Microwave Laboratory Components

In Microwave laboratory, various components are used to characterize and measurement of various microwave component and parameters. The details descriptions of components used are given subsequently.

Waveguides

Waveguides are basically a device ("a guide") for transporting electromagnetic energy from one region to another. Typically, waveguides are hollow metal tubes (often rectangular or circular in cross section). They are capable of directing power precisely to where it is needed, can handle large amounts of power and function as a high-pass filter.

The waveguide acts as a high pass filter in that most of the energy above a certain frequency (the cutoff frequency) will pass through the waveguide, whereas most of the energy that is below the cutoff frequency will be attenuated by the waveguide. Waveguides are often used at microwave frequencies (greater than 300 MHz, with 8 GHz and above being more common).

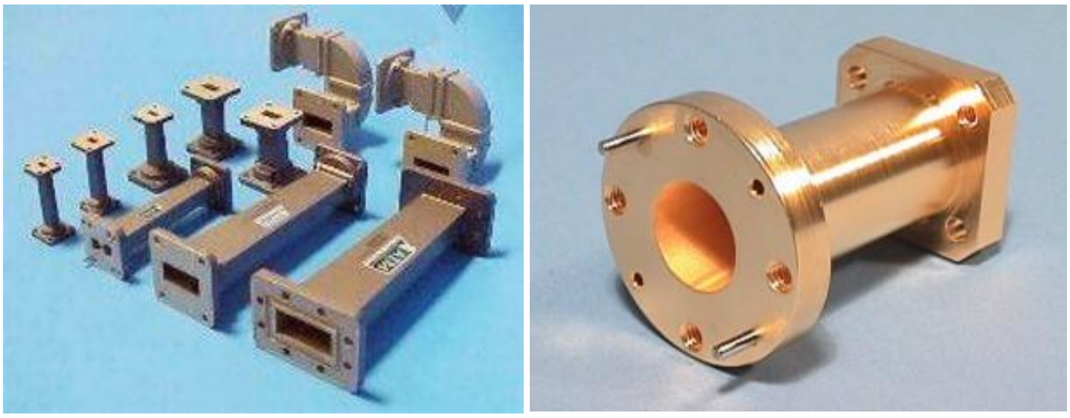

Figure Waveguide

Since waveguides are really only hollow metal pipes, the installation and the physical handling of waveguides have many similarities to ordinary plumbing. In light of this fact, the bending, twisting, joining, and installation of waveguides is commonly called waveguide plumbing

In order to determine the EM field configuration within the waveguide, Maxwell's equations should be solved subject to appropriate boundary conditions at the walls of the guide. Such solutions give rise to a number of field configurations. Each configuration is known as a mode.

The mode with the lowest cutoff frequency is termed the dominant mode of the guide. It is usual to choose the size of the guide such that only this one mode can exist in the frequency band of operation. In rectangular and circular (hollow pipe) waveguides, the dominant modes are designated the TE_{10} mode and TE_{11} modes respectively.

Waveguide Corners, Bends and Twists

The waveguide components are generally used to change the direction of the guide through an arbitrary angle. The bend is designated as E-plane if the E-field line in the cross section changes direction. The bend in which E-field lines are always have same direction is known as H-plane bend. In order to minimize reflection from discontinuities, it is desirable to have the mean length L between continuities equal to an odd number of quarter-wave lengths. That is,

$L=(2n+1)\lambda g/4$, where n=0,1,2…and λg is the wavelength in waveguide

If the mean length L is an odd number of quarter wavelengths, the reflected waves from both ends of the waveguide section are completely cancelled. For the waveguide bend the minimum radius of curvature for a small reflection is given by,

$R=1.5b$ for an E bend

$R=1.5a$ for an H bend

Where a, b are the dimensions of the waveguide bend. Different types of corners, bends and twists are show in the figure below.

Waveguides may be bent in several ways that do not cause reflections. One way is the gradual bend shown in figure. This gradual bend is known as an E bend because it distorts the E fields. The E bend must have a radius greater than two wavelengths to prevent reflections

