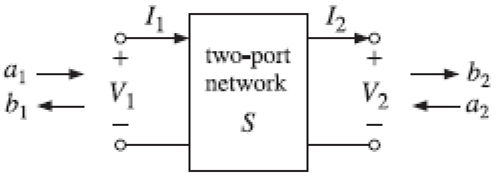
UNIT II
WAVEGUIDE COMPONENTS

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 V1,V2 to the two currents I1, I2:†

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

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

Thus, the transfer and impedance matrices are the 2×2 matrices:

$$T = \begin{bmatrix} A & B \\ C & D \end{bmatrix}, \qquad Z = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix}$$

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:

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

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, the meaning of transmission coefficients.

THE SCATTERING MATRIX

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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.

$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

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 Thus 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.

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

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 a nyone 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 1 and 2 as shown in figure 4.6, the S-parameters have definite values.

COUPLING MECHANISMS:
PROBE, LOOP, APERTURE TYPES>

The three devices used to inject or remove energy from waveguides are PROBES, LOOPS, and SLOTS. Slots may also be called APERTURES or WINDOWS.

As previously discussed, when a small probe is inserted into a waveguide and supplied with microwave energy, it acts as a quarter-wave antenna. Current flows in the probe and sets up an E field such as the one shown in figure 1-39, view (A). The E lines detach themselves from the probe. When the probe is located at the point of highest efficiency, the E lines set up an E field of considerable intensity.

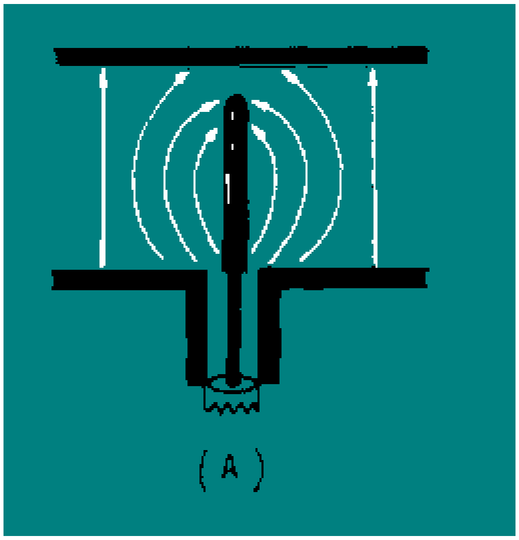


Fig: **Probe coupling** in a rectangular waveguide.

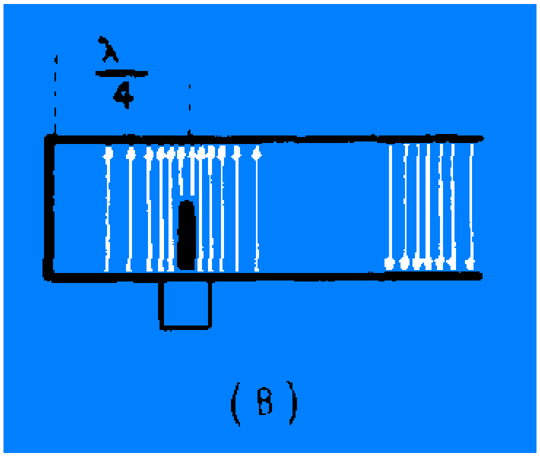


Figure. Probe coupling in a rectangular waveguide.

The most efficient place to locate the probe is in the center of the "a" wall, parallel to the "b" wall, and one quarter-wavelength from the shorted end of the waveguide, as shown in figure 1-39, views (B) and (C). This is the point at which the E field is maximum in the dominant mode. Therefore, energy transfer (coupling) is maximum at this point. Note that the quarter-wavelength spacing is at the frequency required to propagate the dominant mode.

In many applications a lesser degree of energy transfer, called loose coupling, is desirable. The amount of energy transfer can be reduced by decreasing the length of the probe, by moving it out of the center of the E field, or by shielding it. Where the degree of coupling must be varied frequently, the probe is made retractable so the length can be easily changed.

The size and shape of the probe determines its frequency, bandwidth, and power-handling capability. As the diameter of a probe increases, the bandwidth increases. A probe similar in shape to a door knob is capable of handling much higher power and a larger bandwidth than a conventional probe. The greater power-handling capability is directly related to the increased surface area. Two examples of broad-bandwidth probes are illustrated in figure 1-39, view (D). Removal of energy from a waveguide is simply a reversal of the injection process using the same type of probe.

Another way of injecting energy into a waveguide is by setting up an H field in the waveguide. This can be accomplished by inserting a small loop which carries a high current into the waveguide, as shown in figure 1-40, view (A). A magnetic field builds up around the loop and expands to fit the waveguide, as shown in view (B). If the frequency of the current in the loop is within the bandwidth of the waveguide, energy will be transferred to the waveguide.

For the most efficient coupling to the waveguide, the loop is inserted at one of several points where the magnetic field will be of greatest strength. Four of those points are shown in figure 1-40, view (C).

