Government Girls' Polytechnic, Bilaspur

Name of the Lab: **Communication Lab**

Practical: **Antenna & Microwave Communication Lab**

Class : **V Semester (ET&T)**

Teachers Assessment: 10 End Semester Examination:30

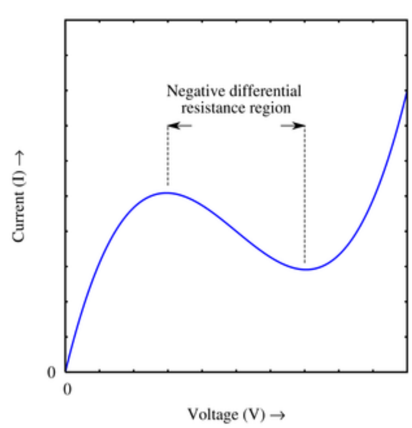
Experiment no 1

Objective: - Performance of Gunn Diode & Gunn Oscillator

Apparatus required – semiconductor material, Gunn diode.

Theory -

Gunn Diode: - A Gunn diode, also known as a transferred electron device (TED), is a form of diode used in high-frequency electronics. It is somewhat unusual in that it consists only of N-doped semiconductor material, whereas most diodes consist of both P and N-doped regions. In the Gunn diode, three regions exist: two of them are heavily N-doped on each terminal, with a thin layer of lightly doped material in between. When a voltage is



The VI curve for a Gunn diode, showing the negative differential resistance region

Applied to the device, the electrical gradient will be largest across the thin middle layer. Conduction will take place as in any conductive material with current being proportional to the applied voltage. Eventually, at higher field values, the conductive properties of the middle layer will be altered, increasing its resistivity and reducing the gradient across it, preventing further conduction and current actually starts to fall down. In practice, this means a Gunn diode has a region of negative differential resistance .

The negative differential resistance, combined with the timing properties of the intermediate layer, allows construction of an RF relaxation oscillator simply by applying a suitable direct current through the device. In effect, the negative differential resistance created by the diode will negate the real and positive resistance of an actual load and thus create a "zero" resistance circuit which will sustain oscillations indefinitely. The oscillation frequency is determined partly by the properties of the thin middle layer, but can be tuned by external factors. Gunn diodes are therefore used to build oscillators in the 10 GHz and higher (THz) frequency range, where a resonator is usually added to control frequency. This resonator can be take the form of a waveguide, microwave cavity or YIG sphere. Tuning is done mechanically, by adjusting the parameters of the resonator, or in case of YIG spheres by changing the magnetic field.

Gallium arsenide Gunn diodes are made for frequencies up to 200 GHz, gallium nitride materials can reach up to 3 terahertz. The Gunn diode is named for the physicist J.B. Gunn who, in 1963, produced the first device based upon the theoretical calculations of Cyril Hilsum.

Performance :-

GaAs has a third band above the conduction band. The gap is indirect, so a phonon is needed or created to deliver the impulse for the transition. The energy stems from the kinetic energy of ballistic electrons. They either start out in a high-energy Fermi-Dirac region or are ensured a sufficiently long mean free path by applying a strong electric field, or they are injected by a cathode with the right energy. For the latter, the cathode material has to be chosen carefully; chemical reactions at the interface need to be controlled during fabrication and additional monatomic layers of other materials inserted. In either case, with forward voltage applied, the Fermi level in the cathode is the same as the third band, and reflections of ballistic electrons starting around the Fermi level are minimized by matching the density of states and using the additional interface layers to let the reflected waves interfere destructively. In GaAs the drift velocity in the third band is lower than in the usual conduction band, so with a small increase in the forward voltage, more and more electrons can reach the third band and current decreases. This creates a region of negative incremental resistance in the voltage/current relationship.

Multiple Gunn diodes in a series circuit are unstable, because if one diode has a slightly higher voltage drop across it, it will conduct less current, and the voltage drop will rise further. In fact, even a single diode is internally unstable, and will develop small slices of low conductivity and high field strength which move from the cathode to the anode. It is not possible to balance the population in both bands, so there will always be thin slices of high field strength in a general background of low field strength. So in practice, with a small increase in forward voltage, a slice is created at the cathode, resistance increases, the slice takes off, and when it reaches the anode a new slice is created at the cathode to keep the total voltage constant. If the voltage is lowered, any existing slice is quenched and resistance decreases again.

Applications

- Negative resistance behavior can be used to amplify
- Common use is a high frequency and high power signal source

A bias tee is needed to isolate the bias current from the high frequency oscillations. Since this is a single-port device, there is no isolation between input and output.

Radio Amateur Use

By virtue of their low voltage operation, Gunn diodes can serve as microwave frequency generators for very low powered (few-milliwatt) microwave transmitters. In the late 1970s they were being used by some radio amateurs in Britain. Designs for transmitters were published in journals. They typically consisted simply of an approximately 3 inch waveguide into which the diode was mounted. A low voltage (less than 12 volt) direct current power supply that could be modulated appropriately was used to drive the diode. The waveguide was blocked at one end to form a resonant cavity and the other end ideally fed a parabolic dish.

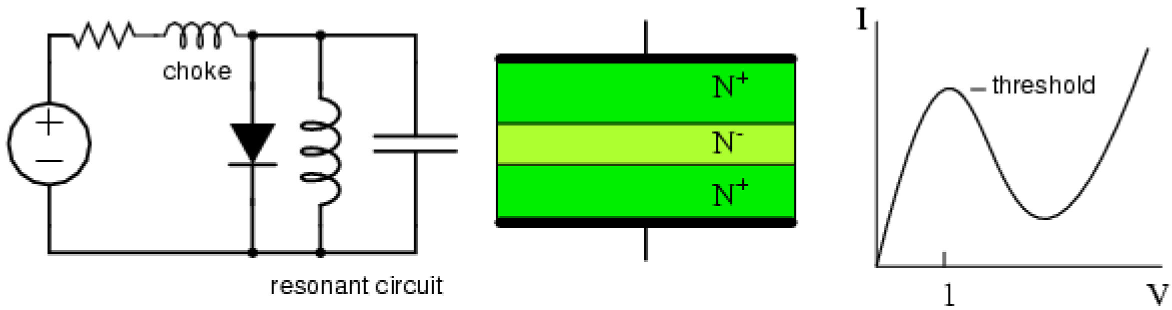
USES:-

1. A Gunn diode as relaxation oscillator

2. as negative resistance oscillators

3. Gunn diode as hot electron injectors: graded gap injector and resonant tunneling injector

A Gunn diode is solely composed of N-type semiconductor. As such, it is not a true diode. Figure shows a lightly doped N_- layer surrounded by heavily doped N+ layers. A voltage applied across the N-type gallium arsenide Gunn diode creates a strong electric field across the lightly doped N^- layer.



Gunn diode: Oscillator circuit and cross section of only N-type semiconductor diode.

As voltage is increased, conduction increases due to electrons in a low energy conduction band. As voltage is increased beyond the threshold of approximately 1 V, electrons move from the lower conduction band to the higher energy conduction band where they no longer contribute to conduction. In other words, as voltage increases, current decreases a negative resistance condition. The oscillation frequency is determined by the transit time of the conduction electrons, which is inversely related to the thickness of the N^- layer .The frequency may be controlled to some extent by embedding the Gunn diode into a resonant circuit. The lumped circuit equivalent shown in Figure is actually a coaxial transmission line or waveguide. Gallium arsenide Gunn diodes are available for operation from 10 to 200 GHz at 5 to 65 mw power. Gunn diodes may also serve as amplifiers.

Result - Performance of Gunn Diode & Gunn Oscillator is observed .

Precautions –

1) all connection should be make properly.

2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).

3) Before the circuit connection it should be check out working condition of all the Component.

Experiment no .-2

Objective : - Performance of Klystron & Reflex klystron tubes.

Apparatus required- linear-beam vacuum tube, amplifiers at microwave and radio frequencies

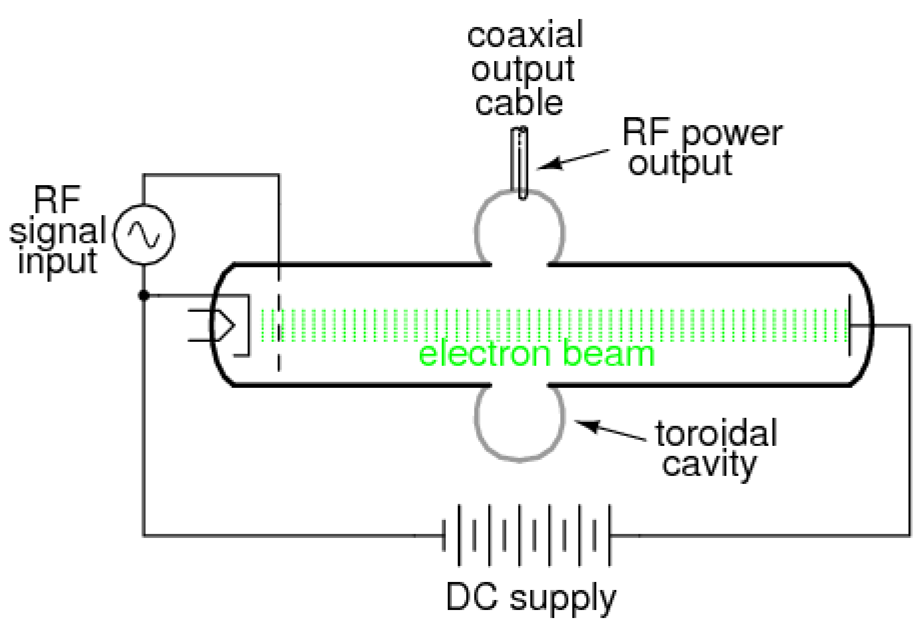
Theroy -

Klystron

For extremely high-frequency applications (above 1 GHz), the interelectrode capacitances and transit-time delays of standard electron tube construction become prohibitive. However, there seems to be no end to the creative ways in which tubes may be constructed, and several high-frequency electron tube designs have been made to overcome these challenges.

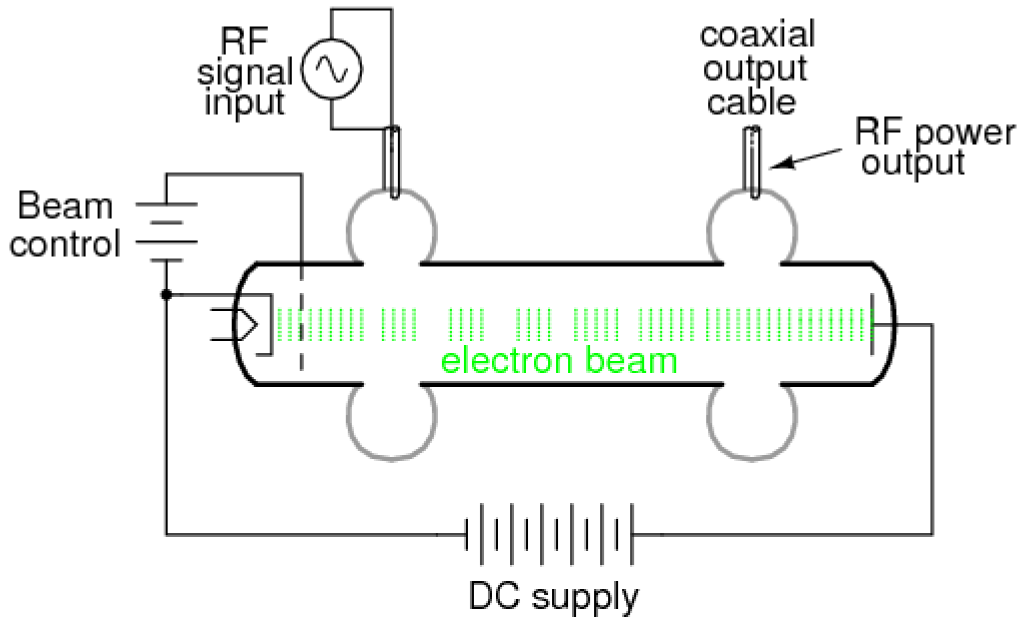
It was discovered in 1939 that a toroidal cavity made of conductive material called a cavity resonator surrounding an electron beam of oscillating intensity could extract power from the beam without actually intercepting the beam itself. The oscillating electric and magnetic fields associated with the beam "echoed" inside the cavity, in a manner similar to the sounds of traveling automobiles echoing in a roadside canyon, allowing radio-frequency energy to be transferred from the beam to a waveguide or coaxial cable connected to the resonator with a coupling loop. The tube was called an inductive output tube, or IOT:

The inductive output tube (IOT)



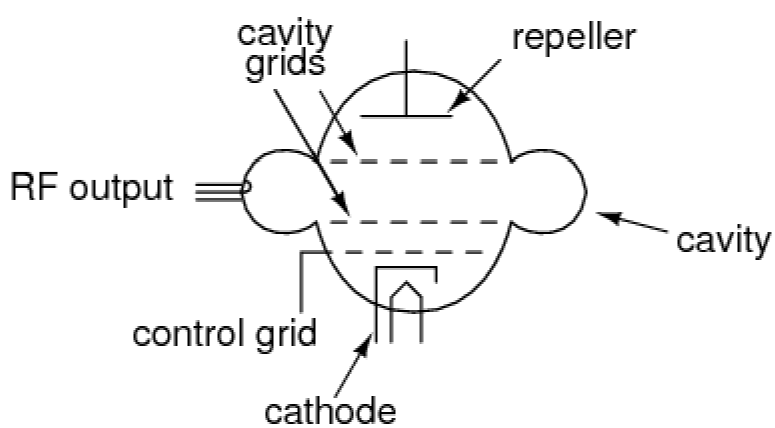
Two of the researchers instrumental in the initial development of the IOT, a pair of brothers named Sigurd and Russell Varian, added a second cavity resonator for signal input to the inductive output tube. This input resonator acted as a pair of inductive grids to alternately "bunch" and release packets of electrons down the drift space of the tube, so the electron beam would be composed of electrons traveling at different velocities. This "velocity modulation" of the beam translated into the same sort of amplitude variation at the output resonator, where energy was extracted from the beam. The Varian brothers called their invention a klystron.

The klystron tube

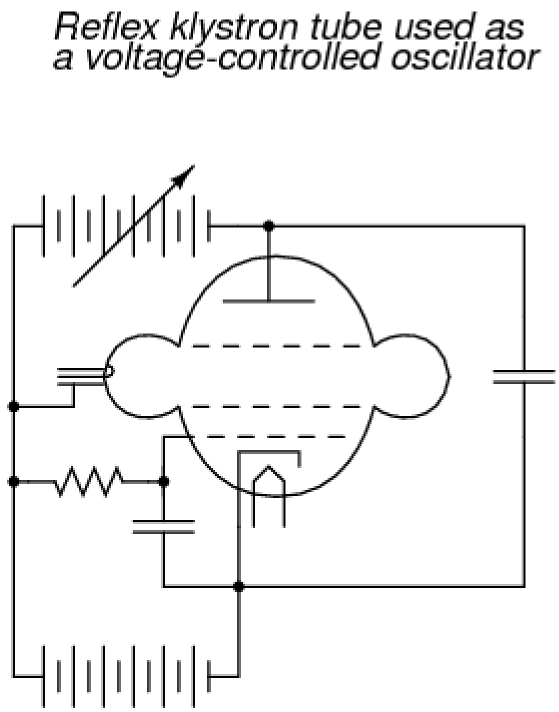


Another invention of the Varian brothers was the reflex klystron tube. In this tube, electrons emitted from the heated cathode travel through the cavity grids toward the repeller plate, then are repelled and returned back the way they came (hence the name reflex) through the cavity grids. Self-sustaining oscillations would develop in this tube, the frequency of which could be changed by adjusting the repeller voltage. Hence, this tube operated as a voltage-controlled oscillator.

The reflex klystron tube



As a voltage-controlled oscillator, reflex klystron tubes served commonly as "local oscillators" for radar equipment and microwave receivers:

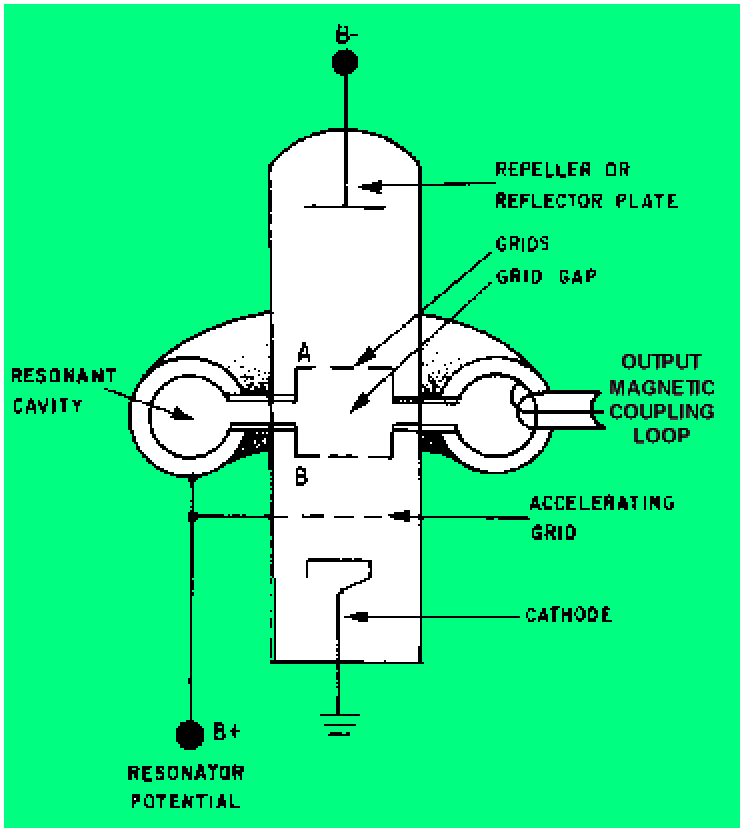


Initially developed as low-power devices whose output required further amplification for radio transmitter use, reflex klystron design was refined to the point where the tubes could serve as power devices in their own right. Reflex klystrons have since been superseded by semiconductor devices in the application of local oscillators, but amplification klystrons continue to find use in high-power, high-frequency radio transmitters and in scientific research applications.One microwave tube performs its task so well and so cost-effectively that it continues to reign supreme in the competitive realm of consumer electronics: the magnetron tube. This device forms the heart of every microwave oven, generating several hundred watts of microwave RF energy used to heat food and beverages, and doing so under the most grueling conditions for a tube: powered on and off at random times and for random durations.

Magnetron tubes are representative of an entirely different kind of tube than the IOT and klystron. Whereas the latter tubes use a linear electron beam, the magnetron directs its electron beam in a circular pattern by means of a strong magnetic field:

Another tube based on velocity modulation, and used to generate microwave energy, is the REFLEX KLYSTRON (figure 2-9). The reflex klystron contains a REFLECTOR PLATE, referred to as the REPELLER, instead of the output cavity used in other types of klystrons. The electron beam is modulated as it was in the other types of klystrons by passing it through an oscillating resonant cavity, but here the similarity ends. The feedback required to maintain oscillations within the cavity is obtained by reversing the beam and sending it back through the cavity. The electrons in the beam are velocity-modulated before the beam passes through the cavity the second time and will give up the energy required to maintain oscillations. The electron beam is turned around by a negatively charged electrode that repels the beam. This negative element is the repeller mentioned earlier. This type of klystron oscillator is called a reflex klystron because of the reflex action of the electron beam.

Figure 2-9. - Functional diagram of a reflex klystron.



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, and (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 (B+) in the body of the tube. Note in figure 2-9 that the resonator potential is common to the resonator cavity, the accelerating grid, and the entire body of the tube.

Performance: -

A klystron is a specialized linear-beam vacuum tube (evacuated electron tube). Klystrons are used as amplifiers 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 modern particle accelerators

High-power klystron used at the Canberra Deep Space Communications Complex. (Klystrons used for generating heterodyne reference frequencies in radar receivers are about the size of a whiteboard pen.)

Klystron amplifiers have the advantage (over the magnetron) of coherently amplifying a reference signal 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.All modern klystrons are amplifiers, since reflex klystrons, which were used as oscillators in the past, have been surpassed by alternative technologies.The pseudo-Greek word klystron comes from the stem form κλυσ- (klys) of a Greek verb referring to the action of waves breaking against a shore, and the end of the word electron.

History

The brothers Russell and Sigurd Varian of Stanford University are the inventors of the klystron. Their prototype was completed in August 1937. Upon publication in 1939, news of the klystron immediately influenced the work of US and UK researchers working on radar equipment. The Varians went on to found Varian Associates to commercialize the technology (for example to make small linear accelerators to generate photons for external beam radiation therapy). In their 1939 paper, they acknowledged the contribution of A. Arsenjewa-Heil and Oskar Heil (wife and husband) for their velocity modulation theory in 1935.

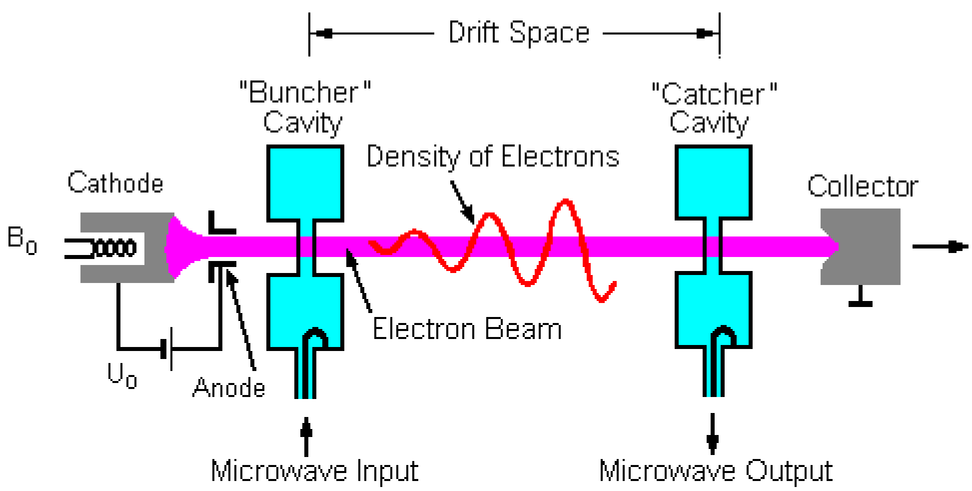
The work of physicist W.W. Hansen was instrumental in the development of klystron and was cited by the Varian brothers in their 1939 paper. His resonator analysis, which dealt with the problem of accelerating electrons toward a target, could be used just as well to decelerate electrons (i.e., transfer their kinetic energy to RF energy in a resonator). During the Second World War, Hansen lectured at the MIT Radiation labs two days a week, commuting to Boston from Sperry Gyroscope Company on Long Island. His resonator, called a "hohlraum" by nuclear physicists and coined "rhumbatron" by the Varian brothers, is used in 2009 in the National Ignition Facility investigating nuclear fusion. Hansen died in 1949 as a result of exposure to beryllium oxide (BeO).

During the second World War, the Axis powers relied mostly on (then low-powered) klystron technology for their radar system microwave generation, while the Allies used the far more powerful but frequency-drifting technology of the cavity magnetron for microwave generation. Klystron tube technologies for very high-power applications, such as synchrotrons and radar systems, have since been developed.

Explanation

Klystrons amplify RF signals by converting the kinetic energy in a DC electron beam into radio frequency power. A beam of electrons is produced by a thermionic cathode (a heated pellet of low work function material), and accelerated by high-voltage electrodes (typically in the tens of kilovolts). This beam is then passed through an input cavity. RF energy is fed into the input cavity at, or near, its natural frequency to produce a voltage which acts on the electron beam. The electric field causes the electrons to bunch: electrons that pass through during an opposing electric field are accelerated and later electrons are slowed, causing the previously continuous electron beam to form bunches at the input frequency. To reinforce the bunching, a klystron may contain additional "buncher" cavities. The RF current carried by the beam will produce an RF magnetic field, and this will in turn excite a voltage across the gap of subsequent resonant cavities. In the output cavity, the developed RF energy is coupled out. The spent electron beam, with reduced energy, is captured in a collector.

Two-cavity klystron amplifier

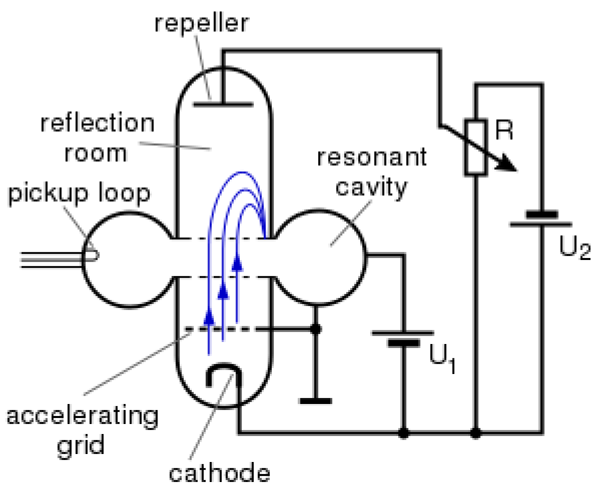


In the two-chamber klystron, the electron beam is injected into a resonant cavity. The electron beam, accelerated by a positive potential, is constrained to travel through a cylindrical drift tube in a straight path by an axial magnetic field. While passing through the first cavity, the electron beam is velocity modulated by the weak RF signal. In the moving frame of the electron beam, the velocity modulation is equivalent to a plasma oscillation. Plasma oscillations are rapid oscillations of the electron density in conducting media such as plasmas or metals. (The frequency only depends weakly on the wavelength). So in a quarter of one period of the plasma frequency, the velocity modulation is converted to density modulation, i.e. bunches of electrons. As the bunched electrons enter the second chamber they induce standing waves at the same frequency as the input signal. The signal induced in the second chamber is much stronger than that in the first.

Two-cavity klystron oscillator

The two-cavity amplifier klystron is readily turned into an oscillator klystron by providing a feedback loop between the input and output cavities. Two-cavity oscillator klystrons have the advantage of being among the lowest-noise microwave sources available, and for that reason have often been used in the illuminator systems of missile targeting radars. The two-cavity oscillator klystron normally generates more power than the reflex klystron—typically watts of output rather than mill watts. Since there is no reflector, only one high-voltage supply is necessary to cause the tube to oscillate, the voltage must be adjusted to a particular value. This is because the electron beam must produce the bunched electrons in the second cavity in order to generate output power. Voltage must be adjusted to vary the velocity of the electron beam (and thus the frequency) to a suitable level due to the fixed physical separation between the two cavities. Often several "modes" of oscillation can be observed in a given klystron.

Reflex klystron



In the reflex klystron (also known as a 'Sutton' klystron after its inventor), the electron beam passes through a 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 re-enters the resonant cavity, thus ensuring a maximum of energy is transferred from the electron beam to the RF oscillations in the cavity. The voltage should always be switched on before providing the input to the reflex klystron as the whole function of the reflex klystron would be destroyed if the supply is provided after the input. 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. This tube is called a reflex klystron because it repels the input supply or performs the opposite function of a klystron.

There are often several regions of reflector voltage where the reflex klystron will oscillate; these are referred to as modes. The electronic tuning range of the reflex klystron is usually referred to as the variation in frequency between half power points—the points in the oscillating mode where the power output is half the maximum output in the mode. It should be noted that the frequency of oscillation is dependent on the reflector voltage, and varying this provides a crude method of frequency modulating the oscillation frequency, albeit with accompanying amplitude modulation as well.Modern semiconductor technology has effectively replaced the reflex klystron in most applications.

Multicavity klystron

Large klystrons as used in the storage ring of the Australian Synchrotron to maintain the energy of the electron beamIn all modern klystrons, the number of cavities exceeds two. A larger number of cavities may be used to increase the gain of the klystron, or to increase the bandwidth.

Tuning a klystron

Some klystrons have cavities that are tunable. Tuning a klystron is delicate work which, if not done properly, can cause damage to equipment or injury to the technician. By adjusting the frequency of individual cavities, the technician can change the operating frequency, gain, output power, or bandwidth of the amplifier. The technician must be careful not to exceed the limits of the graduations, or damage to the klystron can result.

Manufacturers generally send a card with the unique calibrations for a klystron's performance characteristics that lists the graduations to be set to attain any of a set of listed frequencies. No two klystrons are exactly identical (even when comparing like part/model number klystrons), and so every card is specific to the individual unit. Klystrons have serial numbers on each of them to uniquely identify each unit, and for which manufacturers may (hopefully) have the performance characteristics in a database. If not, loss of the calibration card may be an insoluble problem, making the klystron unusable or perform marginally un-tuned.

Other precautions taken when tuning a klystron include using nonferrous tools. Some klystrons employ permanent magnets. If a technician uses ferrous tools, (which are ferromagnetic), and comes too close to the intense magnetic fields that contain the electron beam, such a tool can be pulled into the unit by the intense magnetic force, smashing fingers, injuring the technician, or damaging the unit. Special lightweight nonmagnetic (aka diamagnetic) tools made of beryllium alloy have been used for tuning U.S. Air Force klystrons.Precautions are routinely taken when transporting klystron devices in aircraft, as the intense magnetic field can interfere with magnetic navigation equipment. Special over packs are designed to help limit this field "in the field," and thus allow such devices to be transported safely.

Optical klystron

In an optical klystron the cavities are replaced with undulators. Very high voltages are needed. The electron gun, the drift tube and the collector are still used.

Floating drift tube klystron

The floating drift tube klystron has a single cylindrical chamber containing an electrically isolated central tube. Electrically, this is similar to the two cavity oscillator klystron with a lot of feedback between the two cavities. Electrons exiting the source cavity are velocity modulated by the electric field as they travel through the drift tube and emerge at the destination chamber in bunches, delivering power to the oscillation in the cavity. This type of oscillator klystron has an advantage over the two-cavity klystron on which it is based. It only needs one tuning element to effect changes in frequency. The drift tube is electrically insulated from the cavity walls, and DC bias is applied separately. The DC bias on the drift tube may be adjusted to alter the transit time through it, thus allowing some electronic tuning of the oscillating frequency. The amount of tuning in this manner is not large and is normally used for frequency modulation when transmitting.

Collector

After the RF energy has been extracted from the electron beam, the beam is destroyed in a collector. Some klystrons include depressed collectors, which recover energy from the beam before collecting the electrons, increasing efficiency. Multistage depressed collectors enhance the energy recovery by "sorting" the electrons in energy bins.

Applications : - Klystrons produce microwave power far in excess of that developed by solid state. In modern systems, they are used from UHF (100's of MHz) up through

hundreds of gigahertz (as in the Extended Interaction Klystrons in the CloudSat satellite). Klystrons can be found at work in radar, satellite and wideband high-power communication (very common in television broadcasting and EHF satellite terminals), and high-energy physics (particle accelerators and experimental reactors). At SLAC, for example, klystrons are routinely employed which have outputs in the range of 50 megawatts (pulse) and 50 kilowatts (time-averaged) at frequencies nearing 3 GHz Popular Science's "Best of What's New 2007" included a company Global Resource Corporation using a klystron to convert the hydrocarbons in everyday materials, automotive waste, coal, oil shale, and oil sands into natural gas and diesel fuel.

Result - Performance of Klystron & Reflex klystron tubes is observed.

Precautions –

1) all connection should be make properly.

2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).

3) Before the circuit connection it should be check out working condition of all the Component.

Experiment no – 3

Objective :- To study of magnetron.

Theory of Operation

A magnetron is a high power microwave oscillator in which thepotential energy of an electron cloud near the cathode is convertedinto r.f. energy in a series of cavity resonators similar to the oneshown in Figure 1. As depicted by the low frequency analog, therear wall of the structure may be considered the inductive portion ,and the vane tip region the capacitor portion of the equivalentresonant circuit. The resonant frequency of a microwave cavity isthereby determined by the physical dimension of the resonatortogether with the reactive effect of any perturbations to theinductive or capacitive portion of the equivalent circuit. This is animportant point and will be recalled later.In order to sustain oscillations in a resonant circuit, it is necessaryto continuously input energy in the correct phase. Referring to Figure 2, if the instantaneous r.f.field, due to steady stateoscillations in the resonator, is in the direction shown, and, an electron with velocity was to travel through the r.f. field such thatthe r.f. field retarded the electron velocity by an amount, the decrease in electron energy will be exactly offset by an increase in ther.f. field strength.In a magnetron, the source of electrons is a heated cathode located on theaxis of an anode structure containing a number of microwave resonators. Electrons leave the cathode and are accelerated toward the anode, due tothe dc field established by the voltage source E. The presence of a strongmagnetic field B in the region between cathode and anode produces aforce on each electron which is mutually perpendicular to the dc fieldand the electron velocity vectors, thereby causing the electrons to spiralaway from the cathode in paths of varying curvature, depending uponthe initial electron velocity a the time it leaves the cathode.As this cloud of electrons approaches the anode, it falls under theinfluence of the r.f. fields at the vane tips, and electrons will eitherbe retarded in velocity, if they happen to face an opposing r.f.field, or accelerated if they are in the vicinity of an aiding r.f. field. Since the force on an electron due to the magnetic field B isproportional to the electron velocity through the field, the retarded velocity electrons will experience less "curling force" and will therefore drift toward the anode, while the accelerated velocity electrons will
curl back away from the anode.