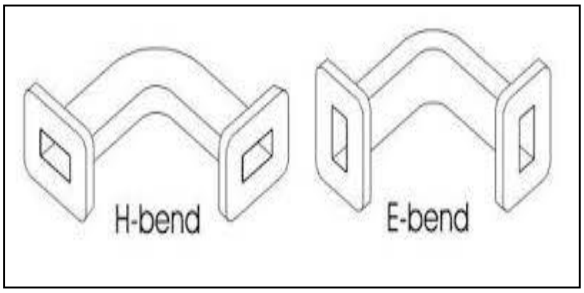

Figure: Waveguide E and H bends

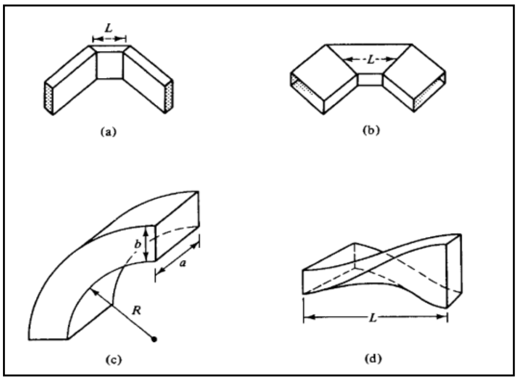

Figure: Waveguide corner, bend and twist (a) E-plane corner, (b) H-plane corner, (c) Bend.(d) Continuous twist

Sometimes the electromagnetic fields must be rotated so that they are in the proper phase to match the phase of the load. This may be accomplished by twisting the waveguide as shown in figure. The twist must be gradual and greater than 2l

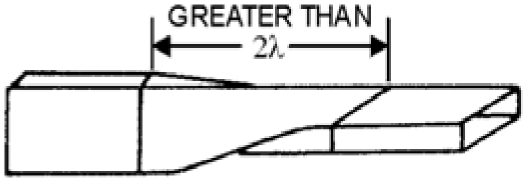

Figure Waveguide twist

Waveguide Tees

In microwave circuits a waveguide or co-axial line junction with three independent ports is commonly referred to as a tee junction. From S- Parameter theory of a microwave junction it is evident that a tee junction should be characterized by a matrix of third order containing nine elements, six of which should be independent . The characteristics of a three port junction can be explained by three theorems of the junction.

1. A short circuit may always be placed in one of the arms of a 3-port junction in such a way that no power can be transferred through the other two arms.
2. If the junction is symmetric about one of its arms, a short circuit can always be placed in that arm so that no reflections occur in power transmission between the other two arms.
3. It possible for a general 3-port junction of arbitrary symmetry to present matched impedances at all 3 arms.

E-plane tee (series tee) – It is called an E-type T junction because the junction arm, i.e. the top of the "T" extends from the main waveguide in the same direction as the E field. It is characterized by the fact that the outputs of this form of waveguide junction are 180° out of phase with each other.

H-plane tee (shunt tee) – This type of waveguide junction is called an H-type T junction because the long axis of the main top of the "T" arm is parallel to the plane of the magnetic lines of force in the waveguide. It is characterized by the fact that the two outputs from the top of the "T" section in the waveguide are in phase with each other.

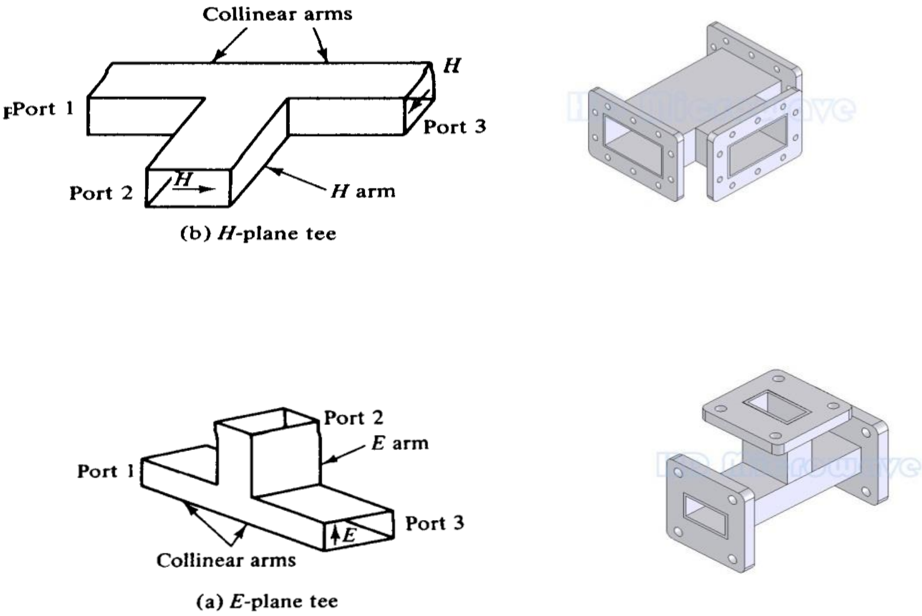

Figure Waveguide Tees

Magic Tees (Hybrid tees)- The magic-T is a combination of the H-type and E-type T junctions. The most common application of this type of junction is as the mixer section for microwave radar receivers. The magic tee has several characteristics

1. If the two ports 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.

2. If a wave is fed into port 4 (H arm), it will be divided equally between port 1 and port 2 of the collinear arms and will not appear in port 3.