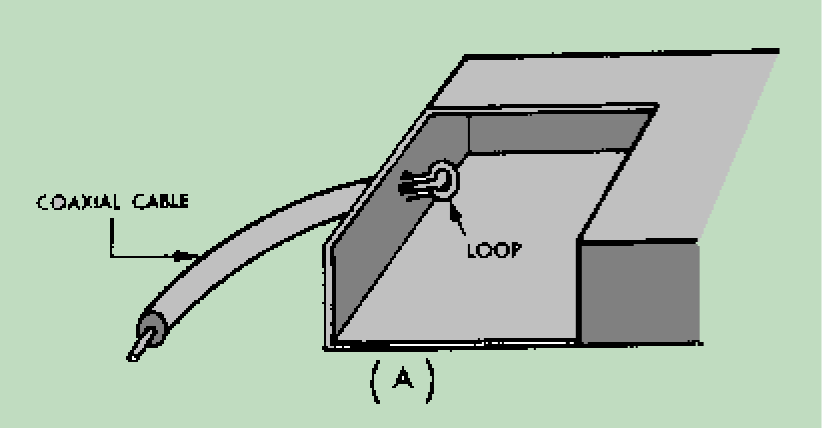
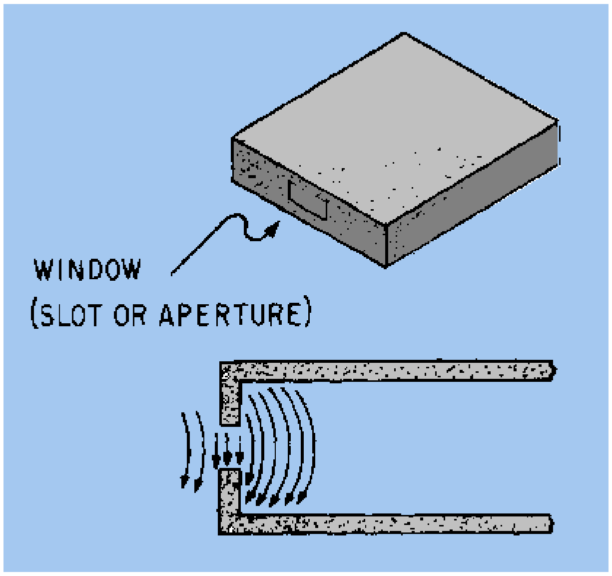


Figure - Loop coupling in a rectangular waveguide.

When less efficient coupling is desired, you can rotate or move the loop until it encircles a smaller number of H lines. When the diameter of the loop is increased, its power-handling capability also increases. The bandwidth can be increased by increasing the size of the wire used to make the loop.

When a loop is introduced into a waveguide in which an H field is present, a current is induced in the loop. When this condition exists, energy is removed from the waveguide.

Slots or apertures are sometimes used when very loose (inefficient) coupling is desired, as shown in figure 1-41. In this method energy enters through a small slot in the waveguide and the E field expands into the waveguide. The E lines expand first across the slot and then across the interior of the waveguide. Minimum reflections occur when energy is injected or removed if the size of the slot is properly proportioned to the frequency of the energy.



After learning how energy is coupled into and out of a waveguide with slots, you might think that leaving the end open is the most simple way of injecting or removing energy in a waveguide. This is not the case, however, because when energy leaves a waveguide, fields form around the end of the waveguide. These fields cause an impedance mismatch which, in turn, causes the development of standing waves and a drastic loss in efficiency.

Impedance matching using a waveguide iris

Irises are effectively obstructions within the waveguide that provide a capacitive or inductive element within the waveguide to provide the impedance matching.

The obstruction or waveguide iris is located in either the transverse plane of the magnetic or electric field. A waveguide iris places a shunt capacitance or inductance across the waveguide and it is directly proportional to the size of the waveguide iris.

An inductive waveguide iris is placed within the magnetic field, and a capacitive waveguide iris is placed within the electric field. These can be susceptible to breakdown under high power conditions - particularly the electric plane irises as they concentrate the electric field. Accordingly the use of a waveguide iris or screw / post can limit the power handling capacity.

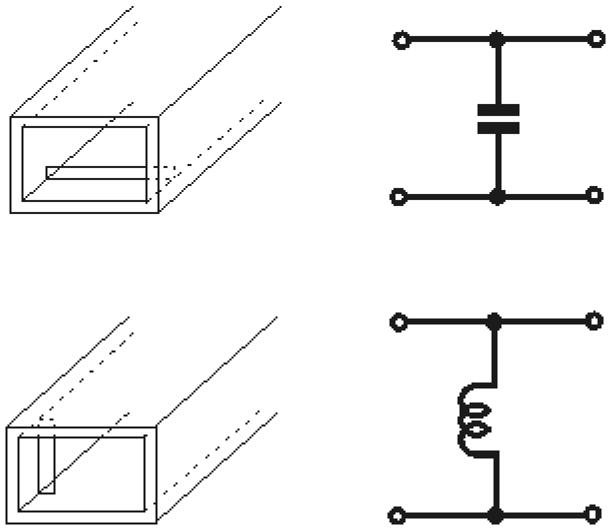


Fig: Impedance matching using a waveguide iris

The waveguide iris may either be on only one side of the waveguide, or there may be a waveguide iris on both sides to balance the system. A single waveguide iris is often referred to as an asymmetric waveguide iris or diaphragm and one where there are two, one either side is known as a symmetrical waveguide iris.

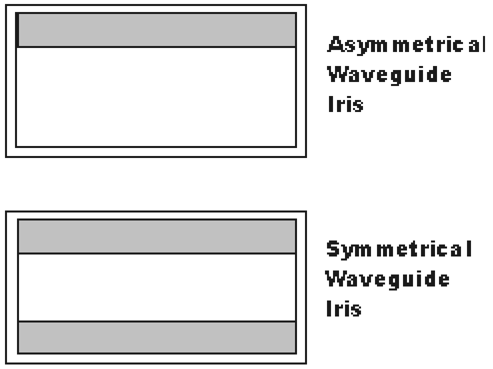


Fig :Symmetrical and asymmetrical waveguide iris implementations

A combination of both E and H plane waveguide irises can be used to provide both inductive and capacitive reactance. This forms a tuned circuit. At resonance, the iris acts as a high impedance shunt. Above or below resonance, the iris acts as a capacitive or inductive reactance.

Impedance matching using a waveguide post or screw

In addition to using a waveguide iris, post or screw can also be used to give a similar effect and thereby provide waveguide impedance matching.

