ;$$

Power delivered to load Z_1 at port ① $= 60\,\Omega$ is

$$P_1 = \frac{1}{2}[b_1]^2 - \frac{1}{2}[\rho_1 b_1]^2 = \frac{1}{2}[b_1]^2[1 - |\rho_1|^2]$$

Power delivered to load Z_2 at port ② $= 75\,\Omega$ is

$$P_2 = \frac{1}{2}[b_2]^2 - \frac{1}{2}[\rho_2 b_2]^2 = \frac{1}{2}[b_2]^2[1 - |\rho_2|^2]$$

Now, the characteristic impedance of the line is $50\,\Omega$

$$\rho_1 = \left|\frac{60-50}{60+50}\right| = \frac{1}{11}$$

$$\rho_2 = \left|\frac{75-50}{75+50}\right| = \frac{1}{5}$$

$$\therefore P_1 = \frac{1}{2}|b_1|^2[1 - |\rho_1|^2] = \frac{1}{2}[10 \times 10^{-3}]^2\left[1 - \frac{1}{121}\right]$$

$$P_1 = 4.958 \times 10^{-5}\ \text{watt}$$

$$P_2 = \frac{1}{2}|b_2|^2[1 - |\rho_2|^2] = \frac{1}{2}[10 \times 10^{-3}]^2\left[1 - \frac{1}{25}\right]$$

$$P_2 = 4.8 \times 10^{-5}\ \text{watt}$$

⑥ A 3-port circulator has an insertion loss of 1 dB, Isolation 30 dB and VSWR = 1.5. Find the S-Matrix?

For perfectly matched and lossless for non-reciprocal

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

Sol:

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

We have,

Insertion loss $= -20 \log |S_{21}|$

$$1 = -20 \log |S_{21}|$$

$$\Rightarrow |S_{21}| = 10^{-1/20} = 0.89$$

$\therefore$ Similarly $|S_{21}| = |S_{13}| = |S_{32}| = 0.89$

Isolation $= -20 \log |S_{12}|$

$$30 = -20 \log |S_{12}|$$

$$\Rightarrow |S_{12}| = 10^{-30/20} = 0.0316$$

$\therefore |S_{12}| = |S_{31}| = |S_{23}| = 0.0316$

$$\rho = \frac{S-1}{S+1} = \frac{1.5-1}{1.5+1} = 0.2$$

$\therefore S_{11} = S_{22} = S_{33} = 0.2$

the Scattering matrix

$$[S] = \begin{bmatrix} 0.2 & 0.0316 & 0.89 \\ 0.89 & 0.2 & 0.0316 \\ 0.0316 & 0.89 & 0.2 \end{bmatrix}$$

(7) A 20 dB directional coupler has a directivity of 30 dB. Calculate the value of isolation?

$$I = C + D = 50\,\text{dB}$$