3. If a wave is fed into port 3 (E arm), it will produce an output of equal magnitude and opposite phase at port 1 and port 2. The output at port 4 is zero.

4. If a wave is fed into one of the collinear arms at port 1 or port 2, it will not appear in the other collinear arm at port 2 or port 1 because the E-arm causes a phase delay while the H-arm causes a phase advance.

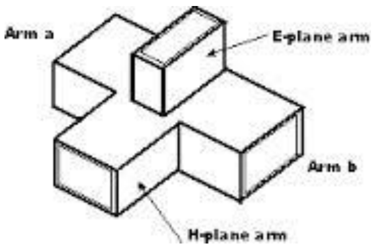

Figure Magic Tee

Directional Couplers

A directional coupler is a four-port waveguide junction. It consists of a primary waveguide and a secondary waveguide. When all the ports are terminated in their characteristic impedance there is no free transmission of power, without reflection between port 1 and port 2, and there is no transmission of power between ports 1 and port3 and between ports 2 and 4 because no coupling exists between these two pair of ports. The degree of coupling between ports 1 and 4 and between ports 2 and 3 depends on the structure of the coupler.

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Figure Directional Couplers

The characteristics of a directional coupler can be expressed in terms of its coupling factor and its directivity. Assuming that the wave is propagating from port 1 to port 2 in the primary line, the coupling factor and the directivity are defined, respectively by

$$\text{Coupling factor(dB)} = 10 \log_{10} (P_1/P_4)$$

$$\text{Directivity(dB)} = 10 \log_{10} (P_4/P_3)$$

Where P_1= power input to port 1
P_3= power output from port 3
P_4= power output from port 4

Circulator

Microwave Isolator is a passive, non-reciprocal device with three or more ports used to transmit microwave energy in a specific direction. This Microwave Isolator is used to prevent reflected microwave energy from the magnetron preventing excessive magnetron heating or molding.

Generally a circulator is a three-port device that can be lossless and matched at all ports; by using the unitary properties of the scattering matrix we were able to show how such a device must be nonreciprocal. The scattering matrix for an ideal circulator thus has the following form:

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

which shows that power flow can occur from ports 1 to 2, 2 to 3, and 3 to 1, but not in the reverse direction.

The make a great antenna interface for a transmit/receive system. Energy can be made to flow from the transmitter (port 1) to the antenna (port 2) during transmit, and from the antenna (port 2) to the receiver (port 3) during receive.

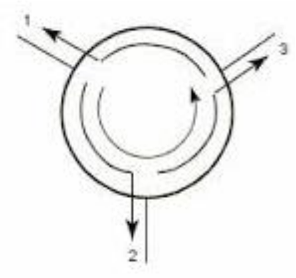

Figure Circulator

Isolators

Microwave Isolator is a passive, non-reciprocal device with three or more ports used to transmit microwave energy in a specific direction. This Microwave Isolator is used to prevent reflected microwave energy from the magnetron preventing excessive magnetron heating or molding. Microwave Isolator is a circulator with an absorbing load, attaching to the port used to transmit the reflected energy that is generated from the magnetron and is transmitted to the load port and absorbed. By terminating one port, a circulator becomes an isolator, which has the property that energy flows on one direction only. This is an extremely useful device for "isolating" components in a chain, so that bad VSWRs don't contribute to gain ripple.

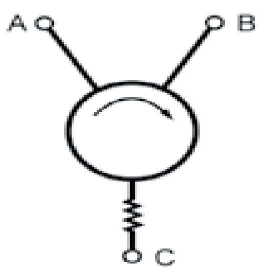

Figure Isolator

Attenuators

Any matched load is of course an attenuator which absorbs almost all of the power. If the load is shortened and a matched taper placed on the output as well as the input, a fixed amount of power can be absorbed by the load while rest is transmitted. Attenuators can use cards or solid lossy materials.

Fixed attenuators: All of the standard fixed attenuators are manufactured from selected waveguide tube. The attenuating element is manufactured from a metalized glass fiber reinforced PTFE, resistive card vane or an absorptive composite material. The vane version is supported in the waveguide using two metal rods and is accurately positioned to give a desired value between 0 and 40dB as required. The composite absorber is positioned and glued into the tube.

Variable Attenuators: Based upon the same construction as the Fixed Attenuators, the metalized glass fiber reinforced PTFE resistive card vane is positioned in the Waveguide using a backlash free, spring controlled piston, precisely fitted in a machined housing to give a high degree of mechanical stability. The attenuation is varied by means of a knurled finger-control knob, and a locking screw is provided for repetitive measurements, or, in the case of the variable precision devices, the attenuation is varied by means of a standard micrometer drive. Movement of the vane is achieved by the means of an eccentric cam attached to the control knob.