The result is an automatic collection of electron "spokes" as the cloud nears theanode each spoke located at a resonator having an opposing r.f. field.On the next half cycle of r.f. oscillation, the r.f. field pattern will havereversed polarity and the spoke pattern will rotate to maintain its presence in an opposing field.The "automatic" synchronism between the electron spoke pattern and the r.f.field polarity in a crossed field device allows a magnetron to maintain relativelystable operation over a wide range of applied input parameters. For example, amagnetron designed for an output power of 200 kw peak will operate quite wellat 100 kw peak output by simply reducing the modulator drive level.

Magnetron Theory of Operation

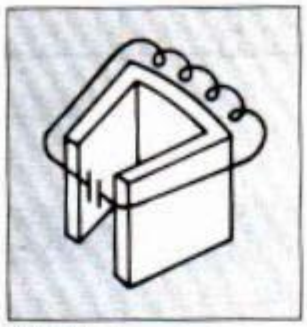


FIGURE 1
MAGNETRON
RESONATOR

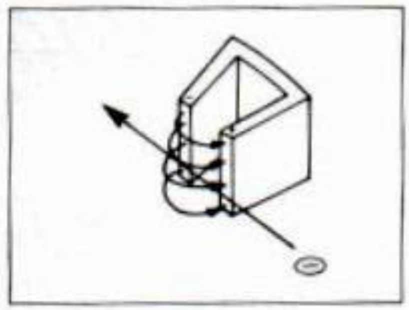


FIGURE 2
ENERGY TRANSFER
MECHANISM

Beverly Microwave Division

We note that the instantaneous r.f. field pattern, shown in Figure 4, has exactly 180o of phase change (radians) between every adjacent pair of resonator vanes and is therefore called the mode. Other oscillation patterns (modes) could be supported by the anode structure; however, the mode pattern will product the maximum number of electron spokes, and therefore the maximum transfer of energy to the r.f. field, i.e., highest efficiency mode. Assuring that the magnetron maintains mode oscillation, to the exclusion of all other modes, is one of the prime concerns of the magnetron designer. The mode controlling techniques in a conventional magnetron, e.g., electrically connecting alternate vane tips together to assure identical potential, employing geometrical similarities between alternate resonators to favor mode oscillation, will adequately maintain mode control in conventional magnetron anodes.

FIGURE 3 ANODE/CATHODE STRUCTURE

Due to mode separationparameters, the number of resonators in conventional magnetron anodesis limited and rarely exceeds 20 resonator vanes. Since the physical sizeof each resonator is fixed by the desired output frequency, the overallsize of the anode is limited, thereby restricting cathode dimensions andheat dissipation capacity. The result is that at higher frequencies theconventional magnetron has reduced power output capability, lowerreliability and a shorter operating lifetime than can be realized at the
lower microwave frequencies.

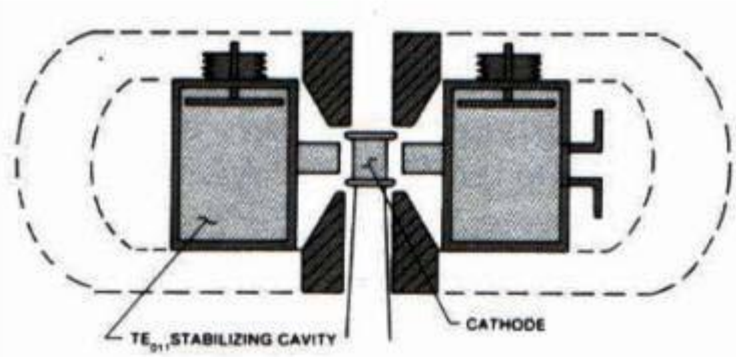


FIGURE 5. COAXIAL MAGNETRON

The distinguishing feature of the coaxial magnetron is the presence of a high Q stabilizing cavity between the anode and the output waveguide. the theory of operation presented for a conventional magnetron applies equally to the anode-cathode region of the coaxial structure. However, the coaxial stabilizing cavity affords very significant improvements in overall magnetron performance.Superior mode control: Operating the cavity in the TE011 mode, and slot coupling alternate anode resonators to the cavity, produces anode control of such intensity as to permit the construction of coaxial magnetrons with many times the number of resonators that can be employed in a conventional type magnetron. This means lower cathode emission density, lower life and higher reliability.

Reduced RF fields in the anode: Whereas all stored energy in a conventional is confined to the vane resonators, in a coaxial magnetron approximately 85% of the total stored energy is contained in the stabilizing cavity. This means reduced r.f. field intensity at the vane tips, and less tendency to arcing.Improved frequency stability: There distribution of stored energy in the coaxial magnetron makes the high Q stabilizing cavity the prime determiner of magnetron output frequency. This means a lower pushing figure, a lower pulling figure, improved spectrum and reduced spurious emissions.Improved tuning: In the conventional magnetron, tuning is accomplished by inserting inductive pins in the rear portion of each resonator, or by capacitive loading in the vane tip region. Both techniques represent an adverse perturbation to the natural geometry of the resonators which often results in power output variation with tuning, starting instabilities, increased susceptibility to arcing and a generally reduced operating lifetime for the magnetron. In contrast the coaxial magnetron is tuned by moving anon contacting plunger in the stabilizing cavity(see Figure 5). The result is a tuning characteristic with no discontinuities, broad tunable bandwidth, and none of the disadvantagesresulting from perturbations in the anode-cathode region.

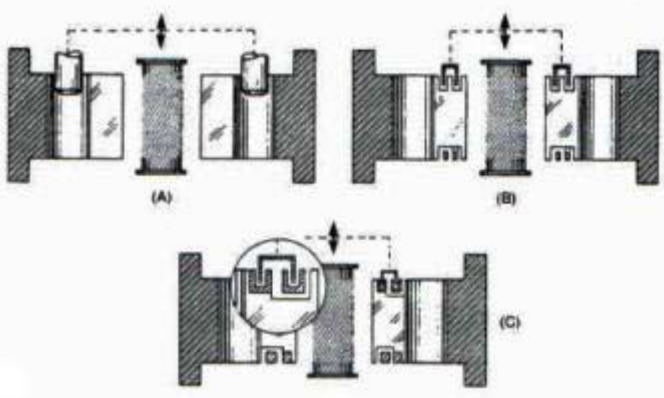


FIGURE 6. THREE TYPES OF TUNING SCHEMES USED IN CONVENTIONAL MAGNETRON RESONATOR SYSTEMS

Mag netrons

Typical Magnetron Parameters

The following is a discussion and explanation of typical magnetron specification parameters.

Thermal Drift

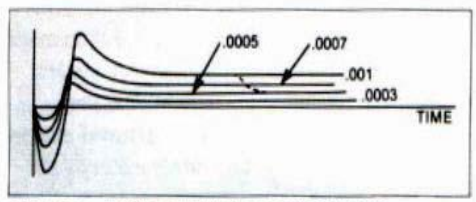


FIGURE 7. TYPICAL THERMAL DRIFT CURVES

At the time high voltage is first applied to a magnetron, the thermal equilibrium of the device is suddenly Altered. The anode vanes being to heat at the tips due to electron bombardment and the entire anode/cathode Structure undergoes a transient change in thermal profile. During the time required for each part of the Magnetron to stabilize at its normal operating temperature, the output frequency of the magnetron will "drift." The curve of output frequency vs. time during the period following initial turn on is called the "Thermal Drift" curves. Generally speaking, the maximum drift occurs during the first few minutes after turn on, and slowly approaches equilibrium over a period ranging from 10 to 30 minutes depending upon the structure mass, power output, type of cooling and basic magnetron design. Thermal drift curves across a variety of magnetron types operating at the samefrequency and output power may differ radically from each other. Each type is usually designed for a particular purpose and subtledifferences in the internal magnetron configuration can produce radical differences in the thermal drift curve.It should be noted that a thermal drift effect will occur not only at initial turn-on, but whenever the peak or average input power to the magnetron is changed, e.g., a change of pulse duration, PRF or duty. Figure 7 shows typical thermal drift curves for a particularmagnetron plotted as a function of duty. The dotted line indicates the effect of a change in duty from .001 to .0005 after thermalequilibrium has been initially achieved.

Temperature Coefficient

After the thermal drift period has expired and a stable operating frequency has been achieved, changes to ambient conditions whichcause a corresponding change in the magnetron temperature will produce a change in the output frequency. In this content ambientchanges include cooling air temperature or pressure in air cooled magnetrons; mounting plate temperature in heat sink cooledmagnetrons; and flow rate or temperature in liquid cooled magnetrons.The change in magnetron output frequency for each degree change in body temperature, as measured at a specified point on theoutside surface of the magnetron body, is defined as the Temperature Coefficient for the magnetron and is usually expressed inMHz/oC. For most magnetrons the temperature coefficient is a negative (frequency decreases as temperature increases) and is essentially constant over the operating range of the magnetron.When estimating magnetron frequency change due to temperature coefficient, keep in mind that the temperature coefficient relatesmagnetron frequency to body temperature and there is not necessarily a 1:1 relation between body temperature and, for example,ambient air temperature. In addition, for airborne systems, the cooling effect of lower air temperature at altitude may offset by acorresponding reduction in air density.

The pushing figure of a magnetron is defined as the change in magnetron frequency due to a change in the peak cathode current.Referring back to the earlier theory discussion, we noted that the resonant frequency of a vane resonator is determined by itsmechanical dimensions plus the

reactive effect of any perturbation. The presence of electrons in the vicinity of the vane tips affectsthe equivalent capacitance of the resonator by an amount proportional to the density of the electrons and,since electron density is similarly related to peak pulse current, changes in pulse current level will produce changes in outputfrequency. The pushing figure expressed in MHz/Amp is represented by the slope of a frequency vs. peak current curve plotted for a particular magnetron type. it can be seen that the slope is not a constant over the full range of operating current. It is therefore meaningless to talk about a specific value for the pushing figure unless one also specifies the range of peak current over which it appliesIt should be noted that since power output is proportional to peak current in a magnetron, the pushing figure at peak current levels well below the normal operating point of the magnetron are usually unimportant because the power output at these current levels islow.MagnetronsThe primary importance of a low pushing figure near the magnetronoperating point is that the pushing figure will determine intrapulse FM,and thereby will affect the spectral quality of the transmitting pulse.The Pulling Figure is defined as the maximum change in output frequencythat results when an external, fixed amplitude mismatch, located in theoutput waveguide, is moved through a distance of one half wavelengthrelative to the magnetron. Stated somewhat less formally, the pulling figure is a measure of a magnetron's ability to maintain a constant outputfrequency against changes in load mismatch.During the design of a magnetron, the degree to which the outputwaveguide is electrically coupled to the internal resonator structure is selected to optimize certain performance parameters. Strong couplingincreases output power and efficiency but also increases time jitter andsensitivity to changes to load mismatch. Generally, the coupling is chosento obtain the best compromise between efficiency and stability.Depending upon the phase relation between incident and reflected power at the output port of a magnetron, reflected power willappear as a reactance across the coupling transformer and effectively change the degree of coupling. Therefore, using a fixedmismatch and varying its distance from the magnetron output port will cause the magnetron frequency to shift and the outputpower to vary concurrently.To standardize the measurement values, pulling figure is normally measured using a fixed 1.5:1 VSWR; however, in very highpower magnetrons a 1.3:1 VSWR is often used. When referring to the pulling figure of a magnetron one should always indicate theVSWR value used in the measurement.
Magnetrons

Frequency Agility

Frequency agility (FA) in regard to radar operations, is defined as the capability to tune the output frequency of the radar withsufficient speed to produce a pulse-to-pulse frequency change greater than the amount required to effectively obtain decorrelationof adjacent radar echoes.It has been firmly established that FA, together with appropriate receiver integration circuits, affords reduced target scintillation/glint, improved ability to detect targets in a clutter environment, elimination of 2nd time around echoes, and improved resistance to electronic countermeasures, over that possible with a fixed frequency or tunable radar system. It is important to note that, with the exception of ECM resistance, increasing the pulse-to-pulse frequency spacing will increase the amount of system performance improvement that can be realized to a maximum occurring at the point where full pulse echo decorrelation is obtained(nominally 1/tp). Pulse-to-pulse frequency spacings greater than this critical value produce no further increase in system performance, and, in fact, may result in a performance decrease due to the large "IF" inaccuracies arising from the need for theft to correct larger pulse to pulse frequency errors.
On the other hand, as regards resistance to electronic jamming (ECCM), the greater the pulse-to-pulse frequency spacing, the more difficult it will be to center a jamming transmitter on the radar frequency to effectively interfere with system operation. Each radar system application must be considered separately to determine which FA parameters will best satisfy the particular need. Just as the FA requirements of each radar differ, so also do the mechanisms differ for optimally producing the required agility parameters. No single tuning scheme has been found which will universally satisfy the requirements of every FA
application. For this reason, CPI produces a broad range of FA tuning mechanisms for coaxial magnetrons; each mechanism offering the optimum combination of parameters for a particular application.

Frequency Agile Magnetron Classes

Frequency agile magnetrons fall into four classes:

Dither Magnetrons (D) -- Output rf frequency varies periodically with a constant excursion, constant rate and a fixed-center frequency.

Tunable/Dither Magnetrons (T/D) -- Output rf frequency varies periodically with a constant excursion and constant rate .The center frequency may be slowly tuned by hand or by external servomotor drive to any point within the tunable band.

Accutune(tm) Magnetrons (A) -- Output rf frequency variations are determined by the wave shape of an externally generated, low level, voltage signal. With appropriate selection of a tuning wave shape, the Accutune magnetron combines the features of dither and tunable/dither magnetrons.

Accusweep (tm) Magnetrons (As) -- Our best and most versatile tuning system. The output rf tuning rate and wave shape are infinitely variable within the design limits of each device. Customer inputs are typically any waveform from random to square wave and a + 5 volt command. All CPI frequency-agile magnetrons provide a reference voltage output which is an accurate analog of the instantaneous rf output frequency. This signal greatly simplifies automatic frequency control of the system local oscillator frequency. The analog voltage

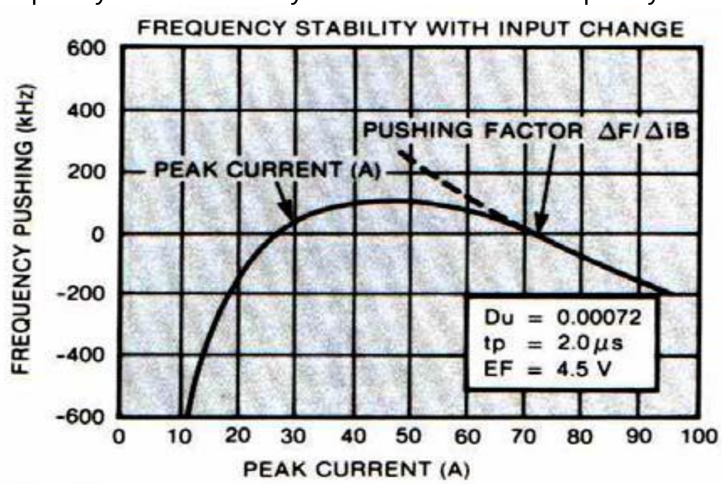
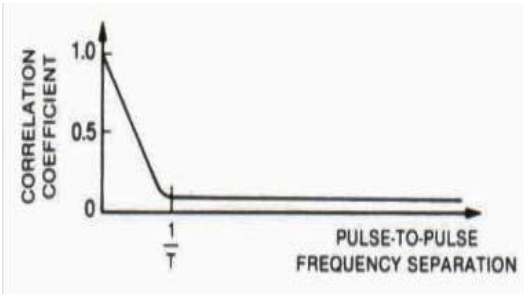


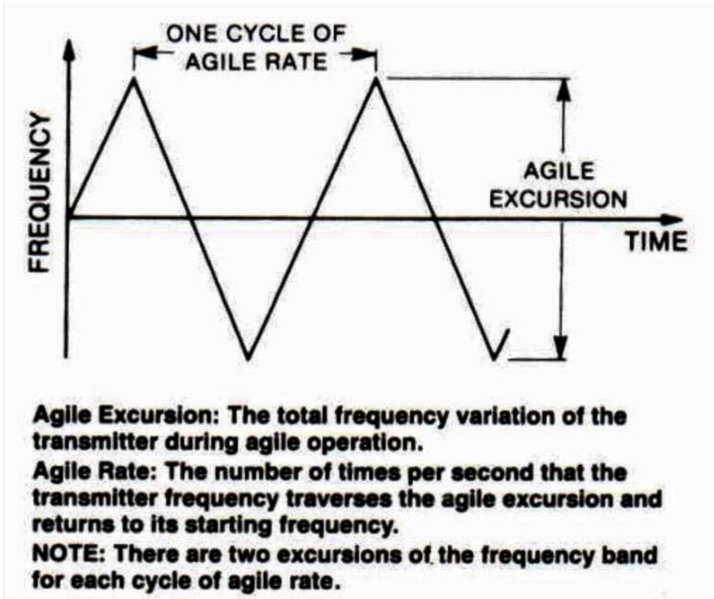
FIGURE 8.
TYPICAL MAGNETRON PUSHING CURVE

is produced either by a self-generating, permanent magnet device requiring no external drive, or by a precision resolve or LVDT(Linear Voltage Displacement Transducer) acting in conjunction with one of CPI's solid-state frequency readout modules. The Accutune and Accusweep magnetrons operate with a servo loop, feedback control, tuner drive and thereby utilize CPI's solid state servo amplifier together with the frequency readout module.

Frequency Agile Magnetrons
Beverly Microwave Division
Agile Magnetron Design Considerations



At first glance one might conclude that the largest frequency change at the highest rate will give the best radar performance. Unfortunately, this is not a true statement. There have been many separate theoretical studies and comprehensive experiments performed to establish the relationship betweenradar performance improvement and pulse-to-pulse frequency difference. An understanding of the theoretical basis for the conclusions reached in these efforts is important. In order to preserve the continuity of our discussion, we will show only the results of these studies in this section. Effective performance improvement is achieved when the frequency difference between radar pulses is large enough to eliminate any correlation between the return echoes. A plot of correlation coefficient versus pulse to pulse frequency difference is shown below. Using this relationship, one finds that a radar operating at a 0.5_s pulse duration will have efficient decorrelation between target echoes if pulses differ in frequency by at least 2 MHz .Note that the required frequency separation is a function only of the pulse duration. According to the plot of the figure, as frequency separation increases above the value 1/T, pulse decorrelation continues to improve; however, the amount of improvement is negligibly small for large increases in pulse frequency separation. Impractical situations, the improvement in decorrelation obtained
By increasing the frequency separation to values greater than1/T is usually more than offset by other factors. For example, as pulse-to-pulse frequency difference Increases, the receiver circuitry needed to assure stable LO (Local Oscillator) tracking also increases, in both complexity and physical size. The accuracy necessary for LO tracking relates directly to the IF bandwidth needed to pass the resultant video signal. Any increase in IF bandwidth, needed to offset inaccuracies in LO tracking, will reduce overall receiver sensitivity and tend to defeat the original Purpose. Experience has shown that if one designs for pulse-to-pulse frequency separation as near as possible to, but not less than,1 /T (where T is the shortest pulse duration used in the radar) optimum system performance will be achieved. Experimental studies have shown that performance improvement varies as N, where N is the number of independent (decor related) pulses integrated within the receiver circuitry, up to a maximum of 20 pulses. It should be noted that the number of pulses, which can be effectively integrated, cannot be greater than the number of pulses placed on the target during one scan of the antenna and, therefore, the antenna beam width and scan rate become factors which must also be considered in determining the integration period of the radar .Using the above, a design value for Agile Excursion can now be expressed in terms of radar operating parameters .Agile Excursion = N/T Where N is the number of pulses placed on the target during one radar scan, or 20 whichever is smaller, and T is the shortest pulse duration used in the system. Determination of the required agile rate is now required. The object is to traverse the full agile excursion range in the time needed to transmit the number of pulses on the target during one antenna scan.

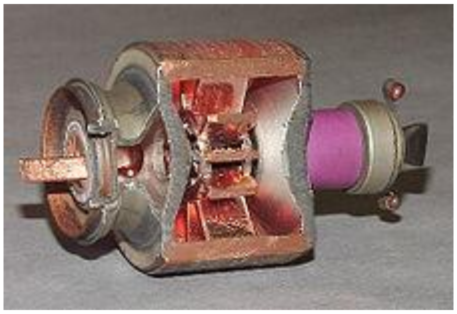


Beacon magnetrons are small conventional magnetrons with peak power output less than 4 kW and average power output of less than 5 watts. Typically, they weigh 8 ounces .The technical requirements for this class of magnetrons demand precise frequency control of the magnetron. The temperature stability factor is of great importance since it allows frequency control without additional electronics in the total radar transponder. The magnetron itself requires tunability but must have the properties of a fixed frequency magnetron after adjustment and locking. Thus, the techniques of temperature compensation must work over a band of frequencies. Also, frequency stability is essential over typical temperature ranges of -65oC to +100oC, and typical shock of 100G, and vibration environments of 15G (generally those of missile and aircraft electronic systems).Construction of beacon magnetrons can be simplified to contain five basic building blocks. They are the anode, tuner, cathode , output, and magnet .These may be arranged in block diagram fashion as shown in Figure 1.The following sections will discuss each of the five parts of the magnetron .

Cavity magnetron

The cavity magnetron is a high-powered vacuum tube that generates microwaves using the interaction of a stream of electrons with a magnetic field. The 'resonant' cavity magnetron variant of the earlier magnetron tube was invented by Randall and Boot in 1940. The high power of pulses from the cavity magnetron made centimeter-band radar practical. Shorter wavelength radars allowed detection of smaller objects. The compact cavity magnetron tube drastically reduced the size of radar sets so that they could be installed in anti-submarine aircraft and escort ships At present, cavity magnetrons are commonly used in microwave ovens and in various radar applications.

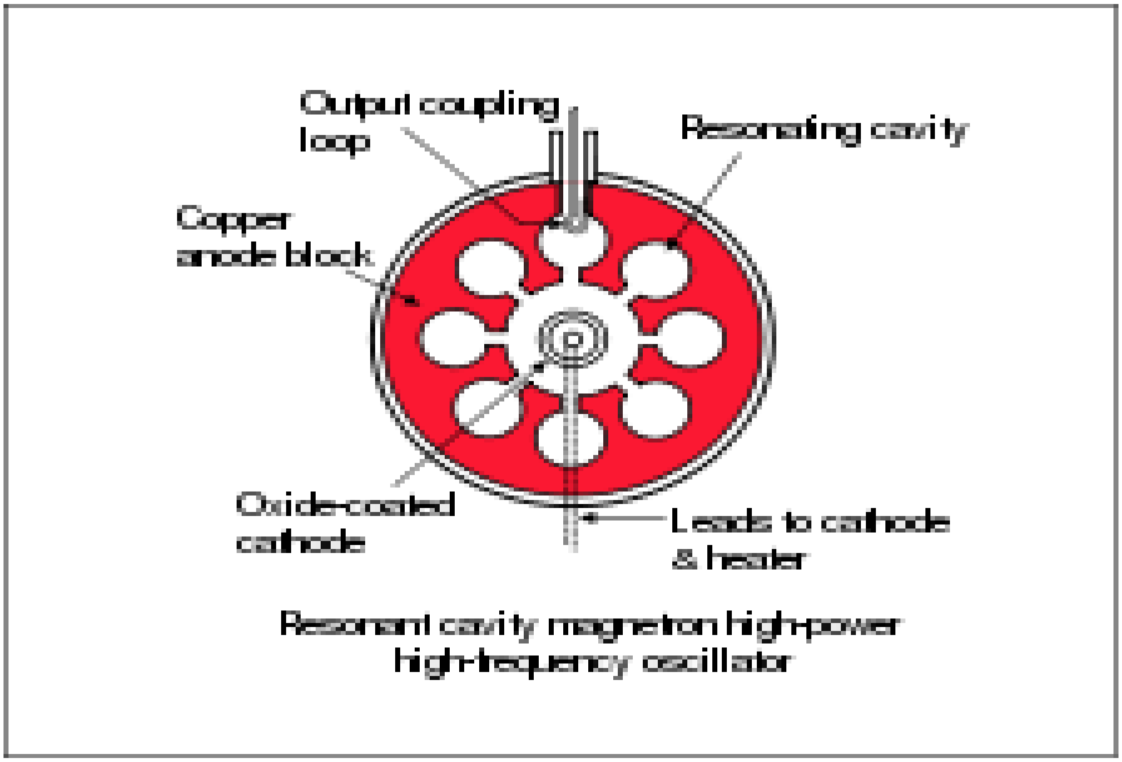
Construction and operation



Magnetron with section removed (magnet is not shown)

A similar magnetron with a different section removed (magnet is not shown).

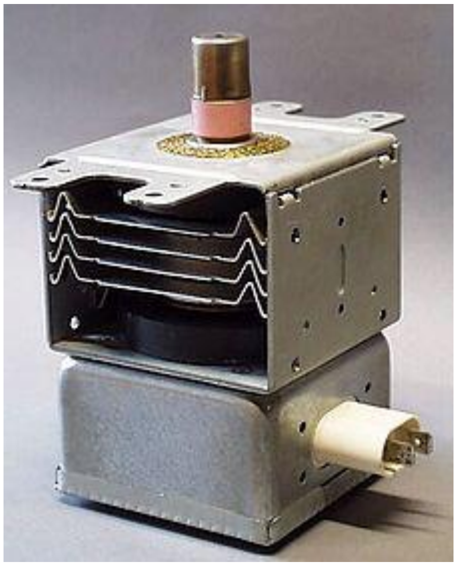
All cavity magnetrons consist of a hot cathode with a high (continuous or pulsed) negative potential by a high-voltage, direct-current power supply. The cathode is built into the center of an evacuated, lobed, circular chamber. A magnetic field parallel to the filament is imposed by a permanent magnet. The magnetic field causes the electrons, attracted to the (relatively) positive outer part of the chamber, to spiral outward in a circular path rather than moving directly to this anode. Spaced around the rim of the chamber are cylindrical cavities. The cavities are open along their length and connect the common cavity space. As electrons sweep past these openings, they induce a resonant, high-frequency radio field in the cavity, which in turn causes the electrons to bunch into groups. A portion of this field is extracted with a short antenna that is connected to a waveguide (a metal tube usually of rectangular cross section). The waveguide directs the extracted RF energy to the load, which may be a cooking chamber in a microwave oven or a high-gain antenna in the case of radar.



A cross-sectional diagram of a resonant cavity magnetron. Magnetic field is perpendicular to the plane of the diagram.

The sizes of the cavities determine the resonant frequency, and thereby the frequency of emitted microwaves. However, the frequency is not precisely controllable. The operating frequency varies with changes in load impedance, with changes in the supply current, and with the temperature of the tube. This is not a problem in uses such as heating, or in some forms of radar where the receiver can be synchronized with an imprecise magnetron frequency. Where precise frequencies are needed, other devices such as the klystron are used. The magnetron is a self-oscillating device requiring no external elements other than a power supply. A well-defined threshold anode voltage must be applied before oscillation will build up; this voltage is a function of the dimensions of the resonant cavity, and the applied magnetic field. In pulsed applications there is a delay of several cycles before the oscillator achieves full peak power, and the build-up of anode voltage must be coordinated with the build-up of oscillator output. The magnetron is a fairly efficient device. In a microwave oven, for instance, a 1.1 kilowatt input will generally create about 700 watt of microwave power, an efficiency of around 65%. (The high-voltage and the properties of the cathode determine the power of a magnetron.) Large S-band magnetrons can produce up to 2.5 megawatts peak power with an average power of 3.75 kW. Large magnetrons can be water cooled. The magnetron remains in widespread use in roles which require high power, but where precise frequency control is unimportant.

Applications



Magnetron with magnet in its mounting box. The horizontal plates form a heat sink, cooled by airflow from a fan

Beacon Magnetrons

Anode

The anode is the foundation of the magnetron circuit. It generally consists of an even number of microwave cavities arranged in radial fashion as shown. There are three possible anode configurations:
_ Hole and slot
_ Vane tip
_ rising sun

FIGURE 2.

Advantages and disadvantages of each type involve consideration of operating characteristics and construction techniques. The hole-and-slot and vane type normally have every other cavity strapped to each other by a conducting metal strip. The hole-and slot type and the rising sun type are usually machined by hobbing methods out of solid copper stock. The vane type is generally made up of individual vanes assembled and brazed into a support ring. This requires assembly labor and brazing fixtures. The anode provides the basic magnetron with its operating frequency. The central area provides C (capacitance) and the outer perimeter contributes L (inductance) to fulfill the relationship

$$F = 1/(2\_\ \sqrt{LC})$$

Each anode is cold checked for "Q" - value and frequency. This involves general microwave impedance and resonance measurements techniques.

Tuner

The tuner is the device which provides some magnetrons with the ability to vary from the basic frequency determined by the anode. Tuners fall into three basic categories:
_ Capacitive
_ Inductive
_ Combination of both

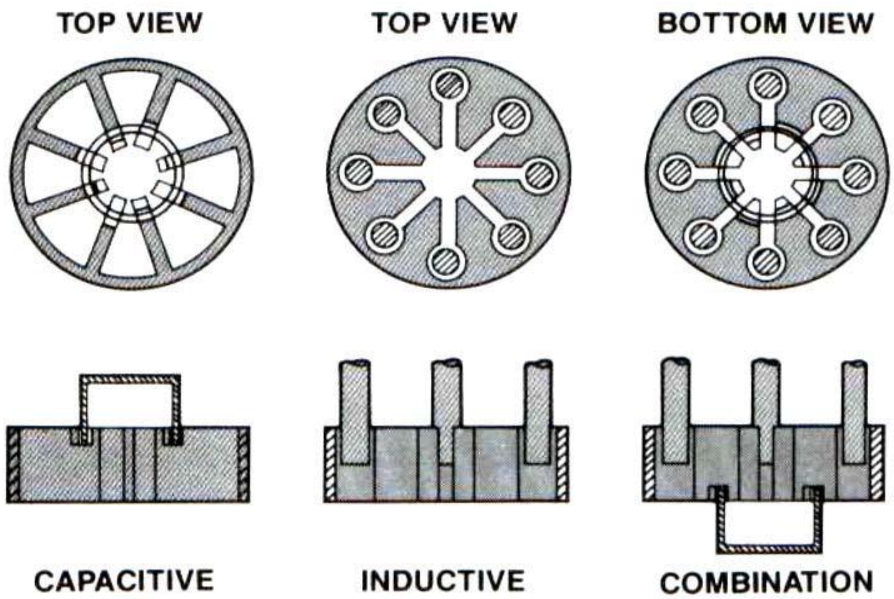


FIGURE 3.

A fundamental description of each is shown in Figure 3. The capacitive type is so named because in it a tuning member is introduced into the anode cavities affecting the E-field and hence the capacitance of the anode. This type can be constructed of either metal (copper) fingers which are inserted between adjacent anode vanes in the central portion of the anode or a dielectric or metallic ring which is inserted into the anode between its central vane straps. The inductive type tuner is much the same as the capacitive but The tuning member enters the cavities in the back wall region where the H-field and Inductance are affected. The combination of the two is a complicated affair which affects both L and C and is used where extremely wide tunability is required. The attachment must necessarily involve bellows or diaphragm arrangement in order to allow for mechanical movement and still contain the necessary vacuum envelope.

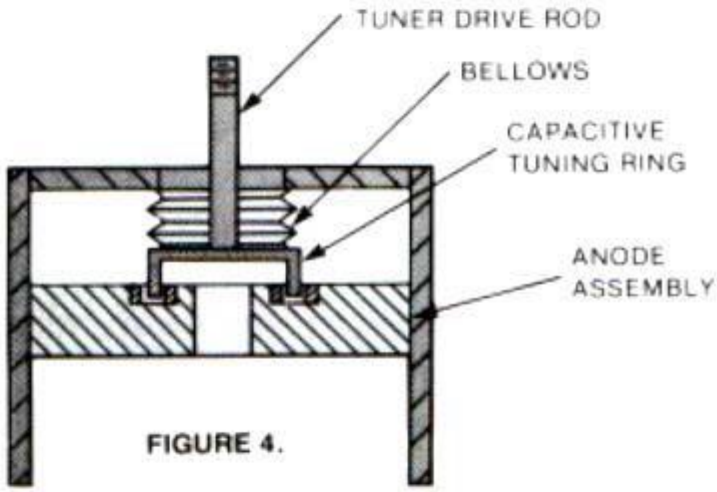


Figure 4 shows a simplified capacitive tuner-anode assembly. The magnetron tuner is generally composed of two parts, internal and external. The internal portion described above is that part which is enclosed by the vacuum envelope. The external portion is attached to the internal portion by some mechanical means and provides the drive mechanism to actually move the tuner the required distance to change Land C and therefore change frequency.