The waveguide post or screw is made from a conductive material. To make the post or screw inductive, it should extend through the waveguide completely making contact with both top and bottom walls. For a capacitive reactance the post or screw should only extend part of the way through.

When a screw is used, the level can be varied to adjust the waveguide to the right conditions.

The diagram shows the electric field across the cross section of the waveguide. The lowest frequency that can be propagated by a mode equates to that were the wave can "fit into" the waveguide.

As seen by the diagram, it is possible for a number of modes to be active and this can cause significant problems and issues. All the modes propagate in slightly different ways and therefore if a number of modes are active, signal issues occur.

It is therefore best to select the waveguide dimensions so that, for a given input signal, only the energy of the dominant mode can be transmitted by the waveguide. For example: for a given frequency, the width of a rectangular guide may be too large: this would cause the TE20 mode to propagate.

As a result, for low aspect ratio rectangular waveguides the TE20 mode is the next higher order mode and it is harmonically related to the cutoff frequency of the TE10 mode. This relationship and attenuation and propagation characteristics that determine the normal operating frequency range of rectangular waveguide

Waveguide Bends

Details of RF waveguide bends allowing changes in the direction of the transmission line waveguide E bend and waveguide H bend.

Waveguide is normally rigid, except for flexible waveguide, and therefore it is often necessary to direct the waveguide in a particular direction. Using waveguide bends and twists it is possible to arrange the waveguide into the positions required.

When using waveguide bends and waveguide twists, it is necessary to ensure the bending and twisting is accomplished in the correct manner otherwise the electric and magnetic fields will be unduly distorted and the signal will not propagate in the manner required causing loss and reflections. Accordingly waveguide bend and waveguide twist sections are manufactured specifically to allow the waveguide direction to be altered without unduly destroying the field patterns and introducing loss.

Types of waveguide bend

There are several ways in which waveguide bends can be accomplished. They may be used according to the applications and the requirements.

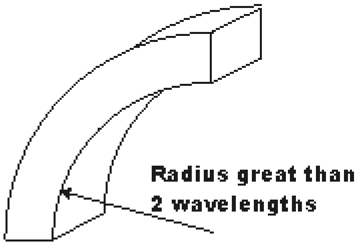
- Waveguide E bend

- Waveguide H bend
- Waveguide sharp E bend
- Waveguide sharp H bend

Each type of bend is achieved in a way that enables the signal to propagate correctly and with the minimum of disruption to the fields and hence to the overall signal.

Ideally the waveguide should be bent very gradually, but this is normally not viable and therefore specific waveguide bends are used.

Most proprietary waveguide bends are common angles - 90° waveguide bends are the most common by far.

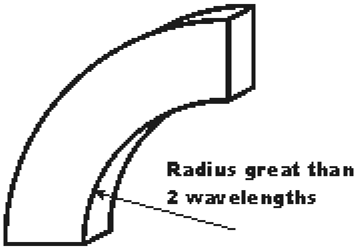


Waveguide E bend

o prevent reflections this waveguide bend must have a radius greater than two wavelengths.

Waveguide H bend

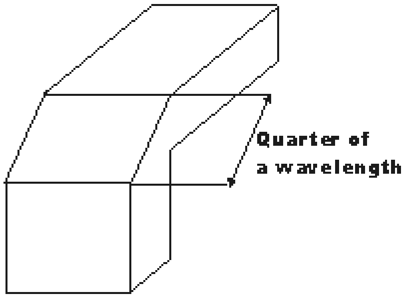
This form of waveguide bend is very similar to the E bend, except that it distorts the H or magnetic field. It creates the bend around the thinner side of the waveguide



Waveguide H bend

Waveguide sharp E bend

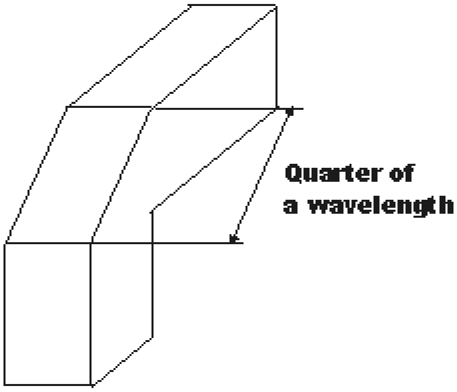
In some circumstances a much shorter or sharper bend may be required. This can be accomplished in a slightly different manner. The techniques is to use a 45° bend in the waveguide. Effectively the signal is reflected, and using a 45° surface the reflections occur in such a way that the fields are left undisturbed, although the phase is inverted and in some applications this may need accounting for or correcting.



Waveguide sharp E bend

Waveguide sharp H bend

This for of waveguide bend is the same as the sharp E bend, except that the waveguide bend affects the H field rather than the E field.



Waveguide sharp H bend

WAVEGUIDE TWISTS

There are also instances where the waveguide may require twisting. This too, can be accomplished. A gradual twist in the waveguide is used to turn the polarisation of the waveguide and hence the waveform.

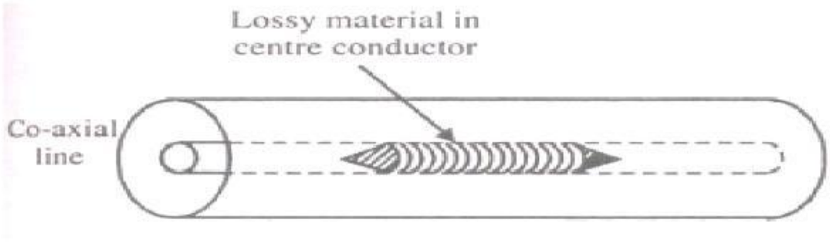
In order to prevent undue distortion on the waveform a 90° twist should be undertaken over a distance greater than two wavelengths of the frequency in use. If a complete inversion is required, e.g. for phasing requirements, the overall inversion or 180° twist should be undertaken over a four wavelength distance.