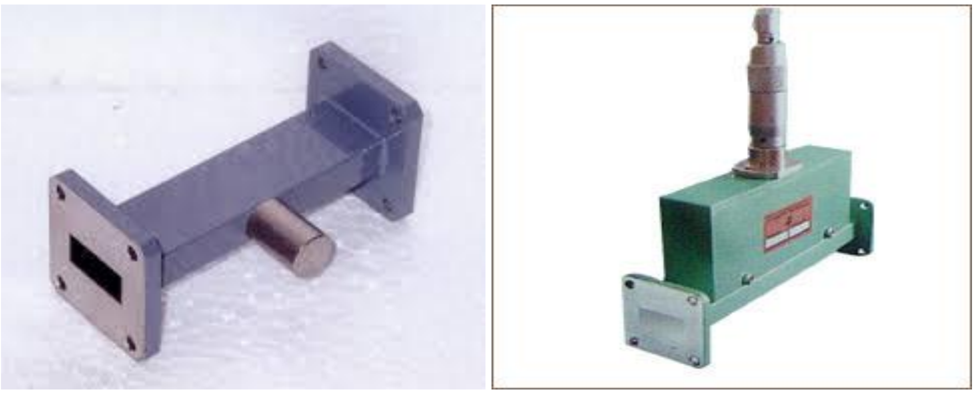

Figure Attenuators (Fixed and Variable)

Matched Load(Terminations):

The device which has an excellent match (zero reflection) and complete absorption of all the power incident on it is called matched load or matched termination. Matched loads are necessary when other microwave components are being developed and tested. A simple form of matched load in waveguide is a piece of resistance card placed in the waveguide parallel to the electric field as shown in figure.

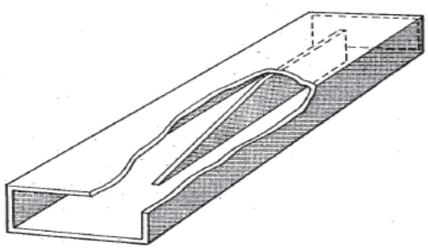

Figure Card load

The front of the card must be tapered so that it presents no discontinuity to the microwave signal. If the card is long enough to absorb almost all of the power, the reflections from far end will be sufficiently small so that the net reflection is negligible. If the card is on the center-line of the waveguide it will produce the greatest attenuation, since it is at the point of maximum field. Any lossy material can be used as a matched load in a waveguide as long as provision is made to avoid a reflection from the front end. Figure 14 shows some configurations of solid loads which fill the wave guide cross section. Materials commonly used for solid loads are lossy dielectrics, dielectric loaded with carbon or powered metal, wood, sand, or in fact anything which is not a good conductor.