Cathode: - The cathode of a magnetron is the part which makes the magnetron an active device . This provides the electrons through which the mechanism of energy transfer is accomplished. The cathode is usually located in the center of the anode and is made up of a hollow cylinder of emissive material surrounding a heater. A cross- section of a simple magnetron cathode is shown in Figure 5. Many types of magnetron cathodes have been developed; each designed for a specific advantage . The fabrication of magnetron cathodes is carried out in very meticulous and precise environments. Each braze and weld must be inspected for completeness in order not to upset the designed heat flow characteristics.

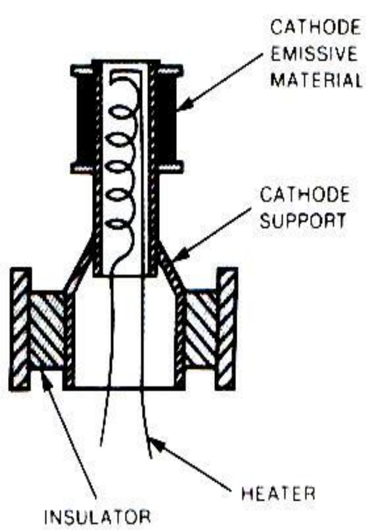


FIGURE 5.

Magnetron cathodes are designed to operate at particular temperatures and owing to the phenomenon called “back bombardment” they cannot tolerate wide variations in construction and assembly techniques. As a further check on operating temperature of cathodes used in high reliability magnetrons, the cathode-heater assembly alone is evacuated and operated at a predetermined heater voltages and the cathode temperature checked with an optical pyrometer. This technique reveals any flaw or defect in construction prior to the time the cathode is actually assembled in a magnetron .The next step in the magnetron's construction is to attach the cathode to the tuner-anode assembly . This procedure also requires extreme care in the axial line-up and orientation of the cathode and anode. Any eccentricity between anode and cathode will produce variations in magnetron operation and can cause serious internal arcing or malfunction.

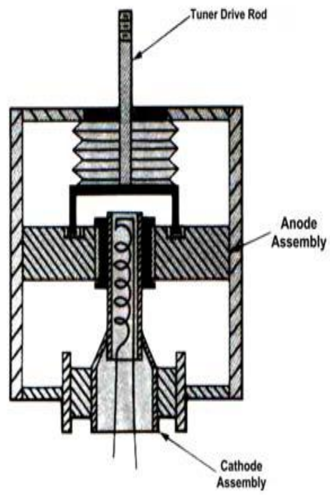


FIGURE 6.

Figure 6 shows a simplified cathode-tuner-anode assembly.

Output

The output circuit in a magnetron is that portion of the device which provides the coupling to the external load. The RF energy produced in the cavities may be coupled by either a coaxial or waveguide type of output. The figure here shows both types. The coaxial design involves either a probe, a loop or a tapped vane coupling to the anode and concentric coaxial line through the vacuum envelope to the output connector. Suitable matching sections must be included along the line to provide for the correct impedance transformations and coupled load which appears at the anode. The center conduction of the coaxial line is insulated and supported along its length by either glass or ceramic beads.

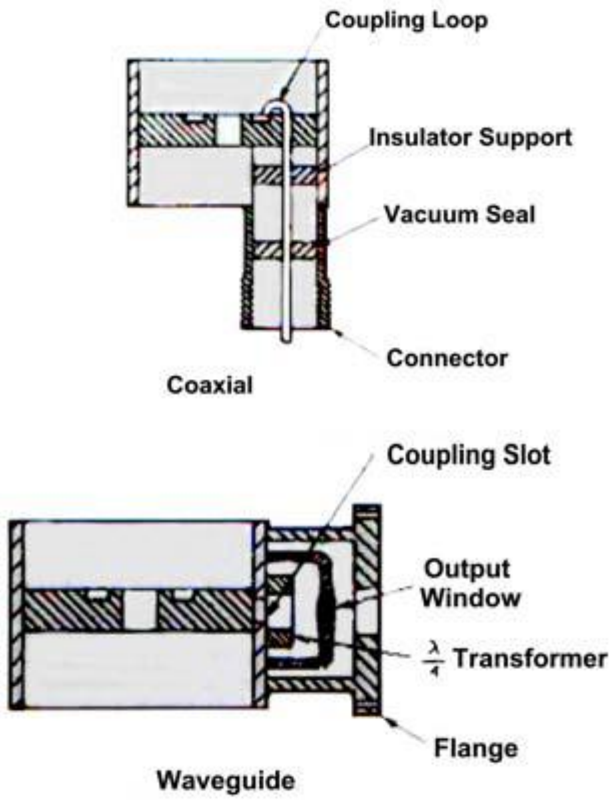


FIGURE 7.

The waveguide type of output is made up of a coupling slot in the back wall of a cavity ,a 1/4 transformer, a vacuum seal window (either glass or ceramic) and a section of output waveguide. The sizes of the coupling slot and 1/4 transformer are determined by frequency, bandwidth and load coupling considerations. The type of vacuum seal window used is determined by the power output and pressurization requirements. Placement of the output window is extremely critical as far as position along the line is concerned , because any high VSWR which may be reflected back from the load that will cause a voltage maximum at the window will cause overheating and subsequent rupture of the vacuum seal.

Magnetic Circuit

The magnetic circuit associated with the magnetron is necessary to provide the crossed field type of operation which provides for the synchronization of the electron trajectories.

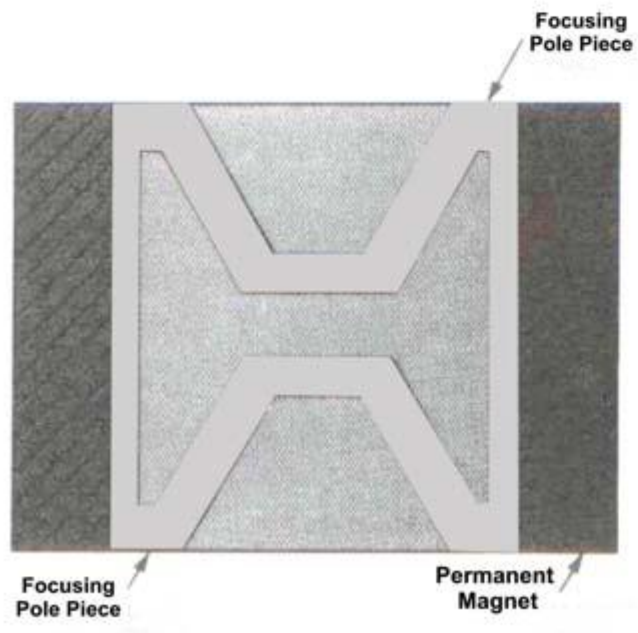
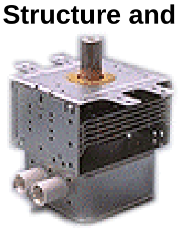


FIGURE 8.

The magnetic circuit shown here is composed of an external permanent magnet and associated internal pole pieces. The type and composition of the permanent magnet vary with particular requirements of field strength and stability. Size and weight are also important considerations .The transmission and focusing of the magnetic field from the external permanent magnet to the interaction gap between the anode and cathode is accomplished by the use of high permeability metal pole pieces shaped to focus the field lines as sharply as possible.

The Magnetron Tube Used In Microwave Ovens

Structure and Operation



The heart of every microwave oven is the high voltage system . Its purpose is to generate microwave energy. The high-voltage components accomplish this by stepping up AC line voltage to high voltage, which is then changed to an even higher DC voltage. This DC power is then converted to the RF energy that cooks the food.

Basic Magnetron Structure

The nucleus of the high-voltage system is the magnetron tube . The magnetron is a diode-type electron tube which is used to produce the required 2450 MHz of microwave energy. It is classed as a diode because it has no grid as does an ordinary electron tube. A magnetic field imposed on the space between the anode (plate) and the cathode serves as the grid. While the external configurations of different magnetrons will vary, the basic internal structures are the same. These include the anode, the filament/cathode, the antenna, and the magnets

The ANODE (or plate) is a hollow cylinder of iron from which an even number of anode vanes extend inward (see Fig. 2). The open trapezoidal shaped areas between each of the vanes are resonant cavities that serve as tuned circuits and determine the output frequency of the tube. The anode operates in such a way that alternate segments must be connected, or strapped, so that each segment is opposite in polarity to the segment on either side. In effect, the cavities are connected in parallel with regard to the output. This will become easier to understand as the description of operation is considered The FILAMENT (also called heater), which also serves as the cathode of the tube, is located in the center of the magnetron, and is supported by the large and rigid filament leads, which are carefully sealed into the tube and shielded. The ANTENNA is a probe or loop that is connected to the anode and extends into one of the tuned cavities. The antenna is coupled to the waveguide , a hollow metal enclosure, into which the antenna transmits the RF energy. The MAGNETIC FIELD is provided by strong permanent magnets, which are mounted around the magnetron so that the magnetic field is parallel with the axis of the cathode.

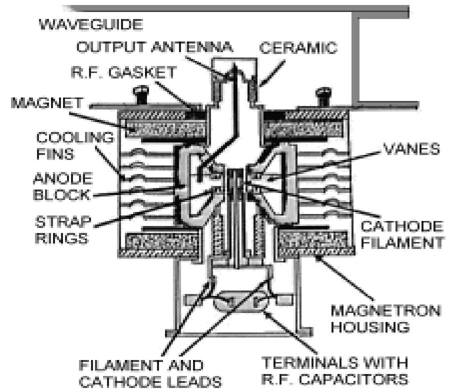


Figure 1 Sectional view of a typical magnetron
(Courtesy of Michael S. Wagner)

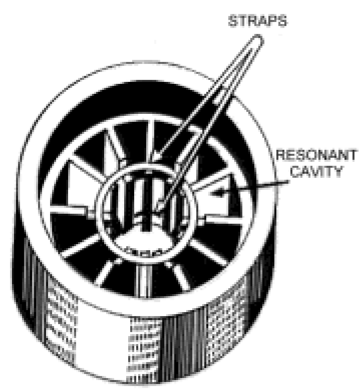


Fig. 2 Typical anode vane block
(Courtesy of Michael S. Wagner)

Basic Magnetron Operation

The theory of magnetron operation is based on the motion of electrons under the combined influence of electric and magnetic fields. For the tube to operate, electrons must flow from the cathode to the anode. There are two fundamental laws that govern their trajectory:

1. The force exerted by an electric field on an electron is proportional to the strength of the field. Electrons tend to move from a point of negative potential toward a positive potential. Figure 3-A shows the uniform and direct movement of the electrons in an electric field with no magnetic field present, from the negative cathode to the positive anode.
2. The force exerted on an electron in a magnetic field is at right angles to both the field itself, and to the path of the electron. The direction of the force is such that the electron proceeds to the anode in a curve rather than a direct path.

Effect of the Magnetic Field

In Figure 3-B two permanent magnets are added above and below the tube structure. In Figure 3-C, assume the upper magnet is a north pole and you are viewing from that position. The lower, south pole magnet, is located underneath the page, so that the magnetic field appears to be coming right through the page. Just as electrons flowing through a conductor cause a magnetic field to build up around that conductor, so an electron moving through space tends to build up a magnetic field around itself. On one side (left) of the electron's path, this self induced magnetic field adds to the permanent magnetic field surrounding it. On the other side (right) of its path, it has the opposite effect of subtracting from the permanent magnetic field. The magnetic field on the right side is therefore weakened, and the electron's trajectory bends in that direction, resulting in a circular motion of travel to the anode.

The process begins with a low voltage being applied to the filament, which causes it to heat up (filament voltage is usually 3 to 4 VAC, depending on the make and model). Remember, in a magnetron tube, the filament is also the cathode. The temperature rise causes increased molecular activity within cathode, to the extent that it begins "boil or emit electrons. Electrons leaving the surface of a heated filament wire might compared to molecules that leave the surface of boiling water in the form steam. Unlike steam, though, the electrons do not evaporate. They loat, or hover, just off the surface of the cathode, waiting for some momentum.

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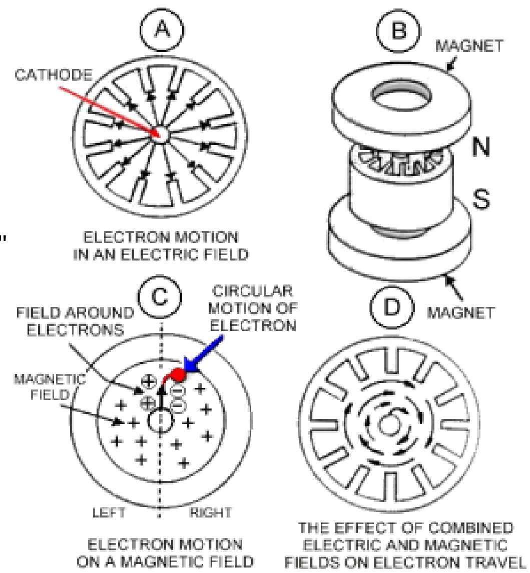


Figure 3 Electron motion in a magnetron tube
(Courtesy of Michael S. Wagner)

Result - . Study of Magnetron is completed .

Precautions – 1) all connection should be make properly.
2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).
3) Before the circuit connection it should be check out working condition of all the Component.

Experiment no. - 4

Objective : - Study of Isolators, directional couplers (cross directional & multihole) slotted line & block diagram of basic microwave bench.

Theory

Isolator

In electrical engineering, a disconnector or isolator switch is used to make sure that an electrical circuit can be completely de-energized for service or maintenance. Such switches are often found in electrical distribution and industrial applications where machinery must have its source of driving power removed for adjustment or repair. High-voltage isolation switches are used in electrical substations to allow isolation of apparatus such as circuit breakers and transformers, and transmission lines, for maintenance. Isolating switches are commonly fitted to domestic extractor fans when used in bathrooms in the UK. Often the isolation switch is not intended for normal control of the circuit and is only used for isolation.

Isolator switches have provisions for a padlock so that inadvertent operation is not possible (see: Lock and tag). In high voltage or complex systems, these padlocks may be part of a trapped-key interlock system to ensure proper sequence of operation. In some designs the isolator switch has the additional ability to earth the isolated circuit thereby providing additional safety. Such an arrangement would apply to circuits which inter-connect power distribution systems where both end of the circuit need to be isolated. The major difference between an isolator and a circuit breaker is that an isolator is an off-load device intended to be opened only after current has been interrupted by some other control device. Safety regulations of the utility must prevent any attempt to open the disconnector while it supplies a circuit.Standards in some countries for safety may require either local motor isolators or lockable overloads (which can be padlocked).

Optical isolator

An optical isolator, or optical diode, is an optical component which allows the transmission of light in only one direction. It is typically used to prevent unwanted feedback into an optical oscillator, such as a laser cavity. The operation of the device depends on the Faraday Effect (which in turn is produced by magneto-optic effect), which is used in the main component, the Faraday rotator.

Faraday Effect :- The main component of the optical isolator is the Faraday rotator. The magnetic field, B, applied to the Faraday rotator causes a rotation in the polarization of the light due to the Faraday Effect. The angle of rotation, β, is given by-

$$\beta = \nu B d,$$

Where, v is the Verdet constant of the material (amorphous or crystalline; solid, liquid, or gaseous) of which the rotator is made, and d is the length of the rotator. This is shown in

. **Polarization dependent isolator**

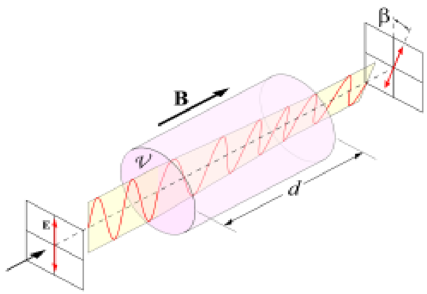


Figure 2: Faraday rotator, with a polarizer and an analyzer

The polarization dependent isolator, or Faraday isolator, is made of three parts, an input polarizer (polarized vertically), a Faraday rotator, and an output polarizer, called an analyzer (polarized at 45 degrees)Light traveling in the forward direction becomes polarized vertically by the input polarizer. The Faraday rotator will rotate the polarization by 45 degrees. The analyzer then enables the light to be transmitted through the isolator. Light traveling in the backward direction becomes polarized at 45 degrees by the analyzer. The Faraday rotator will again rotate the polarization by 45 degrees. This means the light is polarized horizontally (the rotation is insensitive to direction of propagation). Since the polarizer is vertically aligned, the light will be extinguished.

Figure 2 shows a Faraday rotator with an input polarizer, and an output analyzer. For a polarization dependent isolator, the angle between the polarizer and the analyzer, β, is set to 45 degrees. The Faraday rotator is chosen to give a 45 degree rotation. Polarization dependent isolators are typically used in free space optical systems. This is because the polarization of the source is typically maintained by the system. In optical fiber systems, the polarization direction is typically dispersed in non polarization maintaining systems. Hence the angle of polarization will lead to a loss.

Polarization independent isolator

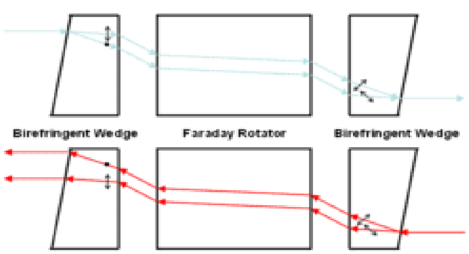


Figure 3: Polarization independent isolator

The polarization independent isolator is made of three parts, an input birefringent wedge (with its ordinary polarization direction vertical and its extra-ordinary polarization direction horizontal), a Faraday rotator, and an output birefringent wedge (with its ordinary polarization direction at 45 degrees, and its extra-ordinary polarization direction at -45 degrees).Light traveling in the forward direction is split by the input birefringent wedge into its vertical (0 degrees) and horizontal (90 degrees) components, called the ordinary ray (o-ray) and the extra-ordinary ray (e-ray) respectively. The Faraday rotator rotates both the o-ray and e-ray by 45 degrees. This means the o-ray is now at 45 degrees, and the e-ray is at -45 degrees. The output birefringent wedge then recombines the two components. Light traveling in the backward direction is separated into is o-ray at 45 degrees, and the e-ray at -45 degrees by the birefringent wedge. The Faraday Rotator again rotates both the rays by 45 degrees. Now the o-ray is at 90 degrees, and the e-ray is at 0 degrees. Instead of being focused by the second birefringent wedge, the rays diverge. Typically collimators are used on either side of the isolator. In the transmitted direction the beam is split and then combined and focused into the output collimator. In the isolated direction the beam is split, and then diverged, so it does not focus at the collimator. Figure 3 shows the propagation of light through a polarization independent isolator. The forward traveling light is shown in blue, and the backward propagating light is shown in red. The rays were traced using an ordinary refractive index of 2, and an extra-ordinary refractive index of 3. The wedge angle is 7 degrees.

The Faraday rotator

Faraday rotator

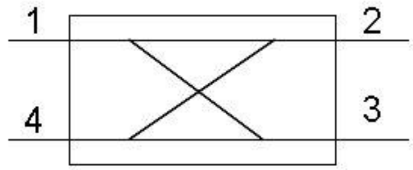
The most important optical element in an isolator is the Faraday rotator. The characteristics that one looks for in a Faraday rotator optic include a high Verdet constant, low absorption coefficient, low non-linear refractive index and high damage threshold. Also, to prevent self-focusing and other thermal related effects, the optic should be as short as possible. The two most commonly used materials for the 700-1100nm range are terbium doped borosilicate glass and terbium gallium garnet crystal (TGG). For long distance fiber communication, typically at 1310 nm or 1550 nm, yttrium iron garnet crystals are used (YIG). Commercial YIG based Faraday isolators reach isolations higher than 30 dB. Optical isolators are different from 1/4 wave plate based isolators because the Faraday rotator provides non-reciprocal rotation while maintaining linear polarization. That is, the polarization rotation due to the Faraday rotator is always in the same relative direction. So the in the forward direction, the rotation is positive 45 degrees. In the reverse direction the rotation is negative 45 degrees. This is due to the change in the relative magnetic field direction, positive one way, negative the other. This then adds to a total of 90 degrees when the light travels in the forward direction and then the negative direction. This allows the higher isolation to be achieved.

Optical isolators and thermodynamics

It might seem at first glance that a device that allows light to flow in only one direction would violate Kirchhoff's law and the second law of thermodynamics, by allowing light energy to flow from a cold object to a hot object and blocking it in the other direction, but the violation is avoided because the isolator must absorb (not reflect) the light from the hot object and will eventually reradiate it to the cold one.

Directional couplers: **-** Directional couplers are four-port circuits where one port is isolated from the input port. Directional couplers are passive reciprocal networks, which you can read more about on our page on basic network theory. All four ports are (ideally) matched, and the circuit is (ideally) lossless. Directional couplers can be realized in micro strip, stripling, coax and waveguide. They are used for sampling a signal, sometimes both the incident and reflected waves (this application is called a reflect meter, which is an important part of a network analyzer). Directional couplers generally use distributed properties of microwave circuits, the coupling feature is generally a quarter (or multiple) quarter-wavelengths. Lumped element couplers can be constructed as well. What do we mean by "directional"? A directional coupler has four ports, where one is regarded as the input, one is regarded as the "through" port (where most of the incident signal exits), one is regarded as the coupled port (where a fixed fraction of the input signal appears, usually expressed in dB), and an isolated port, which is usually terminated. If the signal is reversed so that it enter the "though" port, most of it exits the "input" port, but the coupled port is now the port that was previously regarded as the "isolated port". The coupled port is a function of which port is the incident port.

Looking at the generic directional coupler schematic below, if port 1 is the incident port, port 2 is the transmitted port (because it is connected with a straight line). Either port 3 or port 4 is the coupled port, and the other is the isolated port, depending on whether the coupling mode is forward or backward. How do you know which one is which? We'll talk about that in a second...



Power dividers and directional couplers

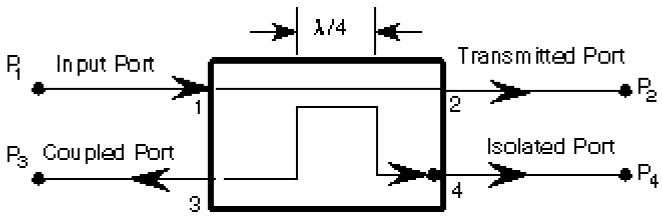


Figure 1. Directional Coupler

10 dB RF directional coupler N connectors from Micro lab/FXR with. From left to right: input, coupled, isolated (terminated with a load) and transmitted port. Power dividers and directional couplers are passive devices used in the field of radio technology. They couple part of the transmission power in a transmission line by a known amount out through another port, often by using two transmission lines set close enough together such that energy passing through one is coupled to the other.

Transmission line coupler description

As shown in Figure 1, a coupler has four ports: input, transmitted, coupled, and isolated. The term "main line" refers to the section between ports 1 and 2. On some directional couplers, the main line is designed for high power operation (large connectors), while the coupled port may use a small SMA connector. Often the isolated port is terminated with an internal or external matched load (typically 50 ohms). It should be pointed out that since the directional coupler is a linear device, the notations on Figure 1 are arbitrary. Any port can be the input, (as in Figure 3) which will result in the directly connected port being the transmitted port, the adjacent port being the coupled port, and the diagonal port being the isolated port (for stripling and microstripline couplers).Physical considerations such as internal load on the isolated port will limit port operation. The coupled output from the directional coupler can be used to obtain the information (i.e., frequency and power level) on the signal without interrupting the main power flow in the system (except for a power reduction - see Figure 2). When the power coupled out to port three is half the input power (i.e. 3 dB below the input power level), the power on the main transmission line is also 3 dB below the input power and equals the coupled power. Such a coupler is referred to as a 90 degree hybrid, hybrid, or 3 dB coupler. The frequency range for coaxial couplers specified by manufacturers is that of the coupling arm. The main arm response is much wider (i.e. if the spec is 2-4 GHz, the main arm could operate at 1 or 5 GHz - see Figure 3). However it should be recognized that the coupled response is periodic with frequency. For example, a λ/4 coupled line coupler will have responses at nλ/4 where n is an odd integer.

Common properties desired for all directional couplers are wide operational bandwidth, high directivity, and a good impedance match at all ports when the other ports are terminated in matched loads. These performance characteristics of hybrid or non-hybrid directional couplers are self-explanatory. Some other general characteristics will be discussed below.

Coupling factor

The coupling factor is defined as: $$C_{3,1} = -10\log\left(\frac{P_3}{P_1}\right) \quad \mathrm{dB}$$

Where P_1 is the input power at port 1 and P_3 is the output power from the coupled port (see Figure 1)The coupling factor represents the primary property of a directional coupler. Coupling is not constant, but varies with frequency. While different designs may reduce the variance, a perfectly flat coupler theoretically cannot be built. Directional couplers are specified in terms of the coupling accuracy at the frequency band center. For example, a 10 dB coupling +/- 0.5 dB means that the directional coupler can have 9.5 dB to 10.5 dB coupling at the frequency band center. The accuracy is due to dimensional tolerances that can be held for the spacing of the two coupled lines. Another coupling specification is frequency sensitivity. Larger frequency sensitivity will allow a larger frequency band of operation. Multiple quarter-wavelength coupling sections are used to obtain wide frequency bandwidth directional couplers. Typically this type of directional coupler is designed to a frequency bandwidth ratio and a maximum coupling ripple within the frequency band. For example a typical 2:1 frequency bandwidth coupler design that produces a 10 dB coupling with a +/- 0.1 dB ripple would, using the previous accuracy specification, be said to have 9.6 +/- 0.1 dB to 10.4 +/- 0.1 dB of coupling across the frequency range.

Loss

In an ideal directional coupler, the main line loss from port 1 to port 2 (P_1 - P_2) due to power coupled to the coupled output port is:

Insertion loss: $$L_{2,1} = 10\log\left(1 - \frac{P_3}{P_1}\right) \quad \mathrm{dB}$$

The actual directional coupler loss will be a combination of coupling loss, dielectric loss, conductor loss, and VSWR loss. Depending on the frequency range, coupling loss becomes less significant above 15 dB coupling where the other losses constitute the majority of the total loss. A graph of the theoretical insertion loss (dB) vs. coupling (dB) for a dissipation less coupler is shown in Figure 2.

Coupling dB	Insertion Loss - dB
3	3.00
6	1.25
10	0.458
20	0.0436
30	0.00435

Figure 2. Coupling Insertion Loss

Isolation

Isolation of a directional coupler can be defined as the difference in signal levels in dB between the input port and the isolated port when the two other ports are terminated by matched loads, or:

Isolation: $$I_{4,1} = -10 \log \left(\frac{P_4}{P_1} \right) \quad \text{dB}$$

Isolation can also be defined between the two output ports. In this case, one of the output ports is used as the input; the other is considered the output port while the other two ports (input and isolated) are terminated by matched loads.

Consequently: $$I_{3,2} = -10 \log \left(\frac{P_3}{P_2} \right) \quad \text{dB}$$

The isolation between the input and the isolated ports may be different from the isolation between the two output ports. For example, the isolation between ports 1 and 4 can be 30 dB while the isolation between ports 2 and 3 can be a different value such as 25 dB. If both isolation measurements are not available, they can be assumed to be equal. If neither are available, an estimate of the isolation is the coupling plus return loss (Standing wave ratio). The isolation should be as high as possible. In actual couplers the isolated port is never completely isolated. Some RF power will always be present. Waveguide directional couplers will have the best isolation.

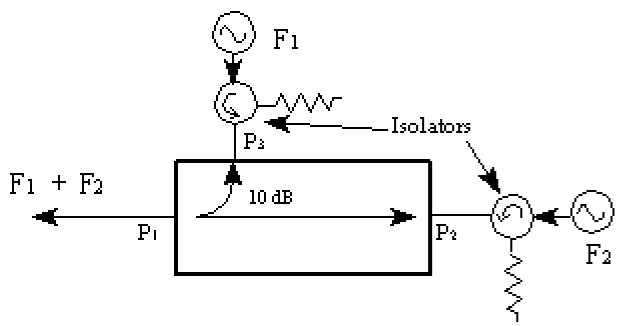


Figure 3. Two-Tone Receiver Tests

If isolation is high, directional couplers are excellent for combining signals to feed a single line to a receiver for two-tone receiver tests. In Figure 3, one signal enters port P_3 and one enters port P_2, while both exit port P_1. The signal from port P_3 to port P_1 will experience 10 dB of loss, and the signal from port P_2 to port P_1 will have 0.5 dB loss. The internal load on the isolated port will dissipate the signal losses from port P_3 and port P_2. If the isolators in Figure 3 are neglected, the isolation measurement (port P_2 to port P_3) determines the amount of power from the signal generator F_2 that will be injected into the signal generator F_1. As the injection level increases, it may cause modulation of signal generator F_1, or even injection phase locking. Because of the symmetry of the directional coupler, the reverse injection will happen with the same possible modulation problems of signal generator F_2 by F_1. Therefore the isolators are used in Figure 3 to effectively increase the isolation (or directivity) of the directional coupler. Consequently the injection loss will be the isolation of the directional coupler plus the reverse isolation of the isolator.

Directivity

Directivity is directly related to isolation. It is defined as:

Directivity: $$D_{3,4} = -10\log\left(\frac{P_4}{P_3}\right) = -10\log\left(\frac{P_4}{P_1}\right) + 10\log\left(\frac{P_3}{P_1}\right) \quad \mathrm{dB}$$

where: P_3 is the output power from the coupled port and P_4 is the power output from the isolated port. The directivity should be as high as possible. The directivity is very high at the design frequency and is a more sensitive function of frequency because it depends on the cancellation of two wave components. Waveguide directional couplers will have the best directivity. Directivity is not directly measurable, and is calculated from the difference of the isolation and coupling measurements as:

$$D_{3,4} = I_{4,1} - C_{3,1} \quad \mathrm{dB}$$

Hybrids

The hybrid coupler, or 3 dB directional coupler, in which the two outputs are of equal amplitude takes many forms. Not too long ago the quadrature (90-degree) 3 dB coupler with outputs 90 degrees out of phase was what came to mind when a hybrid coupler was mentioned. Now any matched 4-port with isolated arms and equal power division is called a hybrid or hybrid coupler. Today the characterizing feature is the phase difference of the outputs. If 90 degrees, it is a 90 degree hybrid. If 180 degrees, it is a 180 degree hybrid. Even the Wilkinson power divider which has 0 degrees phase difference is actually a hybrid although the fourth arm is normally imbedded. Applications of the hybrid include monopulse comparators, mixers, power combiners, dividers, modulators, and phased array radar antenna systems.

A very inexpensive version of this type of coupler is also used in the home to divide cable or over-the-air TV (and FM) signals to different rooms, or to devices without a pass through to the TV set. One port is labeled as an input, while the two, three, or four others are labeled as outputs, often with the dB of loss for each. One of these may have less loss than the others, which might in turn lead to another splitter somewhere else in the home, or to the longest-distance coaxial cable run to the furthest room.

Amplitude balance

This terminology defines the power difference in dB between the two output ports of a 3 dB hybrid. In an ideal hybrid circuit, the difference should be 0 dB. However, in a practical device the amplitude balance is frequency dependent and departs from the ideal 0 dB difference.

Phase balance

The phase difference between the two output ports of a hybrid coupler should be 0, 90, or 180 degrees depending on the type used. However, like amplitude balance, the phase difference is sensitive to the input frequency and typically will vary a few degrees.

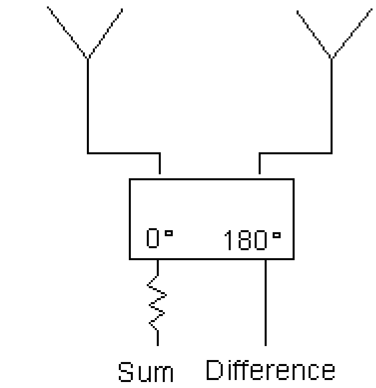


Figure 4. Balanced Antenna Input

The phase properties of a 90-degree hybrid coupler can be used to great advantage in microwave circuits. For example in a balanced microwave amplifier the two input stages are fed through a hybrid coupler. The FET device normally has a very poor match and reflects much of the incident energy. However, since the devices are essentially identical the reflection coefficients from each device are equal. The reflected voltage from the FETs are in phase at the isolated port and are 180 degrees different at the input port. Therefore, all of the reflected power from the FETs goes to the load at the isolated port and no power goes to the input port. This results in a good input match (low VSWR).If phase matched lines are used for an antenna input to a 180° hybrid coupler as shown in Figure 4, a null will occur directly between the antennas. To receive a signal in that position, one would have to either change the hybrid type or line length. To reject a signal from a given direction, or create the difference pattern for a monopulse radar, this is a good approach. Phase-difference couplers can be used to create beam tilt in a VHF FM radio station, by delaying the phase to the lower elements of an antenna array. For medium wave AM stations which use an array of mast radiators, the broadcast range can be completely redirected in this manner, usually done at night to avoid sky wave radio interference to a station in the opposite direction.