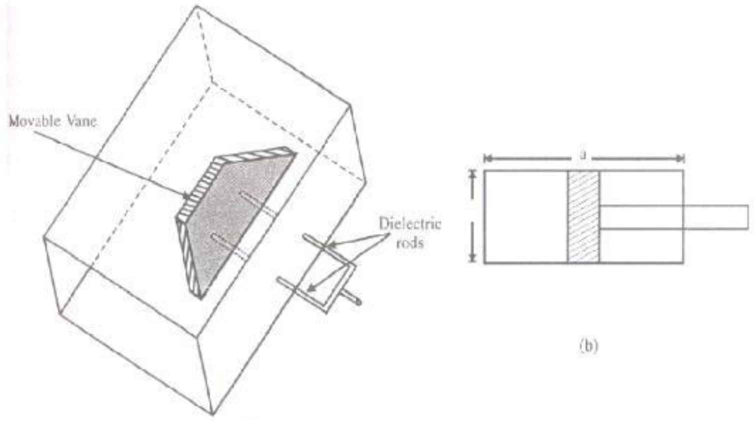
Waveguide bends and waveguide twists are very useful items to have when building a waveguide system. Using waveguide E bends and waveguide H bends and their srap bend counterparts allows the waveguide to be turned through the required angle to meet the mechanical constraints of the overall waveguide system. Waveguide twists are also useful in many applications to ensure the polarisation is correct.

ATTENUATORS:

In order to control power levels in a microwave system by partially absorbing the transmitted microwave signal, attenuators are employed. Resistive films (dielectric glass slab coated with aquadag) are used
in the design of both fixed and variable attenuators.

A co-axial fixed attenuator uses the dielectric lossy material inside the centre conductor of the co-axial line to absorb some of the centre conductor microwave po wer propagating through it dielectric rod decides the amount of attenuation introduced. The microwave power absorbed by the lossy material is dissipated as heat.



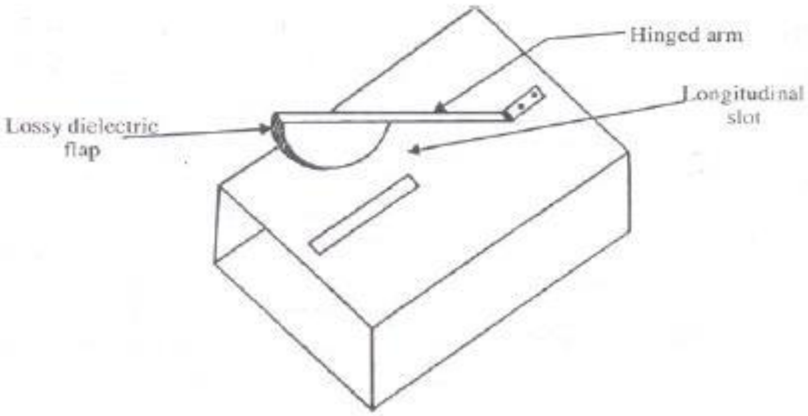


(a)

(b)

In waveguides, the dielectric slab coated with aduadag is placed at the centre of the waveguide parallel to the maximum E-field for dominant TEIO mode. Inducedcurrent on the lossy material due to incoming microwave signal, results in power dissipation, leading to attenuation of the signal. The dielectric slab is tapered at both ends upto a length of more than half wavelength to reduce reflections as shown in figure 5.7. The dielectric slab may be made movable along the breadth of the waveguide by supporting it with two dielectric rods separated by an odd multiple of quarter guidewavelength and perpendicular to electricfield.

When the slab is at the centre, then the attenuation is maximum (since the electric field is concentrated at the centre for TEIO mode) and when it is moved towards one side-wall, the attenuation goes on decreasing thereby controlling the microwave power corning outof the other port.