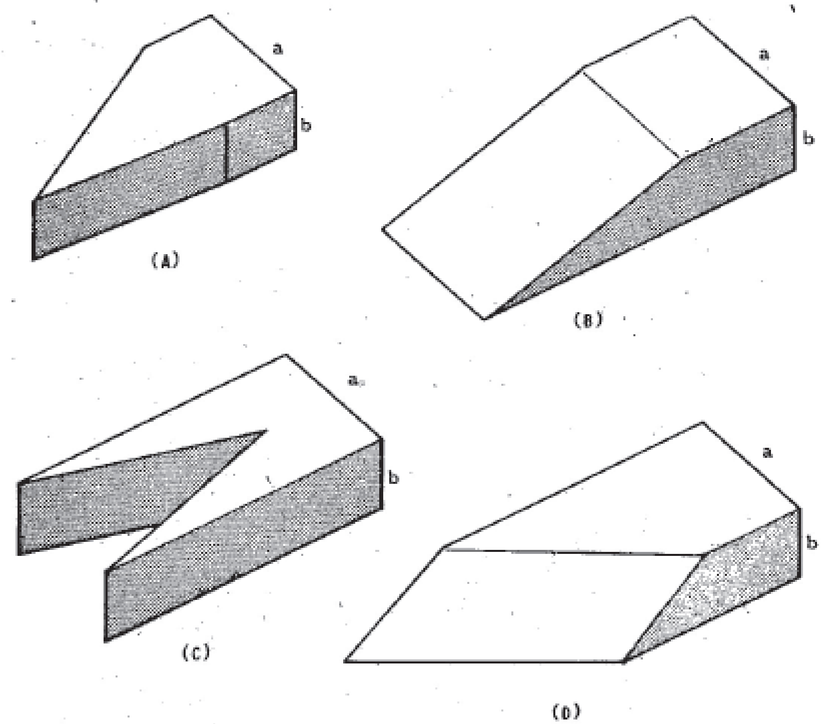

Figure Solid Waveguide loads

Adjustable Waveguide short

It consists of a section of a waveguide in which a movable, low loss, contacting finger wiper or choke type short is fitted. Sometimes a micrometer is connected to locate the position of short precisely or to adjust the short circuit plane position with high displacement accuracy, of the order of .02 mm. Such type of short is known as precision variable short. Adjustable shorts are convenient components for introducing a variable impedance in waveguide system and provide variable short circuit reference point. With a waveguide Tee section, they can form a sub transformer or tuner providing variable reactance. They may also be used as a convenient tuner for crystal or bolometer mount.

Figure Adjustable Waveguide short

Frequency Meter

It consists of a cylindrical tunable cavity mounted with its axis perpendicular to the main waveguide and is coupled to the guide through small hole . The resonant frequency of the cavity can be varied by varying the position of plunger in the cavity. Back of the plunger is coated with the microwave absorbing material such as polyiron to prevent resonance in the back cavity. In order to obtain high accuracy, Q of the cavity is made very high of the order of 1000. A micrometer is attached to plunger to indicate frequency directly. The output of the cavity frequency meter decreases when the cavity is tuned through resonance since the cavity absorbs a part of the power from the main line at resonance. At frequency far from resonance the cavity presents an effective short circuit to the waveguide wall. The frequency measurement would, therefore, consists of tuning the cavity of the frequency meter until maximum dip occurs on the indicating meter and then reading the micrometer position and the corresponding frequency from the calibration chart provided with the frequency meter.

Direct Reading Frequency Meters are simple to operate and offer a high degree of measurement accuracy over the appropriate recommended waveguide frequency range. The design uses a TE_{011} mode high Q cavity tuned by a precision non contacting piston. The drive mechanism is coupled to a helical drum scale directly calibrated in GHz.

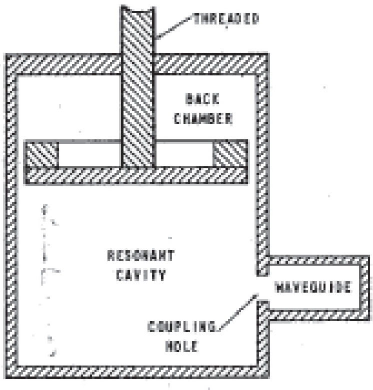

Figure Frequency meter

Horn Antennas

A horn antenna or microwave horn is an antenna that consists of a flaring metal waveguide shaped like a horn to direct radio waves in a beam. A horn antenna is used to transmit radio waves from a waveguide out into space, or collect radio waves into a waveguide for reception. It typically consists of a short length of rectangular or cylindrical metal tube (the waveguide), closed at one end, flaring into an open-ended conical or pyramidal shaped horn on the other end.

These are the common types of horn antenna. Horns can have different flare angles as well as different expansion curves (elliptic, hyperbolic, etc.) in the E-field and H-field directions, making possible a wide variety of different beam profiles.

Pyramidal horn: A horn antenna with the horn in the shape of a four-sided pyramid, with a rectangular cross section. They are a common type, used with rectangular waveguides, and radiate linearly polarized radio waves.

Sectoral horn: A pyramidal horn with only one pair of sides flared and the other pair parallel. It produces a fan-shaped beam, which is narrow in the plane of the flared sides, but wide in the plane of the narrow sides. These types are often used as feed horns for wide search radar antennas.

E-plane horn: A sectoral horn flared in the direction of the electric or E-field in the waveguide.

H-plane horn: A sectoral horn flared in the direction of the magnetic or H-field in the waveguide.

Conical horn: A horn in the shape of a cone, with a circular cross section. They are used with cylindrical waveguides.

Exponential horn (e): A horn with curved sides, in which the separation of the sides increases as an exponential function of length. Also called a *scalar horn*, they can have pyramidal or conical cross sections. Exponential horns have minimum internal reflections, and almost constant impedance and other characteristics over a wide frequency range. They are used in applications requiring high performance, such as feed horns for communication satellite antennas and radio telescopes.

Corrugated horn: A horn with parallel slots or grooves, small compared with a wavelength, covering the inside surface of the horn, transverse to the axis. Corrugated horns have wider bandwidth and smaller side lobes and cross-polarization, and are widely used as feed horns for satellite dishes and radio telescopes.

Ridged horn: A pyramidal horn with ridges or fins attached to the inside of the horn, extending down the center of the sides. The fins lower the cutoff frequency, increasing the antenna's bandwidth.

