AMITEC ELECTRONICS LTD.

MWL10
MICROWAVE LAB
EXPERIMENTAL & OPERATION MANUAL

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CHAPTER -1: INTRODUCTION

The Microwave Lab is developed to provide with the users a comprehensive way of understanding the basic properties of microwave frequencies and also the easiest way of performing a number of microwave experiments using the popular X-band frequencies (8.2~12.4 GHz).

The microwave radio communications network plays very important role nowadays in our daily life. For example high quality long distance telephone calls, sometimes via communications satellites, are made possible using microwave telecommunications systems

The superior characteristics of a microwave system come from the fact that the microwave frequencies have highly directional propagation properties, which are similar to those of light. Also the high degree of noise immunity of the microwave frequencies in the atmosphere makes the microwave communication the top choice in the long distance communications

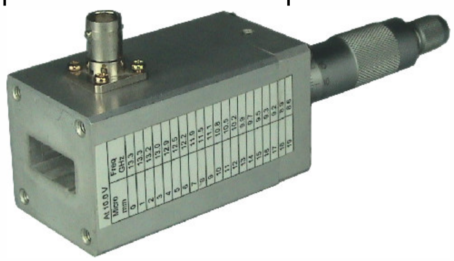
The Microwave Lab, a very effective learning tool on the properties of microwave frequencies, offers a variety of experiments centered on the following key components involved in the microwave frequency oscillation, transmission through antenna and reception at the receiver.

TECHNICAL DESCRIPTION OF COMPONENTS

1. Gunn Oscillator

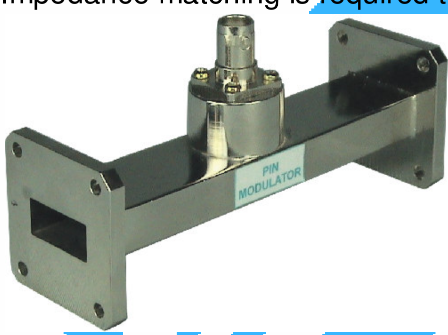
A Gunn oscillator, named after Gunn who discovered the Gunn Effect in 1963 generates microwave frequencies when a Gunn diode, which is loosely coupled to a cavity, is connected to a 8-10V DC power source.

The power output of the Gunn oscillator ranges from 1 to 10 milliwatts depending upon the supply voltage, and the other parameters of the oscillator. It is recommended that output frequencies of X-Band of this manual experiment procedure should be performed at say 11GHz.



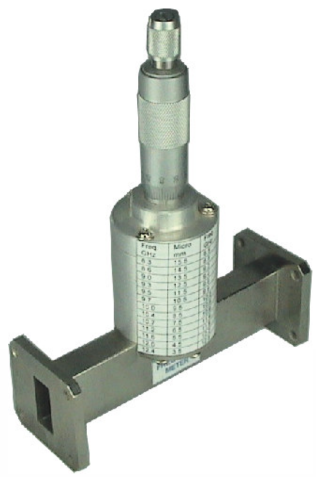
2. PIN-diode modulator

A PIN diode utilizes the property of a pin diode, which is placed across wave-guide in shunt mode. If the pin diode is reverse biased, the insertion loss of diode is so small that it does not affect the energy flow inside the wave-guide. However, when the reverse biased is removed either fully or partially, the diode begins to control the energy flow, thus creating an amplitude or pulse modulation effect. Impedance matching is required to obtain the maximum power output.



3. FREQUENCY METER

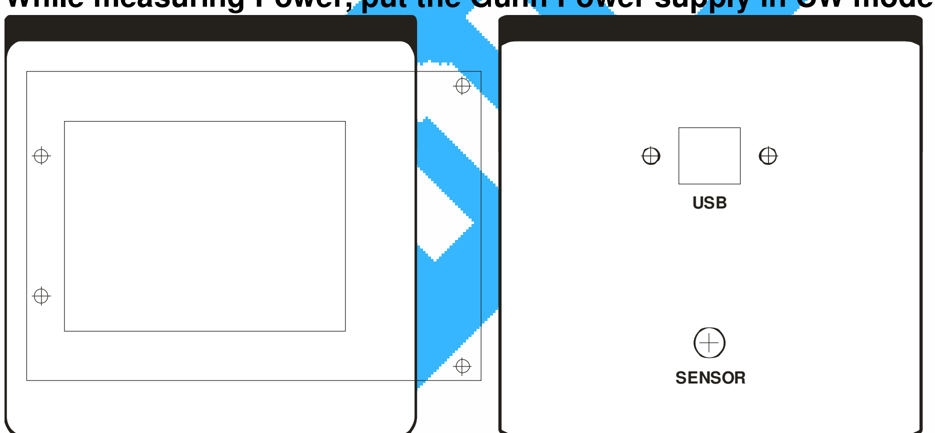
The basic working principle of the frequency meter comes from the high Q resonant characteristic of the resonant cavity, which is attached to a wave-guide. The microwave signal in the wave-guide is coupled to the resonant cavity through a small slot between the cavity and the wave-guide. The effective size of the cavity, and thus the resonant frequency of the cavity, is variable by moving in and out an adjustable plunger, which has a calibrated micrometer assembly. When the resonant frequency of the cavity is equal to the frequency of the waveguide, there is a maximum energy transfer from the waveguide to the cavity. A large power drop on the power meter, which is connected to the waveguide, indicates this condition. The actual frequency is obtained by reading the calibrated micrometer.



4. Power meter

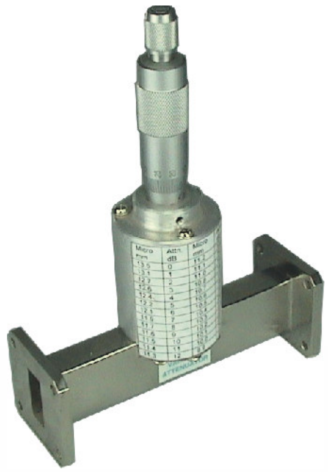
A thermocouple (high frequency materials for the thermo-junctions with low error rate)/diode can convert the microwave energy to a readily measurable DC voltage. The DC voltage is amplified then fed to an analog to digital converter and displayed as power on LCD. The LCD indication is calibrated to represent the power level in the waveguide. The power meter is provided with its 10.5GHz Dielectric Resonant Oscillator source. This can be used for two port network measurements. The DRO source with its built in PIN modulator can be modulated with TTL/CMOS level signal of DC-10KHz, which can be used to transmit data or use with SWR meter.

While measuring Power, put the Gunn Power supply in CW mode.



5. Variable attenuator 20dB

A variable attenuator provides attenuation by varying the degree of insertion of a matched resistive strip into a waveguide. The variable attenuator is used to control a power level or to isolate a source from a load.



6. Fixed attenuator

The purpose of the fixed attenuator used in system is to provide a fixed attenuation of 6dB. The attenuation is obtained by insertion of a thin absorber into a straight portion of a standard waveguide.

7. Directional coupler

The directional coupler, which allows directional coupling of energy in the wave guide is basically a sampling device of the microwave signal A directional coupler is consisted of two wave guides combined together and coupled by holes at the joining section of the two Directional couplers are very popular in microwave systems where measurements of incident and reflected power are needed to determine the Standing Wave Ratio or SWR.

The directivity, which is a figure of merit of a directional coupler, is a measure of how the power can be coupled in the desired direction in the neighbouring waveguide. Usually one end of the neighboring wave guide contains a matched load which absorbs the energy headed towards undesired direction. The directional coupler used in system has a coupling factor of 14dB +/- 2dB and a directivity of 30dB.

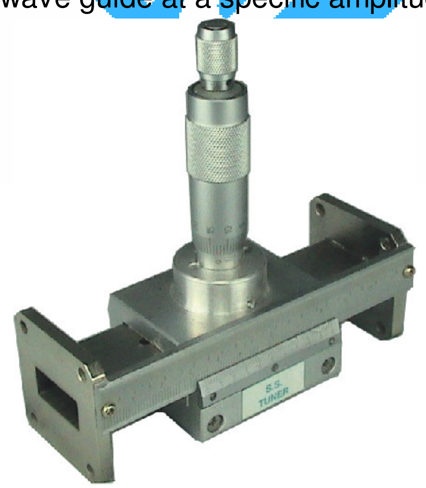
8. Slotted line

In measuring the standing waves inside a wave-guide a slotted line is used to probe the amplitude and the phase of the standing wave pattern. Obtaining the standing wave pattern information allows us to determine the wavelength standing wave ratio and the impedance of the transmission line. As the name indicates a slotted line has a slot along the center inline of the broad side of the waveguide wall. An assembly consisting of a probe and a crystal diode moves along the open slot and as it does, the probe samples the field in the wave guide while the crystal detector provides a rectified signal in proportion to the electric field level inside waveguide. The depth of the probe into the wave-guide is fixed optimally and the strength of the detected signal is proportional to the depth.

The user should be aware of an optimized depth of 2mm is used in slotted line, since too shallow depth should make the detected signal too weak and too deep depth would substantially reduce the main signal power in the wave guide and may even cause field distortion.

9. Slide screw tuner

The primary use of the slide screw tuner is to match loads, detectors, or antennas to the characteristic impedance of the wave guide. Slide screw tuner consists of a probe mounted on a carriage which slides along a waveguide walls. When the adjusting micrometer is turned, depth of the probe inside the waveguide varies. The combination of the depth and the position of the probe causes reflection in the wave guide at a specific amplitude and phase.

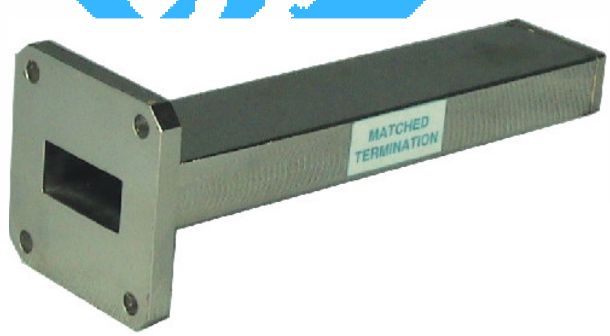


10. Crystal detector.

The crystal diode detector is located inside the waveguide walls which joined to a coaxial connector. The crystal detector basically a diode assembly which responds to the electromagnetic field inside the wave guide. The diode assembly is consists of a small thin piece of silicon, a thin tungsten wire and a case. One side of the silicon is directly connected to the case and the other side is connected to the tip of the tungsten wire. The diode action is due to the different properties of silicon and tungsten. Silicon has few surplus electrons but there are many free electrons in tungsten. Therefore when a voltage is applied across the diode in such a direction as to force electrons to leave silicon and enter tungsten, a very small current results. In contrast, when the direction of the voltage is reversed, a large current flows from tungsten into silicon. This is how the diode can be used for detection of microwave energy The diode is a fragile device it can be easily damaged from an excessive voltage. **The characteristic of a crystal detector (or the relationship between the output voltage and current to the input RF voltage) is such that the device follows a square law within a certain range of input power. The square law characteristic means the output voltage is proportional to the square of the input voltage. It can also be said that the output voltage directly proportional to the input power.**

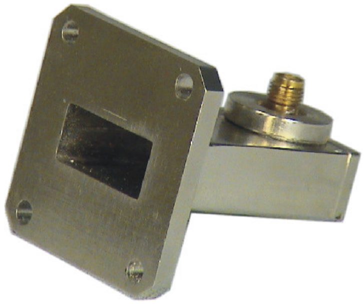
11. Matched termination

The matched termination is essentially a match to the microwave transmission line. As the standing waves occur due to impedance mismatches in the system, the matched termination is used to minimize the SWR in a system. It absorbs all the incoming RF signal inside the waveguide, and does not allow any reflected signal from the shorted end.

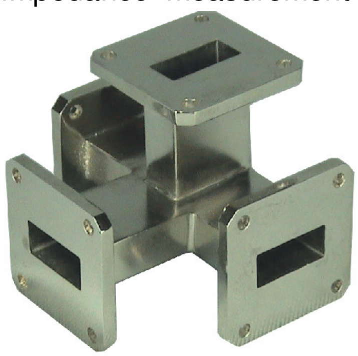


12. Coaxial Adapter

Provides a match between a wave guide and a 50 ohm coaxial. The power flow can be in either direction. However SWR in the adapter should be kept less than 1.2 to allow maximum power transfer.



13. Magic-Tee (or Hybrid-Tee)
A magic-Tee is a four port device which is basically a combination of E plane and H plane Tee. Incident power on any arm splits equally between the two adjacent arms, but there is no power coupled to the opposite arm. The magic-Tee is an essential device in balanced mixers, automatic frequency control circuits and impedance measurement circuits



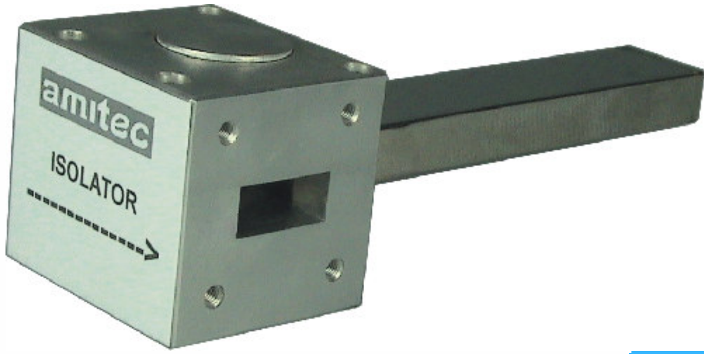
14. REFLECTING SHEET
A means of reflecting electromagnetic waves in free space when measuring the wavelength of a signal.