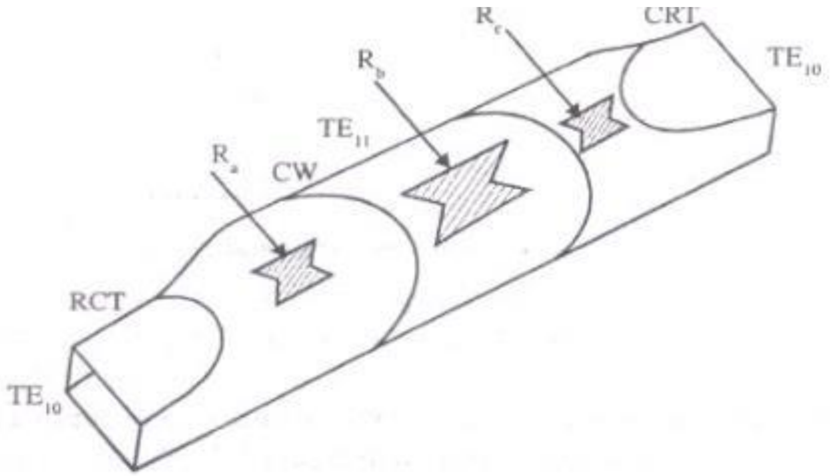


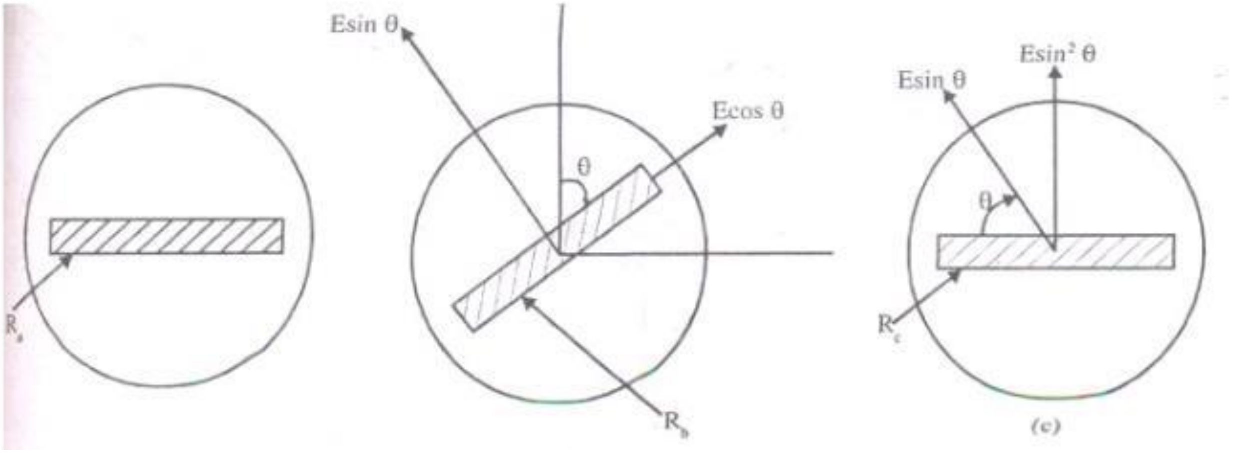
Above figure shows a flap attenuator which is also a variable attenuator. A semi-circular flap made of lossy dielectric is made to descend into the longitude in slot cut at the center of the top wall of rectangular waveguide. When the flap is completely outside the slot, then the attenuation is zero and when it is completely inside, the attenuation is maximum. A maximum direction of 90 dB attenuation is possible with this attenuator with a VSWR of 1.05. The dielectric slab can be properly shaped according to convenience to get a linear variation of attenuation within the depth of insertion.

A precision type variable attenuator consists of a rectangular to circular transition (ReT), a piece of circular waveguide (CW) and a circular-to-rectangular transition (CRT) as shown in below figure . Resistive cards Ra, Rb and Rc are placed inside these sections as shown. The centre circular section containing the resistive card Rb can be precisely rotated by 3600 with respect to the two fixed resistive cards. The induced current on the resistive card R due to the incident signal is dissipated as heat producing attenuation of the transmitted signal. TE mode in RCT is converted into TE in circular waveguide. The resistive cards R and R a kept perpendicular to the electric field of TEIO mode so that it does not absorb the energy. But any component parallel to its plane will be readily abs orbed. Hence, pure TE mode is excited in circular waveguide section II.

If the resistive card in the centre section is kept at an angle 8 relative to the E-field direction of the TEll mode, the component Ecos(θ) parallel to the card get absorbed while the component E sin θis transmitted without attenuation. This component finally comes out as E sin2θ

as shown in figure below.





PHASE SHIFTERS:

A microwave phase shifter is a two port device which produces a variable shift in phase of the incoming microwave signal. A lossless dielectric slab when placed inside the rectangular waveguide produces a phase shift.

PRECISION PHASE SHIFTER

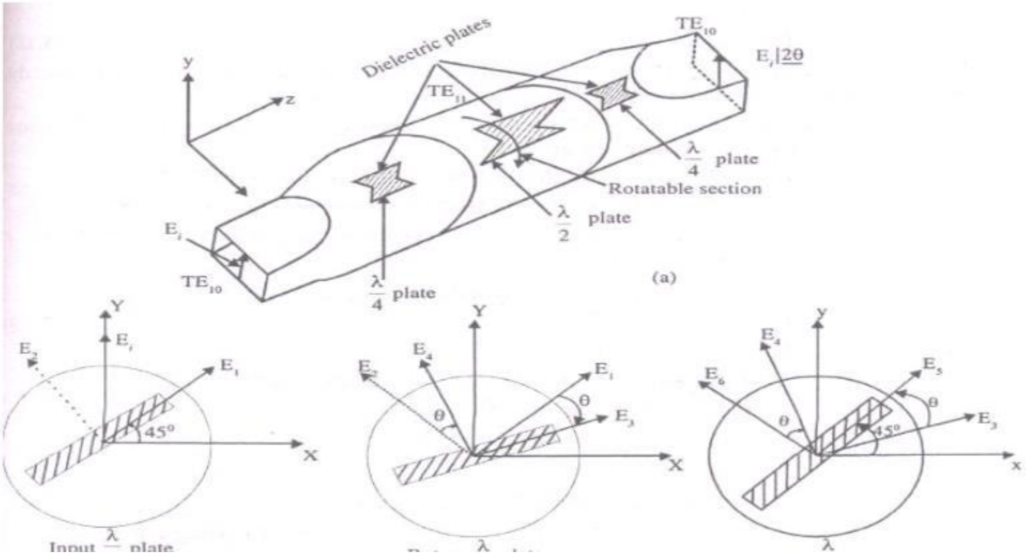
The rotary type of precision phase shifter is shownin figure below which consists of a circular waveguide containing a lossless dielectric plate of length 2lcalled "half-wave section", a section of rectangular-to-circular transition containing a lossless dielectric plate of length l, called "quarter-wave section", oriented at an angle of 45° to the broader wall of the rectangular waveguide and a circular-to-rectangular transition again containing a lossless dielectric plate of same length 1 (quarter wave section) oriented at an angle 45°.