Other power dividers

Both in-phase (Wilkinson) and quadrature (90°) hybrid couplers may be used for coherent power divider applications. The Wilkinson power divider has low VSWR at all ports and high isolation between output ports. The input and output impedances at each port are designed to be equal to the characteristic impedance of the microwave system.

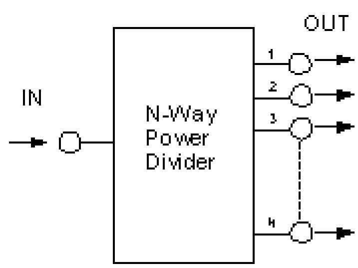


Figure 5. Power Divider

A typical power divider is shown at right. Ideally, input power would be divided equally between the output ports. Dividers are made up of multiple couplers and, like couplers, may be reversed and used as multiplexers. The drawback is that for a four channel multiplexer, the output consists of only 1/4 the power from each, and is relatively inefficient. Lossless multiplexing can only be done with filter networks. Coherent power division was first accomplished by means of simple Tee junctions. At microwave frequencies, waveguide tees have two possible forms - the E-plane and H-plane. These two junctions split power equally, but because of the different field configurations at the junction, the electric fields at the output arms are in-phase for the H-plane tee and are anti-phase for the E-plane tee. The combination of these two tees to form a hybrid tee allowed the realization of a four-port component which could perform the vector sum (Σ) and difference (Δ) of two coherent microwave signals. This device is known as the "magic tee". This approach allows the use of numerous less expensive and lower-power amplifiers in the circuitry instead of a single high-power TWT. Yet another approach is to have each solid state amplifier (SSA) feed an antenna and let the power be combined in space or be used to feed a lens which is attached to an antenna.

Sample problem

If two one-watt peak unmodulated RF carrier signals at 10 GHz are received, how much peak power could one measure?

1. 0 watt
2. 0.5 watt
3. 1 watt
4. 2 watts
5. All of these

The answer is all of these as shown in Figure 7.

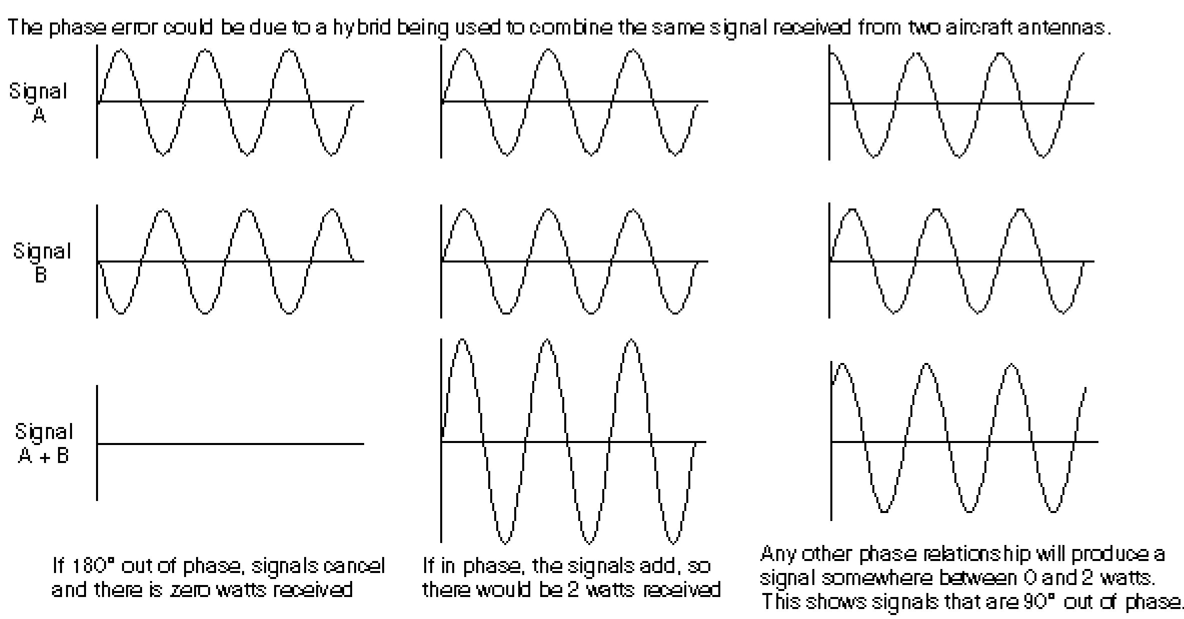
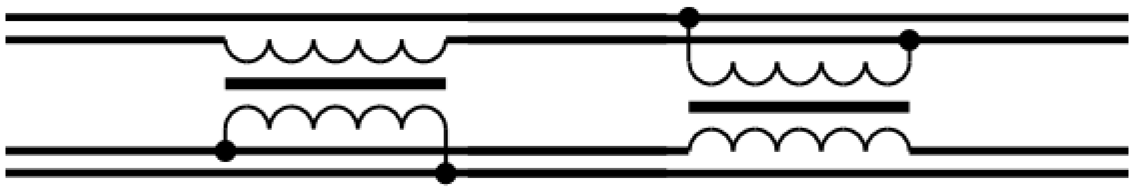


Figure 7. Sinewaves Combined Using Various Phase Relationships

Low-frequency directional couplers

For lower frequencies a compact broadband implementation by means of unidirectional couplers (transformers) is possible. In the figure a circuit is shown which is meant for weak coupling and can be understood along these lines: A signal is coming in one line pair. One transformer reduces the voltage of the signal the other reduces the current. Therefore the impedance is matched. The same argument holds for every other direction of a signal through the coupler. The relative sign of the induced voltage and current determines the direction of the outgoing signal.



For a 3 dB coupling, that is equal splitting of the signal, another view might be more appropriate: Two of the line pairs are combined into a polyphase line. A polyphase transformer can be used to redistribute the signal onto a set of 45°-rotated lines.

Definitions

Let's first look at some definitions using S-parameters. Let port 1 be the input port, port 2 be the "through" port. For a backward wave coupler, port 4 is the coupled port and port 3 is the isolated port. Ideally, power into port 1 will only appear at ports 2 and 4, with no power at port 3, but in real couplers some power leaks to port 3. For an incident signal at port 1 of power P1 (and output powers P2, P3 and P4 at ports 2, 3 and 4), then:

Insertion Loss (IL) = 10*log (P1/P2) =-20*log (S21)

Coupling Factor (CF) = 10*log (P1/P4) =-20*log (S41)

Isolation (I) = 10*log (P1/P3) = -20*log (S31)

Directivity (D) = 10*log (P4/P3) =-20*log (S31/S41)

Note that these numbers are positive in dB. Quite often, microwave engineers present these quantities as negative numbers; it is not a great faux pas, just look at the magnitude, Dude! Note that directivity requires two, two-port S-parameter measurements; the other quantities require only one. Directivity is the ratio of isolation to coupling factor. In decibels, isolation is equal to coupling factor plus directivity. Please send us any comments on the preceding statements, we are operating under a state of partial dyslexia and there is a possibility that we slipped up on a minus sign!

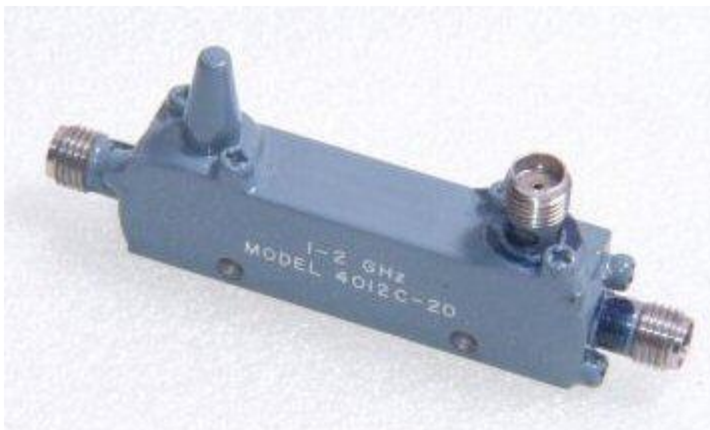
Forward versus backward wave couplers

Waveguide couplers couple in the forward direction (forward-wave couplers); a signal incident on port 1 will couple to port 3 (port 4 is isolated). Micro strip or stripline coupler are "backward wave" couplers. In the schematic above that means for a signal incident on port 1, port 4 is the coupled port (port 3 is isolated).

Coupler rule of thumb

The coupled port on a microstrip or strip line directional coupler is closest to the input port because it is a backward wave coupler. On a waveguide broad wall directional coupler, the coupled port is closest to the output port because it is a forward wave coupler.

The Narda coupler below is made in strip line (you have to cut it apart to know that, but just trust us), which means it is a backward wave coupler. The input port is on the right, and the port facing up is the coupled port (the opposite port is terminated with that weird cone-shaped thingy which voids the warrantee if you remove it. Luckily Narda usually prints an arrow on the coupler to show how to use it, but the arrow is on the side that is hidden in the photo.

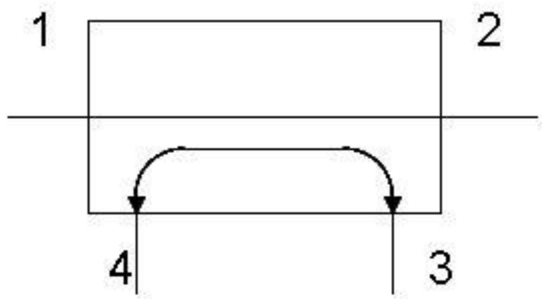


On the waveguide coupler below, the input is on the left, while the coupled port is on the right, pointing toward your left ear. There is a termination built into the guide opposite the coupled port, although you can't see it.

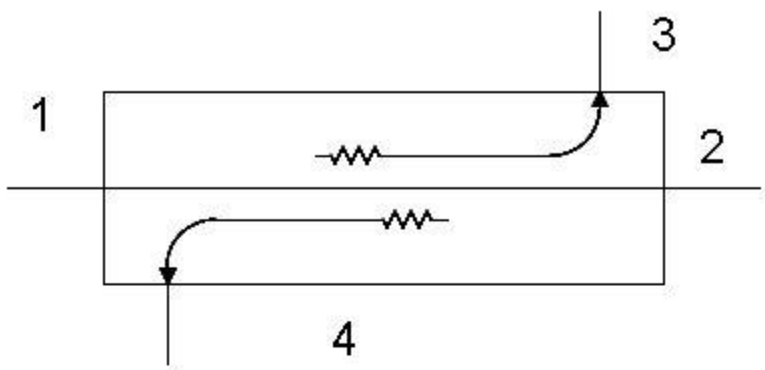
Bethe-hole coupler

This is a waveguide directional coupler, using a single hole, and is works over a narrow band. The two guides are configured to (sorry we need to finish this section!!!)In waveguide, a two-hole coupler, two waveguides share a broad wall. Holes are 1/4 wave apart. In the foreword 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, and...

Bi-directional coupler
A directional coupler where the isolated port is not internally terminated. You can use such a coupler to form a reflectometer, but it is not recommended (use the dual-directional coupler you cheapskate!)



Dual-directional coupler
Here we have two couplers in series, in opposing directions, with the isolated ports internally terminated. This component is the basis for the reflectometer.



Hybrid couplers

A hybrid coupler is a special case, where a 3 dB split is desired between the through path and the coupled path. There are two types of hybrid couplers, 90 degree couplers (such as Langes or branch lines) and 180 degree hybrids (such as rat-races and magic tees). We have a separate page on this topic

Reflectometer

This is the component that allows you to measure S-parameter magnitudes using a analyzer. A directional coupler only does what it is supposed to if it sees a matched impedance at all four ports. Errors due to finite directivity. Directivity can cause errors if load is not matched. 40 dB directivity will have a very small error, 20 dB may be unacceptable accuracy.

C–Band Microwave Bench

Microwave remote sensing is powerful tool for geological & agricultural information regarding rocks, soils & different terrains. This technique involves information regarding Physical properties of soil such as Di-electric constant, Di–electric loss, emissivity etc. The measurements of these properties are done at C–band microwave frequency The usual C –band microwave bench setup is quite useful , however its performance is limited and & time consuming due to manually operated mechanical arrangement of rack & pinion system for moving the detector along the slot line. The data is to be read & recorded for more than one hundred positions of the probe in one set of observation. This causes the work tedious and laborious. These shortcomings are overcome by developing automation of microwave bench set up by modifying it. The changes made consist of modified mechanical assembly a PCADD ON CARD and software development of source code & graphic utility with GR.EXE files. Modified mechanical system consist of 1mm pitch screw with stepper motor which can be operated in auto made or manual scan mode .Data Acquisition System consisting of hardware with two daughter boards are one for analog to digital converter & other for steeper motor controller with suitable software &software development which controls the system in return in Q- basic & hardware routines for steeper motor controllers & for reading data from ADC written in 8088 assembly language The acquired data can be displayed in graphical form with GR- EXE file which helps in taking the decision about quality of stored data, So that insignificant data giving asymmetrical wave pattern can be rejected immediately & fresh reading may be taken.

I. INTRODUCTION :- Microwaves have recently changed the mode of communication and in a way it has changed the face of world. The microwave spectrum as electromagnetic energy has been instrument in creating what is known as.

EXPERIMENTAL SETUP FOR C-BAND

The experimental setup for micro-wave frequencies at C-band requires a microwave source to produce microwave power. A varactor tuned oscillator (VTO 8430) of Avantek is used which supplies microwave power to a maximum level of 10 mW at frequencies from 4.3 GHz to 5.8 GHz. A +15 Volts DC power supply has been used as source power supply. Temperature of VTO may raise while in use, so an electrical fan is used to cool it. The block diagram of experimental setup is shown in Fig.1.

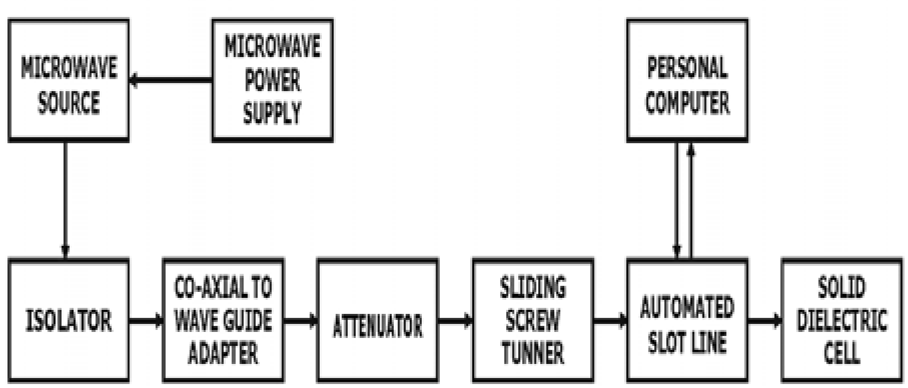


Fig.1 Block Diagram of C-Band Microwave Bench

Fig.1Block Diagram of C-Band Microwave Bench The other components shown in the block diagram are isolator, co-axial connector, attenuator, sliding screw tuner, slotted line section , detector probe and a dielectric cell .In this setup all the components are assembled and microwaves are generated by VTO and are propagated through rectangular waveguide to the dielectric cell. The attenuator is used to keep the desired power in line. A slotted section with tunable probe containing 1N23C crystal with the square low characteristics has been used to measure power (current) along the slotted line. The crystal detector is connected to the micro ammeter and to the PC to read and record the measured power.

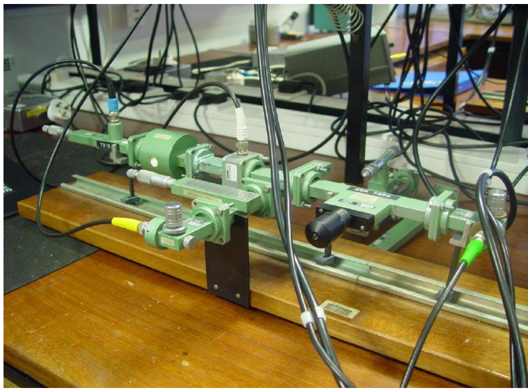
III. AUTOMATION

Mechanical modifications are done in slot line in the usual microwave bench setup for obtaining the required automation. In the existing usual microwave bench setup the detector probe sitting on a mount produces DC output current due to microwaves in the waveguide. The detector mount is attached to rack and pinion arrangement so that the detector probe can be moved in the slot line in forward and reverse direction by rotating the knob in clockwise and anticlockwise direction respectively.

The displacement of the probe can be measured by scale fixed along slot line having vernier arrangement. Instead of rack and penion arrangement lock nut and lead screw is used to modify the mechanical system. The lead screw passes through lock nut which is attached to the detector mount. It is fixed in the position of rack between two supports heading the slot line piece of the wave guide. A set of gears 1:1 is fitted at the FAR end of the lead screw and to the shaft of steeper motor. Thus the stepper motor drive can control the position of the detector probe on the lot line. Two limit switches are fixed to the end positions on either side of the slot line. The limit switch at HOME position will operate when the detector probe mount is brought to that end and the motor takes the probe to start position after removing the back lash in the lock nut. The stepper motor drive can be operated in AUTO mode through PC interfacing to move the detector probe from HOME position to FAR position and current is read and recorded at each 1 mm position along its traverse. The position of the probe and current is displayed on the monitor screen. It takes more than one hundred steps of positions to reach the probe to FAR position where it automatically operates the second limit switch to stop the motor. A solid dielectric cell with perfectly reflecting surface as short circuit is used to measure dielectric constant.

IV. DATA ACQUISITION SYSTEM

The hardware of the system mainly consists of a control mother board, which is fully IBM PC compatible and two daughter boards. One of the daughter boards is for a 13 bit AD analog to digital converter and the other for stepper motor controller. The ADC converts analog current signal from the detector probe into digital form for PC based instrumentation. The stepper motor controller has facilities of a full step and half step rotation in both clockwise and anticlockwise rotation provided by suitable software . This PC controlled rotation of the stepper motor rotates the lead screw through 1:1gear set. Thereby a forward and reverse advancement of the locknut along the slot line is obtained, which ultimately causes motion of the detector probe for reading and recording current sat all positions along the slot line on microwave setup. The hardware is developed by.


An X-band waveguide bench.

V. CONCLUSION

C-band microwave bench setup for PC interfacing hardware is modified and a tedious and labourus work is avoided. Dielectric constant measurements became fast.

Result - Study of Isolators, directional couplers (cross directional & multihole) slotted line &block diagram of basic microwave bench is completed

Precautions – 1) all connection should be make properly.

2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).

3) Before the circuit connection it should be check out working condition of all the Component

Experiment no -5

Objective :- . Performance of VSWR meter

Theory -

VSWR :- Voltage Standing Wave Ratio is the ratio of the voltage maximum (antinode) to the adjacent voltage minimum (node) on a transmission line. The standing wave is produced by the superposition of a forward traveling wave and a reflected traveling wave when the transmission line is terminated in other than its characteristic impedance. The reflected wave is created to reconcile the conditions at the end of the transmission line, including the load impedance and the natural ratio of V/I in the forward and reflected traveling waves. Γ is the ratio of V_r/V_f, and VSWR on a sufficiently long lossless line can be predicted as $(1+|\Gamma|)/(1-|\Gamma|)$ from the conditions at the termination or some other point. Γ, V_r and V_f are phasor quantities, ie can be expressed as complex numbers.Direct measurement of VSWR requires observation of the voltage at a number of points along the line, but VSWR is more often estimated from observed conditions at a point, but such estimates typically assume a sufficiently long lossless line.

Breune style VSWR meter

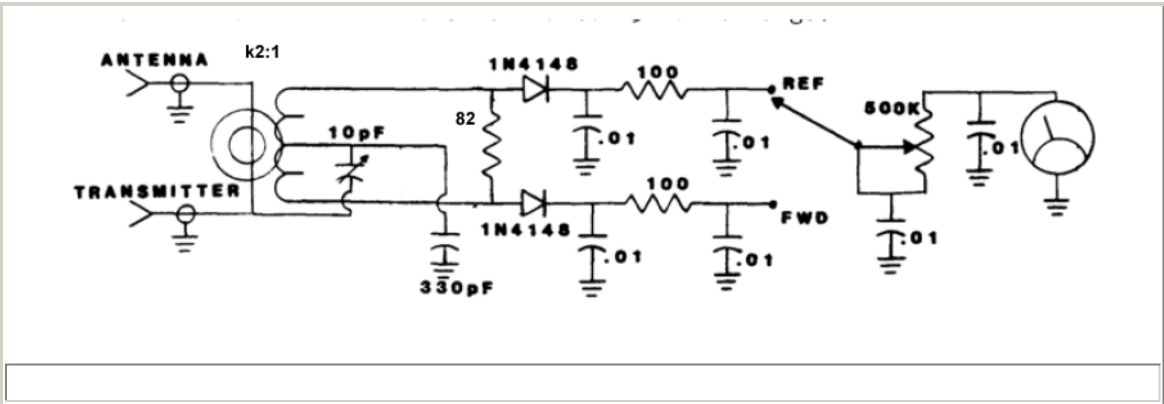


Fig 1 shows a typical VSWR meter based on Breune circuit. The circuit samples voltage and current in a very small region of the transmission line, sufficiently small to consider it a point sample at the frequencies of interest. The circuit contains two directional samplers, one for the forward traveling wave, and one for the reflected traveling wave. A sample of the line voltage is obtained by the voltage divider formed by the 10pF and 330pF capacitors. A sample of the line current is taken by the current transformer, and the secondary current is passed through the 82Ω resistor to develop a voltage at each end of the secondary wrt the centre, that is proportional to the current in the main line and opposite in phase at each end of the winding.

Since the voltage sample is connected to the centre of the secondary, the ends of the secondary will be a voltage that is proportional to the line voltage plus line current times Z_n (the impedance for which the meter is calibrated), and the line voltage minus line current times Z_n for forward and reflected detectors respectively. The 10pF capacitor is adjusted so that in the reflected position with applied RF power, the meter shows zero deflection with a Z_n load (typically 50+j0Ω).

The following describes the circuit in detail in the general sense. V_1 is the RF voltage at the lower end of the secondary (wrt ground) in the circuit above, V2 is the voltage at the upper end of the secondary (wrt ground), Z_x corresponds to half of the 82Ω resistor. The description assumes the components (capacitors, transformer, and diodes) are ideal, and that the VSWR meter loading of the through line is insignificant.

$V_1=|k_1*V+k_2*I*Z_x|$ ...(1)

$V_2=|k_1*V-k_2*I*Z_x|$ ... (2)

The instrument is calibrated by adjustment of the value of k_1 so that V_2 is zero when $Z_l=Z_n$. It can be seen that for V_2 to be zero, $k_1*V=k_2*I*Z_x$, therefore $Z_x=k_1*V/k_2/I$, and since $V/I=Z_n$ then $Z_x=k_1/k_2*Z_n$. So, the two expressions can be rewritten as:

$V_1=|k_1*(V+I*Z_n)|$ ... (3)

$V_2=|k_1*(V-I*Z_n)|$ ... (4)

Fig 2: Equivalent circuit

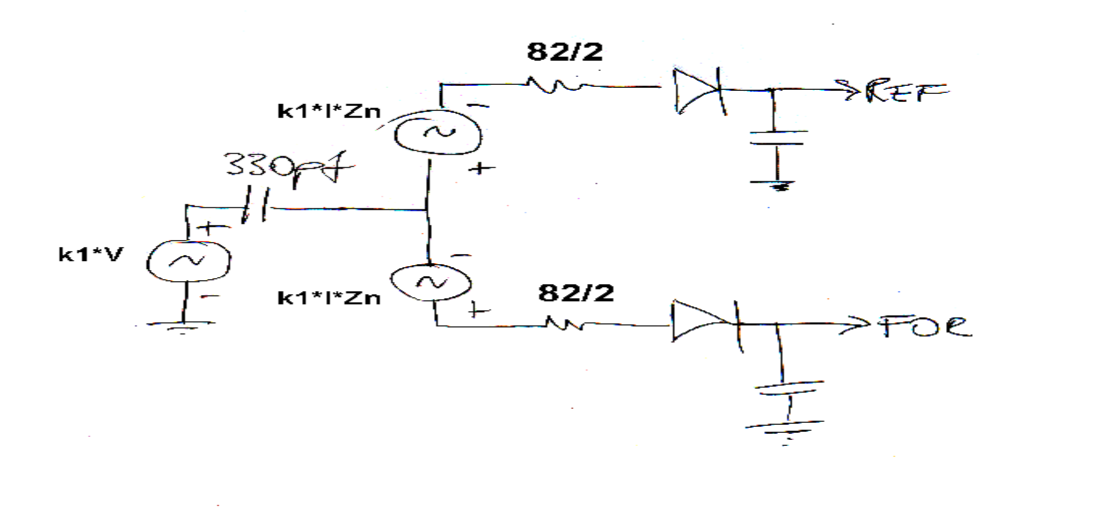


Fig 2 shows the equivalent circuit, a voltage sample of k_1*V, and voltages proportional to current of k_1*I*Z_n .

Since $V=V_f+V_r$, and $V_r=\Gamma*V_f$ and $I=I_f-I_r$, and $I_r=\Gamma*I_f$ eqn (3) can be rewritten as

$V_1=|k_1*(V_f*(1+\Gamma)+I_f*(1-\Gamma)*Z_n)|$ ... (5)

Substituting V_f/Z_n for I_f

$V_1=|k_1*(V_f*(1+\Gamma)+V_f*(1-\Gamma))|$ ... (6)

$V_1=|k_1*V_f*((1+\Gamma)+(1-\Gamma))|$ ... (7)

$V_1=|k_1*2*V_f|$ ... (8)

Similarly, eqn (4) can be transformed to

V_2=|k_1*2*Γ*V_f| ... (8)

So

V_2 /V_1 =|Γ| ... (9)

Substituting ρ for |Γ|

ρ=V_2 /V_1 ... (10)

VSWR can be calculated from ρ, VSWR= (1+ ρ)/(1- ρ), so the indication of V2 relative to V1 can be scaled in VSWR. The instrument can be used to directly measure ρ at a point (being that of the instrument's sampler) and that knowledge can be used to predict the VSWR that would be observed on a sufficiently long length of adjacent lossless transmission line of the same Z_o as the instrument's calibration impedance Z_n

To analyse the circuit of Fig 1 at 100W connected to a 50+j0Ω load, for a current transformer of 1:25+25 turns bifilar, the peak current in the 82Ω resistor is 2^0.5*(100/50)^0.5/50 or 0.04A, yielding a peak half winding voltage of 0.1*82/2 or 1.65V. The 10pf capacitor would be adjusted for 0V on the REF switch terminal which will correspond to about 5.5pF for a voltage sample of 1.65Vpk on the 330pF capacitor. This would give a DC voltage about 2.7V (allowing for diode voltage drop) at the FOR switch terminal and 0V at the REF switch terminal.

It is key to note that the accuracy of the instrument in measuring ρ is dependent of the calibration impedance Z_n and less dependent on the Z_o of the sampler line section where is relatively short (as it is usually).

Other circuits

There are other circuits of VSWR meters; the most common other type uses a pair of short loosely coupled transmission lines with detectors in the sampler line section. Differently to the Breune circuit, the coupling is frequency dependent although some designs achieve compensation over a range of frequencies (eg Bird 43 elements). Frequency dependent samplers cannot be simply calibrated as directional wattmeters. Despite this difference, the same principles apply as explained for the Breune circuit, in that the circuit samples voltage and current in a very small region of the transmission line, sufficiently small to consider it a point sample at the frequencies of interest. From there on, the explanation is the same (though k_1 and k_2 may be frequency dependent).

There are other methods for indirect measurement of VSWR that would not be classed as a VSWR meter, eg a true directional transmission line or waveguide coupler with power meters on the coupled ports. This configuration comes into its own on microwave frequencies where it is difficult to construct other types of samplers that are small enough to not disturb the system being measured.

Directional Wattmeter

Since the forward and reflected detectors in the instrument described above responds to V_f and V_r respectively, the question arises as to whether the instrument can be calibrated in power. The power passing any point in a transmission line is given by P=real (V*conjugate (I)). When Z_n is real (lossless lines and distortion less lines), this can be simplified to V_f*I_f-V_r*I_r, often expressed loosely as forward power less reflected power.

Instruments are usually calibrated to a nominal Z_n that is real (eg 50+j0), and in that case, with better quality instruments, the calibration of the scale(s) in Watts (where $P_f=V_f^2/Z_n$ and $P_r=V_r^2/Z_n$), and calculation of power as $P=P_f-P_r$ is sound. The term directional wattmeter is a bit of a misnomer in that the values of P_f and P_r are not of themselves meaningful, but the difference of the two is the power at that point. Beware, these comments apply to the type of directional detector described above, and not to a simple line RF voltmeter that is incorporated in some instruments and calibrated only for power when VSWR=1.

- The magnitude of line voltage and line current show the classic standing wave patterns.
- The green line is the calculated VSWR on the line (which has a characteristic impedance of 75-j0.8Ω).
- The VSWR(50) line shows the VSWR that would be indicated on a short VSWR meter calibrated for 50+j0Ω, but that should not be interpreted as the VSWR on the actual RG6/U transmission line.
- Note also how the real VSWR falls smoothly from 1.54 at the load to 1.48 at a distance of 20m from the load, a result of line loss.
- Power increase smoothly from the load to the source end, but the slope of the line changes minutely in this example with line current, the slope (meaning the attenuation per unit length) is highest approximately where current is highest, meaning the main loss is I^2R loss in the centre conductor.

The VSWR meter captures ρ which is the magnitude of Γ, the phase of Γ is lost and so the VSWR meter is unable to be used to predict the value of Z at a point, except in the special case where VSWR=1 and therefore Z is Z_n . Fig 4 above shows the impedance

along the line for the example. It can be seen that impedance continually changes along the line, and that is true in the general case except where VSWR=1.

Errors

There are many sources of errors in VSWR meters, the most common ones are:

- accuracy of the impedance at which the detectors null;
- scale shape (ie the relationship between scale markings and meter current);
- diode voltage drop (related to previous item);
- balance of both detectors;
- length of the sampler;
- power calibration;
- frequency sensitivity / compensation accuracy;
- insertion VSWR (the VSWR caused by insertion of the sampler element in a line, related to the coupling and the accuracy of Zo of the sampler section;
- loss (loss in the sampler section);
- detector / meter response to modulated waveforms;
- Application - what to measure, and how to extrapolate that measurement to another place (eg adjacent transmission line or a far end load, and the errors inherent in that extrapolation).

The greatest error is probably the last. VSWR meters are widely used, and ingenious as they are, the results are often incorrectly interpreted. It is possible to achieve a good null (ie low VSWR) on a nominal dummy load, even though an instrument might itself cause higher VSWR because of an inaccurate line section or excessive coupling.

Mismatch loss or loss due to standing waves can be determined accurately knowing the propagation constant (γ) of the line and the complex reflection coefficient (Γ) at a known point on the line. An approximation of the mismatch loss can be made using the propagation constant (γ) (in fact just the attenuation component) and VSWR (which depends only on the magnitude of the complex reflection coefficient (Γ) that is reasonably accurate only on medium length lines with low VSWR and low loss. This has affects the accuracy of a directional wattmeter of this type for assessing the matched line loss of a s/c or o/c length of line, but for most purposes the effect is small and the test gives good results (providing the VSWR meter gives accurate readings at high VSWR).

Testing a VSWR meter

The tests here need to be interpreted in the context of whether the device under test (DUT) has only calibrated power scales, or a VSWR Set/Reflected mode of measurement, and whether directional coupler scales are identical for both directions.

1. Connect a calibrated dummy load of the nominal impedance on the instrument output and measure the VSWR at upper and lower limit frequencies and some in between frequencies. The VSWR should be 1. (Checks nominal calibration impedance);
2. Repeat Test 1 at a selection of test frequencies and for each test, without changing transmitter power, reverse the DUT and verify that repeat the forward/set and reflected readings swap, but are of the same amplitude (checks the symmetry / balance of the detectors under matched line conditions).
3. Connect a s/c to the instrument output and measure the VSWR at upper and lower limit frequencies and some in between frequencies. The VSWR should be infinite. (Discloses averaging due to excessive sampler length);
4. Connect an o/c to the instrument output and measure the VSWR at upper and lower limit frequencies and some in between frequencies. The VSWR should be infinite. (Discloses averaging due to excessive sampler length);
5. Connect a calibrated wattmeter / dummy load of the nominal impedance on the instrument output and measure calibration accuracy of power / ρ / VSWR scales at a range of power levels in both forward and reflected directions (Checks scale shape and absolute power calibration accuracy).
6. Repeating Test 1additionally with a calibrated VSWR meter connected to the input to the DUT, and measure the VSWR caused by the DUT at a range of test frequencies (Checks Insertion VSWR).

It is not unusual for low grade instruments to pass Test 1, but to fail Test 6 (and some others, especially Test 3 and Test 4) towards the higher end of their specified frequency range.