15. Shorting plate.
When measuring the wavelength inside of a waveguide a shorting plate is used to create a short (zero impedance) at the open end of a wave-guide

16. Circulator / Isolator

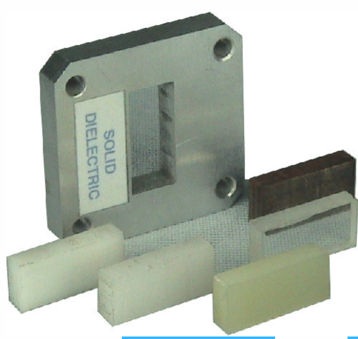
The isolator is a two port device with small insertion loss in forward direction and a large in reverse attenuation. It thus allows power flow in one direction only. It can thus absorb reflected power from a mismatched load and isolate the gunn source.

Circulator is a three port junction that permits transmission in say clockwise direction only. A wave incident in port1 is coupled to port2 only; a wave incident at port2 is coupled to port3 only and so on.



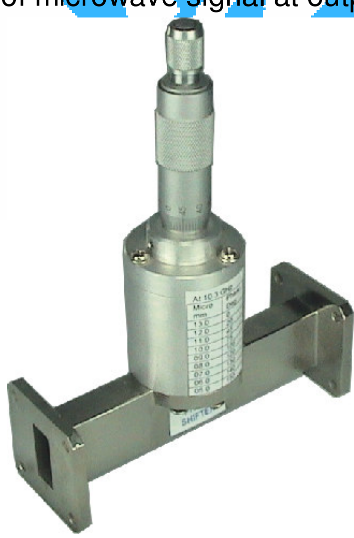
17. Solid Liquid Dielectric

The cell have waveguide cavity which can be used to hold solid or liquid dielectric for measurement of dielectric constant and loss tangent.



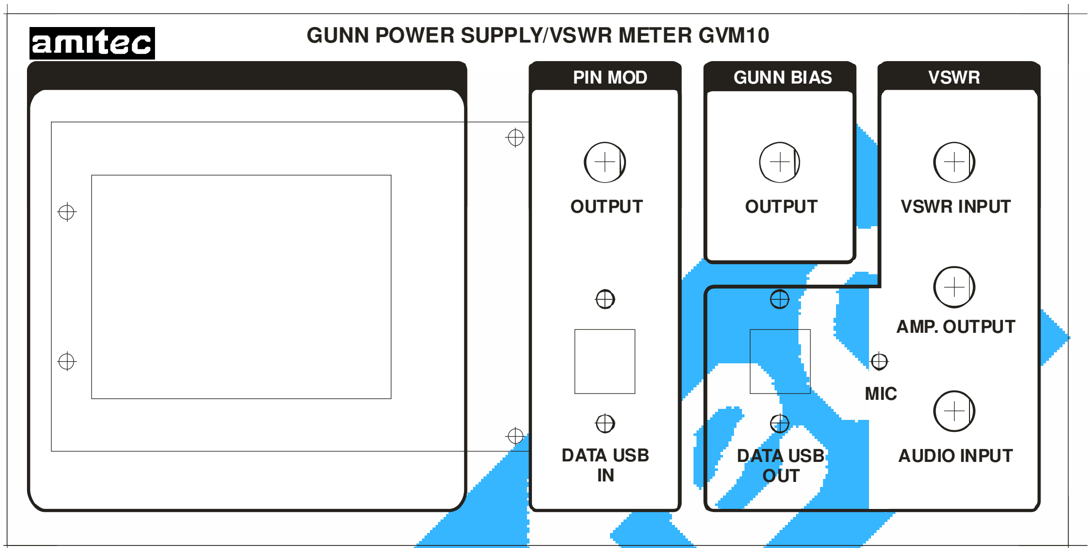
18. Phase Shifter

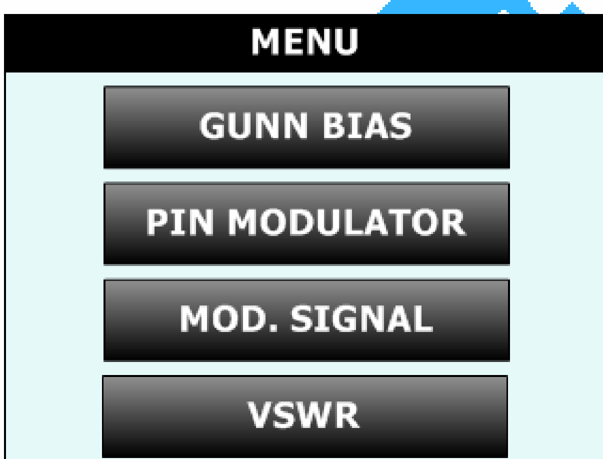
It consists of dielectric vane, which is inserted in waveguide to change the phase of microwave signal at output port.



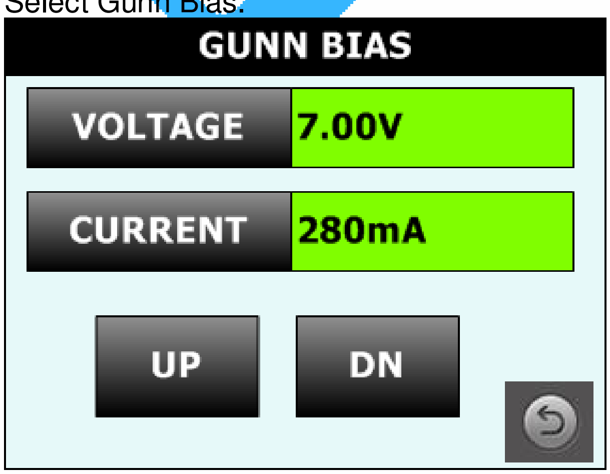
19. Gunn Power supply / VSWR meter GVM10

The Gunn power supply has built in 1KHz square waveform for modulating the PIN diode for detecting by SWR meter. It has a builtin microphone for modulating on PIN diode. It also has a USB connector, which converts an incoming serial data from PC serial port to a modulating signal for PIN diode. It has low noise glitch free dc power supply for Gunn diode with a digital display of voltage and current.

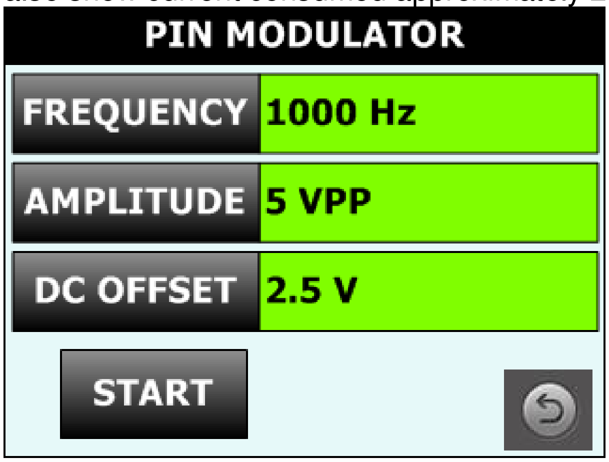




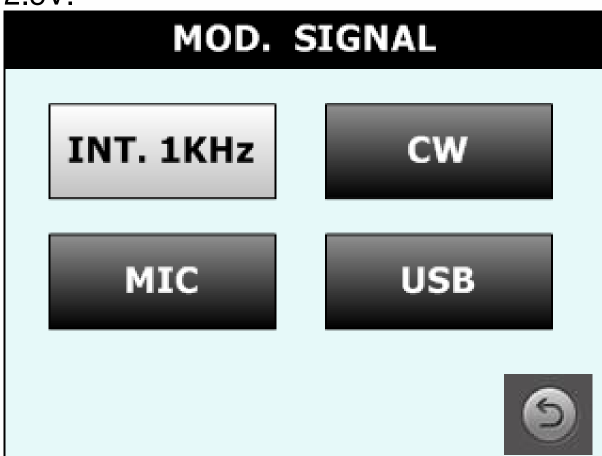
Select Gunn Bias.



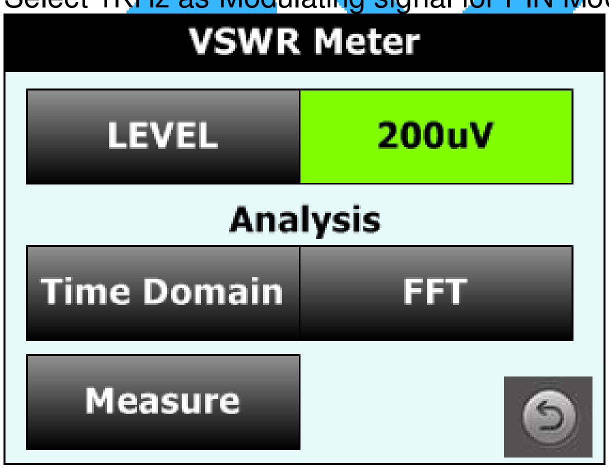
Press Up key in Gunn Bias menu till voltage reaches 7 Volts. Rising voltage to 7 Volts has been deliberately made slow so as to protect Gunn Diode. Display will also show current consumed approximately 280mA by Gunn Diode.



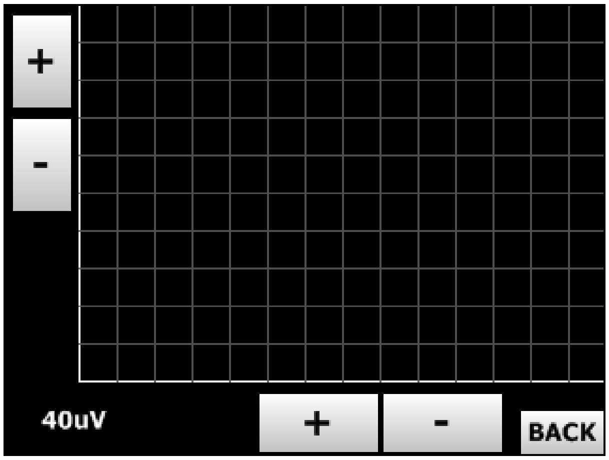
Select Frequency in Pin Modulator as 1000 Hz, Amplitude as 5V and DC offset as 2.5V.



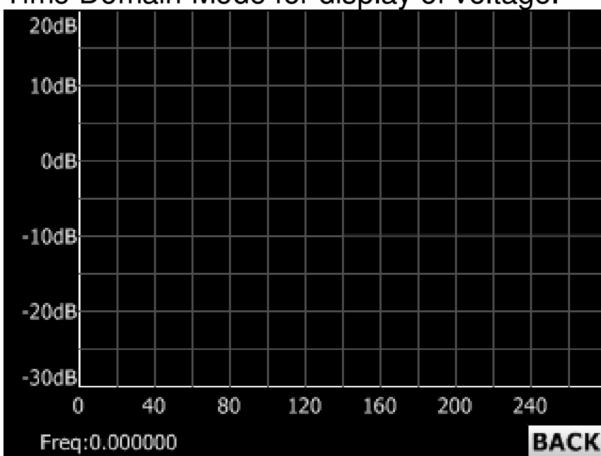
Select 1KHz as Modulating signal for PIN Modulator.



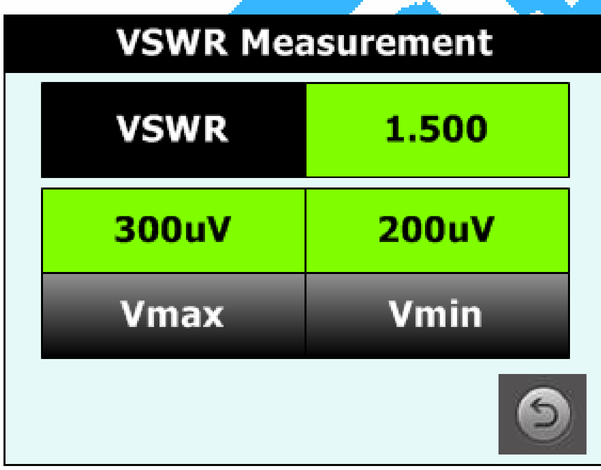
VSWR meter displays instantaneous voltage as Level = 200uV. You can select Time Domain or FFT to visualize instantaneous voltage.



Time Domain Mode for display of voltage.



FFT Mode for display of voltage.

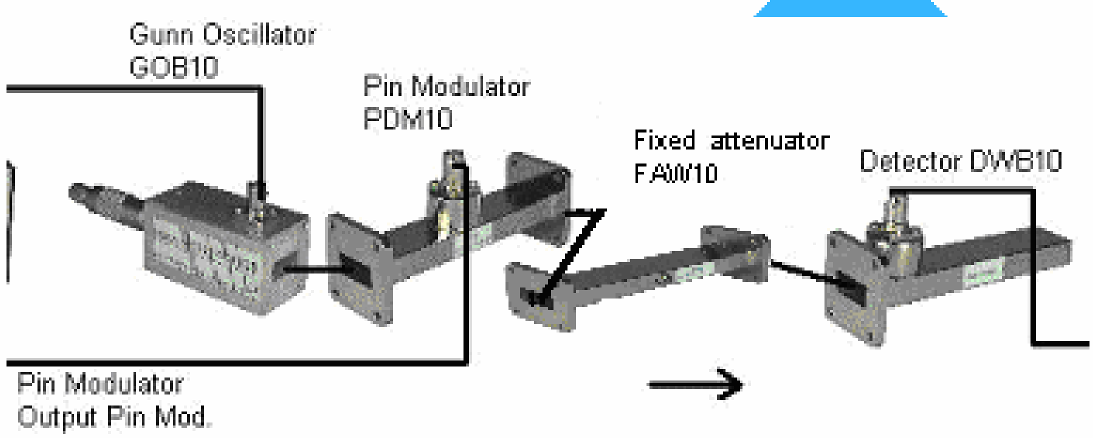


Pressing Vmax will select Voltage Maxima and Pressing Vmin will display Voltage minima and shall instantaneously display VSWR also.