Septum horn: A horn which is divided into several subhorns by metal partitions (septums) inside, attached to opposite walls.

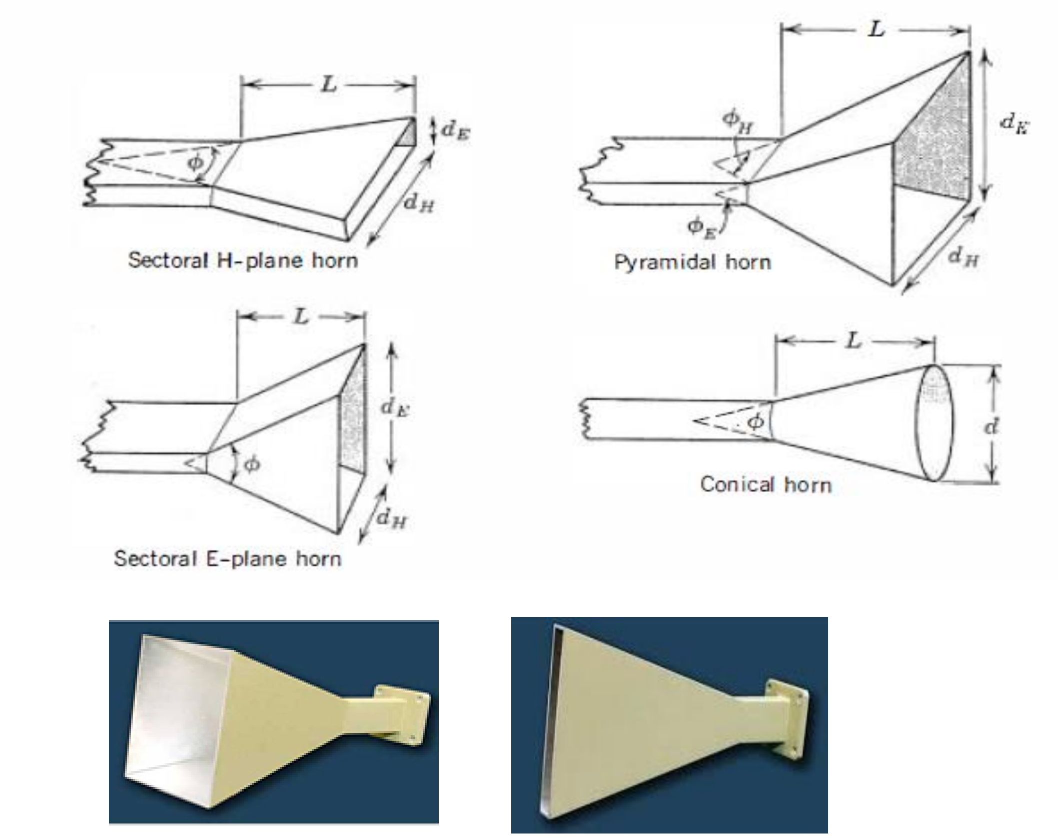

Figure Horn Antennas

Waveguide Detector Mount (Tunable)

Tunable Detector Mount is simple and easy to use instrument for detecting microwave power through a suitable detector. It consists of a detector crystal mounted in a section of a Wave guide and shorting plunger for matching purpose. The output from the crystal may be fed to an indicating instrument

Figure Detector Mount

Slide Screw Tuner

Tuners are based on precision slide screw technology that utilizes broadband slab line transmission structure and passive probes to create impedances for devices.

The probes are designed to be very close to one-quarter wavelength in the linear dimension at the mid-band of each range. Slide screw tuners are used for matching purposes by changing the penetration and position of a screw in the slot provided in the centre of the wave guide. These consist of a section of wave guide flanged on both ends and a thin slot is provided in the broad wall of the Wave guide. A carriage carrying the screw is provided over the slot. A VSWR upto 20 can be tuned to a value less than 1.02 at certain frequency

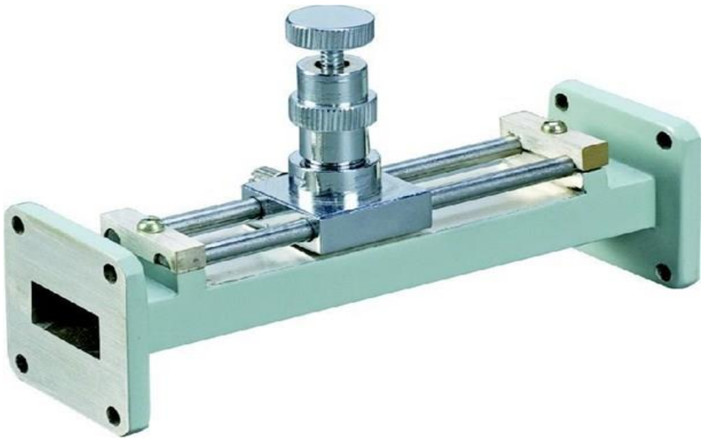

Figure Slide Screw Tuner

Slotted Line and tunable probe

The waveguide slotted line with probe consists of an accurately machined section of waveguide in which a small longitudinal slot has been cut and a probe. This is used for monitoring standing wave patterns into wave guide system, measuring the VSWR and impedance of the unknown load.