Term	Meaning
Distortion less line	R/L=G/C. A lossless line is a special case of a distortion less line.
Γ	The reflection coefficient (a complex quantity with real and imaginary parts)
Lossless line	R=0, G=0
ρ	The magnitude of Γ
VSWR	Voltage Standing Wave Ratio is the ratio of the voltage maximum (antinode) to the adjacent voltage minimum (node) on a transmission line

Result - Performance of VSWR meter is observed.

Precautions – 1) all connection should be make properly.

2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).
3) Before the circuit connection it should be check out working condition of all the Component

Experiment no - 6

Objective :- Measurement of frequency of microwave

Apparatus required - Doppler module, metal rule, Vacuum tube devices, tunable resonator.

Theory -

Microwaves: **-** Microwaves are electromagnetic waves with wavelengths ranging from as long as one meter to as short as one millimeter, or equivalently, with frequencies between 300 MHz (0.3 GHz) and 300 GHz. This broad definition includes both UHF and EHF (millimeter waves), and various sources use different boundaries. In all cases, microwave includes the entire SHF band (3 to 30 GHz, or 10 to 1 cm) at minimum, with RF engineering often putting the lower boundary at 1 GHz (30 cm), and the upper around 100 GHz (3mm).

Microwave frequency bands

The microwave spectrum is usually defined as electromagnetic energy ranging from approximately 1 GHz to 100 GHz in frequency, but older usage includes lower frequencies. Most common applications are within the 1 to 40 GHz range. Microwave frequency bands, as defined by the Radio Society of Great Britain (RSGB), are shown in the table below:

ITU Radio Band Numbers

1 2 3 4 5 6 7 8 9 10 11

ITU Radio Band Symbols

ELF SLF ULF VLF LF MF HF VHF UHF SHF EHF

NATO Radio bands

A B C D E F G H I J K L M

IEEE Radar bands

HF VHF UHF L S C X K_u K K_a Q V W

v d e

Microwave frequency bands

Letter Designation	Frequency range
L band	1 to 2 GHz
S band	2 to 4 GHz
C band	4 to 8 GHz
X band	8 to 12 GHz
K_u band	12 to 18 GHz
K band	18 to 26.5 GHz
K_a band	26.5 to 40 GHz
Q band	30 to 50 GHz
U band	40 to 60 GHz
V band	50 to 75 GHz
E band	60 to 90 GHz
W band	75 to 110 GHz

F band	90 to 140 GHz
D band	110 to 170 GHz

Microwave frequency measurement

Microwave frequency can be measured by either electronic or mechanical techniques. Frequency or high frequency heterodyne systems can be used. Here the unknown frequency is compared with harmonics of a known lower frequency by use of a low frequency generator, a harmonic generator and a mixer. Accuracy of the measurement is limited by the accuracy and stability of the reference source. Mechanical methods require a tunable resonator such as an absorption wave meter, which has a known relation between a physical dimension and frequency.

Wave meter for measuring in the Ku band

In a laboratory setting, Lecher lines can be used to directly measure the wavelength on a transmission line made of parallel wires, the frequency can then be calculated. A similar technique is to use a slotted waveguide or slotted coaxial line to directly measure the wavelength. These devices consist of a probe introduced into the line through a longitudinal slot, so that the probe is free to travel up and down the line. Slotted lines are primarily intended for measurement of the voltage standing wave ratio on the line. However, provided a standing wave is present, they may also be used to measure the distance between the nodes, which are equal to half the wavelength. Precision of this method is limited by the determination of the nodal locations.

Frequency measurement:-

For amateur frequency measurement, this principle can be directly applied at the kitchen table level. For a typical Doppler module, enough signal is reflected from an ordinary metal tea tray 10 ft away to be readable on a mixer current meter. Apart from the tea tray, all that is then needed is a metal tape measure and some adhesive tape. The general arrangement can be seen above. First, make a scribed mark at some convenient point on the Doppler module (or its casing) adjacent to the metal rule. Then stand the tea tray on its end about 2 ft in front of the module, though the precise angle and distance do not matter as long as the tray does not move relative to the rule.

Next, move the Doppler unit backwards or forwards until the meter shows a maximum. (Such maxima will occur every 1.5 cm for a 10 GHz rig). Choose one such maximum and note carefully the measurement on the rule corresponding to the scribed mark on the equipment. If the module is then slowly moved away from the tray, the mixer current will fall and rise in successive cycles. In theory one could measure the distance moved in just one cycle, but the accuracy would be too low for practical purposes. It is therefore best to measure the distance over which the mixer current has gone through 20 or more cycles. (How many depends entirely on the length of the kitchen table and the strength of the reflected signal. When the distance is too great the meter movements are too small to read accurately.) To calculate the frequency, remember that any movement of the module must be doubled to get the change of path length. The relationship is as follows:

Frequency = (Velocity of EMR in free space x No of measured cycles) / 2 x measured distance

Simplifying and putting in practical units, this becomes:

Frequency (GHz) = (14.99 x N) / ΔD

Where N = number of cycles and ΔD = measured distance

To take a practical example: suppose that 40 cycles were measured over a distance of 59 cm. inserting the data into the equation:

$F = (14.99 \times 40) / 59 = 10.16$GHz

The accuracy of this method is determined largely by the accuracy of measurement. In the above example assume that the 59 cm were measured to an accuracy of 1 mm; not too difficult in practice. The accuracy would then be approximately one part in 600, ie within 17 MHz at 10 GHz. One other possible source of inaccuracy is the effect on the Gunn oscillator stability of too much signal being reflected back into the horn. For this reason the tea tray should be kept at least 1ft from the module, and preferably more. It should also be borne in mind that if the module is fitted to any other antenna or waveguide system, the change of loading could also alter the frequency. Nevertheless, for getting a simple microwave rig roughly on frequency and safely within the allocated band, there can scarcely be a simpler method.

Observation table -

S.no	N	ΔD	Frequency (GHz) = (14.99 x N) / ΔD

Microwave sources

Vacuum tube devices operate on the ballistic motion of electrons in a vacuum under the influence of controlling electric or magnetic fields, and include the magnetron, klystron, traveling-wave tube (TWT), and gyrotron. These devices work in the density modulated mode, rather than the current modulated mode. This means that they work on the basis of clumps of electrons flying ballistically through them, rather than using a continuous stream. Cutaway view inside a cavity magnetron as used in a microwave oven Low power microwave sources use solid-state devices such as the field-effect transistor (at least at lower frequencies), tunnel diodes, Gunn diodes, and IMPATT diodes. A maser is a device similar to a laser, which amplifies light energy by stimulating the emitted radiation. The maser, rather than amplifying light energy, amplifies the lower frequency, longer wavelength microwaves. The sun also emits microwave radiation, and most of it is blocked by Earth's atmosphere. The Cosmic Microwave Background Radiation (CMBR) is a source of microwaves that supports the science of cosmology's Big Bang theory of the origin of the Universe.

Uses:-

1. Communication

2. Radar

3. Radio astronomy

4. Navigation

5. Power

Microwave frequencies typically ranging from 110 - 140 GHz are used in stellarators and more notably in tokamak experimental fusion reactors to help heat the fuel into a plasma state. The upcoming ITER Thermonuclear Reactor is expected to range from 110-170 GHz and will employ Electron Cyclotron Resonance Heating (ECRH) Microwaves can be used to transmit power over long distances, and post-World War II research was done to examine possibilities. NASA worked in the 1970s and early 1980s to research the possibilities of using solar power satellite (SPS) systems with large solar arrays that would beam power down to the Earth's surface via microwaves. Less-than-lethal weaponry exists that uses millimeter waves to heat a thin layer of human skin to an intolerable temperature so as to make the targeted person move away. A two-second burst of the 95 GHz focused beam heats the skin to a temperature of 130 °F (54 °C) at a depth of 1/64th of an inch (0.4 mm).

Result - Measurement of frequency of microwave is done

Precautions – 1) all connection should be make properly.

2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).

3) Before the circuit connection it should be check out working condition of all the Component

Experiment no - 7

Objective - Measurement of guide wavelength

Apparatus required –

Theory –

Guide wavelength-

Guide wavelength is defined as the distance between two equal phase planes along the waveguide. The guide wavelength is a function of operating wavelength (or frequency) and the lower cutoff wavelength, and is always longer than the wavelength would be in free-space. Here's the equation for guide wavelength:

$$\lambda_{guide} = \frac{\lambda_{freespace}}{\sqrt{1 - \left(\frac{\lambda_{freespace}}{\lambda_{cuttoff}}\right)^2}}$$

$$\lambda_{guide} = \frac{c}{f} \times \frac{1}{\sqrt{1 - \left(\frac{c}{2a \cdot f}\right)^2}}$$

Guide wavelength is used when you design distributed structures in waveguide. For example, if you are making a PIN diode switch with two shunt diodes spaces 3/4 wavelength apart, use the 3/4 of a guide wavelength in your design. The guide wavelength in waveguide is longer than wavelength in free space. This isn't intuitive, it seems like the dielectric constant in waveguide must be less than unity for this to happen... don't think about this too hard you will get a headache.

Observation table –

S. no	c	f	x = [c/2af]^2	λguide = 1/(√1- x)

Phase velocity and group velocity

P**hase velocity** is an almost useless piece of information you'll find in waveguide mathematics; here you multiply frequency times guide wavelength, and come up with a number that exceeds the speed of light!

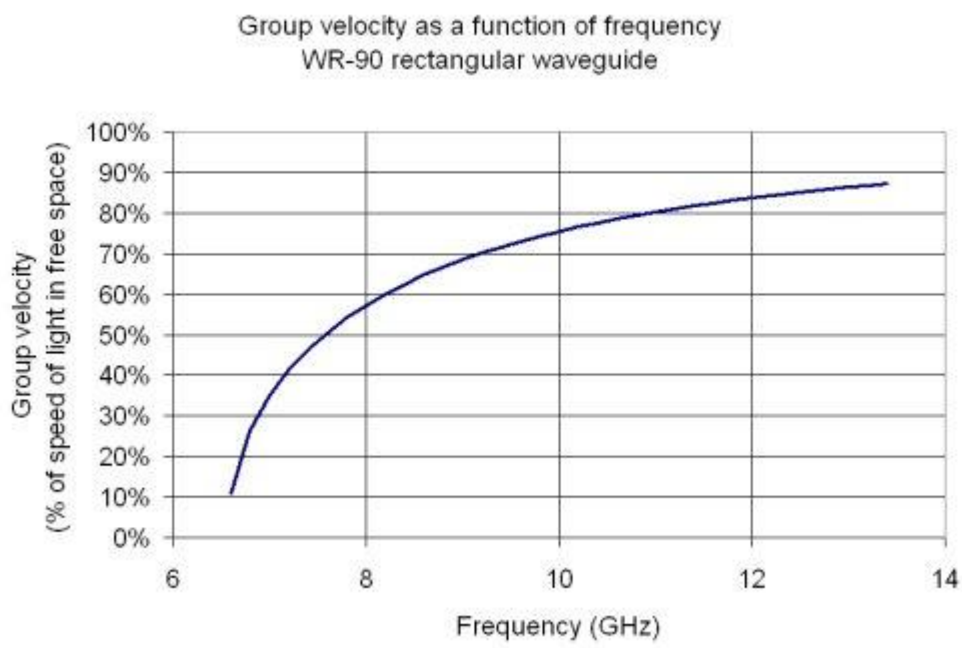
$$v_{phase} = \frac{c}{\sqrt{1-\left(\frac{c}{2a \cdot f}\right)^2}}$$

Be assured that the energy in your wave is not exceeding the speed of light, because it travels at what is called the **group velocity** of the waveguide:

$$v_{group} = c \times \sqrt{1-\left(\frac{c}{2a \cdot f}\right)^2}$$

The group velocity is always less than the speed of light, we like to think of that this is because the EM wave is ping-ponging back and forth as it travels down the guide. Note that group velocity x phase velocity = c^2.Group velocity in a waveguide is speed at which EM energy travels in the guide. Plotted below as a percentage of the speed of light (c), we see how group velocity varies across the band for WR-90 (X-band) waveguide. Note that the recommended operating band of WR-90 is from 8.2 to 12.4 GHz. At 8.2 GHz the signal is slowed to 60% of the free-space speed of light. At the lower cutoff (6.56 GHz), the wave is slowed to zero, and you can outrun it without breathing hard.

graph -

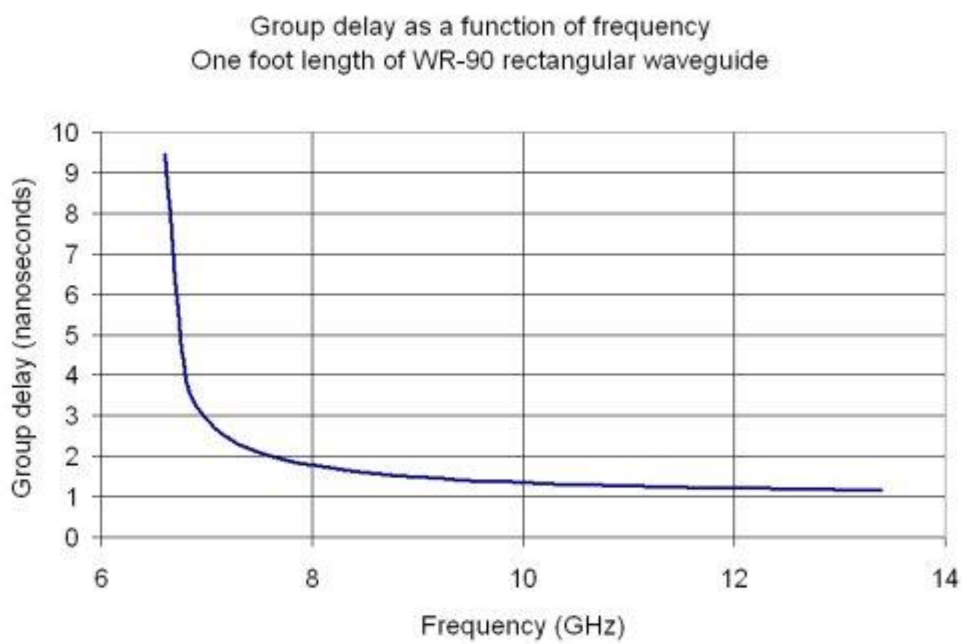


Group delay in waveguide

Now that we know the group velocity, we can calculate the group delay of any piece of waveguide, noting that time is distance divided by velocity:

$$group\ delay = \frac{length}{c \times \sqrt{1 - \left(\frac{c}{2a \cdot f}\right)^2}}$$

The group delay of rectangular waveguide components is a function of the frequency you are applying. Near the lower cutoff, the group delay gets longer and longer, as the EM wave ping-pongs down the guide, and can easily be 10X the free-space group delay. But at the upper end of a waveguide's band, the group delay approaches the free-space group delay, which follows the rule-of-thumb, approximately one foot per nanosecond, independent of frequency.To compare with the one nanosecond/foot rule of thumb, below is a plot of the group delay of one foot of WR-90 waveguide. At the upper end of the band you will see that very nearly the free-space group delay is achieved.



The problem of electromagnetic energy traveling at different speeds over frequency is commonly called dispersion. Soon we will have a page on this topic as well.

Result - Measurement of guide wavelength is done

Precautions – 1) all connection should be make properly.

2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).

3) Before the circuit connection it should be check out working condition of all the Component

Experiment no - 8

Objective :-Measurement of Standing wave ration (VSWR).

Apparatus required – VSWR meter , **Breune circuit**

Theory - VSWR

Voltage Standing Wave Ratio is the ratio of the voltage maximum (antinode) to the adjacent voltage minimum (node) on a transmission line. The standing wave is produced by the superposition of a forward traveling wave and a reflected traveling wave when the transmission line is terminated in other than its characteristic impedance. The reflected wave is created to reconcile the conditions at the end of the transmission line, including the load impedance and the natural ratio of V/I in the forward and reflected traveling waves. Γ is the ratio of V_r/V_f, and VSWR on a sufficiently long lossless line can be predicted as $(1+|\Gamma|)/(1-|\Gamma|)$ from the conditions at the termination or some other point. Γ, V_r and V_f are phasor quantities, ie can be expressed as complex numbers.Direct measurement of VSWR requires observation of the voltage at a number of points along the line, but VSWR is more often estimated from observed conditions at a point, but such estimates typically assume a sufficiently long lossless line.

Indirect measurement of VSWR

Indirect measurement of VSWR means observation of some other parameters than the voltage standing wave itself (eg using a voltage probe).Indirect measurement has become the most common way of measuring VSWR, the term VSWR is often used to mean the "notional" result of an indirect measurement wrt a nominal Z_o rather than that which would be measured on a practical transmission line. That gives rise to the use of the term VSWR as a means of qualifying a tolerance range for a load impedance, eg a transmitter might be specified for a nominally 50Ω load with VSWR<1.5.

There are many methods of indirect measurement of VSWR, but one of the most common, and quite an ingenious device in its simplicity and usefulness is the Breune VSWR bridge. This article will use the Breune circuit as a vehicle for explaining principles that are common to similar instruments.

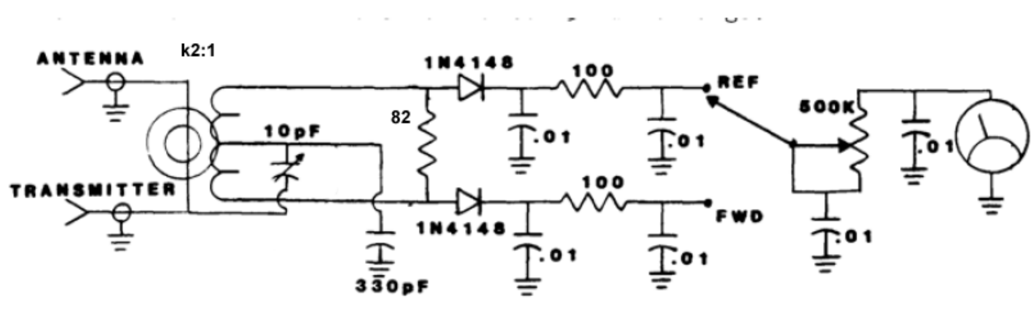


Fig 1: Typical VSWR meter based on the Breune circuit.

Fig 1 shows a typical VSWR meter based on Breune circuit. The circuit samples voltage and current in a very small region of the transmission line, sufficiently small to consider it a point sample at the frequencies of interest. The circuit contains two directional samplers, one for the forward traveling wave, and one for the reflected traveling wave. A sample of the line voltage is obtained by the voltage divider formed by the 10pF and 330pF capacitors. A sample of the line current is taken by the current transformer, and the secondary current is passed through the 82Ω resistor to develop a voltage at each end of the secondary wrt the centre, that is proportional to the current in the main line, and opposite in phase at each end of the winding.

Since the voltage sample is connected to the centre of the secondary, the ends of the secondary will be a voltage that is proportional to the line voltage plus line current times Z_n (the impedance for which the meter is calibrated), and the line voltage minus line current times Z_n for forward and reflected detectors respectively. The 10pF capacitor is adjusted so that in the reflected position with applied RF power, the meter shows zero deflection with a Z_n load (typically 50+j0Ω).The following describes the circuit in detail in the general sense. V_1 is the RF voltage at the lower end of the secondary (wrt ground) in the circuit above, V_2 is the voltage at the upper end of the secondary (wrt ground), Z_x corresponds to half of the 82Ω resistor. The description assumes the components (capacitors, transformer, diodes) are ideal, and that the VSWR meter loading of the through line is insignificant.

$V_1=|k_1*V+k_2*I*Z_x|$ ...(1)

$V_2=|k_1*V-k_2*I*Z_x|$ ...(2)

The instrument is calibrated by adjustment of the value of k_1 so that V_2 is zero when $Z_l=Z_n$. It can be seen that for V_2 to be zero, $k_1*V=k_2*I*Z_x$, therefore $Z_x=k_1*V/k_2/I$, and since $V/I=Z_n$ then $Z_x=k_1/k_2*Z_n$. So, the two expressions can be rewritten as:

$V_1=|k_1*(V+I*Z_n)|$ ...(3)

$V_2=|k_1*(V-I*Z_n)|$ ...(4)

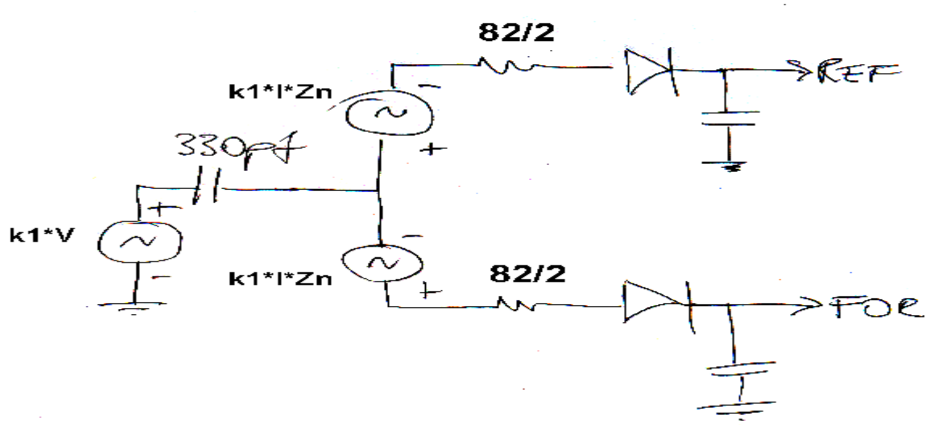


Fig 2 shows the equivalent circuit, a voltage sample of k_1*V, and voltages proportional to current of k_1*I*Z_n .

Since $V=V_f+V_r$, and $V_r=\Gamma*V_f$ and $I=I_f-I_r$, and $I_r=\Gamma*I_f$ eqn (3) can be rewritten as

$V_1=|k_1*(V_f*(1+\Gamma)+I_f*(1-\Gamma)*Z_n)|$ ...(5)

Substituting V_f/Z_n for I_f

$V_1=|k_1*(V_f*(1+\Gamma)+V_f*(1-\Gamma))|$ ...(6)

$V_1=|k_1*V_f*((1+\Gamma)+(1-\Gamma))|$ ...(7)

$V_1=|k_1*2*V_f|$ ...(8)

Similarly, eqn (4) can be transformed to

$V_2=|k_1*2*\Gamma*V_f|$ ...(8)

So

$V_2 /V_1 =|\Gamma|$ ...(9)

Substituting ρ for $|\Gamma|$

$\rho=V_2 /V_1$ ...(10)

VSWR can be calculated from ρ , VSWR=(1+ ρ)/(1- ρ), so the indication of V2 relative to V1 can be scaled in VSWR. The instrument can be used to directly measure ρ at a point (being that of the instrument's sampler) and that knowledge can be used to predict the VSWR that would be observed on a sufficiently long length of adjacent lossless transmission line of the same Z_o as the instrument's calibration impedance Z_nTo analyse the circuit of Fig 1 at 100W connected to a 50+j0Ω load, for a current transformer of 1:25+25 turns bifilar, the peak current in the 82Ω resistor is 2^0.5*(100/50)^0.5/50 or 0.04A, yielding a peak half winding voltage of 0.1*82/2 or 1.65V. The 10pf capacitor would be adjusted for 0V on the REF switch terminal which will correspond to about 5.5pF for a voltage sample of 1.65Vpk on the 330pF capacitor. This would give a DC voltage about 2.7V (allowing for diode voltage drop) at the FOR switch terminal and 0V at the REF switch terminal. It is key to note that the accuracy of the instrument in measuring ρ is dependent of the calibration impedance Z_n and less dependent on the Z_o of the sampler line section where is relatively short (as it is usually).

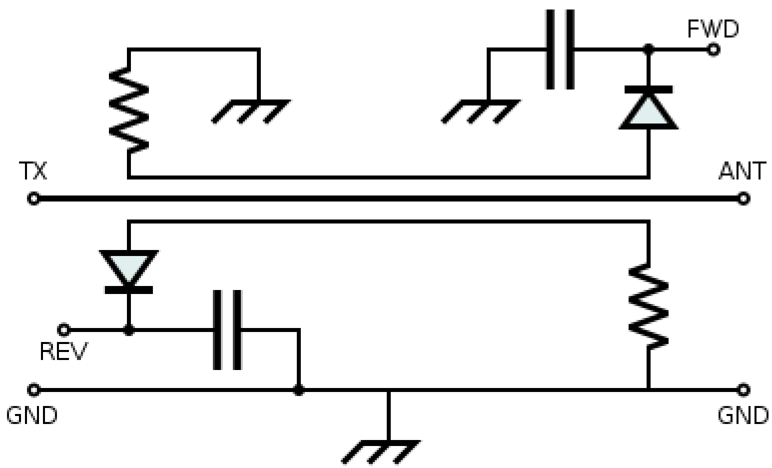
Other circuits

SWR meter

An SWR meter to be used with CB radio equipment

The SWR meter or VSWR (voltage standing wave ratio) 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.



A simple SWR meter Referring to the above diagram, the transmitter (TX) and antenna (ANT) terminals are connected via an internal transmission line. This main line is electromagnetically coupled to two smaller sense lines which are connected to resistors at one end, and diode rectifiers at the other. The resistors are chosen to match the characteristic impedance of the sense lines. One sense line senses the forward wave (connected to FWD), and the other the reflected wave (connected to REV). The diodes convert these to FWD and REV DC voltages respectively, the ratio of which is used to determine the VSWR. In a passive meter, this is indicated on a non-linear meter scale.

To calculate the VSWR, first calculate the reflection coefficient:

$$\Gamma = \frac{V_{rev}}{V_{fwd}} = \sqrt{\frac{P_{rev}}{P_{fwd}}}$$

Then calculate the VSWR:

$$VSWR = \frac{1+\Gamma}{1-\Gamma}$$

Observation table –

S.no	Γ	1+ Γ	1- Γ	VSWR = (1+ Γ) / (1- Γ)

Note that an SWR meter does not measure the actual impedance of a load (ie the resistance and reactance), but only the mismatch ratio. To measure the actual impedance, an antenna analyzer or other similar RF measuring device is required. Note also that for accurate readings, the SWR meter must be matched to the have switches on the rear, to select the appropriate load resistance for the sense lines.

If a mismatch exists between the transmission line and load, the line will act as an impedance transformer. In this case, the impedance seen at the input to the line will depend on its electrical length, although (for a lossless line) the VSWR will be the same at any point along the line. Mismatched transmission lines are often used for impedance transformation, especially at UHF and microwave frequencies where their dimensions can be very short. For more information on this handy technique. When not actually measuring VSWR, it is best to remove the more usual type of passive SWR meter from the line. This is because the internal diodes of such meters can generate harmonics when transmitting, and intermodulation products when receiving. Because active SWR meters do not usually suffer from this effect, they can normally be left in without causing such problems.

There are other circuits of VSWR meters, the most common other type uses a pair of short loosely coupled transmission lines with detectors in the sampler line section. Differently to the Breune circuit, the coupling is frequency dependent although some designs achieve compensation over a range of frequencies (eg Bird 43 elements). Frequency dependent samplers cannot be simply calibrated as directional wattmeters. Despite this difference, the same principles apply as explained for the Breune circuit, in that the circuit samples voltage and current in a very small region of the transmission line, sufficiently small to consider it a point sample at the frequencies of interest. From there on, the explanation is the same (though k_1 and k_2 may be frequency dependent).There are other methods for indirect measurement of VSWR that would not be classed as a VSWR meter, eg a true directional transmission line or waveguide coupler with power meters on the coupled ports. This configuration comes into its own on microwave frequencies where it is difficult to construct other types of samplers that are small enough to not disturb the system being measured.

Directional Wattmeter

Since the forward and reflected detectors in the instrument described above responds to V_f and V_r respectively, the question arises as to whether the instrument can be calibrated in power. The power passing any point in a transmission line is given by P=real(V*conjugate(I)). When Z_n is real (lossless lines and distortion less lines), this can be simplified to $V_f*I_f-V_r*I_r$, often expressed loosely as forward power less reflected power. Instruments are usually calibrated to a nominal Z_n that is real (eg 50+j0), and in that case, with better quality instruments, the calibration of the scale(s) in Watts (where $P_f=V_f^2/Z_n$ and $P_r=V_r^2/Z_n$), and calculation of power as $P=P_f-P_r$ is sound. The term directional wattmeter is a bit of a misnomer in that the values of P_f and P_r are not of themselves meaningful, but the difference of the two is the power at that point. Beware, these comments apply to the type of directional detector described above, and not to a simple line RF voltmeter that is incorporated in some instruments and calibrated only for power when VSWR=1.

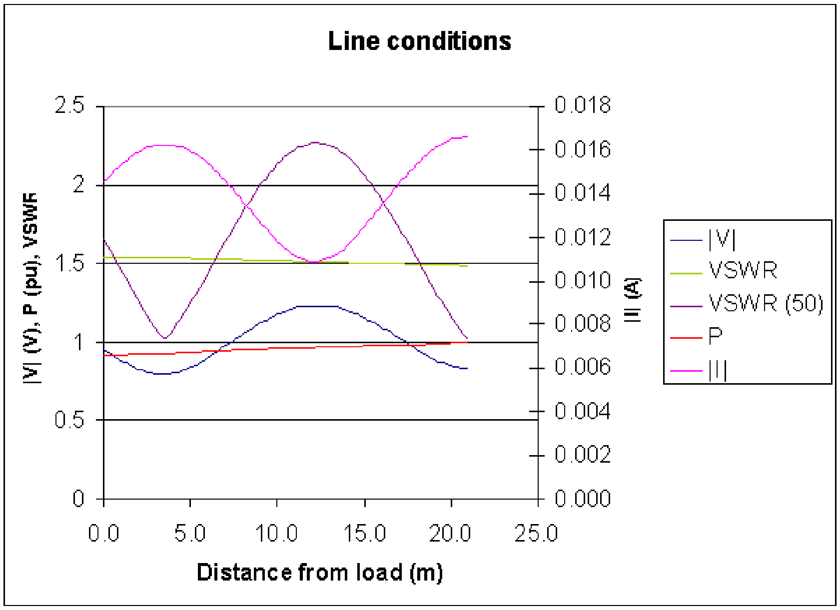


Fig 3 shows the conditions a length of RG6/U terminated in a load of 60-j26Ω. The model is based on a detailed lossy model of the line.

> The magnitude of line voltage and line current show the classic standing wave patterns.
> The green line is the calculated VSWR on the line (which has a characteristic impedance of 75-j0.8Ω).
> The VSWR(50) line shows the VSWR that would be indicated on a short VSWR meter calibrated for 50+j0Ω, but that should not be interpreted as the VSWR on the actual RG6/U transmission line.
> Note also how the real VSWR falls smoothly from 1.54 at the load to 1.48 at a distance of 20m from the load, a result of line loss.
> Power increase smoothly from the load to the source end, but the slope of the line changes minutely in this example with line current, the slope (meaning the attenuation per unit length) is highest approximately where current is highest, meaning the main loss is I^2R loss in the centre conductor.

Performance curve -

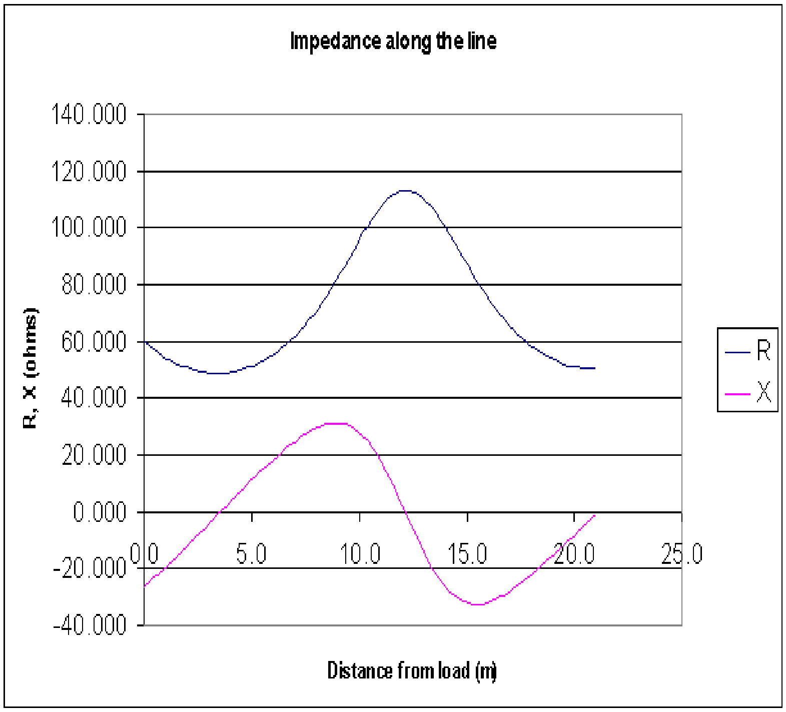


Fig 4: Impedance along the transmission line

The VSWR meter captures ρ which is the magnitude of Γ, the phase of Γ is lost and so the VSWR meter is unable to be used to predict the value of Z at a point, except in the special case where VSWR=1 and therefore Z is Z_n . Fig 4 above shows the impedance along the line for the example. It can be seen that impedance continually changes along the line, and that is true in the general case except where VSWR=1.