VSWR has two inputs.
One is tuned 1KHz VSWR INPUT BNC at front panel, which is used to read the SWR. The demodulated output of detector or slotted line is filtered with a band pass filter with center frequency of 1KHz and bandwidth of 100Hz and amplified with high gain amplifier. This signal passes through several attenuators operated through MCU internally. Each attenuator reduces incoming signal power by 10 times or 10dB. This signal is converted to a DC voltage to display the meter. The

meter is calibrated for square law response of detector. VSWR can be read directly by first pressing Vmax for full scale deflection for maximum reading of slotted line and then pressing Vmin for minima reading of Slotted line.

The other is a broadband low noise input, which can amplify a 20Hz-15KHz signal. This signal is amplified and fed to speaker for voice communication and fed to comparators which convert the demodulated ASK data to digital waveform. This digital waveform is the converted to serial data for compatibility to PC serial port for serial communication.



Basic Gunn Test Bench setup.

Equipment Setup:

1. Press Up key in Gunn Bias menu till voltage reaches 7 Volts.
2. Now, connect the Gunn Bias output BNC to Gunn Oscillator GOB10 BNC using a BNC-BNC cable. Tune the micrometer of Gunn oscillator to around 10 GHz by reading the calibration chart on Gunn oscillator.
3. Now, Turn ON the GVM10 Gunn Power supply / VSWR meter from back panel. This procedure ensures that floating ground currents are isolated.
4. Rising voltage to 7 Volts has been deliberately made slow so as to protect Gunn Diode. Display will also show current consumed approximately 280mA by Gunn Diode.
5. Connect PIN Modulator PDM10 at output Flange of Gunn Oscillator.
6. Connect output Pin Mod BNC of Pin Modulator block of GVM10 to CRO/ Oscilloscope. Select Frequency in Pin Modulator as 1000 Hz, Amplitude as 5V and DC offset as 2.5V.
7. It ensures that the Pin Modulating signal remains 1KHz.
8. Now, disconnect output Pin Mod BNC of Pin Modulator block of GVM10 from CRO and connect it to BNC of waveguide PIN Modulator PDM10.
9. Connect Fixed Attenuator/ Isolator at Pin Modulator output.
10. Now, connect variable attenuator at output of isolator. Keep the micrometer fully upwards. This ensures minimum attenuation and maximum power flow.
11. Now, connect frequency meter to output of variable attenuator.
12. Now, connect waveguide detector at output of frequency meter.
13. Now, connect BNC output of waveguide detector to VSWR input BNC of VSWR meter of GVM10.
14. Pressing Vmax will select Voltage Maxima and Pressing Vmin will display Voltage minima and shall instantaneously display VSWR also.

CHAPTER-2: USAGE

Cares for use

1. In order to improve the measuring reliability, the connection of each micro waves should be made correctly and should adhere to the following rules.
    - The central rectangle of waveguide should be kept in a line and the edge should be matched.
    - Two flanges should be tightly jointed with four screws and nuts so the microwave doesn't leak.

2. The components of this experiment set should not be used for any other experimental purpose.

3. No drop or shock should be applied to any component

4. Keep away from humidity or heat.

5. Should avoid using in a dusty area and should be kept in its storage case after use.

6. Check whether any foreign substance is attached on the entry/exit of waveguide before the assembly for the experiment circuit construction of components removes the foreign substance if existing.

7. While the oscillator is oscillating, the internal part of oscillator must not be observed through the output part.

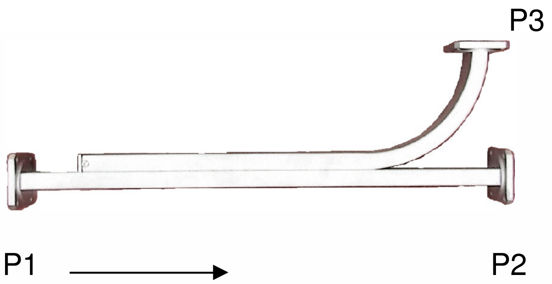
Because the oscillator used in this experiment unit a relatively small power, output is not dangerous to other body parts, but eyes may be damaged.

THE WAY TO USE COMPONENT WITH DIRECTIONS

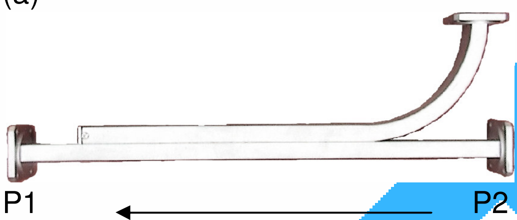
Among microwave components, there are components which have the pre-set connection. These components are not transmitted in one certain the wave only to a specific direction. The following are these.

- Directional Coupler
- Magic-Tee (also called as Hybrid Tee)

The following picture is an example of using a directional coupler and the arrows indicate the possible wave directions.



(a)



(b)

The directional coupler of picture (a) shows that in the case that the wave enters to PI; the same PI wave is transmitted to P2 and P3. However, picture (b) shows an opposite case of (a) which the wave enters through P2.Although this wave is transmitted to PI from P2; it is not transmitted to P3. If using these characteristics, one M/W antenna can be made for transmission and reception and the reflection wave in the wave-guide circuit can be detected.

The Way to Use POWER METER

MWL Microwave Trainer provides the M/W Power meter Model MPM20A. The following picture shows an example of using the Power Meter MPM20A.

[Note] MPM20A Power Meter measures up to several 10mW through a probe. If the RF power over 100mW is directly measured without attenuation, the microwave detection thermo probe may be damaged. The power meter measures absolute power level and does not need modulation unlike VSWR meter.

MPM20A has the frequency measurement range of 8.2GHz -12. 4GHz. It has 50dB dynamic range of –30dBm to +20dBm.

The Way to Use a Gunn Power supply

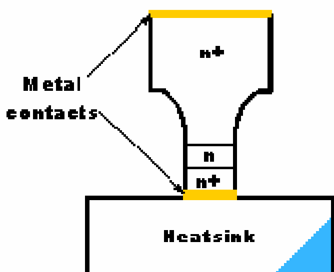
The Gunn power supply generates slow rising clean DC voltage of 8-10V to bias the Gunn diode. This oscillator, by applying the square wave bias voltage of 1KHz to Pin Modulator, modulates the CW output of the Gunn diode. This AM envelope allows for detection of X band signal by demodulation with a diode in detector. This demodulated output of 1KHz is proportional to the power level of X band signal.

Experiment 1. : THE GUNN OSCILLATOR

1. Objectives:
The objectives of this experiment are to obtain the knowledge on the theory and the operation of the Gunn oscillator as a source of microwave frequencies.

2. Theory:
A. The Gunn Effect
The Gunn effect or the transferred electron effect which was discovered by Gunn in 1963 states that when a small DC voltage is applied across a thin slice of semiconductor materials, it exhibits negative resistance under certain conditions Gunn used in his case gallium arsenide (GaAs} and indium phosphide Once the negative resistance is developed, one can easily generate oscillations by connecting the negative resistance element to a tuned circuit

One of the requirements in maintaining the negative resistance state in the semiconductor materials is to keep the voltage gradient across the material over 3000V/cm. The most appropriate tuned circuit to be connected the semiconductors for microwave frequencies are a tuned cavity.

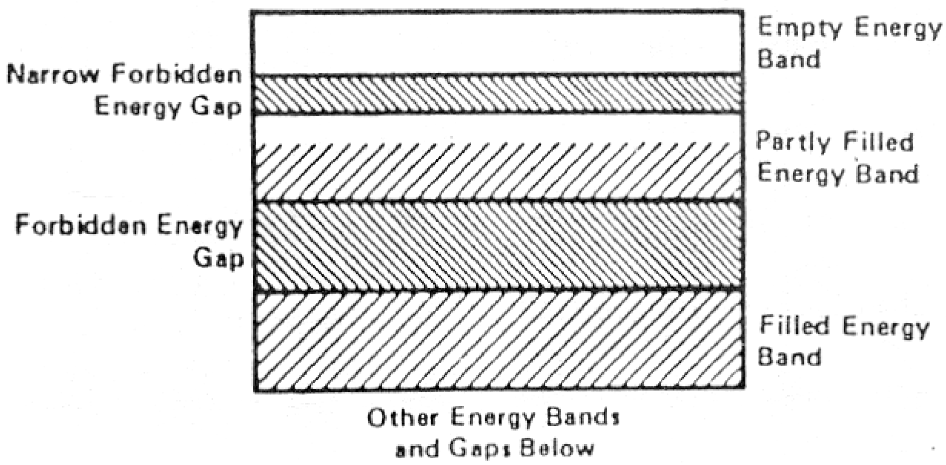


The Side view of an epitaxial GaAs Gunn Semiconductor

The Gunn effect, which takes Place only in n-type semiconductor materials, is a result of the property of the semiconductor itself. It is found that any parameters associated with junction or contact properties as well as voltage or current do not affect the Gunn effect. Only the electric field is required to be above the threshold to maintain oscillation. The Gunn diode is insensitive to the magnetic field and thus it does not respond to any incident magnetic field. The frequency of oscillation is mainly determined by the time the electrons, in a form of a bunch, take to transfer the slice of material.

B. Negative resistance and transferred electron effect

The energy bands and energy levels of GaAs are shown in figure below. Notice that this material possesses an empty energy band at the top of the energy level The partially filled energy band is bellow the empty band When the material is doped with n-type material, there excess electrons in the material ready to flow when a voltage is applied across the diode



The Energy level in a GaAs Gunn diode

The current flowing in the diode is proportional to the voltage and the current is oriented towards the positive end of the GaAs. The situation of higher the voltage the larger the current is equivalent to positive resistance. However when the level of applied voltage reaches a sufficiently high value, electrons instead of trying to travel even faster, transfer to the higher energy band, which is empty and less mobile. As a result, the current flow decreases, exhibiting negative resistance phenomenon.

The electron transfer from a lower energy level to a higher level is called transferred electron effect. If the voltage level is increased even further, the mobility of the electrons in the higher energy band begins to improve resulting in an increased current

C. Gunn domains

The frequency, of the oscillations in the GaAs has to do with the formation and the transit time of the electrons, which form themselves in “electron bunches.” The negative resistance effect is an important factor in understanding the Gunn oscillator, however, the negative resistance effect alone does not explain everything that is happening inside the oscillator. The other important element is the formation of domains, or Gunn domains. The amount of free electrons available in the GaAs depends upon the density of the n-type material doped in the GaAs. Since the density of doping is not necessarily uniform across the GaAs, There are fewer free electrons where the doping density is low

Fewer free electrons mean less conductivity and, therefore, the potential difference in such area becomes greater than the area where there are more free electrons. Hence as the applied voltage is increased, eventually the transferred electron effect takes place at this area first due to a sufficient voltage gradient, resulting in a negative resistance domain. The domain as described above is considered to be unstable. What is happening in such a domain is that as electrons are taken out of circulation at a fast rate, the electrons in front travel forward rapidly and the ones behind bunch up (electron bunches). This way, the whole domain moves across the slice and toward the positive and with an average speed of about I07cm per second.

As the transferred electron effect takes place in a domain, moving electrons to less conductive higher energy band, fewer electrons are left behind in the conduction band, making this region less conductive at this time. As was explained in the previous section, this causes the potential gradient to increase, making the domain capable of traveling. Thus, this process of electron transfer and domain traveling repeats itself and is said to be "self perpetuating".

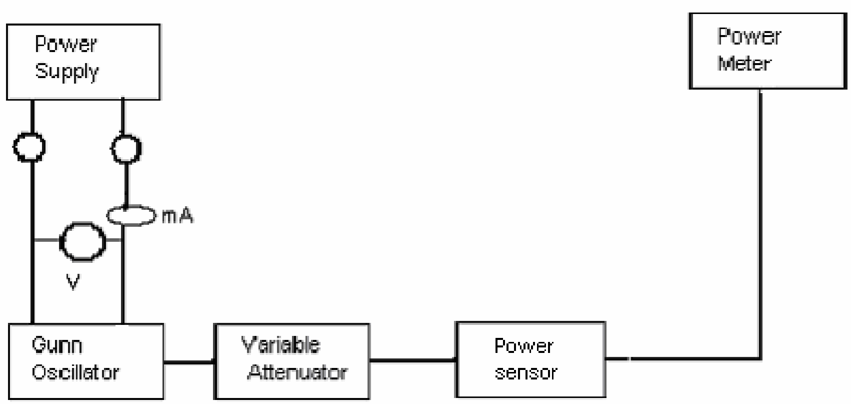
When the domain reaches to the anode of the diode, a pulse is applied: to the associated resonant tank circuit, resulting in oscillations. In fact, the pulse causes it arriving at the anode rather than the negative resistance property of the diode the oscillations of the Gunn diode.