The incident TE10 mode becomes TEll mode in circular waveguide section. The half-wave section produces a phase shift equal to twice that produced by the quarter wave section. The dielectric plates are tapered at both ends to reduce reflections due to discontinuity.

$$E_1 = (E_i \cos 45^0)\, e^{-j\beta_1 l} = E_0\, e^{-j\beta_1 l}$$

and $$E_2 = (E_i \sin 45^0)\, e^{-j\beta_2 l} = E_0\, e^{-j\beta_2 l}$$

Where $$E_0 = \frac{E_i}{\sqrt{2}}$$



When TE10 mode is propagated through the input rectangular waveguide of the rectangular to circular transition, then it is converted into TEll in the circular waveguide section. Let E; be the maximum elelectric field strength of this mode which is resolved into components, EI parallel to the plate and E2 perpendicular to El as shown in figure 5.12 (b). After propagation through the plate these components are given by

The length I is adjusted such that these two components E1 and Ez have equal amplitude but differing in phase by = 90

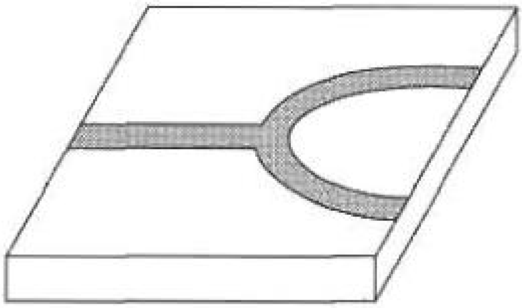
The quarter wave sections convert a linearly polarized TEll wave into a circularly polarized wave and vice-versa. After emerging out of the half-wave section,the electric field components parallel and perpendicular

to the half-wave plate After emerging out of the half-wave section, the field components E3 and E4 as given in above equations, may again be resolved into two TEll modes, polarized parallel and perpendicular to the output quarter-wave plate. At the output end of this quarter-wave plate, the field components parallel and perpendicular to the quarter wave plate, by referring to figure above.

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.

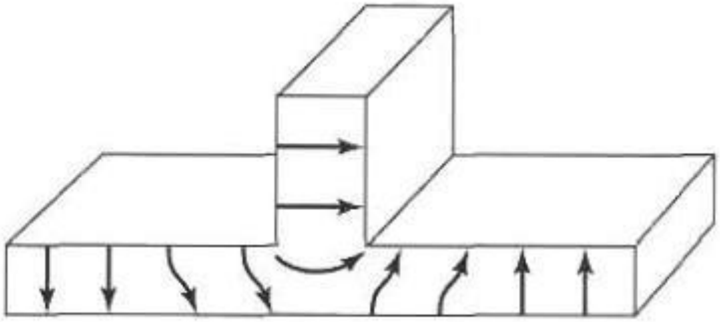


For very high frequency, power divider using waveguide is of 4 types

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

E-PLANE TEE:

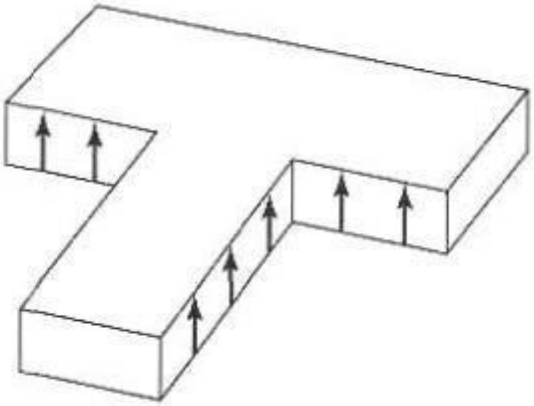
Diagram



- It can be constructed by making a rectangular slot along the wide dimension of the main waveguide and inserting another auxiliary waveguide along the direction so that it becomes a 3-port network.
- Port-1 and Port-2 are called collinear ports and Port-3 is called the E-arm.
- E-arm is parallel to the electric field of the main waveguide.
- If the wave is entering into the junction from E-arm it splits or gets divided into Port-1 and Port-2 with equal magnitude but opposite in phase
- If the wave is entering through Port-1 and Port-2 then the resulting field through Port-3 is proportional to the difference between the instantaneous field from Port-1 and Port-2

H-PLANE TEE:

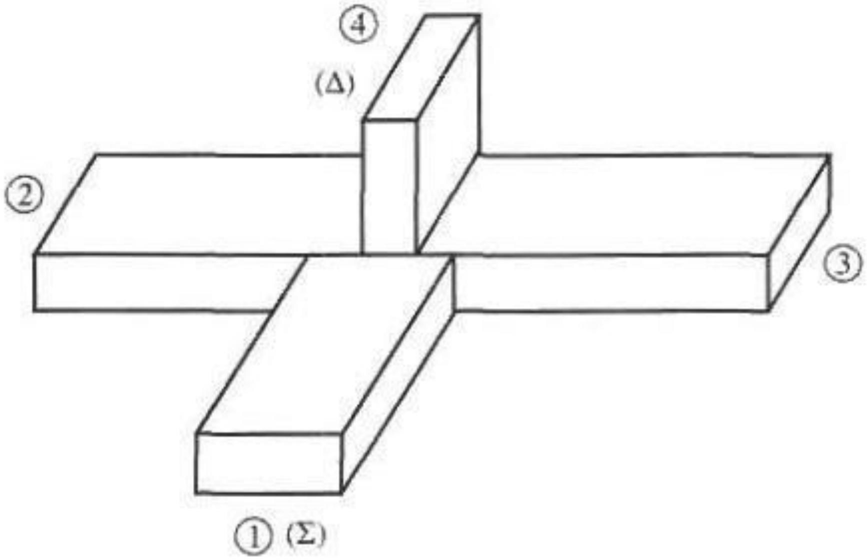
Diagram:



- An H-plane tee is formed by making a rectangular slot along the width of the main waveguide and inserting an auxiliary waveguide along this direction.
- In this case, the axis of the H-arm is parallel to the plane of the main waveguide.
- The wave entering through H-arm splits up through Port-1 and Port-2 with equal magnitude and same phase
- If the wave enters through Port-1 and Port-2 then the power through Port-3 is the phasor sum of those at Port-1 and Port-2.
- E-Plane tee is called PHASE DELAY and H-Plane tee is called PHASE ADVANCE.