Errors

There are many sources of errors in VSWR meters, the most common ones are:

accuracy of the impedance at which the detectors null;
scale shape (ie the relationship between scale markings and meter current);
diode voltage drop (related to previous item);
balance of both detectors;
length of the sampler;
power calibration;
frequency sensitivity / compensation accuracy;
insertion VSWR (the VSWR caused by insertion of the sampler element in a line, related to the coupling and the accuracy of Zo of the sampler section;
loss (loss in the sampler section);
detector / meter response to modulated waveforms;
application - what to measure, and how to extrapolate that measurement to another place (eg adjacent transmission line or a far end load, and the errors inherent in that extrapolation).

The greatest error is probably the last. VSWR meters are widely used, and ingenious as they are, the results are often incorrectly interpreted.

It is possible to achieve a good null (ie low VSWR) on a nominal dummy load, even though an instrument might itself cause higher VSWR because of an inaccurate line section or excessive coupling.

Mismatch loss or loss due to standing waves can be determined accurately knowing the propagation constant (γ) of the line and the complex reflection coefficient (Γ) at a known point on the line. An approximation of the mismatch loss can be made using the propagation constant (γ) (in fact just the attenuation component) and VSWR (which depends only on the magnitude of the complex reflection coefficient (Γ) that is reasonably accurate only on medium length lines with low VSWR and low loss. This has affects the accuracy of a directional wattmeter of this type for assessing the matched line loss of a s/c or o/c length of line, but for most purposes the effect is small and the test gives good results (providing the VSWR meter gives accurate readings at high VSWR).

Testing a VSWR meter

The tests here need to be interpreted in the context of whether the device under test (DUT) has only calibrated power scales, or a VSWR Set/Reflected mode of measurement, and whether directional coupler scales are identical for both directions.

1. Connect a calibrated dummy load of the nominal impedance on the instrument output and measure the VSWR at upper and lower limit frequencies and some in between frequencies. The VSWR should be 1. (Checks nominal calibration impedance);
2. Repeat Test 1 at a selection of test frequencies and for each test, without changing transmitter power, reverse the DUT and verify that repeat the forward/set and reflected readings swap, but are of the same amplitude (checks the symmetry / balance of the detectors under matched line conditions).
3. Connect a s/c to the instrument output and measure the VSWR at upper and lower limit frequencies and some in between frequencies. The VSWR should be infinite. (Discloses averaging due to excessive sampler length);
4. Connect an o/c to the instrument output and measure the VSWR at upper and lower limit frequencies and some in between frequencies. The VSWR should be infinite. (Discloses averaging due to excessive sampler length);
5. Connect a calibrated wattmeter / dummy load of the nominal impedance on the instrument output and measure calibration accuracy of power / ρ / VSWR scales at a range of power levels in both forward and reflected directions (Checks scale shape and absolute power calibration accuracy).
6. Repeating Test 1additionally with a calibrated VSWR meter connected to the input to the DUT, and measure the VSWR caused by the DUT at a range of test frequencies (Checks Insertion VSWR).

It is not unusual for low grade instruments to pass Test 1, but to fail Test 6 (and some others, especially Test 3 and Test 4) towards the higher end of their specified frequency range.

Result - Performance of VSWR meter is observed.

Precautions – 1) all connection should be make properly.
2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).
3) Before the circuit connection it should be check out working condition of all the Component

Experiment no 9

Objective- Measurement of reflection coefficient

Apparatus required – SWR meter, power cables

Theory –

Reflection Coefficient: Reflection coefficient (Rho) is the ratio of the amplitude of the reflected wave and the amplitude of the incident wave. Or at a discontinuity in a transmission line, it is the complex ratio of the electric field strength of the reflected wave to that of the incident wave

$$\rho = \frac{V_R}{V_I}$$

Where ρ = Reflection Coefficient, V_R = Reflected Voltage, and V_I = Incident Voltage.

When an electrical signal is transmitted down a transmission line, the electrical wave travels without interference as long as there are no discontinuities within the line. Discontinuities are changes in the impedance within the transmission line, and acts as a barrier to the flow of the electrical signal[1]. These barriers cause the electrical signal to bounce back towards the signal source. This is called a reflected wave and is in the opposite direction of the signal being transmitted. The amount of reflected signal is a function of the change in impedance within the transmission line

Observation table:-

S no	V_R	V_I	$\rho = V_R / V_I$

Result - Measurement of reflection coefficient is done.

Precautions – 1) all connection should be make properly.

2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).

3) Before the circuit connection it should be check out working condition of all the Component

Experiment no 10

Objective - . Measurement of cutoff wavelength (TE10 mode) Using C=2/(m/a) + (n/b)=2a.

Theory ;-

Microwaves: - Microwaves are high frequency radio waves (> 1GHz) and they propagate much like any other electromagnetic phenomenon in free space. Because they are electromagnetic waves and not electrons, they do not propagate well down copper cables. Instead, the waves are guided down hollow conductors.

Waveguides

Two boundary conditions must be met in a waveguide for a wave to travel down the guide:

- The electric field must terminate normally on the conductor (the tangential component of the electric field must be zero).
- The magnetic field must lie entirely tangent along the wall surface. (the normal component of the magnetic field must be zero).

Consequently, TEM waves cannot be conducted in a waveguide. (Recall that in a TEM wave, the electric and magnetic fields are at right angles to each other and the direction of propagation.)The most common wave used in waveguides is the TE_{10}, meaning transverse electric. The subscript TE_{ab} denotes the number of half cycles which appear in the a and b dimensions of the waveguide. When $\lambda = 2a$, the guide wavelength becomes infinite. This corresponds to a TEM wave bouncing from side to side in the guide with no velocity component along the guide. This is cutoff wavelength and represents the lowest frequency that can be propagated.

Phase & Group Velocity

The equations above can be manipulated to obtain. This means that the phase velocity is always greater than the speed of light. The TEM components zigzag through the guide at the speed of light, but they convey power at the group velocity. The group velocity is always less than the speed of light.

Analogy

Nothing physical can exceed the speed of light, but it is possible for some aspect of a wave to exceed light speed. For example, the splash that occurs when a wave washes up on the beach can travel faster than the wave, if it strikes at some angle other than 90^0.

Example: - A rectangular waveguide measuring 0.9 by 0.45 inches is fed with a 10 GHz carrier. Determine if a TE_{10} wave will propagate, and if so, determine its guide wavelength, group velocity and phase velocity.

Since $\lambda < \lambda_c$, a TE_{10} wave will propagate.

Wave Impedance :- The TE_{10} wave consists of two equal TEM waves where the electric field is transverse along the b dimension but the magnetic field is along the a dimension is described by: $H_a = H\sin\alpha$. Consequently, the wave impedance is:

A TE wave has a characteristic impedance Ω > 120π. As the cutoff frequency is approached, the impedance approaches infinity. These modes are generated by means of a vertical probe antenna.

A TM wave has a characteristic impedance Ω < 120π. As the cutoff frequency is approached, the impedance approaches zero. These modes are generated by means of a horizontal probe antenna.

A waveguide with a dielectric other than air will have its cutoff wavelength increased by the square root of the dielectric constant. Waveguide attenuation characteristics are quite complex and are generally derived empirically. Attenuation varies with interior wall coating, guide dimensions, and operating frequency Attenuation can occur because the induced wall currents are electrons interacting with the guide. There is a limit to the amount of power which can be conveyed in a guide. If this limit is exceeded, electrical arcing will occur and severe attenuation results. The maximum power handling capability of an air filled rectangular waveguide operating in the TE mode is:

Result - Measurement of reflection coefficient is done.

Precautions – 1) all connection should be make properly.

2) It should be care that the values of the components of the circuit is does not exceed to their ratings (maximum value).

3) Before the circuit connection it should be check out working condition of all the Component

Experiment no 11

Objective - Study of E- plane tee, H- plane tee & Magic tee

Theory –

E-plane and H-plane

Within a waveguide cross-section the electric field is normal to the broad wall and the magnetic field line is normal to the short wall. The maximum positive and negative voltage crests of the wave travel down the center of the waveguide and the voltage decreases to zero along the waveguide side walls. When high power waveguide systems fail, the electrical arcs are usually between the top and bottom walls of the waveguide in the center where the voltage is greatest.

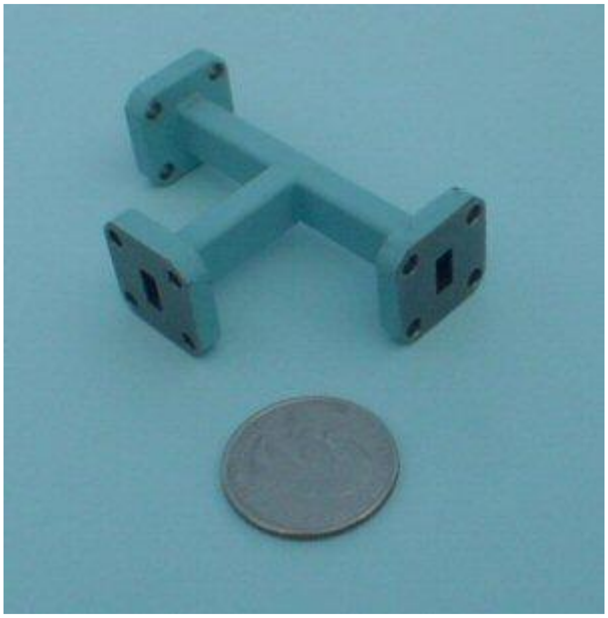
**Waveguide E-plane and H-plane Rule of Thumb**

Somebody in the lab asks you to get them an E-plane bend or an H-plane bend. You can't remember which way the fields go in the waveguide, but you don't want to look stupid by asking. Don't panic, there is an easy way to remember which is which. The E-plane bend is bent the "easy way", and the H-plane bend is bent the "hard way", which you can see in the photo below. If it isn't obvious to you what is meant by easy and hard way when you are bending a rectangular rod, it is not too late to consider a career shift to the software industry.

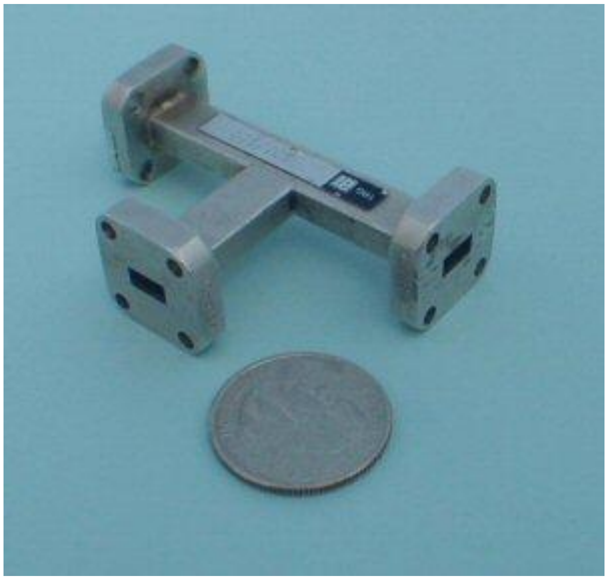
H-plane bend and E-plane bend (WR-28)

Waveguide components

All manner of waveguide components exist, including circulators, isolators, attenuators, loads, mixers, amplifiers, you name it. Below are some pictures of some waveguide splitters you may find in your lab. Note that basic network theory says that you can't make a three-port splitter that is lossless and matched at all three ports, so if you want to split a signal, your best bet is the magic tee, just feed the sum port, terminate the delta port and the outputs are the co-linear ports.



E-plane tee (WR-28)



H-plane tee (WR-28)

Magic tee (WR-62)

When you are building up a waveguide experiment or system, you often end up with two waveguides that you need to connect, but you don't have a piece that is an exact fit between them, and you don't have the time and money to fabricate one. Fear not, there is flexible waveguide for just such an emergency. There are two primary types of flexible waveguide. One is flexible and twistable, the other is non-twistable. A picture of the latter type is shown here:

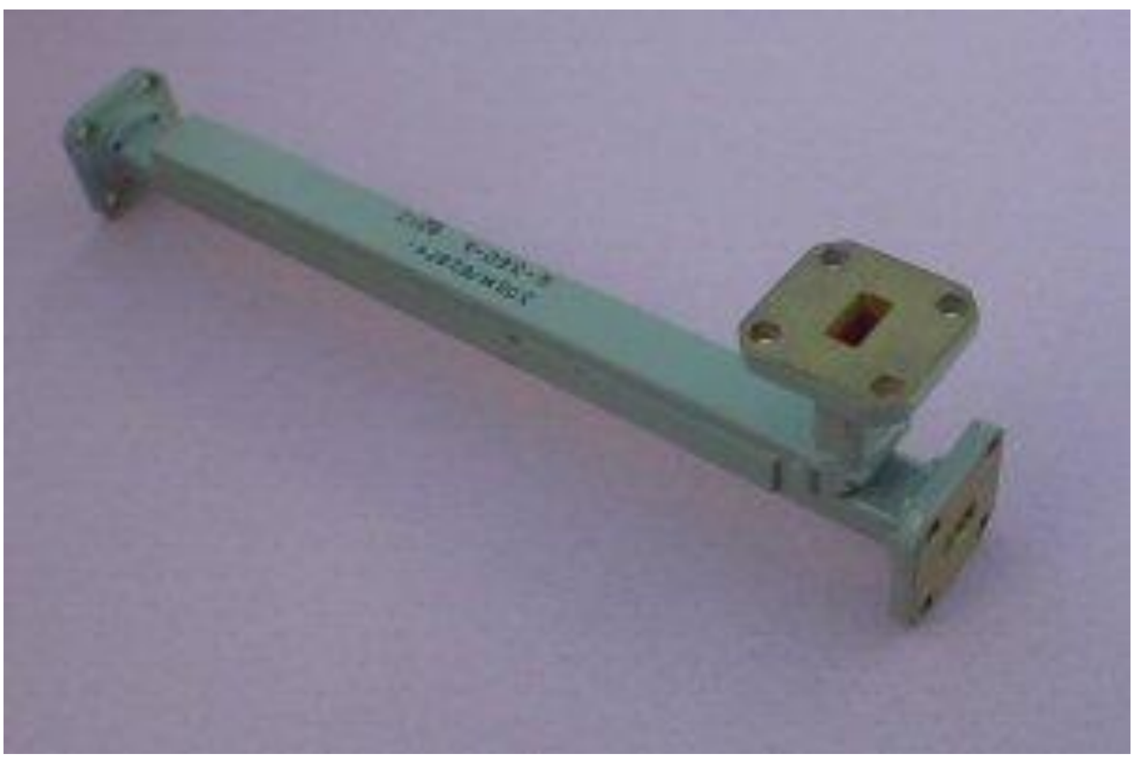
Flex guide (non-twistable)

Below are two "cross-guide" couplers. One has a resistive termination built in. By the way, we should mention that waveguides do NOT have characteristic impedance of fifty ohms, which is the standard for coax, but that subject will have to wait for another day. Thanks, Leslie!

WR-42 cross-guide coupler with terminated port

WR-42 cross-guide coupler

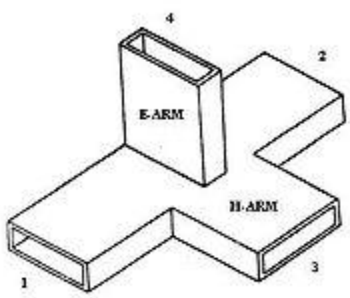
Here's a broad wall coupler, a better type of waveguide coupler than the cross-guide. It has much more directivity than the ones above, but it is a lot bigger.



Waveguide to coax adapter
(WR-62 to type N)

Between series adapter (WR-51 to WR-42)

Magic tee



A magic T consisting of four rectangular waveguide meeting in a single tree-dimensional junction A magic tee (or magic T or hybrid tee) is a hybrid or 3dB coupler used in microwave systems. It is an alternative to the rat-race coupler. In contrast to the rat-race, the three-dimensional structure of the magic-tee makes is less readily constructed in planar technologies such as microstrip or stripline.The magic tee was originally developed in World-War II, and first published by W. A. Tyrell (of Bell Labs) in a 1947 IRE paper[1]. Robert L. Kyhl and Bob Dicke independently created magic tees around the same time period.

Structure

The magic tee is a combination of E and H plane tees. Arm 3 forms an H-plane tee with arms 1 and 2. Arm 4 forms an E-plane tee with arms 1 and 2. Arms 1 and 2 are sometimes called the side or collinear arms. Port 3 is called the H-plane port, and is also called the Σ port, sum port or the P-port (for Parallel). Port 4 is the E-plane port, and is also called the Δ port, difference port, or S-port (for Series). There is no one single established convention regarding the numbering of the ports.

To function correctly the magic tee must incorporate an internal matching structure. This structure typically consists of a post inside the H-plane tee and an inductive iris inside the E-plane limb, though many alternative structures have been proposed. Dependence on the matching structure means that the magic tee will only work over a limited frequency band.

Operation

The name magic tee is derived from the way in which power is divided among the various ports. A signal injected into the H-plane port will be divided equally between ports 1 and 2, and will be in phase. A signal injected into the E-plane port will also be divided equally between ports 1 and 2, but will be 180 degrees out of phase. If signals are fed in through ports 1 and 2, they are added at the H-plane port and subtracted at the E-plane port.[2] Thus, with the ports numbered as shown, and to within a phase factor, the full scattering matrix for an ideal magic tee is

$$S = \frac{1}{\sqrt{2}}\begin{pmatrix} 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & -1 \\ 1 & 1 & 0 & 0 \\ 1 & -1 & 0 & 0 \end{pmatrix}$$

Magic

If by means of a suitable internal structure, the E-plane (difference) and H-plane (sum) ports are simultaneously matched, then by symmetry, reciprocity and conservation of energy it may be shown that the two collinear ports are also matched, and are **magically** isolated from each other. The E-field of the dominant mode in each port is perpendicular to the broad wall of the waveguide. The signals in the E-plane and H-plane ports therefore have orthogonal polarizations, and so (considering the symmetry of the structure) there can be no communication between these two ports. For a signal entering the H-plane port, a well-designed matching structure will prevent any of the power in the signal being reflected back out of the same port. As there can be no communication with the E-plane port, and again considering the symmetry of the structure, then the power in this signal must be divided equally between to the two collinear ports. Similarly for the E-plane port, if the matching structure eliminates any reflection from the this port, then the power entering it must be divided equally between the two collinear ports.

Now by reciprocity, the coupling between any pair of ports is the same in either direction (the scattering matrix is symmetric). So if the H-plane port is matched, then half the power entering either one of the collinear ports will leave by the H-plane port. If the E-plane port is also matched, then half power will leave by the E-plane port. In this circumstance, there is no power 'left over' either to be reflected out of the first collinear port or to be transmitted to the other collinear port. Despite apparently being in direct communication with each other, the two collinear port are magically isolated. The isolation between the E-plane and H-plane ports is wide-band and is as perfect as is the symmetry of the device. The isolation between the collinear ports is however limited by the performance of the matching structure.

Result - . Study of E-plane, H-plane and Magic Tee's are completed.

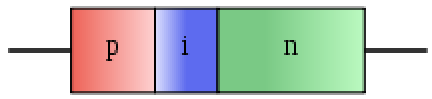
Experiment no 12

Objective - Performance of pin diode and pin modulator.

Theory

A PIN diode is a diode with a wide, lightly doped 'near' intrinsic semiconductor region between a p-type semiconductor and an n-type semiconductor region. The p-type and n-type regions are typically heavily doped because they are used for ohmic contacts. The wide intrinsic region is in contrast to an ordinary PN diode. The wide intrinsic region makes the PIN diode an inferior rectifier (the normal function of a diode), but it makes the PIN diode suitable for attenuators, fast switches, photodetector, and high voltage power electronics applications.

PIN diode



Layers of a PIN diode

Operation

A PIN diode operates under what is known as high-level injection. In other words, the intrinsic "i" region is flooded with charge carriers from the "p" and "n" regions. Its function can be likened to filling up a water bucket with a hole on the side. Once the water reaches the hole's level it will begin to pour out. Similarly, the diode will conduct current once the flooded electrons and holes reach an equilibrium point, where the number of electrons is equal to the number of holes in the intrinsic region. When the diode is forward biased, the injected carrier concentration is typically several orders of magnitudes higher than the intrinsic level carrier concentration. Due to this high level injection, which in turn is due to the depletion process, the electric field extends deeply (almost the entire length) into the region. This electric field helps in speeding up of the transport of charge carriers from p to n region, which results in faster operation of the diode, making it a suitable device for high frequency operations.

Characteristics

A PIN diode obeys the standard diode equation for low frequency signals. At higher frequencies, the diode looks like an almost perfect (very linear, even for large signals) resistor. There is a lot of stored charge in the intrinsic region. At low frequencies, the charge can be removed and the diode turns off. At higher frequencies, there is not enough time to remove the charge, so the diode never turns off. The PIN diode has a poor reverse recovery time.

The high-frequency resistance is inversely proportional to the DC bias current through the diode. A PIN diode, suitably biased, therefore acts as a variable resistor. This high-

frequency resistance may vary over a wide range (from 0.1 ohm to 10 kΩ in some cases the useful range is smaller, though).The wide intrinsic region also means the diode will have a low capacitance when reverse biased. In a PIN diode, the depletion region exists almost completely within the intrinsic region. This depletion region is much larger than in a PN diode, and almost constant-size, independent of the reverse bias applied to the diode. This increases the volume where electron-hole pairs can be generated by an incident photon. Some photodetector devices, such as PIN photodiodes and phototransistors (in which the base-collector junction is a PIN diode), use a PIN junction in their construction The diode design has some design tradeoffs. Increasing the dimensions of the intrinsic region (and its stored charge) allows the diode to look like a resistor at lower frequencies. It adversely affects the time needed to turn off the diode and its shunt capacitance. PIN diodes will be tailored for a particular use.

Applications

PIN diodes are useful as RF switches, attenuators, and photodetectors.

RF and Microwave Switches

A PIN Diode RF Microwave Switch

Under zero or reverse bias, a PIN diode has a low capacitance. The low capacitance will not pass much of an RF signal. Under a forward bias of 1 mA, a typical PIN diode will have an RF resistance of about 1 ohm, making it a good RF conductor. Consequently, the PIN diode makes a good RF switch.Although RF relays can be used as switches, they switch very slowly (on the order of 10 milliseconds). A PIN diode switch can switch much more quickly (e.g., 1 microsecond). The capacitance of an off discrete PIN diode might be 1pF. At 320MHz, the reactance of 1pF is about 500 ohms. In a 50 ohm system, the off state attenuation would be about 20dB -- which may not be enough attenuation. In applications that need higher isolation, switches are cascaded to improve the isolation. Cascading three of the above switches would give 60dB of attenuation.PIN diode switches are used not only for signal selection, but they are also used for component selection. For example, some low phase noise oscillators use PIN diodes to range switch inductors.

RF and Microwave Variable Attenuators

A RF Microwave PIN diode Attenuator.

By changing the bias current through a PIN diode, it's possible to quickly change the RF resistance.At high frequencies, the PIN diode appears as a resistor whose resistance is an inverse function of its forward current. Consequently, PIN diode can be used in some variable attenuator designs as amplitude modulators or output leveling circuits.PIN diodes might be used, for example, as the bridge and shunt resistors in a bridged-T attenuator.

Limiters

PIN diodes are sometimes used as input protection devices for high frequency test probes. If the input signal is within range, the PIN diode has little impact as a small capacitance. If the signal is large, then the PIN diode starts to conduct and becomes a resistor that shunts most of the signal to ground.

Photodetector and photovoltaic cell

The PIN photodiode was invented by Jun-ichi Nishizawa and his colleagues in 1950.PIN photodiodes are used in fibre optic network cards and switches. As a photodetector, the PIN diode is reverse biased. Under reverse bias, the diode ordinarily does not conduct (save a small dark current or I_s leakage). A photon entering the intrinsic region frees a carrier. The reverse bias field sweeps the carrier out of the region and creates a current. Some detectors can use avalanche multiplication. The PIN photovoltaic cell works in the same mechanism. In this case, the advantage of using a PIN structure over conventional semiconductor junction is the better long wavelength response of the former. In case of long wavelength irradiation, photons penetrate deep into the cell. But only those electron-hole pairs generated in and near the depletion region contribute to current generation. The depletion region of a PIN structure extends across the intrinsic region, deep into the device. This wider depletion width enables electron-hole pair generation deep within the device. This increases the quantum efficiency of the cell.Typically, amorphous silicon thin-film cells use PIN structures. On the other hand, CdTe cells use NIP structure, a variation of the PIN structure. In a NIP structure, an intrinsic CdTe layer is sandwiched by n-doped CdS and p-doped ZnTe. The photons are incident on the n-doped layer unlike a PIN diode.The advantages of both active and passive modelocking techniques are realized within a single device by providing a p-i-n modulator formed at antiresonance within a Fabry-Perot etalon. The p-i-n modulator actively modulates light within the laser cavity by introducing periodic loss in response to changing voltages applied to the modulator. The p-i-n modulator includes an intrinsic region that is disposed between a p-doped region and an n-doped region. The modelocking performance of the p-i-n modulator is enhanced by the saturable absorber action of the intrinsic region.

Result - Performance of pin diode and pin modulator.

Experiment no 13

Objective - . Measurement of guided power
Apparatus required – waveguide.

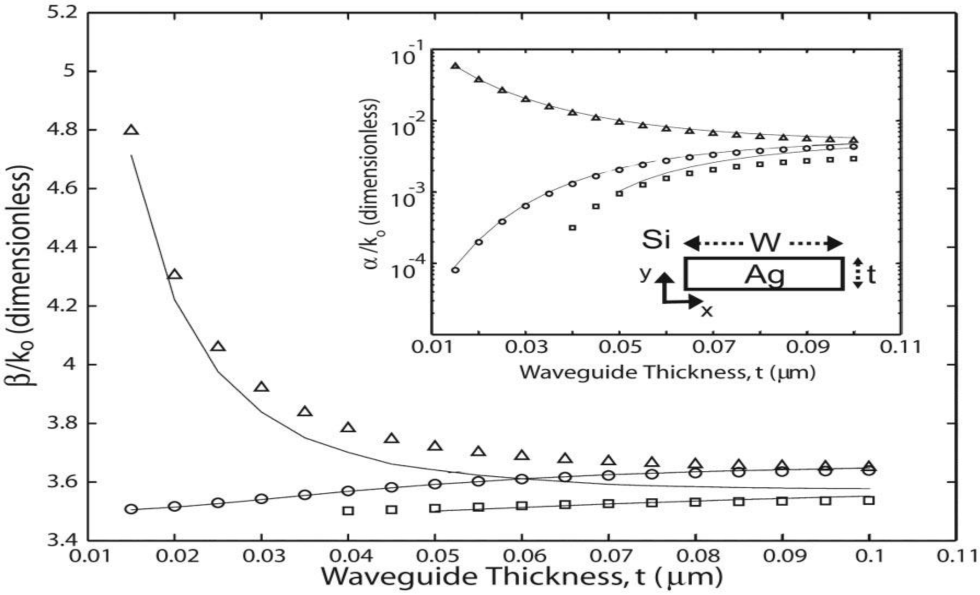
Theory -

The laser-guiding experiment was performed using a 100 TW class Ti: sapphire laser system at the LOASIS facility. A schematic of the LPA experiment is shown in Fig. 2. An input laser was focused on the entrance of the hydrogen filled capillary discharge waveguide [10, 11] by an off-axis parabolic mirror used at f/20. For a Gaussian transverse128intensity profile of I = I0 exp(□2r2=r20), the average focal spot size was r0 ' 22 mm and the pulse duration was 45 fsin full width at half maximum. The experiment discussed in this paper was performed with low-intensity laser pulses(_1016 W=cm2). While laser pulses with intensities greater than 1018 W=cm2 are used for laser-plasma acceleration, working with low intensity laser pulses allowed us to investigate a regime where we could neglect non-linear effects such as self-focusing. This allowed us to concentrate closely on the effects of the plasma channel and laser-guiding. FIGURE 2. The experimental layout. Laser was focused onto capillary waveguide using a 2 m focal length off-axis parabolic mirror. Output laser pulse was attenuated with several wedged mirrors and weakly focused onto the wave front sensor using a 1.5 m focal length spherical mirror. Laser energy and mode images were measured along with the wave front. The waveguide was laser-machined in sapphire plates, forming a 13.5 mm long by 250 mm diameter capillary. Hydrogen gas was introduced with a pressure of 100 Torr through a slot located at the end of the capillary. A high voltage discharge between electrodes placed at the ends of the capillary fully ionized the gas and formed a plasma channel. The plasma channel evolved from hydrodynamic motion in the capillary on the scale of tens of nanoseconds. Various channel conditions were formed by varying the time between the initiation of the discharge and arrival of the laser pulse. For this setup, electron density was _1_1018 cm□3 with a matched spot size of _ 45 mm based on a scaling law derived from the simulation in Ref. [12]. Since this particular capillary had only one gas slot, the plasma density within the capillary formed a gradient in the direction of the laser propagation. This feature made matched guiding impossible over the full length and made it difficult to predict the laser evolution in the channel. Laser pulses exiting the plasma channel were imaged using a 1.5 m focal length spherical mirror to minimize chromatic aberration. The wavefront sensor used to measure the radius of curvature was located _ 5 cm upstream of the image focus. The wavefront was measured using a lateral shearing interferometer, SID4, manufactured by Phasics .The SID4 wavefront sensor includes a 2D diffraction grating that splits the incident beam into four identical beams. These four beams form an interferogram pattern on the charge coupled device (CCD) of the camera. Deformations in the pattern are related to phase gradients. Using spectral analysis, SID4 retrieves a phase map for each laser pulse.

Procedure -

The best-studied guided polariton modes involvesurface plasmon polaritons supported by finite-width metal stripes.5 Although such modes have proved difficult to calculate, recent characterization by nearfield scanning optical microscopy has probed their localized light intensities.6 Based on published bound modal solutions, initial interpretation of these images led to conclusions that surface plasmon modes are inconsistent with dielectric waveguide theory. However, recent solutions for the experimentally relevant leaky modes may provide for an interpretation that is consistent with ray optics.7 In this Letter we investigate the applicability of dielectric waveguide theory to surface polariton modes along finite-width interfaces. By combining previous research on the optics of surface polaritons8 with a ray-optics model for guided waves, we demonstrate that an equivalent dielectric slab waveguide can be used to approximate

Graph for t



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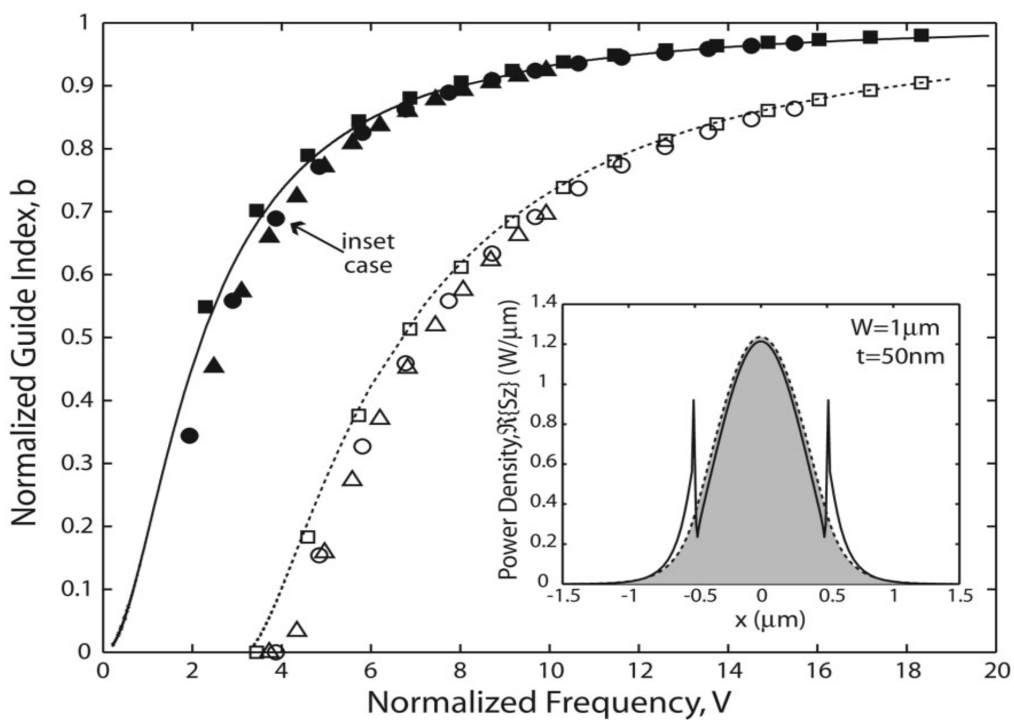


Result -. Measurement of guided power is done

Experiment no 14

Objective - Measurement of attenuation in dB for a given component

Theory

Attenuation is the loss of optical power as a result of absorption, scattering, bending, and other loss mechanisms as the light travels through the fiber. The total attenuation is a function of the wavelength l of the light. The total attenuation A between two arbitrary points X and Y on the fiber is $A(dB) = 10 \log_{10} (P_x/P_y)$. P_x is the power output at point X. P_y is the power output at point Y. Point X is assumed to be closer to the optical source than point Y. The attenuation coefficient or attenuation rate a is given by a(dB/km) = A/L. Here L is the distance between points X and Y. Absolute measurements of attenuation are very difficult to obtain because the echo amplitude depends on factors in addition to amplitude. The most common method used to get quantitative results is to use an ultrasonic source and detector transducer separated by a known distance. By varying the separation distance, the attenuation can be measured from the changes in the amplitude. To get accurate results, the influence of coupling conditions must be carefully addressed. To overcome the problems related to conventional ultrasonic attenuation measurements, ultrasonic spectral parameters for frequency-dependent attenuation measurements, which are independent from coupling conditions are also used. For example, the ratio of the amplitudes of higher frequency peak to the lower frequency peak, has been used for microstructural characterization of some materials

MEASUREMENT SYSTEMS

Many different and ingenious **ways** of measuring attenuation have been developed over the years, and most methods in use today embody the following principles:

1. Power ratio
2. Voltage ratio
3. **AF** substitution
4. IF substitution
5. RF substitution

Power Ratio Method

The power ratio method of measuring attenuation is perhaps one of the easiest to configure.