D. Gunn oscillator

Although the oscillator is designed to prevent spurious mode oscillations, tuning features are provided with the oscillator in case fine adjustments are necessary

3. Experiment procedure,

1. Set up the equipment as shown in figure below.



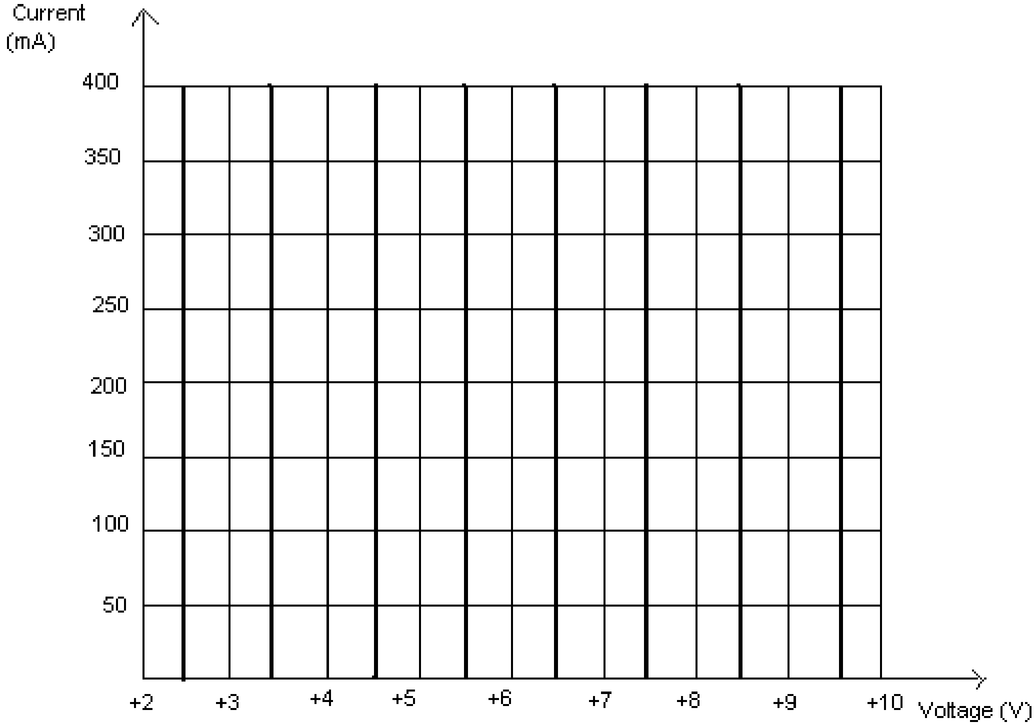
SETUP FOR MEASURING THE CURRENT VS. VOLTAGE CHARACTERISTICS OF THE GUNN DIODE

A. **The Current vs. Voltage Characteristics**

1. Set the voltage to 4V. Set the variable attenuator to 10 dB. This will ensure proper isolation to the Gunn oscillator
2. Raise the voltage in 0.5V increment. Measure and record the current each time in table below.

Supply voltage V	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	10.0
Supply current mA													

3 Reduce the voltage to 0V from table 1-1Construct a V-I suggested in figure below



Current vs. Voltage characteristics of Gunn diode

B. Measurement of the oscillator output power vs. supply voltage

1. Turn the power meter on and wait for it to settle to zero.
2. Raise the Gunn diode voltage in 0.5V increment and record, the power indication on the power meter and the attenuator setting,
3. Convert the obtained power reading in milliwatts to dBm. Then add the attenuation to dbm.

Example: Assume the power reading is 6.3mW with the supply voltage of 8.5V. Then the power in dBm = 101log 6.3 = 8dBm. Add 3dB attenuation to 8dBm The total power is 11dBm.
Now convert the 11 dBm, which is the Gunn diode output power back to the milliwatts
Log =Pout/1 mw = 11/10
Pout = 12.6mW

4. Repeat step (3) and complete the table below
5 Draw a graph showing the relationships between the supply voltage and output power

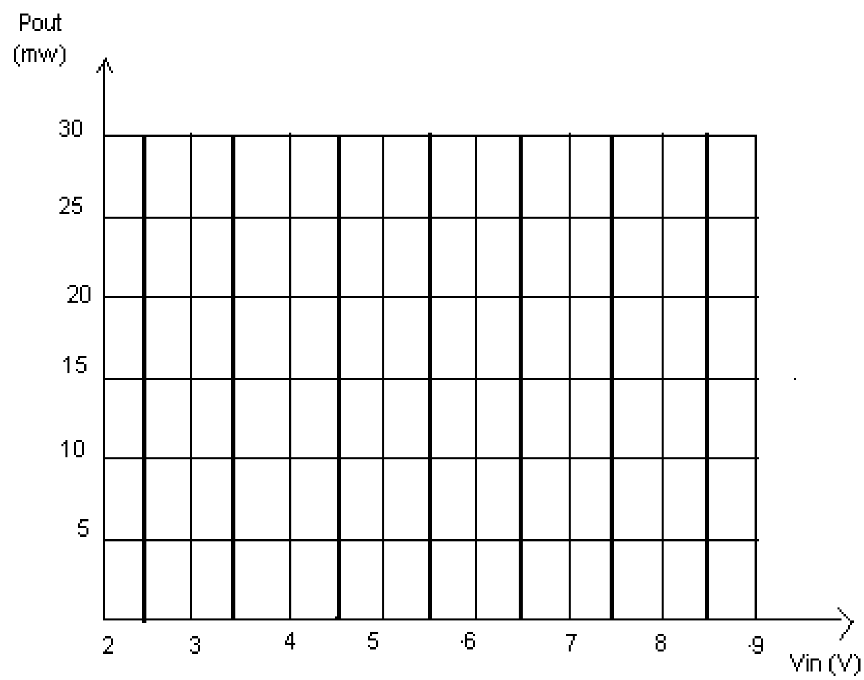
Supply Voltage (V)	+4 +4.5V
Power meter reading (mw)	
Converted Power (dBm)	
Attenuator Setting (dB)	
Gunn diode output (dbm)	
Gunn diode output (mw)	

Data for the supply voltage and the output

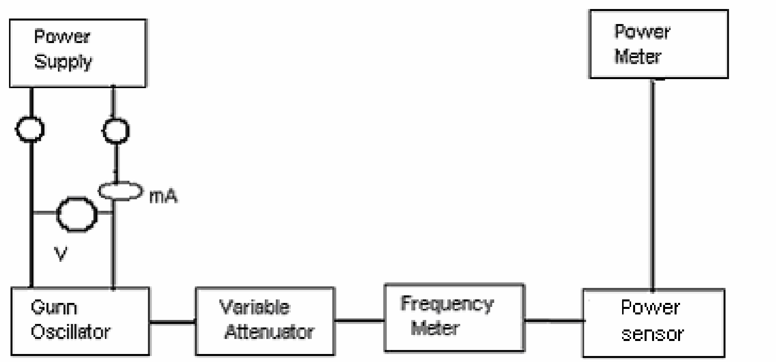
C.Measurement of the oscillator output frequency vs supply voltage

1. Set up the equipment as shown in figure below. Set the supply voltage to 7V. Set the attenuator to the maximum attenuation. Switch on Power meter. Reduce the attenuation until the Power meter reading is close to approximately 0.8 to 1 mW. Slowly turn the frequency meter. Observe a dip on the power meter when the frequency meter is exactly same as the frequency of the Gunn oscillator.

(2) From the lowest supply voltage at which oscillations occur to max of 10V supply, vary the voltage in an increment of 1V. Notice that the frequency meter is calibrated on 100MHz increment. Interpolate.



Gunn diode supply voltage vs. output power characteristics



Setup for mesuring the oscillator output frequency vs. supply voltage

Supply Voltage (V)	
Measured Frequency (MHz)	

Supply voltage vs. measured Frequency

EXPERIMENT2: PIN MODULATOR AND CRYSTAL DETECTOR.

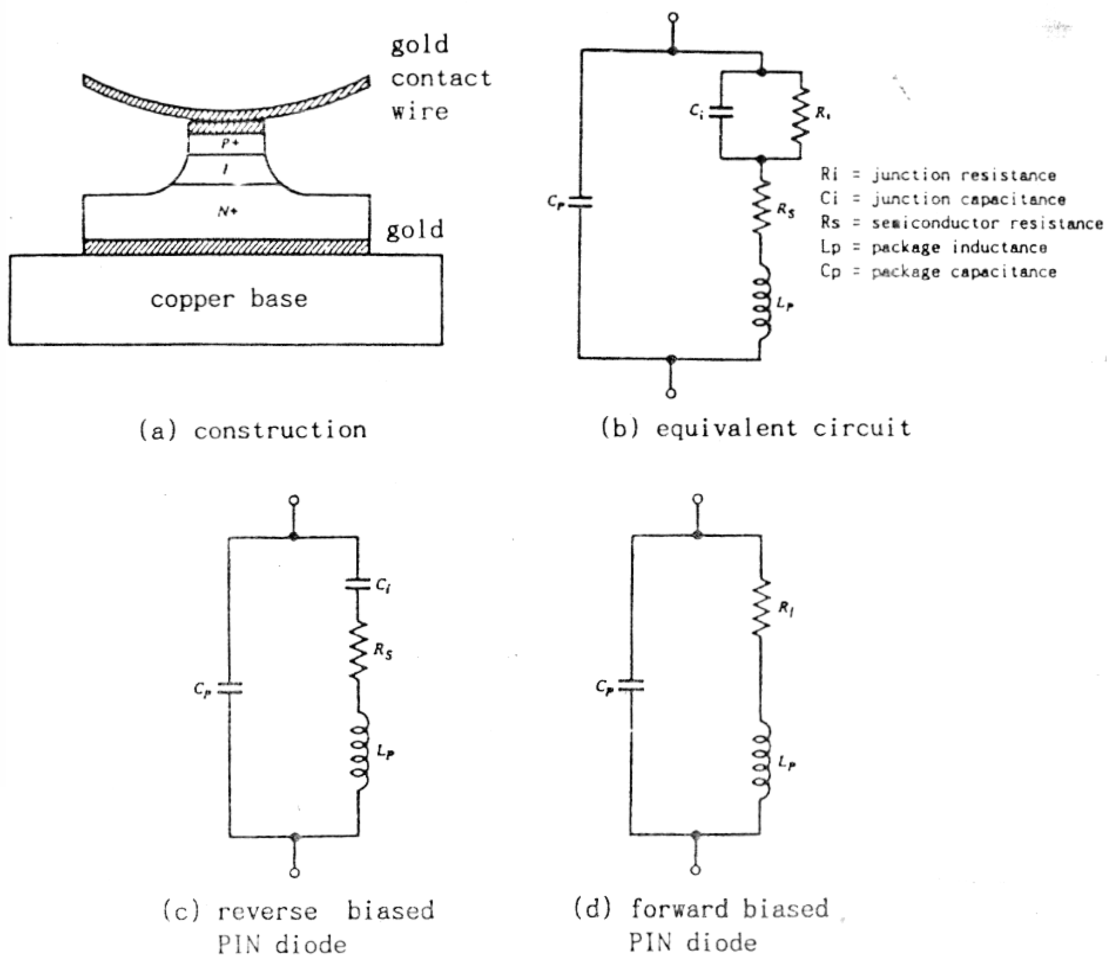
1. Objectives:

- Learn the basic theory and the operation of the PIN diode modulator.
- Learn the basic theory and the operation of the crystal detector.

2. Theory.

a. Pin diode.

As is shown in figure below, the PIN diode is constructed with a thin insulator sandwiched between P and N materials, hence the name PIN diode. The thickness of the P and N is much heavier than the insulator. In case of reverse bias condition, the PIN diode is a high resistive and capacitive device in the microwave frequency. It is an avalanche effect device: under a forward bias condition, an avalanche effect takes place in the insulator, allowing holes from P and electrons from N to flow. Thus, the insulator becomes effectively conductive



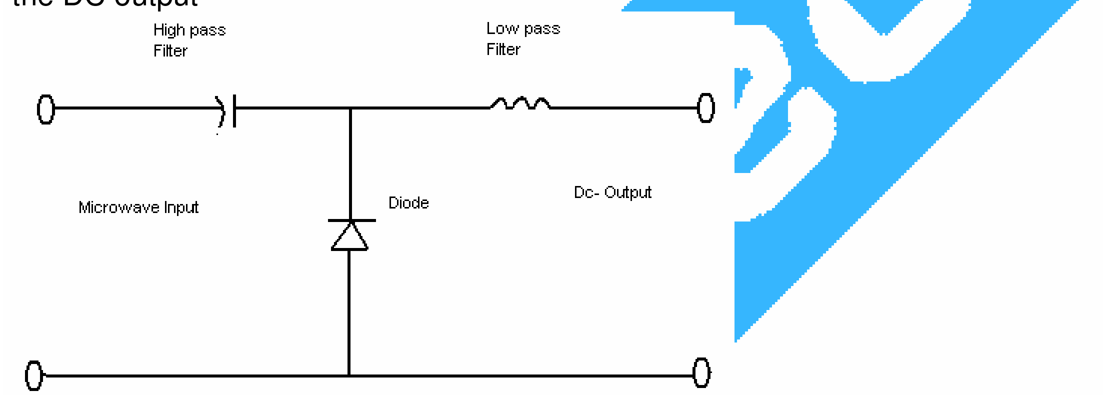
The construction and equivalent circuits of a PIN diode

The PIN-diode modulator has a diode connected across a waveguide. The diode functions as a modulator when the biasing conditions vary due to a sufficiently large square wave (low frequency) signal applied across the diode under the presence of a microwave signal inside the wave guide. When the diode is reversed biased, it does not affect the energy flow. Full or partial removal of the reverse bias allows the diode to control the energy flow.