E-H PLANE TEE/MAGIC TEE:

Diagram:

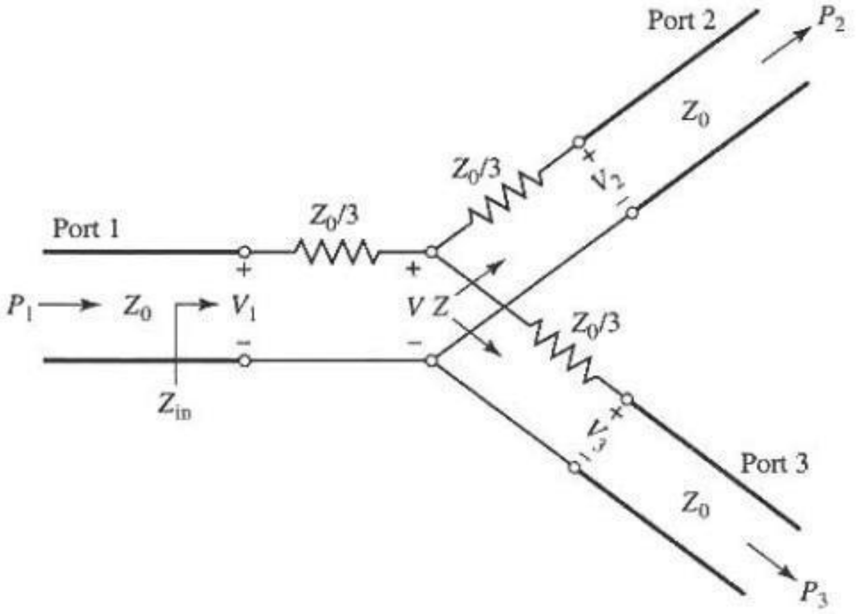


- It is a combination of E-Plane tee and H-Plane tee.

- If two waves of equal magnitude and the same phase are fed into Port-1 and Port-2, the output will be zero at Port-3 and additive at Port-4.
- If a wave is fed into Port-4 (H-arm) then it will be divided equally between Port-1 and Port-2 of collinear arms (same in phase) and will not appear at Port-3 or E-arm.
- If a wave is fed in Port-3 then it will produce an output of equal magnitude and opposite phase at Port-1 and Port-2 and the output at Port-4 will be zero.
- If a wave is fed in any one of the collinear arms at Port-1 or Port-2, it will not appear in the other collinear arm because the E-arm causes a phase delay and the H-arm causes phase advance.

T-JUNCTION POWER DIVIDER USING TRANSMISSION LINE:

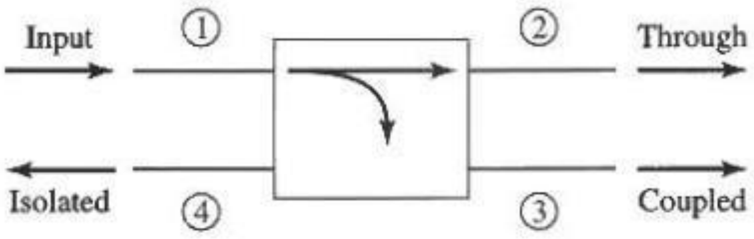
Diagram:

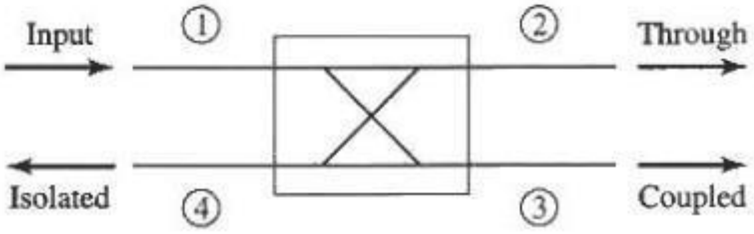


- It is a junction of 3 transmission lines
- In this case, if P1 is the input port power then P2 and P3 are the power of output Port-2 and Port-3 respectively.
- To transfer maximum power from port-1 to port-2 and port-3 the impedance must match at the junction.

DIRECTIONAL COUPLER:

Diagram:





- It is a 4- port waveguide junction consisting of a primary waveguide 1-2 and a secondary waveguide 3-4.
- When all the ports are terminated in their characteristic impedance there is free transmission of power without reflection between port-1 and port-2 and no power transmission takes place between port-1 and port-3 or port-2 and port-4 a sno coupling exists.
- The characteristic of a directional coupler is expressed in terms of its coupling factor and directivity.
- The coupling factor is the measure of ratio of power levels in primary and secondary lines.
- Directivity is the measure of how well the forward travelling wave in the primary waveguide couples only to a specific port of the secondary waveguide.
- In ideal case, directivity is infinite i.e. power at port-3 =0 because port-2 and port-4 are perfectly matched.
- Let wave propagates from port-1 to port-2 in primary line then:

Coupling factor (dB) =10 log10 (P1/P4)
Directivity (dB) = 10 log10 (P4/P3)

Where P1=power input to port-1
P3=power output from port-3 and P4=power output from port-4

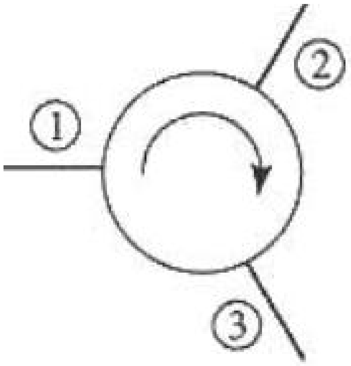
CIRCULATORS AND ISOLATORS:

Both microwave circulators and microwave isolators are non-reciprocal transmission devices that use Faraday rotation in the ferrite material.