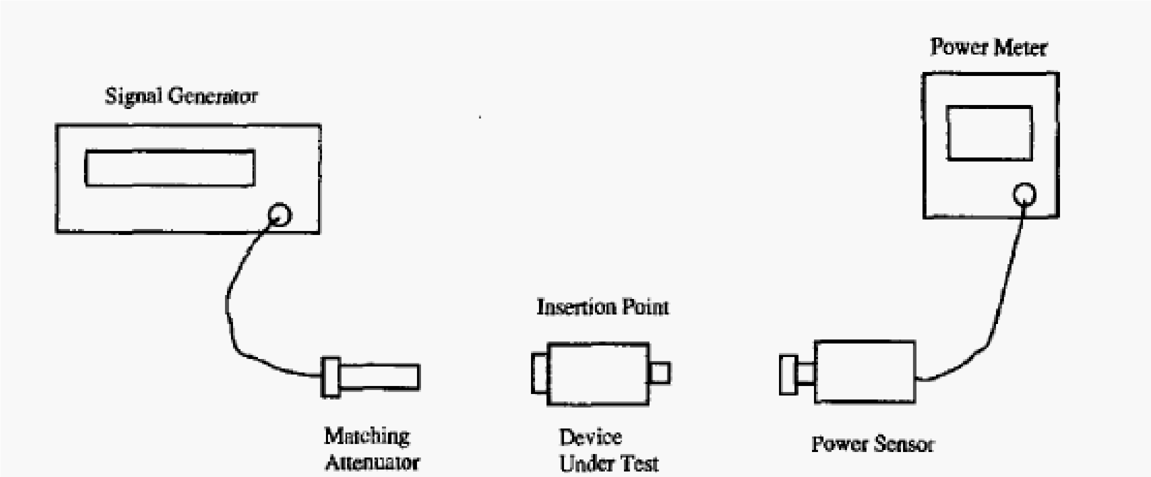


Diagram represents a simple power ratio configuration. **First,** the power sensor is connected directly to the matching attenuator and the power meter indication noted P1. Next, the device under test is inserted between the matching pad and power sensor and the power meter indication again noted **P2.** Insertion loss is then calculated using:

Ldb= 10Log10(P1/P2)

Observation table –

S. no.	P1	P2	(P1/P2)	Ldb= 10Log10(P1/P2)

Note that unless the reflection coefficient of the generator and load at the insertion point is known to be zero, or that the mismatch factor has been calculated and taken into consideration, measured insertion loss and not attenuation is quoted.

This simple method **has** some Limitations:
1. Amplitude stability and dnft of the signal generator.
2. Power linearity of the power **sensor.**
3. Zero carry over.
4. Range switching and resolution.

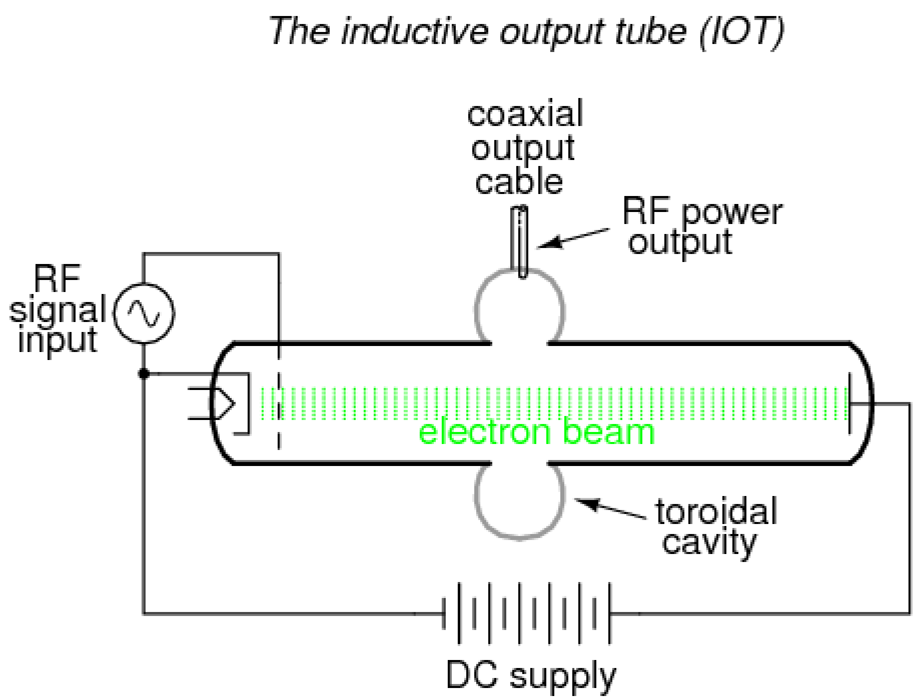
Result - Measurement of attenuation in dB for a given component is done .

Experiment no - 17

Objective : - Measurement of characteristics of klystron tube & Gunn Oscillator.

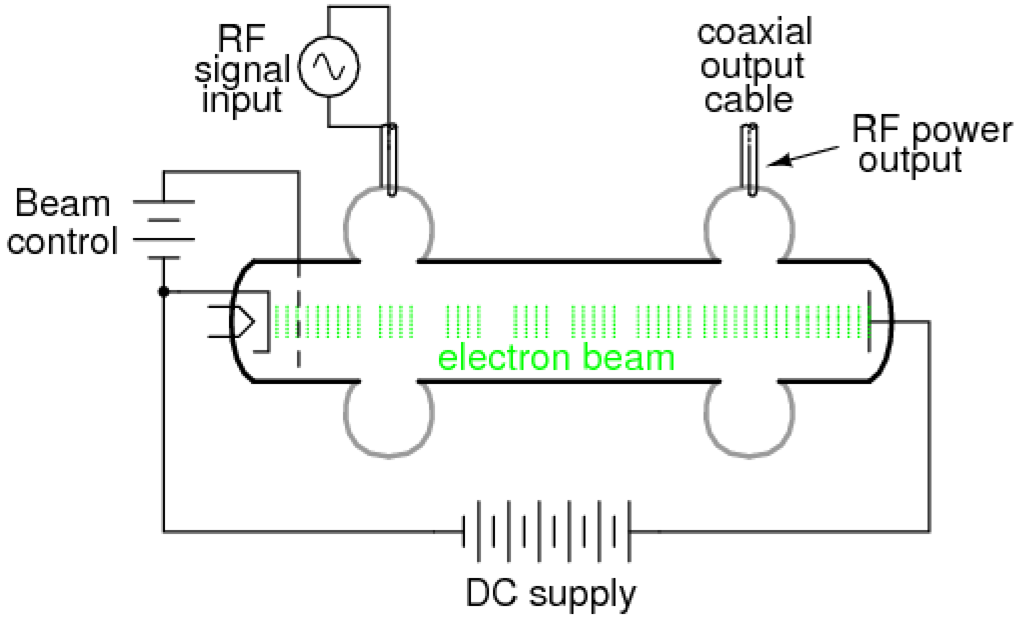
Klystron tube

For extremely high-frequency applications (above 1 GHz), the interelectrode capacitances and transit-time delays of standard electron tube construction become prohibitive. However, there seems to be no end to the creative ways in which tubes may be constructed, and several high-frequency electron tube designs have been made to overcome these challenges. It was discovered in 1939 that a toroidal cavity made of conductive material called a cavity resonator surrounding an electron beam of oscillating intensity could extract power from the beam without actually intercepting the beam itself. The oscillating electric and magnetic fields associated with the beam "echoed" inside the cavity, in a manner similar to the sounds of traveling automobiles echoing in a roadside canyon, allowing radio-frequency energy to be transferred from the beam to a waveguide or coaxial cable connected to the resonator with a coupling loop. The tube was called an inductive output tube, or IOT:



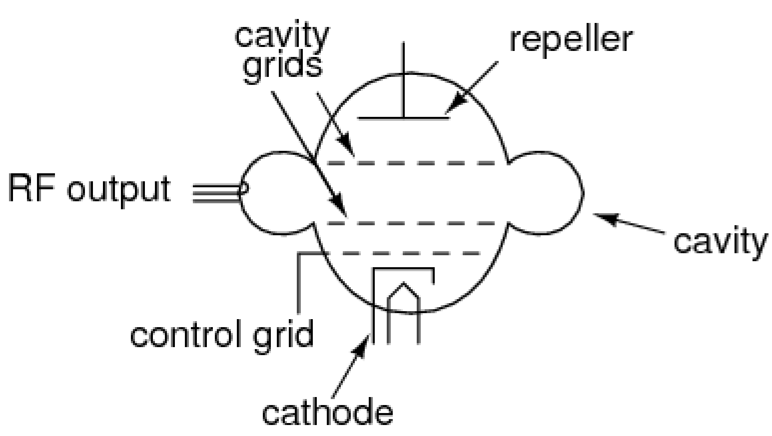
Two of the researchers instrumental in the initial development of the IOT, a pair of brothers named Sigurd and Russell Varian, added a second cavity resonator for signal input to the inductive output tube. This input resonator acted as a pair of inductive grids to alternately "bunch" and release packets of electrons down the drift space of the tube, so the electron beam would be composed of electrons traveling at different velocities. This "velocity modulation" of the beam translated into the same sort of amplitude variation at the output resonator, where energy was extracted from the beam. The Varian brothers called their invention a klystron.

The klystron tube



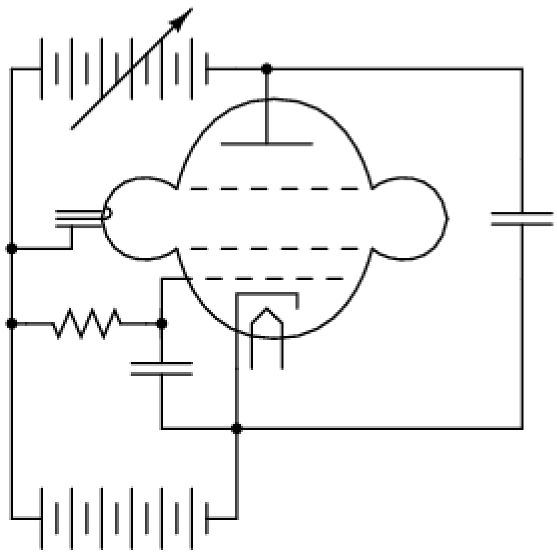
Another invention of the Varian brothers was the reflex klystron tube. In this tube, electrons emitted from the heated cathode travel through the cavity grids toward the repeller plate, then are repelled and returned back the way they came (hence the name reflex) through the cavity grids. Self-sustaining oscillations would develop in this tube, the frequency of which could be changed by adjusting the repeller voltage. Hence, this tube operated as a voltage-controlled oscillator.

The reflex klystron tube



As a voltage-controlled oscillator, reflex klystron tubes served commonly as "local oscillators" for radar equipment and microwave receivers:

Reflex klystron tube used as
a voltage-controlled oscillator



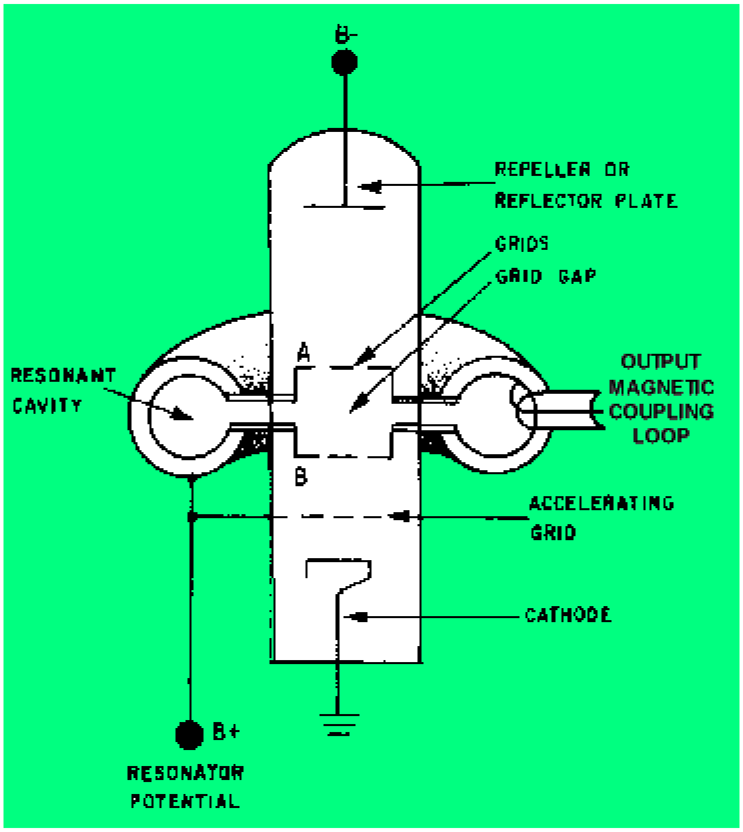
Initially developed as low-power devices whose output required further amplification for radio transmitter use, reflex klystron design was refined to the point where the tubes could serve as power devices in their own right. Reflex klystrons have since been superseded by semiconductor devices in the application of local oscillators, but amplification klystrons continue to find use in high-power, high-frequency radio transmitters and in scientific research applications.

One microwave tube performs its task so well and so cost-effectively that it continues to reign supreme in the competitive realm of consumer electronics: the magnetron tube. This device forms the heart of every microwave oven, generating several hundred watts of microwave RF energy used to heat food and beverages, and doing so under the most grueling conditions for a tube: powered on and off at random times and for random durations.

Magnetron tubes are representative of an entirely different kind of tube than the IOT and klystron. Whereas the latter tubes use a linear electron beam, the magnetron directs its electron beam in a circular pattern by means of a strong magnetic field:

Another tube based on velocity modulation, and used to generate microwave energy, is the REFLEX KLYSTRON (figure 2-9). The reflex klystron contains a REFLECTOR PLATE, referred to as the REPELLER, instead of the output cavity used in other types of klystrons. The electron beam is modulated as it was in the other types of klystrons by passing it through an oscillating resonant cavity, but here the similarity ends. The feedback required to maintain oscillations within the cavity is obtained by reversing the beam and sending it back through the cavity. The electrons in the beam are velocity-modulated before the beam passes through the cavity the second time and will give up the energy required to maintain oscillations. The electron beam is turned around by a negatively charged electrode that repels the beam. This negative element is the repeller mentioned earlier. This type of klystron oscillator is called a reflex klystron because of the reflex action of the electron beam.

Figure 2-9. - Functional diagram of a reflex klystron.



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, and (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 (B+) in the body of the tube. Note in figure 2-9 that the resonator potential is common to the resonator cavity, the accelerating grid, and the entire body of the tube.

Performance: - A klystron is a specialized linear-beam vacuum tube (evacuated electron tube). Klystrons are used as amplifiers 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 modern particle accelerators

High-power klystron used at the Canberra Deep Space Communications Complex. (Klystrons used for generating heterodyne reference frequencies in radar receivers are about the size of a whiteboard pen.)

Klystron amplifiers have the advantage (over the magnetron) of coherently amplifying a reference signal 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.

All modern klystrons are amplifiers, since reflex klystrons, which were used as oscillators in the past, have been surpassed by alternative technologies.

The pseudo-Greek word klystron comes from the stem form κλυσ- (klys) of a Greek verb referring to the action of waves breaking against a shore, and the end of the word electron.

History

The brothers Russell and Sigurd Varian of Stanford University are the inventors of the klystron. Their prototype was completed in August 1937. Upon publication in 1939, news of the klystron immediately influenced the work of US and UK researchers working on radar equipment. The Varians went on to found Varian Associates to commercialize the technology (for example to make small linear accelerators to generate photons for external beam radiation therapy). In their 1939 paper, they acknowledged the contribution of A. Arsenjewa-Heil and Oskar Heil (wife and husband) for their velocity modulation theory in 1935.

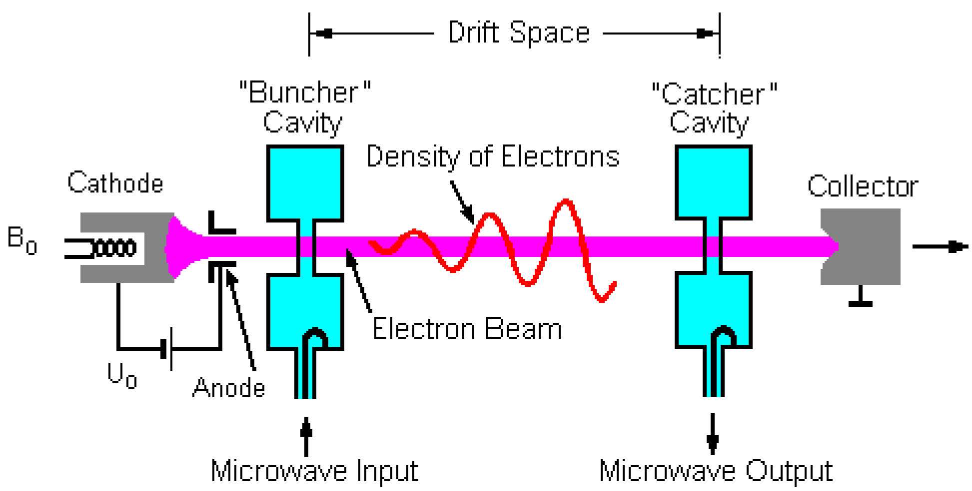
The work of physicist W.W. Hansen was instrumental in the development of klystron and was cited by the Varian brothers in their 1939 paper. His resonator analysis, which dealt with the problem of accelerating electrons toward a target, could be used just as well to decelerate electrons (i.e., transfer their kinetic energy to RF energy in a resonator). During the Second World War, Hansen lectured at the MIT Radiation labs two days a week, commuting to Boston from Sperry Gyroscope Company on Long Island. His resonator, called a "hohlraum" by nuclear physicists and coined "rhumbatron" by the Varian brothers, is used in 2009 in the National Ignition Facility investigating nuclear fusion. Hansen died in 1949 as a result of exposure to beryllium oxide (BeO).

During the second World War, the Axis powers relied mostly on (then low-powered) klystron technology for their radar system microwave generation, while the Allies used the far more powerful but frequency-drifting technology of the cavity magnetron for microwave generation. Klystron tube technologies for very high-power applications, such as synchrotrons and radar systems, have since been developed.

Explanation

Klystrons amplify RF signals by converting the kinetic energy in a DC electron beam into radio frequency power. A beam of electrons is produced by a thermionic cathode (a heated pellet of low work function material), and accelerated by high-voltage electrodes (typically in the tens of kilovolts). This beam is then passed through an input cavity. RF energy is fed into the input cavity at, or near, its natural frequency to produce a voltage which acts on the electron beam. The electric field causes the electrons to bunch: electrons that pass through during an opposing electric field are accelerated and later electrons are slowed, causing the previously continuous electron beam to form bunches at the input frequency. To reinforce the bunching, a klystron may contain additional "buncher" cavities. The RF current carried by the beam will produce an RF magnetic field, and this will in turn excite a voltage across the gap of subsequent resonant cavities. In the output cavity, the developed RF energy is coupled out. The spent electron beam, with reduced energy, is captured in a collector.

Two-cavity klystron amplifier

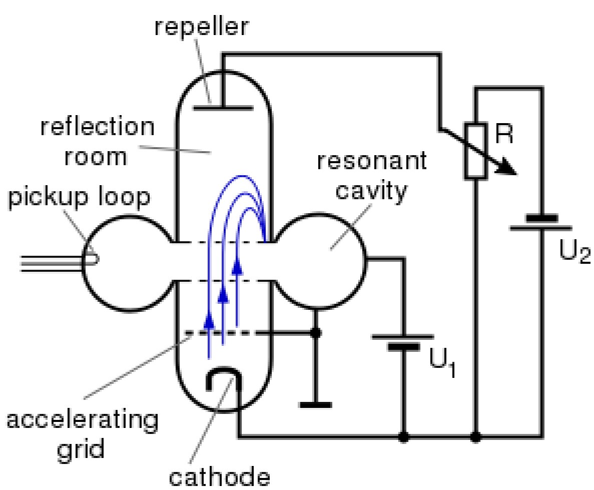


In the two-chamber klystron, the electron beam is injected into a resonant cavity. The electron beam, accelerated by a positive potential, is constrained to travel through a cylindrical drift tube in a straight path by an axial magnetic field. While passing through the first cavity, the electron beam is velocity modulated by the weak RF signal. In the moving frame of the electron beam, the velocity modulation is equivalent to a plasma oscillation. Plasma oscillations are rapid oscillations of the electron density in conducting media such as plasmas or metals. (The frequency only depends weakly on the wavelength). So in a quarter of one period of the plasma frequency, the velocity modulation is converted to density modulation, i.e. bunches of electrons. As the bunched electrons enter the second chamber they induce standing waves at the same frequency as the input signal. The signal induced in the second chamber is much stronger than that in the first.

Two-cavity klystron oscillator

The two-cavity amplifier klystron is readily turned into an oscillator klystron by providing a feedback loop between the input and output cavities. Two-cavity oscillator klystrons have the advantage of being among the lowest-noise microwave sources available, and for that reason have often been used in the illuminator systems of missile targeting radars. The two-cavity oscillator klystron normally generates more power than the reflex klystron—typically watts of output rather than mill watts. Since there is no reflector, only one high-voltage supply is necessary to cause the tube to oscillate, the voltage must be adjusted to a particular value. This is because the electron beam must produce the bunched electrons in the second cavity in order to generate output power. Voltage must be adjusted to vary the velocity of the electron beam (and thus the frequency) to a suitable level due to the fixed physical separation between the two cavities. Often several "modes" of oscillation can be observed in a given klystron.

Reflex klystron



In the reflex klystron (also known as a 'Sutton' klystron after its inventor), the electron beam passes through a 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 re-enters the resonant cavity, thus ensuring a maximum of energy is transferred from the electron beam to the RF oscillations in the cavity. The voltage should always be switched on before providing the input to the reflex klystron as the whole function of the reflex klystron would be destroyed if the supply is provided after the input. 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. This tube is called a reflex klystron because it repels the input supply or performs the opposite function of a klystron.

There are often several regions of reflector voltage where the reflex klystron will oscillate; these are referred to as modes. The electronic tuning range of the reflex klystron is usually referred to as the variation in frequency between half power points—the points in the oscillating mode where the power output is half the maximum output in the mode. It should be noted that the frequency of oscillation is dependent on the reflector voltage, and varying this provides a crude method of frequency modulating the oscillation frequency, albeit with accompanying amplitude modulation as well.Modern semiconductor technology has effectively replaced the reflex klystron in most applications.

Multicavity klystron

Large klystrons as used in the storage ring of the Australian Synchrotron to maintain the energy of the electron beam

In all modern klystrons, the number of cavities exceeds two. A larger number of cavities may be used to increase the gain of the klystron, or to increase the bandwidth.

Tuning a klystron

Some klystrons have cavities that are tunable. Tuning a klystron is delicate work which, if not done properly, can cause damage to equipment or injury to the technician. By adjusting the frequency of individual cavities, the technician can change the operating frequency, gain, output power, or bandwidth of the amplifier. The technician must be careful not to exceed the limits of the graduations, or damage to the klystron can result.

Manufacturers generally send a card with the unique calibrations for a klystron's performance characteristics that lists the graduations to be set to attain any of a set of listed frequencies. No two klystrons are exactly identical (even when comparing like part/model number klystrons), and so every card is specific to the individual unit. Klystrons have serial numbers on each of them to uniquely identify each unit, and for which manufacturers may (hopefully) have the performance characteristics in a database. If not, loss of the calibration card may be an insoluble problem, making the klystron unusable or perform marginally un-tuned.

Other precautions taken when tuning a klystron include using nonferrous tools. Some klystrons employ permanent magnets. If a technician uses ferrous tools, (which are ferromagnetic), and comes too close to the intense magnetic fields that contain the electron beam, such a tool can be pulled into the unit by the intense magnetic force, smashing fingers, injuring the technician, or damaging the unit. Special lightweight nonmagnetic (aka diamagnetic) tools made of beryllium alloy have been used for tuning U.S. Air Force klystrons.

Precautions are routinely taken when transporting klystron devices in aircraft, as the intense magnetic field can interfere with magnetic navigation equipment. Special over packs are designed to help limit this field "in the field," and thus allow such devices to be transported safely.

Optical klystron

In an optical klystron the cavities are replaced with undulators. Very high voltages are needed. The electron gun, the drift tube and the collector are still used.

Floating drift tube klystron

The floating drift tube klystron has a single cylindrical chamber containing an electrically isolated central tube. Electrically, this is similar to the two cavity oscillator klystron with a lot of feedback between the two cavities. Electrons exiting the source cavity are velocity modulated by the electric field as they travel through the drift tube and emerge at the destination chamber in bunches, delivering power to the oscillation in the cavity. This type of oscillator klystron has an advantage over the two-cavity klystron on which it is based. It only needs one tuning element to effect changes in frequency. The drift tube is electrically insulated from the cavity walls, and DC bias is applied separately. The DC bias on the drift tube may be adjusted to alter the transit time through it, thus allowing some electronic tuning of the oscillating frequency. The amount of tuning in this manner is not large and is normally used for frequency modulation when transmitting.

Collector

After the RF energy has been extracted from the electron beam, the beam is destroyed in a collector. Some klystrons include depressed collectors, which recover energy from the beam before collecting the electrons, increasing efficiency. Multistage depressed collectors enhance the energy recovery by "sorting" the electrons in energy bins.

Applications : - Klystrons produce microwave power far in excess of that developed by solid state. In modern systems, they are used from UHF (100's of MHz) up through

hundreds of gigahertz (as in the Extended Interaction Klystrons in the CloudSat satellite). Klystrons can be found at work in radar, satellite and wideband high-power communication (very common in television broadcasting and EHF satellite terminals), and high-energy physics (particle accelerators and experimental reactors). At SLAC, for example, klystrons are routinely employed which have outputs in the range of 50 megawatts (pulse) and 50 kilowatts (time-averaged) at frequencies nearing 3 GHz Popular Science's "Best of What's New 2007" included a company

Global Resource Corporation using a klystron to convert the hydrocarbons in everyday materials, automotive waste, coal, oil shale, and oil sands into natural gas and diesel fuel.

Result - Measurement of characteristics of klystron tube & Gunn Oscillator is done.

Experiment no - 19

Objective : - Assembling the microwave bench

Theory -

I. INTRODUCTION

Microwaves have recently changed the mode of communication and in a way it has changed the face of world. The microwave spectrum as electromagnetic energy has been instrument in creating what is known as

GLOBAL VILLAGE.

The microwaves form a part of a radio spectrum the frequency ranges from 1 GHz to 30 GHz is known as microwaves, above 30 GHz is known as millimeter waves. This frequency range has applications in areas like communication, remote sensing, industrial and biomedical.

According to Indian conditions there is a great need to investigate and study dielectric properties of soil, sand etc. The reflectivity and emissivity of these is a function of its dielectric constant. Therefore it is necessary to know laboratory measurements of complex dielectric constant of these at microwave frequency to interpret the remote sensing data. Complex dielectric constant is given by

$$\varepsilon = \varepsilon' - j\,\varepsilon''$$

The real part ε' is known as dielectric constant and imaginary part ε" is known as dielectric loss. e' and ε" are calculated from the standing wave patterns of the empty cell and sample filled with dry sand. From ε' and ε" the emissivity 'e' of the dry sand calculated 'e' is given by.

$e = 1 - \dot{\rho}$

Where '$\dot{\rho}$' is normal incidence reflectivity.

II. EXPERIMENTAL SETUP FOR C-BAND

The experimental setup for micro-wave frequencies at C-band requires a microwave source to produce microwave power. A varactor tunned oscillator (VTO 8430) of Avantek is used which supplies microwave power to a maximum level of 10 mW at frequencies from 4.3 GHz to 5.8 GHz. A +15 Volts DC power supply has been used as source power supply. Temperature of VTO may raise while in use, so an electrical fanis used to cool it. The block diagram of experimental setup is shown in Fig.1.

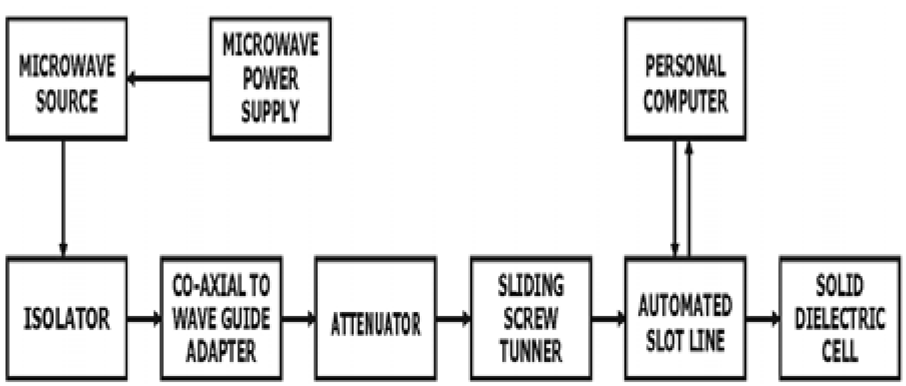


Fig.1- Block Diagram of C-Band Microwave Bench

Fig.1Block Diagram of C-Band Microwave Bench The other components shown in the block diagram are isolator, co-axial connector, attenuator, sliding screw tuner, slotted line section , detector probe and a dielectric cell .In this setup all the components are assembled and microwaves are generated by VTO and are propagated through rectangular waveguide to the dielectric cell. The attenuator is used to keep the desired power in line. A slotted section with tunable probe containing 1N23C crystal with the square low characteristics has been used to measure power (current) along the slotted line. The crystal detector is connected to the micro ammeter and to the PC to read and record the measured power.

III. AUTOMATION

Mechanical modifications are done in slot line in the usual microwave bench setup for obtaining the required automation. In the existing usual microwave bench setup the detector probe sitting on a mount produces DC output current due to microwaves in the waveguide. The detector mount is attached to rack and pinion arrangement so that the detector probe can be moved in the slot line in forward and reverse
Direction by rotating the knob in clockwise and anticlockwise direction respectively.

The displacement of the probe can be measured by scale fixed along slot line having vernier arrangement. Instead of rack and penion arrangement lock nut and lead screw is used to modify the mechanical system. The lead screw passes through lock nut which is attached to the detector mount. It is fixed in the position of rack between two supports heading the slot line piece of the wave guide. A set of gears 1:1 is fitted at the FAR end of the lead screw and to the shaft of steeper motor. Thus the stepper motor drive can control the position of the detector probe on the lot line. Two limit switches are fixed to the end positions on either side of the slot line. The limit switch at HOME position will operate when the detector probe mount is brought to that end and the motor takes the probe to start position after removing the back lash in the lock nut. The stepper motor drive can be operated in AUTO mode through PC interfacing to move the detector probe from HOME position to FAR position and current is read and recorded at each 1 mm position along its traverse. The position of the probe and current is displayed on the monitor screen. It takes more than one hundred steps of positions to reach the probe to FAR position where it automatically operates the second limit switch to stop the motor. A solid dielectric cell with perfectly reflecting surface as short circuit is used to measure dielectric constant.

IV. DATA ACQUISITION SYSTEM

The hardware of the system mainly consists of a control mother board, which is fully IBM PC compatible and two daughter boards. One of the daughter boards is for a 13 bit AD analog to digital converter and the other for stepper motor controller. The ADC converts analog current signal from the detector probe into digital form for PC based instrumentation. The stepper motor controller has facilities of a full step and half step rotation in both clockwise and anticlockwise rotation provided by suitable software . This PC controlled rotation of the stepper motor rotates the lead screw through 1:1gear set. Thereby a forward and reverse advancement of the locknut along the slot line is obtained, which ultimately causes motion of the detector probe for reading and recording current sat all positions along the slot line on microwave setup. The hardware is developed by. Ayub Pathan.