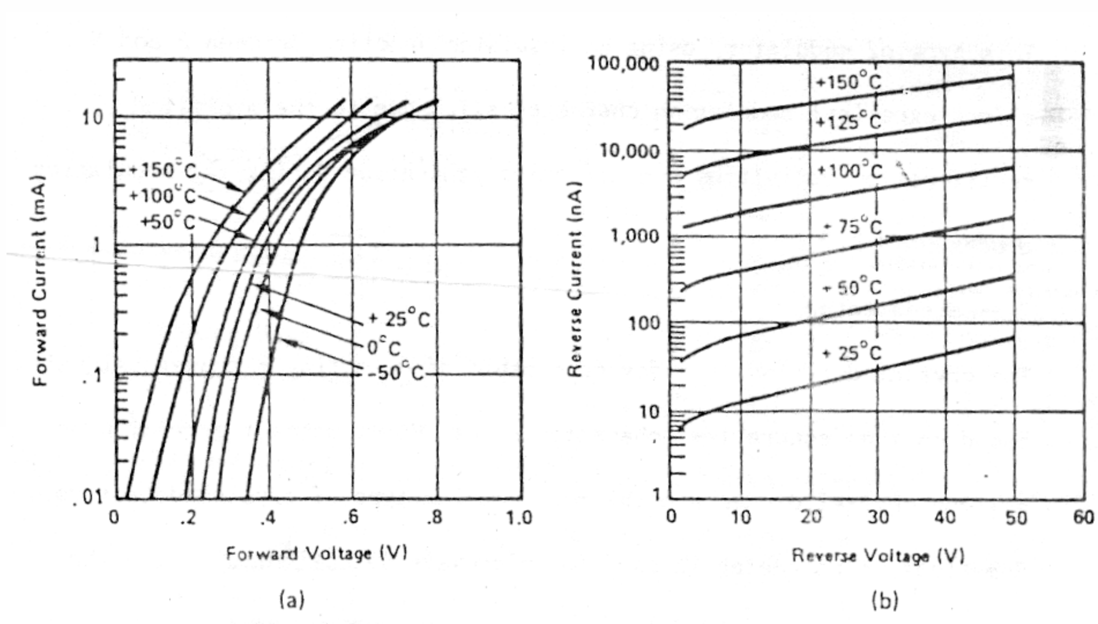
This type of modulator using an insulator junction between P and N offers excellent modulation characteristics due to the minimized rectification activities and harmonics generation during the modulation process.

b. Crystal detector

The crystal detector is a device capable of detecting microwave signals based on the 'square law" characteristics. Point contact germanium or silicon crystal diodes are the most popular type of crystal detectors. Sometimes, a bolometer is used for microwave detection, although the device is mainly intended for microwave power measurements. A typical crystal detector circuit and associated characteristic curves of a crystal detector are presented in figure below. The two filters (input high-pass and output low-pass) are to separate the microwave frequencies from the DC output



Typical crystal detector circuit



The V-I characteristics of a crystal diode

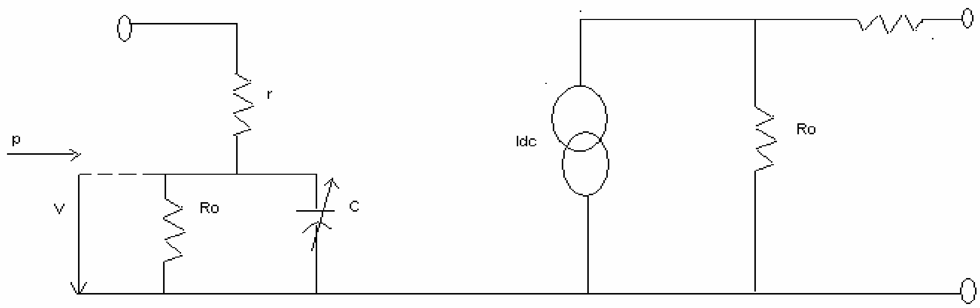
In figure above we are interested in finding the relationship between the diode current and the diode voltage. In general the curves like the one in figure can be approximated by the Taylor series expressed in terms of the powers of the voltage
$i = a_0 + a1V + a2V2^{+} a_3V^{3}$

The first three terms are sufficient to approximate the entire function the voltage is expressed as
V = A coswt
Where A is the amplitude and w is equal to 2pif. Substituting V into (2-1) yields
$i = a_0 + a_1(A\cos wt) + a_2 (A\cos wt)^{2}$
$\cos^{2} wt = ½ (1 + \cos 2wt)$

Now the characteristics of the square law become clear. The dc component is contained in the term. The second harmonics is expressed as
$i = a_0 + a_1(A\cos wt) + a_2 A^2/2 (1 + \cos 2wt)$

Therefore we can say current in the detector is proportional to the square of the amplitude A of the microwave voltage. This concept is only valid up to a certain signal level.

In addition to the detector circuit of figure above, the diode itself can be expressed in terms of an equivalent circuit. In figure below, a complete equivalent circuit of a detector is presented.



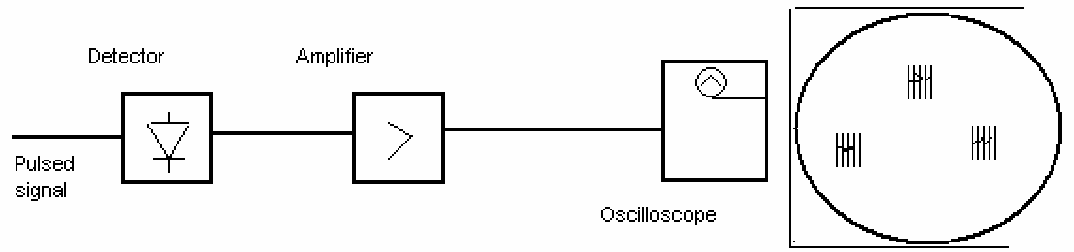
Equivalent circuit of a detector

R_o and C represent the impedance of the junction and r is the body resistance of the diode. A figure of merit of a detector is the and current sensitivity of the detection function which is expressed as

Voltage sensitivity = open circuit voltage/ input power = R_0Idc/pin
Current sensitivity = short circuit current / input power = $R_0 / (r + R_o)$ / Pin

In order to maximize the output power, it is necessary to match the microwave impedance of the diode to the characteristic impedance of the wave-guide. Another reason for the impedance matching is to minimize the reflection from the detector since the measurement accuracy is affected by the reflection.

The minimum signal level a diode can detect depends on the noise in the diode. The ability of a diode to detect a signal in the presence of noise is called the tangential sensitivity

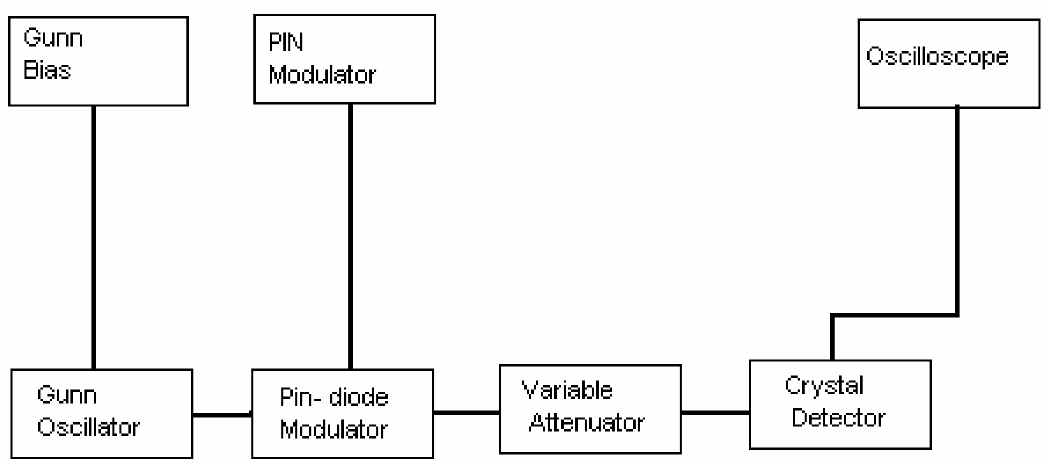


The TSS of a diode

In figure above microwave signal which is pulse modulated is detected amplified and displayed an oscilloscope. The real meaning of TSS is there has to be a minimum microwave power level to make the pulse ride above the noise. The TSS of a detector is very much dependent upon the bandwidth of the amplifier which follows the detector since the noise amplitude of the scope is determined by the bandwidth. One MHz bandwidth and –50 dBm of TSS are typical values of a microwave detector.

3. Experiment Procedure

A. Square wave modulation.



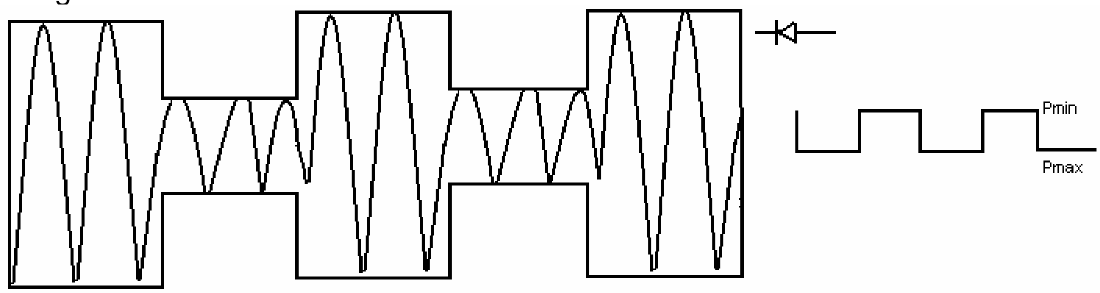
Setup diagram for Square Wave modulation

(1) Set up equipment as shown in figure above.
(2) Apply +7V to the Gunn oscillator.
(3) Set the variable attenuator to 10 dB.
(4) Adjust the square wave generator to 1kHz and 2Vp-p output.
Connect the generator to the PIN modulator.
(5) Adjust the scope so that the top of the square wave aligns to the zero level on the screen.
(6) Adjust the attenuator so that the bottom of the square wave aligns to the zero level on the screen.
(7) Repeat above measurement for 1Vp-p square wave.
(8) Calculate the modulation depth for the two modulating inputs of 2Vp-p and 1 Vp-p using the following equations

AdB = 20 log (Vmax / Vmin)

Where A is the difference in the attenuator settings between step (3) and (6).
M = (Vmax/Vmin –1) / (Vmax/Vmin + 1)
Where m is the modulation depth

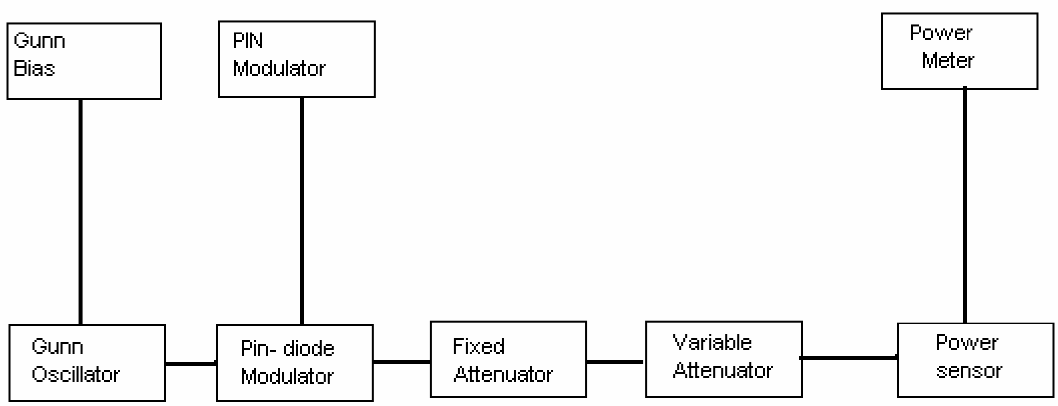
A sketch of the waveforms of the square wave modulation and detection Is shown in Figure



Square wave modulation and detection.

As one can see from figure above, the attenuator setting deviation A can be expressed as
A dB = 10 log (Pmax / Pmin) = 20 log (Vmax / Vmin).
With Pin Modulator On power read on Power meter is less when Gunn Power supply is on CW mode. This is because of chopping off of Gunn oscillator O/P by PIN modulator.

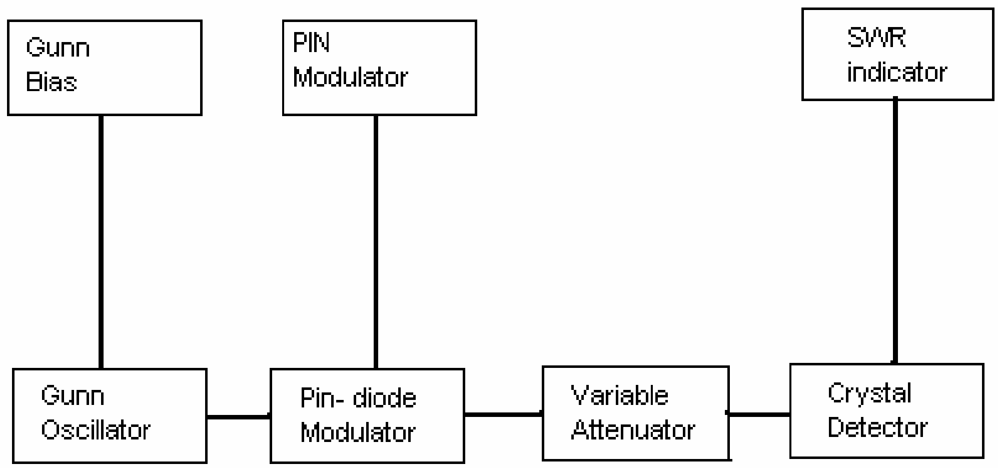
B. The square law characteristics of the crystal detector



Setup diagram for output power level setting

(1) Set up equipment as shown in figure above. Switch on the power meter. Observe the meter for a few minutes. Make sure the calibration is maintained.
(2) Apply voltage to the Gunn oscillator to the PIN modulator. Do not apply 1 kHz square wave to pin modulator. At this point modulation should not take place.
(3) Set the variable attenuator to 0. Convert the display to read dBm.
(4) As shown in figure below, replace the waveguide to coax adapter, the thermocouple mount (Power meter sensor) and the power meter with a crystal

detector and a SWR indicator and apply 1 KHz to Pin Modulator. Adjust the modulating frequency such that the Vmax of the VSWR meter is maximized.