Slotted lines are used for microwave measurements and consist of a movable probe inserted into a slot in a transmission line. It consists of a waveguide, with a movable insulated probe inserted into a longitudinal slot cut into the line. In a rectangular waveguide, the slot is usually cut along the center of the broad wall of the waveguide. Circular waveguide slotted lines are also possible.

The slotted line works by sampling the electric field inside the transmission line with the probe. For accuracy, it is important that the probe disturbs the field as little as possible. For this reason the probe diameter and slot width are kept small (usually around 1 mm) and the probe is inserted in no further than necessary. It is also necessary in waveguide slotted lines to place the slot at a position where the current in the waveguide walls is parallel to the slot. The current will then not be disturbed by the presence of the slot as long as it is not too wide. For the dominant mode this is on the center-line of the broad face of the waveguide, but for some other modes it may need to be off-center. This is not an issue for the co-axial line because this operates in the TEM (transverse electromagnetic) mode and hence the current is everywhere parallel to the slot. The slot may be tapered at its ends to avoid discontinuities causing reflections.

The disturbance to the field inside the line caused by the insertion of the probe is minimized as far as possible. There are two parts to this disturbance. The first part is due to the power the probe has extracted from the line and manifests as a lumped equivalent circuit of a resistor. This is minimized by limiting the distance the probe is inserted into the line so that only enough power is extracted for the detector to operate effectively. The second part of the disturbance is due to energy stored in the field around the probe and manifests as a lumped equivalent of a capacitor. This capacitance can be cancelled out with an inductance of equal and opposite impedance. Lumped inductors are not practical at microwave frequencies; instead, an adjustable stub with an inductive equivalent circuit is used to "tune out" the probe capacitance. The result is an equivalent circuit of a high impedance in shunt across the line which has little effect on the transmitted power in the line. The probe is more sensitive as a result of this tuning and the distance it is inserted can be further limited as a result. The probe is connected to a detector and a VSWR meter. The detector can be a crystal detector or a Schottky barrier diode. The detector is mounted on the probe assembly, usually a distance λ/4 from the probe tip. This is because the detector looks almost like a short circuit to the transmission line, and this distance will convert it to an open circuit through the quarter-wave impedance transformer effect. Thus, the detector has minimal effect on loading the line. The probe tuning stub branching from the line linking the probe to the detector

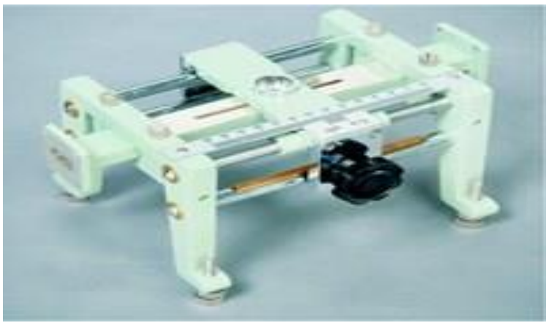

Figure Slotted Line and Tunable Probe

Klystron and Klystron Power Supply

A klystron is a specialized vacuum tube (evacuated electron tube) called a linear-beam tube. The pseudo-Greek word klystron comes from the stem form -(klys) of a Greek verb referring to the action of waves breaking against a shore, and the end of the word electron

Klystrons are used as an oscillator or amplifier at microwave and radio frequencies to produce both low power reference signals for super heterodyne radar receivers and to produce high-power carrier waves for communications and the driving force for linear accelerators. It has the advantage (over the magnetron) of coherently amplifying a reference signal and so its output may be precisely controlled in amplitude, frequency and phase. Many klystrons have a waveguide for coupling microwave energy into and out of the device, although it is also quite common for lower power and lower frequency klystrons to use coaxial couplings instead. In some cases a coupling probe is used to couple the microwave energy from a klystron into a separate external waveguide.