V. SOFTWARE DEVELOPMENT

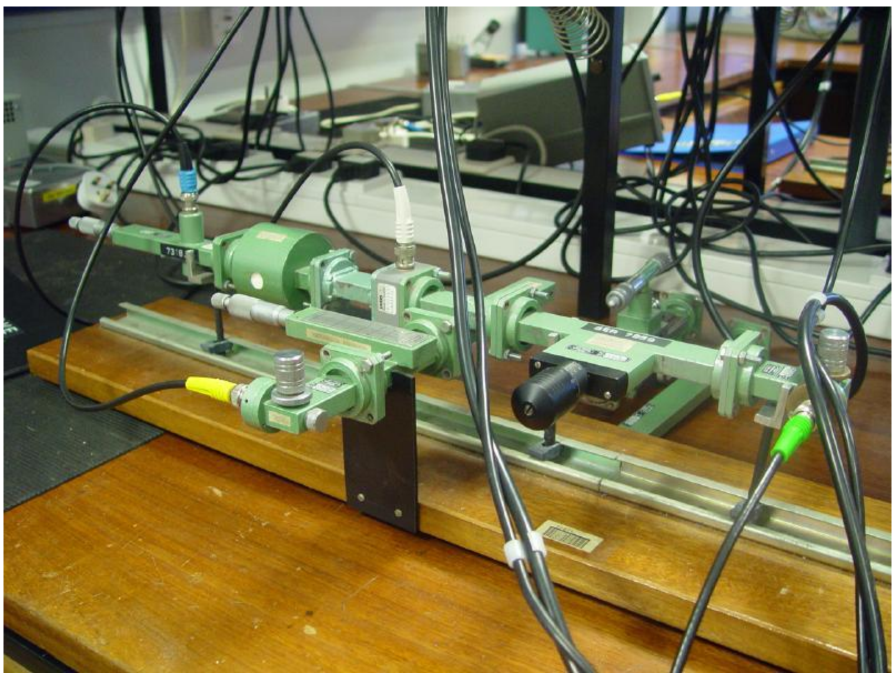
The software which controls the system is written in quick basic and hardware routines for stepper motor control and for reading data from ADC are written in 8088 assembly language .The software was developed with the help of Dr. Ayub Pathan. After executing the program the following main menu appears on the screen with options from 1 to 5 to be typed.

V. CONCLUSION

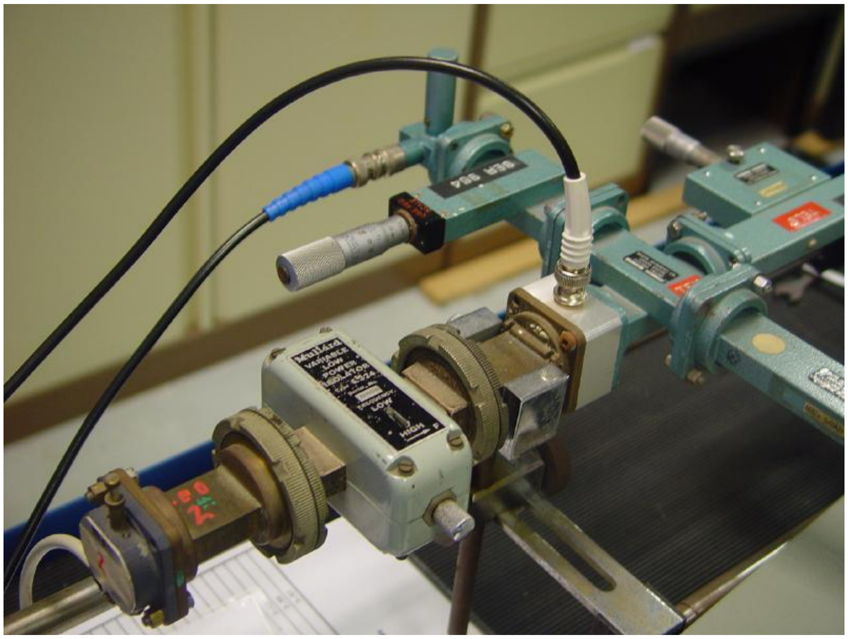
C-band microwave bench setup for PC interfacing hardware is modified and a tedious and labourus work is avoided. Dielectric constant measurements became fast.

Microwave waveguide benches.

These demonstration benches introduce the novice student to the essentials of the behavior of microwaves in the laboratory. The wavelength is convenient at frequency in X band (8-12 GHz approx) The waveguide used is WG90, so called because the principal waveguide dimension is 0.900 inches, 900 "thou" or "mils" depending on whether you are using British or American parlance. The guide wavelength at 10 GHz in WG90 is notionally 3.98 cm (the free space wavelength is 3 cm) so the standing wave pattern repeats at a distance of about 2 cm.



An X-band waveguide bench.

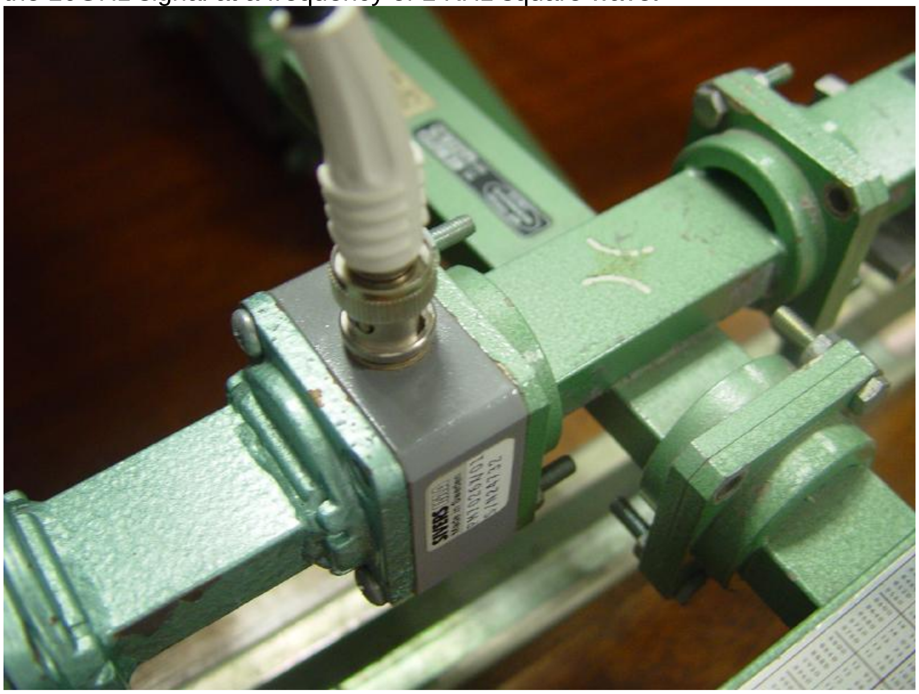


Another X-band waveguide bench, used for transmitting.

The benches include an attenuator, and an isolator. Both of these help to stop the reflected power from reaching the oscillator and pulling the frequency of the cavity and Gunn diode off tune when the load impedance is varied.

An isolator, made from a magnet and ferrite-loaded waveguide.

There is a dual directional coupler, arranged as a pair of crossed waveguides, which samples some of the forward wave power and couples it to a calibrated cavity wave meter for measuring the oscillator frequency. Taken together with a measurement of guide wavelength, we have then two independent checks on the oscillator frequency. There is also a PIN modulator which chops the 10GHz signal at a frequency of 1 KHz square wave.



The PIN modulator, directional coupler, and part of the wave meter scale.

The guide wavelength is an important property to be measured, and should not be changed during the course of a series of measurements. A half guide wavelength (about 2 cm) represents a plot of once round the SMITH chart. As remarked, we can determine the position of a minimum to about 1/20mm precision, or about 1 degree of angle around the chart. That represents 0.00125 lambda error in the phase plot on the SMITH chart.

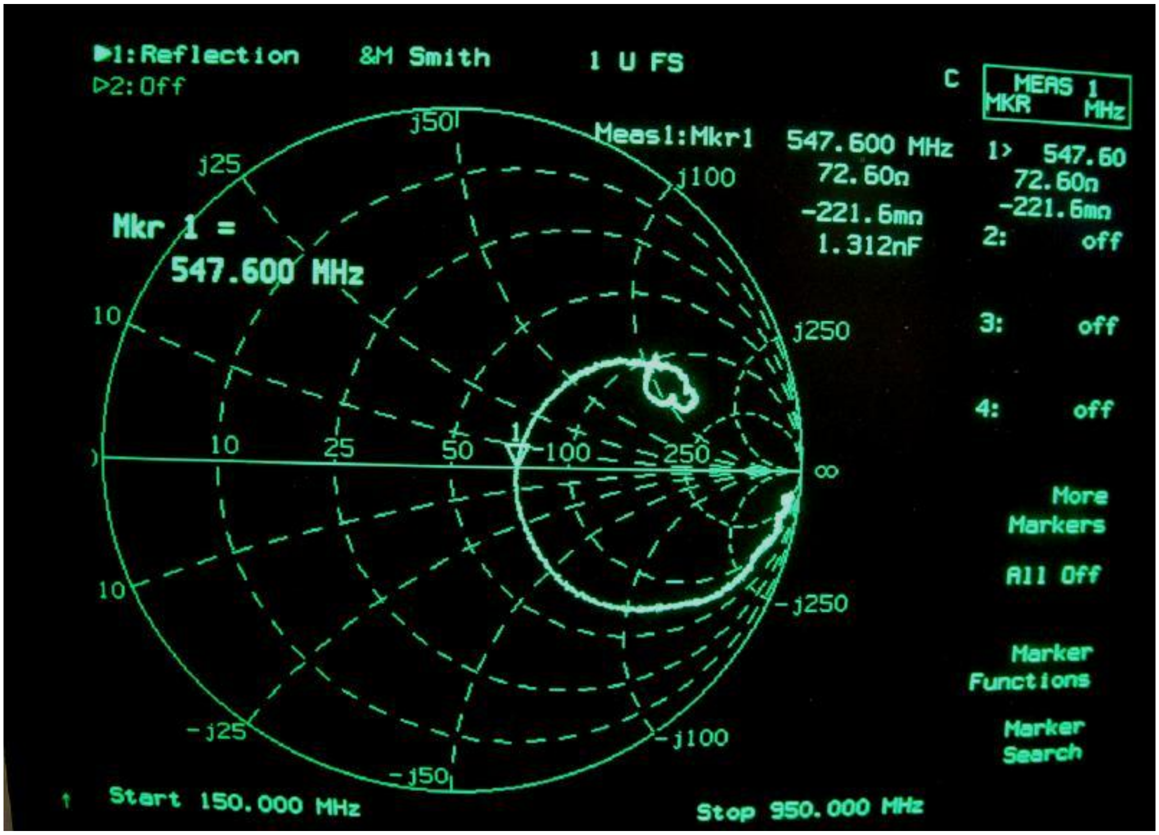
Network analysers:-

A network analyzer makes measurements of complex reflection coefficients on 2-port microwave networks. In addition, it can make measurements of the complex amplitude ratio between the outgoing wave on one port and the incoming wave on the other. There are thus four possible complex amplitude ratios which can be measured. If we designate the two ports 1 and 2 respectively, these ratios may be written s11 s12 s21 s22. These are the four "s-parameters" or "scattering parameters" for the network. Together they may be assembled into a matrix called the "s-matrix" or "scattering matrix".

The network analyzer works on a different principle to the slotted line. It forms sums and differences of the port currents and voltages, by using a cunning bridge arrangement. The phase angles are found by using synchronous detection having in-phase and quadrature components. From the measured voltage and currents it determines the incoming and outgoing wave amplitudes. , $V+ = (V + ZoI)/2$ and $V- = (V - ZoI)/2$.

Network analysers can be automated and controlled by computer, and make measurements at a series of different frequencies derived from a computer controlled master oscillator. They then plot the s-parameters against frequency, either on a SMITH chart or directly.

The important experimental technique to the use of a network analyzer lies in the calibration procedure. It is usual to present the analyzer with known scattering events, from matched terminations and short circuits at known places. It can then adjust its presentation of s-parameters for imperfections in the transmission lines connecting the analyzer to the network, so that the user never has to consider the errors directly providing he/she can trust the calibration procedure. It is even possible to calibrate out the effects of intervening transmission components, such as chip packages, and measure the "bare" s-parameters of a chip at reference planes on-chip.



A network analyser SMITH chart plot of a dipole

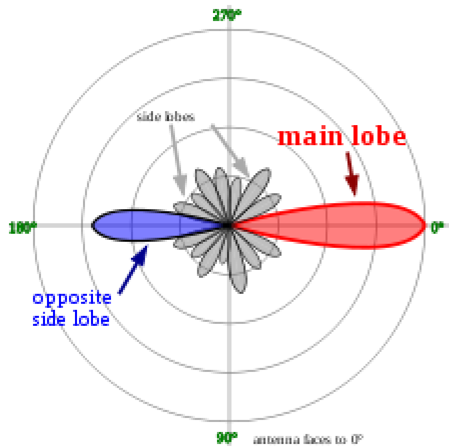
Result - microwave bench is Assembled.

Experiment no – 21

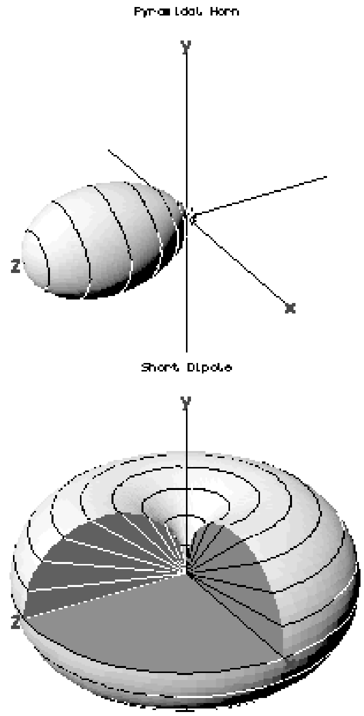
Objective :- Study of radiation pattern for different antennas

Theory -

Radiation pattern



polar plots of the horizontal cross sections of a (virtual) Yagi-Uda-antenna. Outline connects points with 3db field power compared to an ISO emitter.The radiation pattern of an antenna is the geometric pattern of the relative field strengths of the field emitted by the antenna. For the ideal isotropic antenna, this would be a sphere. For a typical dipole, this would be a toroid. The radiation pattern of an antenna is typically represented by a three dimensional graph, or polar plots of the horizontal and vertical cross sections. The graph should show side lobes and backlobes, where the antenna's gain is at a minima or maxima.



Antenna radiation patterns

In the field of antenna design the term 'radiation pattern' most commonly refers to the directional (angular) dependence of radiation from the antenna or other source (synonyms: antenna pattern, far-field pattern). Particularly in the fields of fiber optics, lasers, and integrated optics, the term radiation pattern, or near-field radiation pattern, may also be used as a synonym for the near-field pattern or Fresnel pattern. This refers to the positional dependence of the electromagnetic field in the near-field, or Fresnel region of the source. The near-field pattern is most commonly defined over a plane placed in front of the source, or over a cylindrical or spherical surface enclosing it.

The far-field pattern of an antenna may be determined experimentally at an antenna range, or alternatively, the near-field pattern may be found using a near-field scanner, and the radiation pattern deduced from it by computation. The far field radiation pattern may be represented graphically as a plot of one of a number of related variables, including; the field strength at a constant (large) radius (an amplitude pattern or field pattern), the power per unit solid angle (power pattern) and the gain or directive gain. Very often, only the relative amplitude is plotted, normalized either to the amplitude on the antenna boresight, or to the total radiated power. The plotted quantity may be shown on a linear scale, or in dB. The plot is typically represented as a three dimensional graph (as at right), or as separate graphs in the vertical plane and horizontal plane.

Reciprocity

Reciprocity applied to antennas

It is a fundamental property of antennas that the receiving pattern (sensitivity as a function of direction) is identical to the far-field radiation pattern. This is a consequence of the reciprocity theorem.

Proof

For a complete proof, see the reciprocity (electromagnetism) article. Here, we present a common simple proof limited to the approximation of two antennas separated by a large distance compared to the size of the antenna, in a homogeneous medium. The first antenna is the test antenna whose patterns are to be investigated; this antenna is free to point in any direction. The second antenna is a reference antenna, which points rigidly at the first antenna.Each antenna is alternately connected to a transmitter having a particular source impedance, and a receiver having the same input impedance (the impedance may differ between the two antennas).It will be assumed that the two antennas are sufficiently far apart that the properties of the transmitting antenna are not affected by the load placed upon it by the receiving antenna. Consequently, the amount of power transferred from the transmitter to the receiver can be expressed as the product of two independent factors; one depending on the directional properties of the transmitting antenna, and the other depending on the directional properties of the receiving antenna.

For the transmitting antenna, by the definition of gain, G, the radiation power density at a distance r from the antenna (i.e. the power passing through unit area) is

$$\mathrm{W}(\theta,\Phi) = \frac{\mathrm{G}(\theta,\Phi)}{4\pi r^2}P_t \; .$$

Here, the arguments θ and Φ indicate a dependence on direction from the antenna, and P_t stands for the power the transmitter would deliver into a matched load. The gain G may be broken down into three factors; the directive gain (the directional redistribution of the power), the radiation efficiency (accounting for ohmic losses in the antenna), and lastly the loss due to mismatch between the antenna and transmitter. Strictly, to include the mismatch, it should be called the realized gain,[4] but this is not common usage.

For the receiving antenna, the power delivered to the receiver is

$$P_r = \mathrm{A}(\theta,\Phi)W \; .$$

Here W is the power density of the incident radiation, and A is the effective area or effective aperture of the antenna (the area the antenna would need to occupy in order to intercept the observed captured power). The directional arguments are now relative to the receiving antenna, and again A is taken to include ohmic and mismatch losses.

Putting these expressions together, the power transferred from transmitter to receiver is

$$P_r = A\frac{G}{4\pi r^2}P_t \; ,$$

where G and A are directionally dependent properties of the transmitting and receiving antennas respectively. For transmission from the reference antenna (2), to the test antenna (1), that is

$$P_{1r} = \mathrm{A}_1(\theta,\Phi)\frac{G_2}{4\pi r^2}P_{2t} \; ,$$

and for transmission in the opposite direction

$$P_{2r} = A_2 \frac{\mathrm{G}_1(\theta, \Phi)}{4\pi r^2} P_{1t}.$$

Here, the gain G_2 and effective area A_2 of antenna 2 are fixed, because the orientation of this antenna is fixed with respect to the first.Now for a given disposition of the antennas, the reciprocity theorem requires that the power transfer is equally effective in each direction, i.e.

$$\frac{P_{1r}}{P_{2t}} = \frac{P_{2r}}{P_{1t}},$$

where

$$\frac{\mathrm{A}_1(\theta, \Phi)}{\mathrm{G}_1(\theta, \Phi)} = \frac{A_2}{G_2}.$$

But the right hand side of this equation is fixed (because the orientation of antenna 2 is fixed), and so

$$\frac{\mathrm{A}_1(\theta, \Phi)}{\mathrm{G}_1(\theta, \Phi)} = \mathrm{constant},$$

i.e. the directional dependence of the (receiving) effective aperture and the (transmitting) gain are identical (QED). Furthermore, the constant of proportionality is the same irrespective of the nature of the antenna, and so must be the same for all antennas. Analysis of a particular antenna (such as a Hertzian dipole), shows that this constant is $\frac{\lambda^2}{4\pi}$, where λ is the free-space wavelength. Hence, for any antenna the gain and the effective aperture are related by

$$\mathrm{A}(\theta, \Phi) = \frac{\lambda^2 \mathrm{G}(\theta, \Phi)}{4\pi}.$$

Even for a receiving antenna, it is more usual to state the gain than to specify the effective aperture. The power delivered to the receiver is therefore more usually written as

$$P_r = \frac{\lambda^2 G_r G_t}{(4\pi r)^2} P_t$$

The effective aperture is however of interest for comparison with the actual physical size of the antenna.

Practical consequences

- When determining the pattern of a receiving antenna by computer simulation, it is not necessary to perform a calculation for every possible angle of incidence. Instead, the radiation pattern of the antenna is determined by a single simulation, and the receiving pattern inferred by reciprocity.

- When determining the pattern of an antenna by measurement, the antenna may be either receiving or transmitting, whichever is more convenient.

Result - Study of radiation pattern for different antennas is completed.

Experiment no. 22

Objective : - Measurement of characteristic for different antennas.

Apparatus required – different antenna kit ,wires

Theory -

Antenna Reciprocity The ability of an antenna to both transmit and receive electromagnetic energy is known as its reciprocity. Antenna reciprocity is possible because antenna characteristics are essentially the same for sending and receiving electromagnetic energyEven though an antenna can be used to transmit or receive, it cannot be used for both functions at the same time. The antenna must be connected to either a transmitter or a receiver.

Antenna Feed Point Feed point is the point on an antenna where the RF cable is attached. If the RF transmission line is attached to the base of an antenna, the antenna is end-fed. If the RF transmission line is connected at the center of an antenna, the antenna is mid-fed or center-fed

Directivity The directivity of an antenna refers to the width of the radiation beam pattern. A directional antenna concentrates its radiation in a relatively narrow beam. If the beam is narrow in either the horizontal or vertical plane, the antenna will have a high degree of directivity in that plane. An antenna can be highly directive in one plane only or in both planes, depending upon its use. In general, we use three terms to describe the type of directional qualities associated with an antenna: omnidirectional, bidirectional, and unidirectional. Omnidirectional antennas radiate and receive equally well in all directions, except off the ends. Bidirectional antennas radiate or receive efficiently in only two directions. Unidirectional antennas radiate or receive efficiently in only one direction. Most antennas used in naval communications are either omnidirectional or unidirectional. Bidirectional antennas are rarely used. Omnidirectional antennas are used to transmit fleet broadcasts and are used aboard ship for medium-to-high frequencies. A parabolic, or dish, antenna (figure 2-14) is an example of a unidirectional antenna. As we can see in the figure, an antenna (normally a half wave) is placed at the "focal" point and radiates the signal back into a large reflecting surface (the dish).

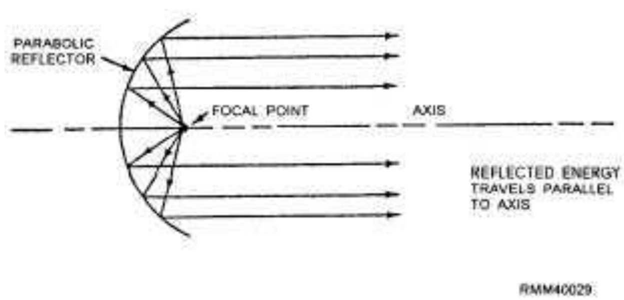


Figure 2-14.—Principle of parabolic reflection

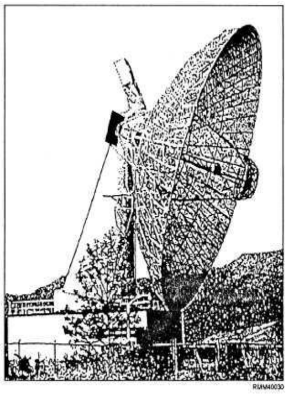


Figure 2-15.—Unidirectional parabolic antenna. 2-1

The effect is to transmit a very narrow beam of energy that is essentially unidirectional. Figure 2-15 shows a large, unidirectional parabolic antenna. Directional antennas are commonly used at shore installations. Wave Polarization of a radio wave is a major consideration in the efficient transmission and reception of radio signals. If a single-wire antenna is

Antenna Characteristics

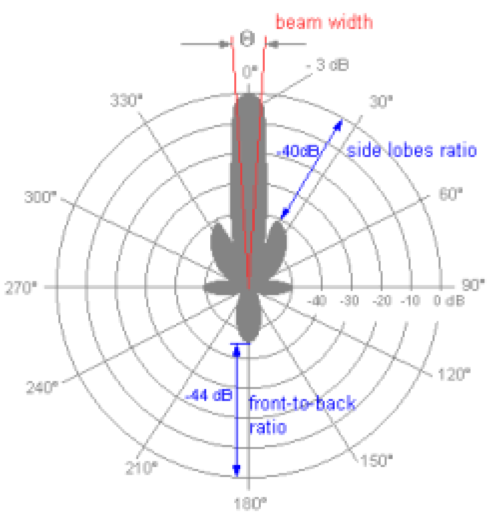


Figure 1: Antenna pattern in a polar-coordinate graph

Antenna Gain

Independent of the use of a given antenna for transmitting or receiving, an important characteristic of this antenna is the gain. Some antennas are highly directional; that is, more energy is propagated in certain directions than in others. The ratio between the amount of energy propagated in these directions compared to the energy that would be propagated if the antenna were not directional (Isotropic Radiation) is known as its gain. When a transmitting antenna with a certain gain is used as a receiving antenna, it will also have the same gain for receiving.

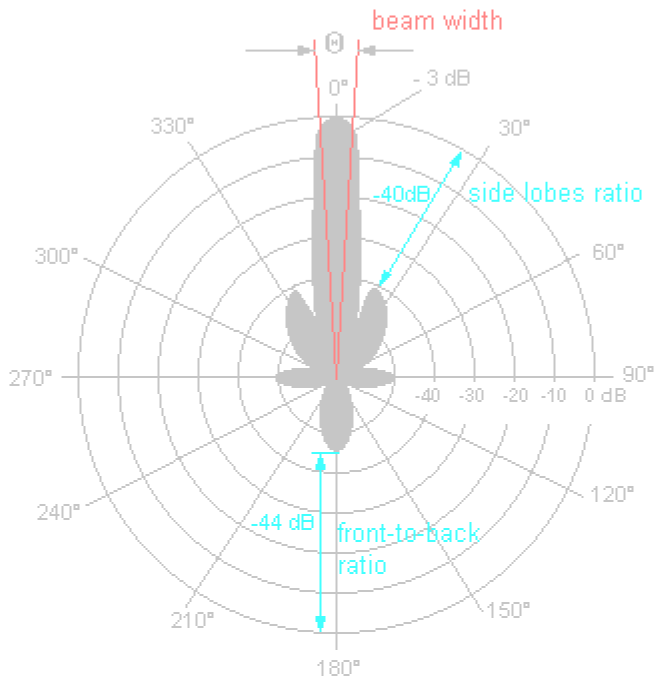


Figure 1: Antenna pattern in a polar-coordinate graph

Antenna Pattern

Most radiators emit (radiate) stronger radiation in one direction than in another. A radiator such as this is referred to as anisotropic. However, a standard method allows the positions around a source to be marked so that one radiation pattern can easily be compared with another.The energy radiated from an antenna forms a field having a definite radiation pattern. A radiation pattern is a way of plotting the radiated energy from an antenna. This energy is measured at various angles at a constant distance from the antenna. The shape of this pattern depends on the type of antenna used.To plot this pattern, two different types of graphs, rectangular-and polar-coordinate graphs are used. The polar-coordinated graph has proved to be of great use in studying radiation patterns. In the polar-coordinate graph, points are located by projection along a rotating axis (radius) to an intersection with one of several concentric, equally-spaced circles. The polar-coordinate graph of the measured radiation is shown in Figure 1.The main beam (or main lobe) is the region around the direction of maximum radiation (usually the region that is within 3 dB of the peak of the main beam). The main beam in Figure 1 is northbound.The sidelobes are smaller beams that are away from the main beam. These sidelobes are usually radiation in undesired directions which can never be completely eliminated. The sidelobe level (or sidelobe ratio) is an important parameter used to characterize radiation patterns. It is the maximum value of the sidelobes away from the main beam and is expressed in Decibels. One sidelobe is called backlobe. This is the portion of radiation pattern that is directed opposing the main beam direction.

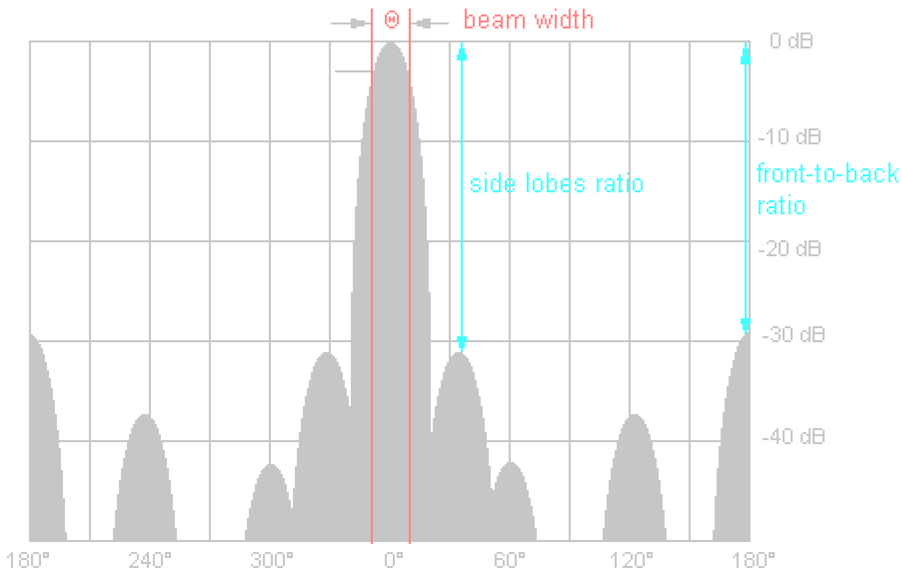


Figure 2: The same antenna pattern in a rectangular-coordinate graph

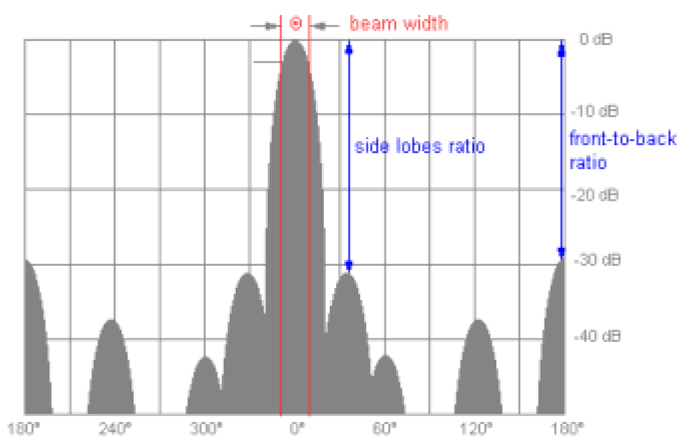


Figure 2: The same antenna pattern in a rectangular-coordinate graph

The now following graph shows the rectangular-coordinated graph for the same source. In the rectangular-coordinate graph, points are located by projection from a pair of stationary, perpendicular axes. The horizontal axis on the rectangular-coordinate graph corresponds to the circles on the polar-coordinate graph. The vertical axis on the rectangular-coordinate graph corresponds to the rotating axis (radius) on the polar-coordinate graph. The measurement scales in the graphs can have linear as well as logarithmic steps.For the analysis of an antenna pattern the following simplifications are used:

Beam Width -The angular range of the antenna pattern in which at least half of the maximum power is still emitted is described as a „Beam With". Bordering points of this major lobe are therefore the points at which the field strength has fallen in the room around 3 dB regarding the maximum field strength. This angle is then described as beam width or aperture angle or half power (- 3 dB) angle - with notation Θ (also φ). The beamwidth Θ is exactly the angle between the 2 red marked directions in the upper pictures. The angle Θ can be determined in the horizontal plane (with notation Θ_{AZ}) as well as in the vertical plane (with notation Θ_{EL}).

Aperture

The effective aperture of an antenna A_e is the area presented to the radiated or received signal. It is a key parameter, which governs the performance of the antenna. The gain is related to the effective area by the following relationship:

$$G = \frac{4\pi \cdot A_e}{\lambda^2} \quad ; A_e = K_a \cdot A \quad (1)$$

Where:
- λ = wave length
- A_e = effective antenna aperture
- A = physical area of the antenna
- K_a = antenna aperture efficiency

The aperture efficiency depends on the distribution of the illumination across the aperture. If this is linear then K_a= 1. This high efficiency is offset by the relatively high level of sidelobes obtained with linear illumination. Therefore, antennas with more practical levels of sidelobes have an antenna aperture efficiency less than one ($A_e < A$).

Major and Side Lobes (Minor Lobes)

The pattern shown in the upper figures has radiation concentrated in several lobes. The radiation intensity in one lobe is considerably stronger than in the other. The strongest lobe is called major lobe; the others are (minor) side lobes. Since the complex radiation patterns associated with arrays frequently contain several lobes of varying intensity, you should learn to use appropriate terminology. In general, major lobes are those in which the greatest amount of radiation occurs. Side or minor lobes are those in which the radiation intensity is least.

Front-to-Back Ratio

The front-to-back ratio of an antenna is the proportion of energy radiated in the principal direction of radiation to the energy radiated in the opposite direction. A high front-tobackratio is desirable because this means that a minimum amount of energy is radiated in the undesired direction.

Result - Measurement of characteristic for different antennas is completed .