Setup diagram for measuring square law characteristics of a crystal detector

(5) Vary the attenuator setting up to 20 dB in 1dB increment. At each step record the SWR meter reading (in db) in Table

A dB	Input Power	VSWR meter	
		Vmax	Vmin
	dBm	dB	dB

Experiment 3: Propagation modes, wavelength and phase velocity in wave guide

1. Objectives
   - Learn the theory of waveguide.
   - Experiment the propagation characteristics of microwave in free space as well as in wave guide

2. THEORY

A microwave wave guide is a hollow metallic pipe having rectangular or circular cross section In our experiments rectangular waveguides are The following mathematical analysis are based on the rectangular wave- guides Also it is assumed that the user has basic knowledge about the wave equation Circular waveguides can be analyzed in the similar way using cylindrical coordinate We begin our analysis with the wave equation.

a. Wave equation

The reduced wave equation is expressed as

$\delta^2\phi + K^2\phi = 0$

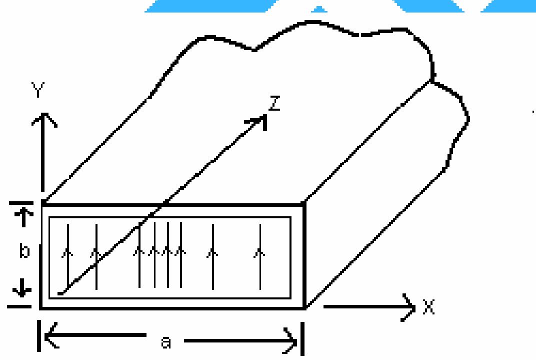
where (x, y, z) is the scalar wave function and k the wave number is defined as

$K^2 = \omega^2\mu\varepsilon$ in a perfect dielectric.

In rectangular coordinate system, becomes

$\delta^2\phi/\delta x^2 + \delta^2\phi/\delta y^2 + \delta^2\phi/\delta z^2 + K^2\phi = 0$

The rectangular coordinate system is established in this case such that z is the direction of propagation as shown in Figure.



Rectangular waveguide in rectangular coordinate system

Our goal is to obtain a solution which has a form of

g(x,y) f(z) ....

where f is a function of z only and 9 is a function of x and y or other suitable transverse coordinates only

Solving for ϕ using the separation of variables method gives

$\phi =$ {A1 Cos (KxX) + A2 Sin (KxX) {B1 Cos (KyY) + B2 Sin (KyY)}

Since the propagation takes place only in the z-direction
$\{c_1 e^{-j\beta gz} + c_2 e^{+j\beta gz}\}$
Where Kx2 + $Ky^2 = K^2$

A wave propagating in the positive z-direction is represented by and therefore e z- corresponds to a wave propagating in the negative z- direction.

Three types of propagation modes are of particular interest for us:

- TEM (transverse electromagnetic) modes: In these modes, both electric and magnetic fields are transverse to the direction of propagation. Thus, there is no field components in the direction of travel. TEM modes do not exist in waveguides

- TE (transverse electric} modes or H-modes: In these modes, No electric field exists in the z-direction. However, magnetic field does exist in the z-direction. All the field components, therefore, maybe derived from the axial component H_z of magnetic field.

- TM (transverse magnetic) modes or E-modes: In these modes, no magnetic field exists in the z-direction. However, electric field does exist in the z-direction All the field components. Therefore, maybe derived from the axial component E_z of electric field.

TE and TM modes are the modes of propagation in a hollow empty waveguide. We will continue our efforts in mathematically deriving field components. The inside walls of the waveguide are assumed to be made out of perfect conductor. Also the wave-guide is assumed to be filled with perfect dielectric. These conditions are necessary to simplify the field solutions.

a. TEmn modes
The equation can be rewritten for Hz, considering only for +z direction.

The boundary conditions are applied at the waveguide walls: the normal component of the transverse magnetic field must vanish at the perfectly conducting waveguide walls. Also, tangential electric field also vanishes on the waveguide walls. Then the requirements of the D is was defined as
$\delta D / \delta X = 0$ at X= 0, a ……………………………………………
$\delta D / \delta Y = 0$ at Y= 0, b ……………………………………………..

Applying two last equation to third last specifies the values of the characteristics constants Kx and Ky.
K_x = n□□ a n=0, 1, 2,
K_y = mλ□□□a m = 0, 1, 2,……………………………………………
Using the above relation and substituting A1B1 = Anm the solutions for D are:
D = Anm Cos nλX / a.Cos mλY/ b ……………………………
The final form of H_z is
Hz = Anm Cos nλX / a.Cos mλY/ b ……………………………
The significance of the integer n and m: the values of n and m indicate the no. of half cycles variations of each field component with respect to X and Y. Another

word, each combination of m and n values represent a different field configuration in the wave guide.
TM modes: Very much the same steps are required to obtain the field solutions for TM modes except that this time, Hz must be set to 0.

b. Characteristics of the rectangular waveguide
Cut off frequency and cut off wavelength.
The exponential form of represents a wave traveling in the +z direction Let us re-examine the relationship of

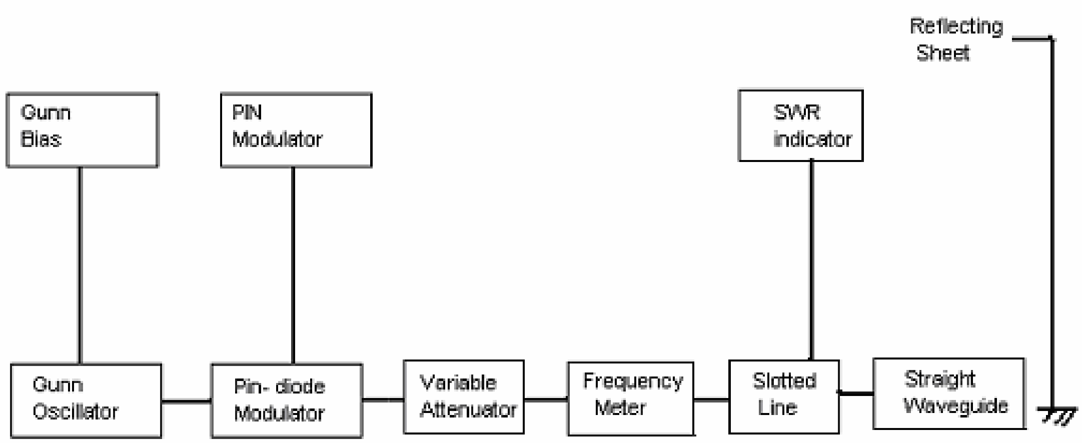
$$\lambda g = (K^2 - Kc^2)1/2$$

1) K>Kc: The is real and is indeed traveling in +z direction (propagating)
2) K<Kc: The λg is imaginary and the propagation mode decays rapidly with distance z in the +z direction.

In order to support propagation in the waveguide, the guide wavelength is longer than the wavelength in the free space

Phase velocity the phase velocity or the velocity of a constant-phase point in wave guide is readily obtained from the frequency and the guide wavelength. It should be noted that the phase velocity in the wave-guide can exceed the speed of light in free space which is 3×10^8m/sec

3. Experiment procedure.
Set up equipment as shown in Figure below.
Equipment setup for measurements of frequency,



Equipment setup for the measurements of the frquency

A. Frequency measurement.
(1) Apply voltage to the Gunn oscillator. Also apply 1 KHz, 2Vp-p square wave to the PIN modulator.
(2) Adjust the variable attenuator to 10 dB. Press the VSWR Vmax to 0 dB.
(3) Adjust the frequency of the square wave generator so that the Vmax of VSWR meter is maximized.
(4) Turn the frequency meter until there is a significant drop on Vmin of the VSWR meter. Record the frequency in table. Detune the frequency meter.

B. Measurement of free space wavelength and guide wavelength

(1) The reflecting sheet is moved toward the open end of the waveguide with the reflecting sheet oriented at right angle to the waveguide. The standing waves are formed between waveguide and reflecting sheet in free space. On movement of sheet the standing wave pattern would vary due to the reflections from the plate. The probe in the slotted line detects this variation of the standing wave. Find two adjacent positions where the two detected values are minimum. Do not move the probe on slotted line. The distance between these two points corresponds to the half wavelength in free space. Record the distance in following Table.

(2) Cover the output of the slotted Line with the shorting plate. Vary the position of probe on the slotted Line and locate a position where the detected output voltage is minimum. From that point find another adjacent point where a minimum is detected again. The distance between two points is the half of the guide wavelength

FREQUENCY					
MEASURED λ					
MEASURED λg					
CALCULATED λ					
CALCULATED λg					

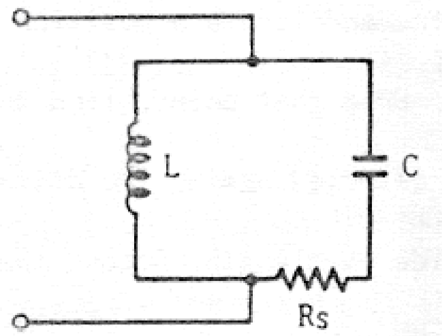
Comparison of measured and calculated values of frequency, free space wavelength

Experiment: 4

Q AND BANDWITH OF A RESONANT CAVITY

1. Objectives:
- Learn the theory of a resonance cavity.
- Experiment the relationship between Q and bandwidth. Learn how to measure the Q and bandwidth Learn how to measure the Q of a resonance cavity

2. Theory.
Resonant circuits are of great importance for microwave oscillators, tuned amplifiers and frequency measurements, etc. A resonant circuit such as the one shown in figure below can be defined in terms of R, L, C when the frequency is limited up to approximately 100 MHz.



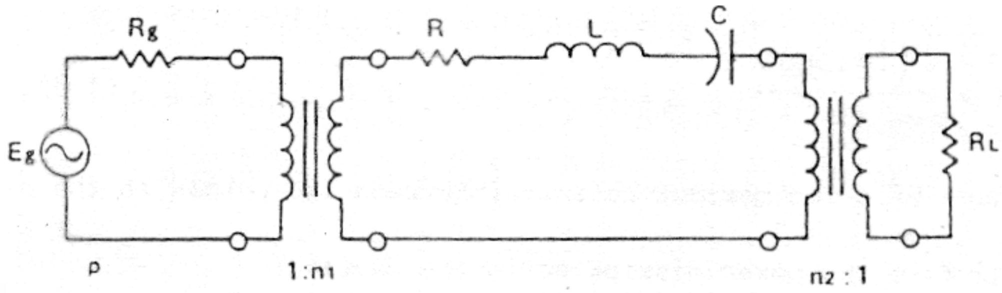
A Transmission cavity

A resonant circuit frequency
L = Ro/ wo Qo, C =Qo / woRo
Rs = Ro/ Qo
Where Ro is the parallel equivalent resistance
wo is the resonant frequency
Qo is the Q of the resonant tank

However, in microwave circuits the analysis of the resonant cavity becomes difficult due to the extremely high value of Q. The other characteristics of the microwave resonator, which make the analysis difficult, are:
-The circuit parameters vary depending upon the propagation modes
-Unlike the low frequency case, the meaning of the voltage and the current in the tank becomes ambiguous, making the definition of Ro difficult.

The $w_{o,}$ Q_o and R_o of simple cavities can be found from the dimensions of the cavity and the power loss on the cavity walls. However, due to the complexity of the cavity structure, it is almost impossible to calculate $w_{o,}$ Q_o and R_o. Instead, actual measurements of a few parameters of the cavity make it possible to determine the entire characteristics of the device.

In Figure Z_{01} is the characteristic impedance of the input. - Waveguide.
Z_{02} is the characteristic impedance of the output
Rg is the internal resistance of the generator.
R_L is the load resistor.



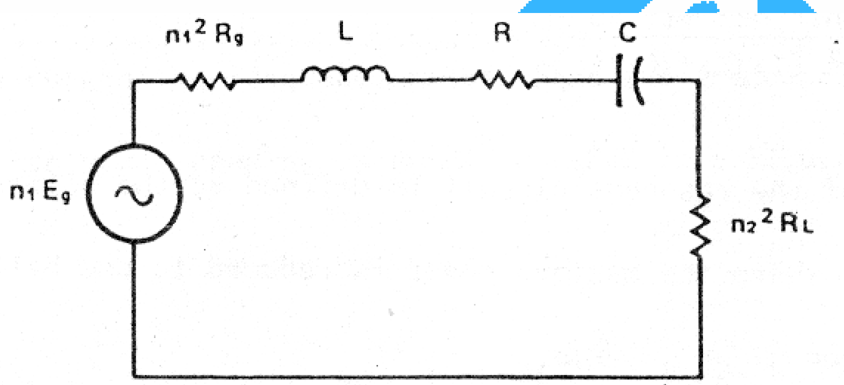
An equivalent circuit of fig.