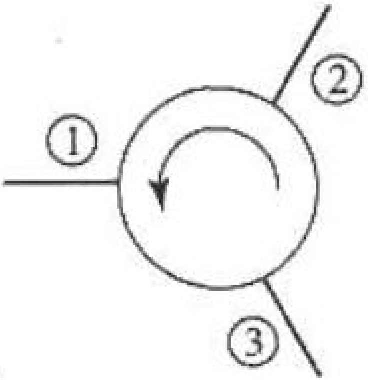
CIRCULATOR:

- A microwave circulator is a multiport waveguide junction in which the wave can flow only in one direction i.e. from the nth port to the (n+1)th port.
- It has no restriction on the number of ports
- 4-port microwave circulator is most common.
- One of its types is a combination of two 3-dB side hole directional couplers and a rectangular waveguide with two non reciprocal phase shifters.

Diagram:



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



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

- Each of the two 3db couplers introduce phase shift of 90 degrees
- Each of the two phase shifters produce a fixed phase change in a certain direction.
- Wave incident to port-1 splits into 2 components by coupler-1.
- The wave in primary guide arrives at port-2 with 180 degrees phase shift.
- The second wave propagates through two couplers and secondary guide and arrives at port-2 with a relative phase shift of 180 degrees.
- But at port-4 the wave travelling through primary guide phase shifter and coupler-2 arrives with 270 degrees phase change.
- Wave from coupler-1 and secondary guide arrives at port-4 with phase shift of 90 degrees.

Power transmission from port-1 to port-4 =0 as the two waves reaching at port-4 are out of phase by 180 degrees.

$$\mathbf{w1-w3 = (2m+1)\,\pi\ rad/s}$$
$$\mathbf{w2-w4 = 2n\pi\ rad/s}$$

Power flow sequence: 1-> 2 -> 3 -> 4-> 1

MICROWAVE ISOLATOR:

- A non reciprocal transmission device used to isolate one component from reflections of other components in the transmission line.
- Ideally complete absorption of power takes place in one direction and lossless transmission is provided in the opposite direction
- Also called UNILINE, it is used to improve the frequency stability of microwave generators like klystrons and magnetrons in which reflections from the load affects the generated frequency.
- It can be made by terminating ports 3 and 4 of a 4-port circulator with matched loads.
- Additionally it can be made by inserting a ferrite rod along the axis of a rectangular waveguide.

DIRECTIONAL COUPLER (DC):

Directional coupler is a 4 port wave guide junction. It consists of a primary wave guide and a secondary wave guide connects together through apertures. These are uni directional devices. Directional couplers are required to satisfy (1) reciprocity (2) conservation of energy (3) all ports matched terminated.

The characteristics of a **DC** can be expressed in terms of its:

1) Coupling factor: The ratio, in dB, of the power incident and the power coupled in auxiliary arm in forward direction.

Where Pi = Incident power; Pc = Coupled Power

2) Directivity: The ratio expressed in decibels, of the power coupled in the forward direction to the power coupled in the backward direction of the auxiliary arm with unused terminals matched terminated.

$$D = 10\log_{10}(P_c/P_r)\ \mathrm{dB}$$

Where Pr = Reverse Power

Pc = Coupled Power

3) Insertion loss: The Ratio, expressed in decibels, of the power incident to the power transmitted in the main line of the coupler when auxiliary arms are matched terminated.

$I = 10\log_{10}(P_i / P_{i1})$

Where Pi1 = Received power at the transmitted port

4) Isolation: The ratio, expressed in decibels of the power incident in the main arm to the backward power coupled in the auxiliary arm, with other ports matched terminated.

$$L= 10\log_{10} (Pi/Pr) \text{ Db}$$

For an ideal coupler D & I are infinite while C& L are Zero

Several types of directional couplers exist,
such as

1. Two hole directional coupler, Schwinger
2. directional coupler and Bethi - hole directional coupler.

Directional couplers are very good power samplers.

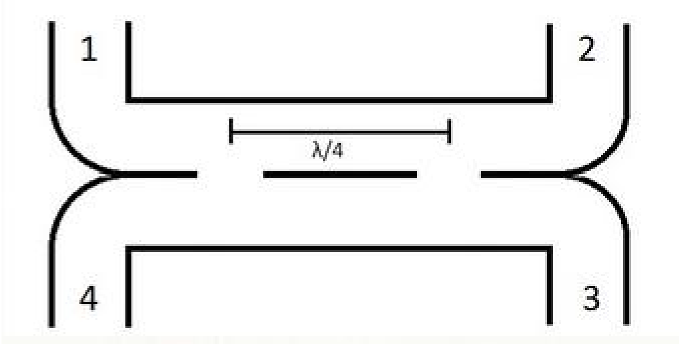
Bethe-hole coupler

Bethe-hole is a waveguide directional coupler, using a single hole, and it works over a narrow band. The Bethe-hole is a reverse coupler, as opposed to most waveguide couplers that use multi-hole and are forward couplers.

The origin of the name comes from a paper published by H A Bethe, titled "Theory of Diffraction by Small Holes", published in the Physical Review, back in 1942. If you google it you might find it, even though it is probably subject to copyright protection. This is a tough read, unless you like to ponder equations....

Multi-hole coupler

In waveguide, a two-hole coupler, two waveguides share a broad wall. The holes are 1/4 wave apart. In the forward case the coupled signals add, in the reverse they subtract (180 apart) and disappear. Coupling factor is controlled by hole size. The "holes" are often x-shaped, or perhaps other proprietary shapes. It is possible to provide very flat coupling over an entire waveguide band if you know what you are doing (think "Chebychev"...)



TWO HOLE DIRECTIONAL COUPLERS:

A two hole directional coupler with traveling wave propagating in it is illustrated. The spacing between the centers of two holes is

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

A fraction of the wave energy entered into port 1 passes through the holes and is radiated into the secondary guide as he holes act as slot antennas. The forward waves in the secondary guide are in same phase , regardless of the hole space and are added at port 4. the backward waves in the secondary guide are out of phase and are cancelled in port 3.