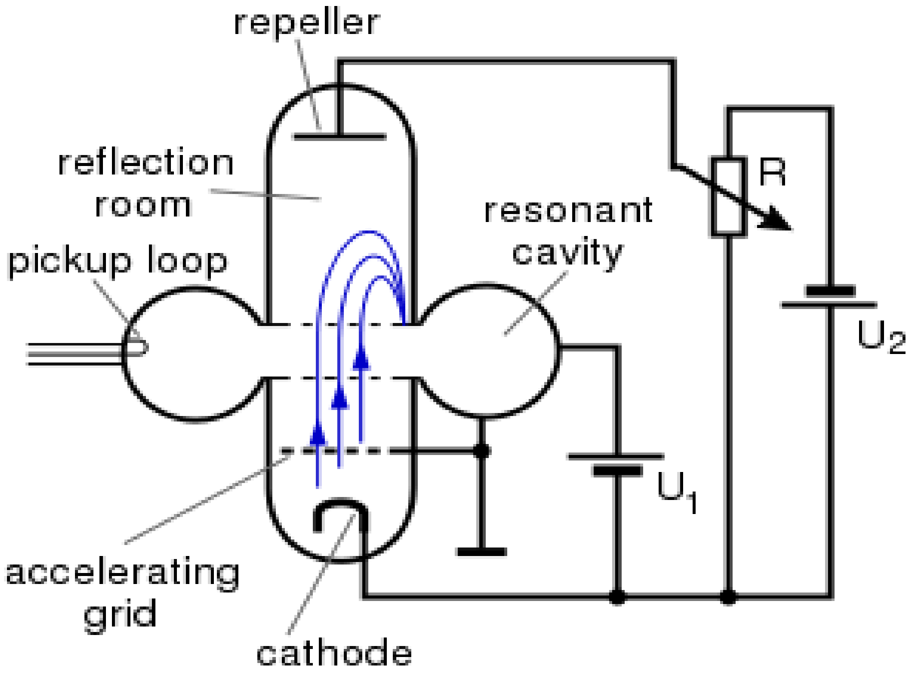

Figure Reflex Klystron

In Reflex klystron, electron beam passes through single resonant cavity. The electrons are fired into one end of the tube by an electron gun. After passing through the resonant cavity they are reflected by a negatively charged reflector electrode for another pass through the cavity, where they are then collected. The electron beam is velocity modulated when it first passes through the cavity. The formation of electron bunches takes place in the drift space between the reflector and the cavity. The voltage on the reflector must be adjusted so that the bunching is at a maximum as the electron beam reenters the resonant cavity, thus ensuring a maximum of energy is transferred from the electron beam to the RF oscillations in the cavity. The reflector voltage may be varied slightly from the optimum value, which results in some loss of output power, but also in a variation in frequency. This effect is used to good advantage for automatic frequency control in receivers, and in frequency modulation for transmitters. The level of modulation applied for transmission is small enough that the power output essentially remains constant. At regions far from the optimum voltage, no oscillations are obtained at all. There are often several regions of reflector voltage where the reflex klystron will oscillate; these are referred to as modes.

Three power sources are required for reflex klystron operation:

(1) Filament power

(2) Positive resonator voltage (often referred to as beam voltage) used to accelerate the electrons through the grid gap of the resonant cavity

(3) Negative repeller voltage used to turn the electron beam around.

The electrons are focused into a beam by the electrostatic fields set up by the resonator potential in the body of the tube. In addition to these voltage klystron power supply has the mode control switch of selecting CW or AM or FM. There also knobs provided for changing amplitude and frequency of the AM and FM.

Figure Reflex Klystron and power supply

VSWR meter

The VSWR meter measures the standing wave ratio in a transmission line. This is an item of radio equipment used to check the quality of the match between the antenna and the transmission line. The VSWR meter should be connected in the line as close as possible to the antenna. This is because all practical transmission lines have a certain amount of loss, causing the reflected power to be attenuated as it travels back along the cable, and producing an artificially low VSWR reading on the meter. If the meter is installed close to the antenna, then this problem is minimized.

The VSWR meter basically consists of high gain, high Q, low noise voltage amplifier normally tuned at fixed frequency (1 kHz) at which the microwave signal modulated. The VSWR meter used the detected signal out of microwave detector as its input, amplifies the same and provides the output on a calibrated voltmeter. The meter itself can be calibrated in terms of VSWR.

The VSWR meter has a gain control to adjust the reading to a desired value, by fine or coarse adjusting knobs. Normally, the overall gain is about 125dB that can be adjusted in steps of 10. Also there are three scales on the VSWR meter- normal

SWR, Expanded SWR and dB scales. Normal SWR scale can be used when the VSWR is between 1 and 4, when value up to 10 bottom of normal scale is used. The expanded scale is graduated from 1 to 1.3. The dB scale is at the bottom along with an expanded dB for measuring VSWR directly in dB.

Figure VSWR Meter