In Figure above the cavity is effectively a series resonant circuit coupled by two ideal transformers with 1:n_1 and n_2:1 and n_2:1 turns ratio. The output power in this case is Po; Ey_2 / 4Zo.

Where F is the ratio B/W the maximum power and the power of the two points on the curve

Is the bandwidth of the cavity

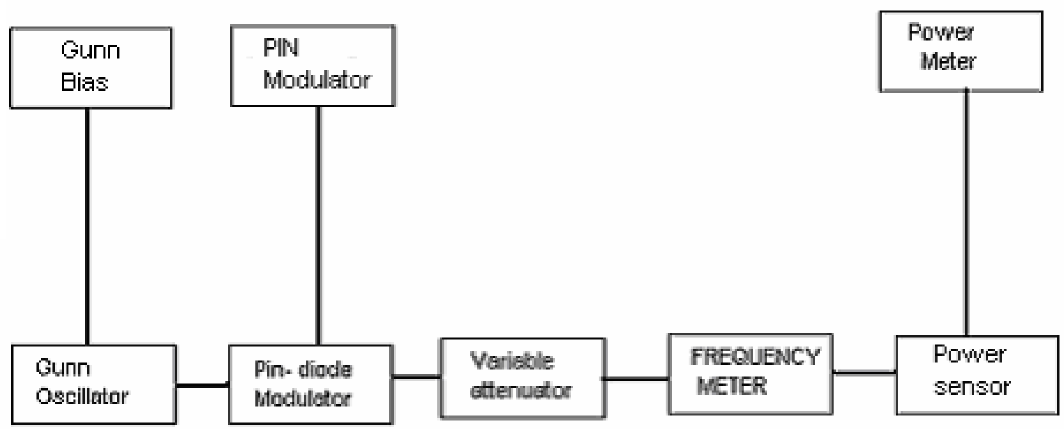
Is the bandwidth coefficient.



Equivalent circuit of the cavity portion

3. Experiment Procedures.

Measurement of Q using the power measurement techniques



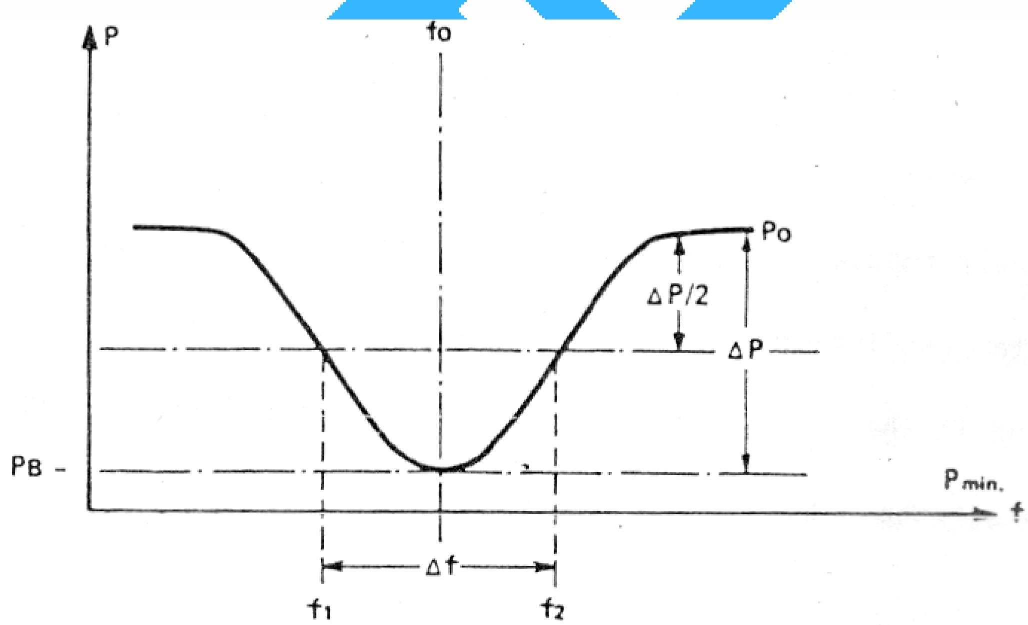
Setup diagram of Q-measurement

(1) Set up equipment as shown in Figure above.

(2) Apply voltage to the Gunn oscillator. Switch on power meter. Adjust the variable attenuator for the maximum reading. Refer this value as P_o.

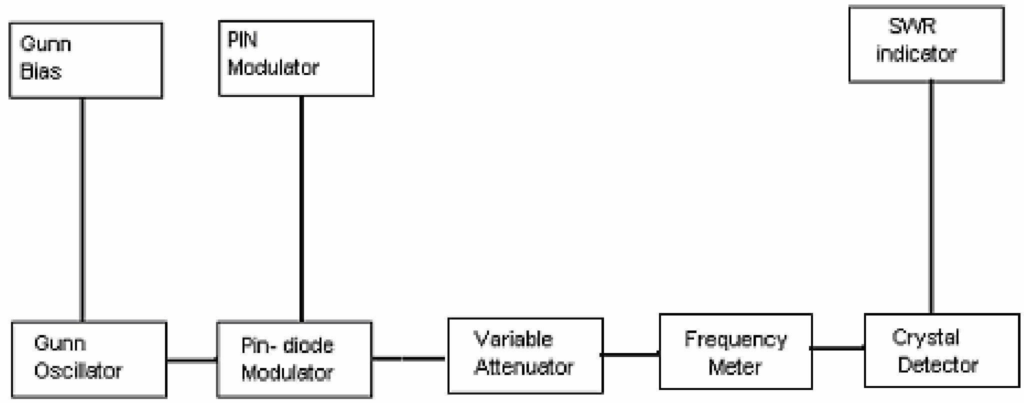
(3) Turn the frequency meter slowly and find the power and frequency reading when the power meter reading is minimized. Call these values P_B for power and f_o for frequency.

(4) Slowly rotate the frequency meter. Find two frequencies (fl and f2} where the power reading is equal to DeltaP/2.



The resonant curve of a resonant cavity

Measurement of Q using SWR meter



SETUP DIAGRAM FOR THE MEASUREMENT OF Q USING SWR METHOD

(1) Set up equipment as shown in Figure above.
(2) Turn the Gunn oscillator on and set the attenuator to 10dB.
(3) Adjust the attenuator switch and Press the VSWR Vmax to 0 dB.
(4) Slowly rotate the frequency meter. Find the point where the VSWR meter reading is minimum. Press the VSWR Vmin and read the dB indication on the meter (P).
(5) Plug in the value obtained from (4) in to the following equation to get the ratio P_b.
P db = 10 log $(1/P_b)$
(6) Since DeltaP = $1-P_B$, calculate P_B + DeltaP/2 and convert it to dB.
(7) Slowly rotate the frequency meter and find f1,f2 and delta f, where the SWR meter reading indicates X dB as calculated above.

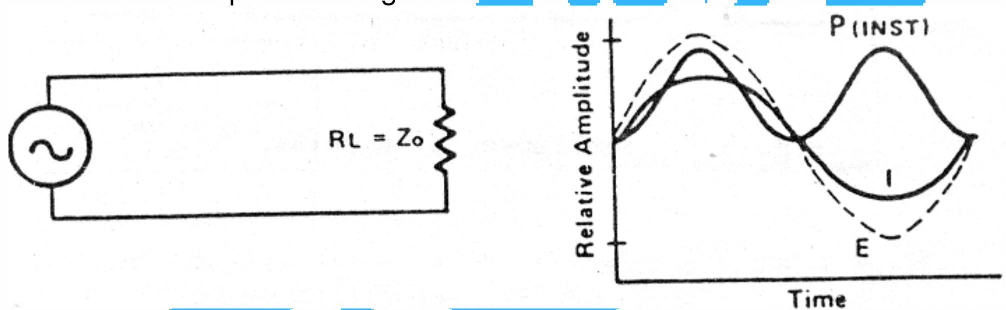
Experiment- 5

POWER MEASUREMENTS

1. Objectives:
   - Learn different ways of measuring power.
   - Learn how to evaluate the accuracy of the power measurements.

2. Theory:

In general the power is defined as the time rate of transforming energy. In case of microwave, the energy is used in many different forms: exchange of information over long distance, heating a microwave oven, or acceleration of particles in nuclear engineering etc. The most common practice of power measurement at low frequencies is to measure the voltage and the current of the device under test, then calculate the power from the lumped value of the circuit parameters. However at microwave frequencies, the difficulty arises due to the distributed nature of the circuit elements. Another factor affecting is the reflection of the signal at wherever there is an impedance mismatch. Two types of power measurements are involved in the microwave power measurements: average power or peak power measurement. The average power is the time average of the sum of the product of the instantaneous voltage and current over the time period and the mathematical expression is given below.



Instantaneous power appearing at the load resistor
Pavg = 1 / T integral limit 0 to t of ei dt
Where T=period
e = instantaneous voltage
I = instantaneous current

It should be noted in figure that the frequency of the instantaneous power (Pinst) is two times of the frequency of e and i. The average power in an alternating current circuit is expressed as:

$P_{avg} = E_{RMS} \cdot I_{RMS} \cdot \cos\theta$

Where θ is the phase angle between E and I

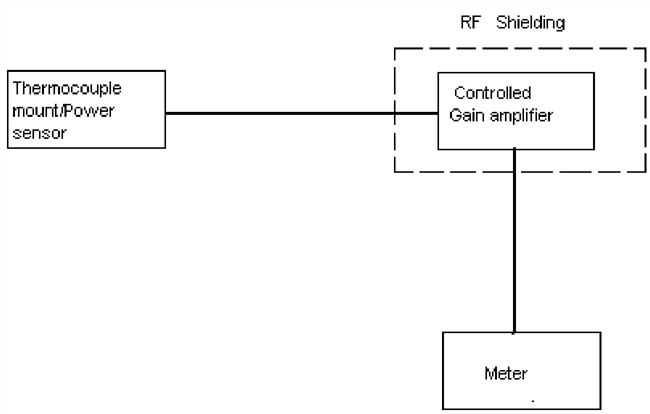
Now, consider a duty cycled pulse.

The peak power of the pulse is related to the average power of the pulse by the duty cycle of the pulse.

Ppeak = Pavg/ duty cycle

Where duty cycle = τ / T

Usually average power is involved in the microwave circuit, which has a continuous signal source. In contrast, where pulsed signals serve as a signal source, peak power is more meaningful way of expressing the power. Let's take a look at the details of the thermocouple power measurement method. The main advantage of using thermocouple wires is the possibility of measuring the power by measuring the DC volts developed across the Thermocouples wires. The DC voltage is generated as the wires conduct the high frequency current and heat is generated across the two different metal contacts. In contrast, a power meter works as the voltage is applied to a meter and the meter is calibrated to indicate the power. The usability of the thermocouple wires used to be omitted to low frequencies. However the recent thin film technology offered a breakthrough in frequency. There are thermocouple materials suitable for microwave applications, such as bismuth and antimony. These materials develop heat by absorbing the input power resulting in an electromotive force (voltage). Figure below shows the construction of the power meter.

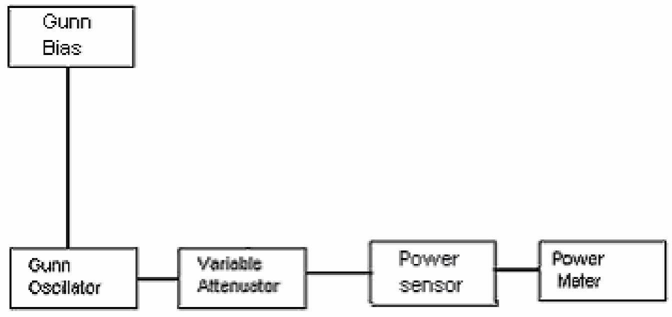


Construction of the Thermocouple power meter

3. Experiment Procedure.

A. Direct measurement

1. Setup equipment as shown in Figure

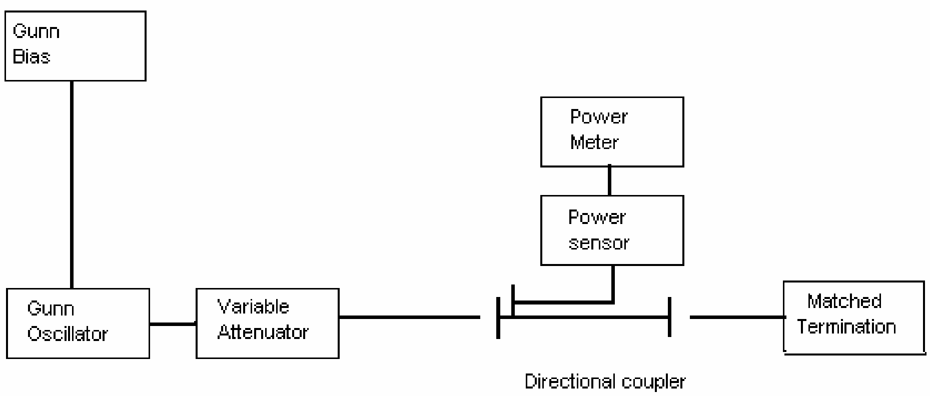


Direct power measurement setup

2. Without the signal activated, switch on the power meter and allow it to adjust the meter to zero.
3. Turn on the Gunn oscillator. Adjust the variable attenuator to 3dB. Read the power meter and record the reading.

B. Power measurement using a directional coupler.

1. Set up equipment as shown in Figure.

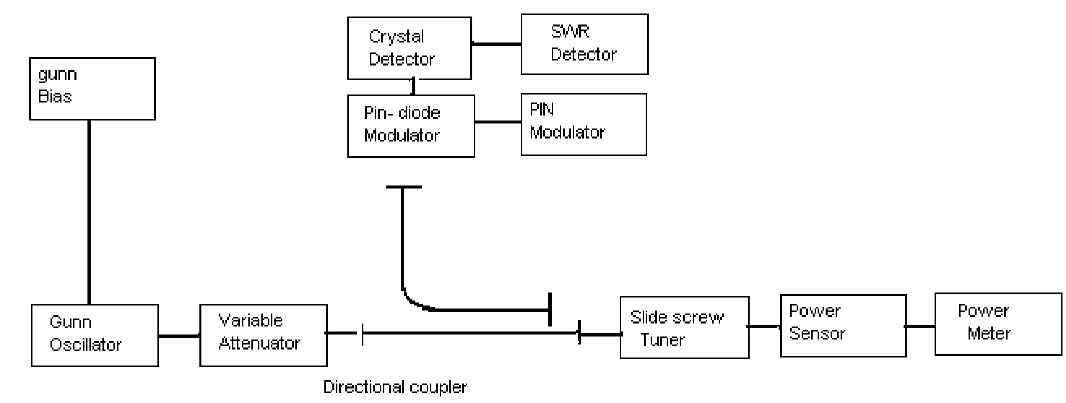


SETUP FOR POWER MEASUREMENT USING A DIRECTIONAL COUPLER

2. Do not alter settings on the power supply, Gunn oscillator and the variable attenuator. Take the reading of the power meter.

C. Measurement of conjugate and Zo power.

1. Set up equipment as shown in figure.



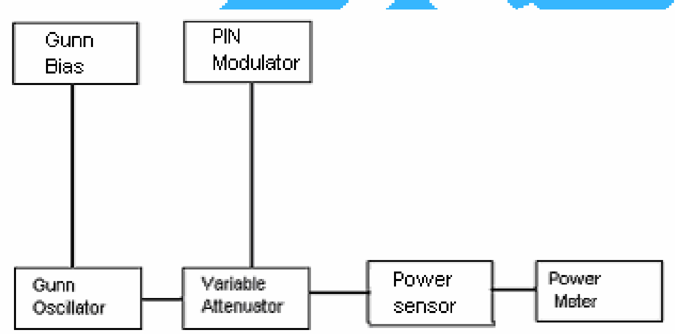
SETUP FOR MEASUREMENT OF CONJUGATE AND Zo Power

2. Modulate the output of the directional coupler with a square wave of 1000Hz. Adjust the pulse frequency to maximize the Vmax of VSWR meter.

Zo power:
3. Do not change the signal power level. Adjust the slide screw tuner for the minimum indication of SWR meter. Record the reading on the power meter.

Conjugate power:
4. Adjust the slide screw tuner to get the maximum indication on the power meter. Record the reading.

D. Modulated signal



1. Adjust the variable attenuator to 10dB.
2. Adjust the output of the pulse generator to 0 volt peak to peak. Offset the output by +0.5VDC. Observe the power meter and record the meter reading.
3. Adjust the output of the pulse to 2 volt peak to peak. Record the power meter reading. Set the offset to 0 volt
4. Replace the thermocouple mount and the power meter with crystal detector. Connect oscilloscope to the crystal detector. Adjust the vertical position of the scope to align the top of the square wave to the zero level on the screen. The reason for this adjustment is that the output of the crystal detector is negative, Therefore, the power at the top of the pulse is actually less than the power at the bottom of the pulse.

5. Reduce the attenuation of the attenuator until the bottom of the square wave lines up with the zero level of the scope. Record the change in attenuation.

E. The dB-scale.

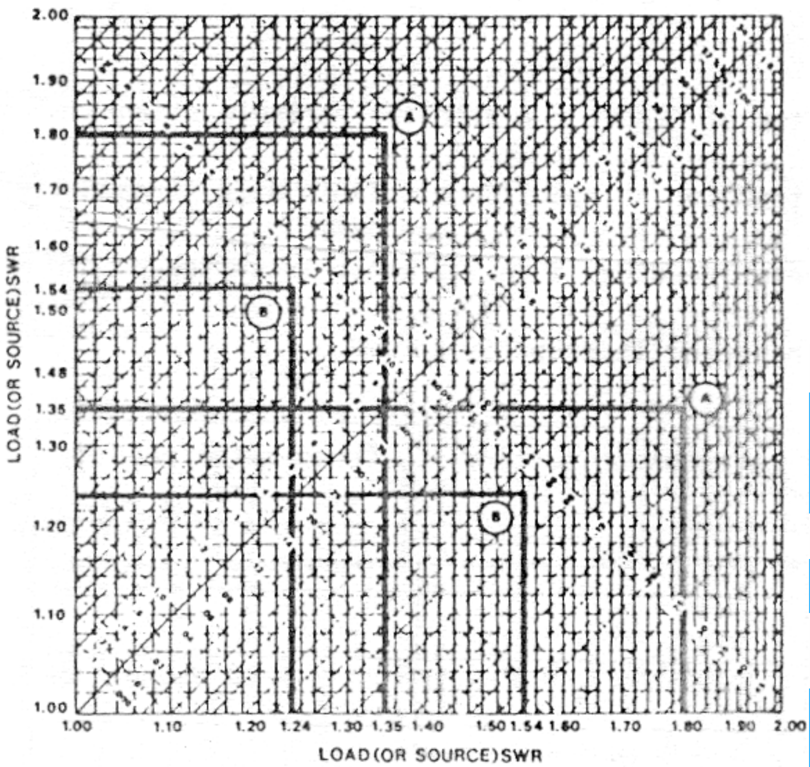
Attenuator Setting [dB]	Power meter reading [mw]
5	
8	
10	
12	
15	
20	

Attenuation position vs. power meter reading

Repeat the setup of Figure with the variable attenuator set at 20dB
1. Vary the attenuator as specified in Table above. At each time record the power meter reading. When the meter is switched on make sure the meter is properly zeroed.

F. Considerations of mismatch loss and maximum power transfer
Mismatch loss is defined as the power loss in the system due to reflections. In fact the impedance mismatch between the generator and the load causes multiple reflections, which produce a random phase determined by the electrical equivalent length of the wave guide. The random phase makes the power and attenuation measurements difficult due to the errors occurring and the power level deviations. When the SWR are known for the source and the load, the maximum and the minimum of the signal level deviations can be found, assuming the attenuation of the waveguide can be ignored. One way to determine the deviation values is to use a chart such as the one shown in Figure below.

The maximum power transfer takes place when the load impedance is equal to the complex conjugate of the source impedance. For e.g. a source with 50+j25 ohm impedance delivers the max power to the load when the load impedance is 50-j25 ohm. When the load impedance is not the conjugate of the source impedance,



Conjugate mismatch loss chart

The conjugate mismatch loss= (the available power of the source)/ (power delivered to the load)
The above relationship can brief expressed in terms of the reflection coefficient.

Mismatch loss= $[1 - \rho_s \rho_L]^2 / \{1 - [\rho_s]^2\} \{ 1-[\rho_L]^2\}$

Where ρ_s is reflection coefficient of the source
ρ_L is reflection coefficient of the load
Although ρ_s and ρ_L are not directly known in most cases the above equation are useful in determining the maximum and minimum mismatch power losses.

A. Maximum mismatch loss: This happens when the argument of ρ_s plus ρ_L is equal to 180degrees.
Maximum Mismatch = $[1 + \rho_s \rho_L]^2 / \{1 - [\rho_s]^2\} \{ 1-[\rho_L]^2\}$

= $1+ \{SWRs* SWR_L- 1\}^2 / 4 - SWRs* SWR_L\}$

B. Min mismatch loss: This happens when the argument if ρ_s plus ρ_L is equal to zero degrees.

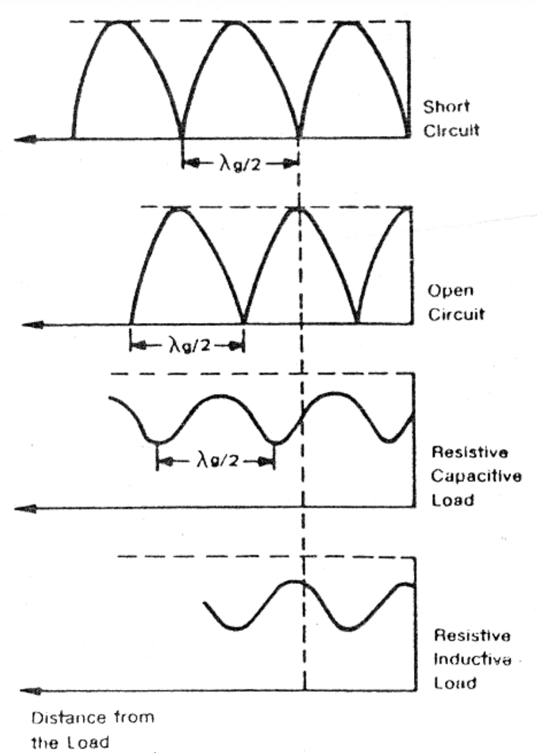
Minimum mismatch=$[1 - \rho_s \rho_L]^2 / \{1 - [\rho_s]^2\} \{ 1-[\rho_L]^2\}$
Example: For SWRs = 1.5 SWRL= 1.25
Cal the max and min mismatch loss
Max mismatch loss= $1+ (1.5* 1.25-1)^2/ 4*1.5* 1.25 = 1.102$
Min mismatch loss = $1+ (1.5- 1.25)^2 / 4*1.5*1.25 = 1.009$

EXPERIMENT 6

STANDING WAVE MEASUREMENTS

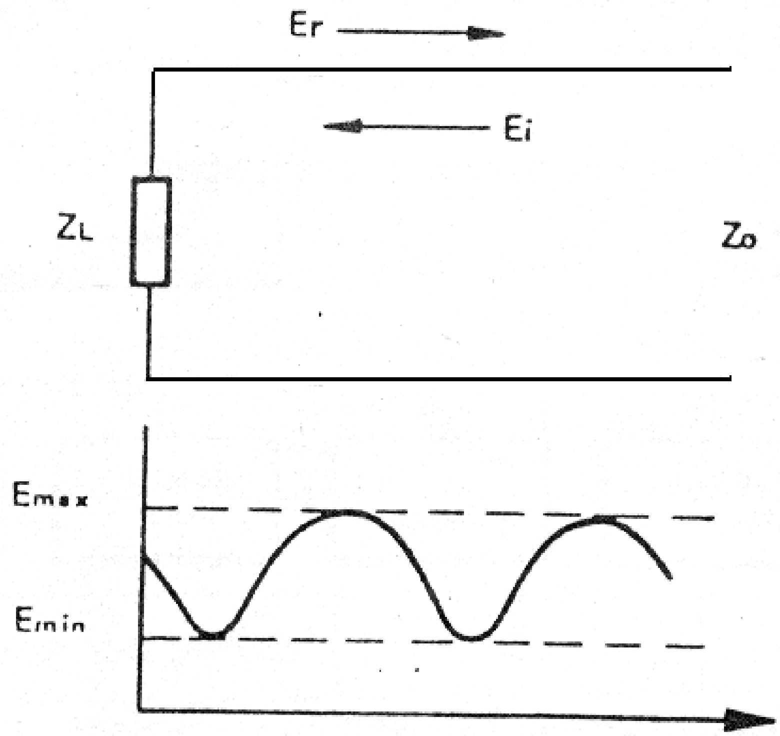
1. Objectives:
Learn how to determine SWR using slotted line or SWR indicator.

2. Theory:
At any point along a transmission line we can think of the electromagnetic field as a sum of two waveforms: one is traveling towards load and other towards generator. The reason for the reflection is due to impedance mismatch. Any open spot on the line is considered as impedance mismatches and becomes a cause of reflection as well. The amplitude and the phases of the reflected wave depend on the load impedance. The degree of the attenuation of the line affects amplitude of the reflected wave also. The only way reflection can be eliminated is either the line is infinitely long or there is impedance match between load and transmission line. A standing wave results from two traveling waves in opposite direction. The vector sum the two waves create the minimum and maximum points on standing wave pattern in a loss less transmission line.



Standing wave pattern in a lossless line

In figure below a voltage standing waveform in a transmission line having a characteristic impedance of Z_o and a load impedance of Z_L is shown.



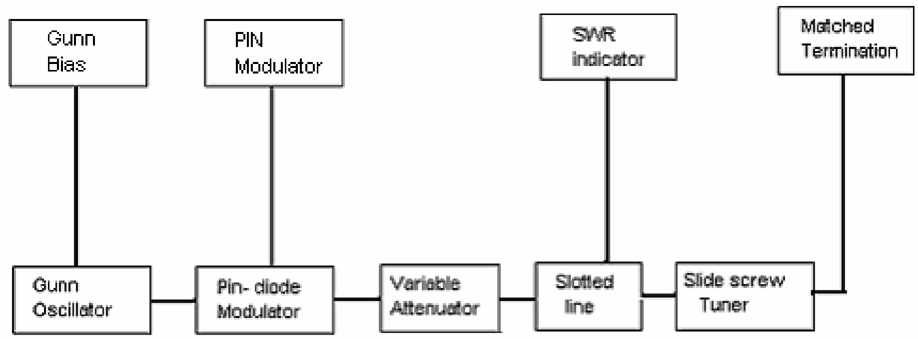
In figure above, the complex reflection coefficient is
$\underline{\rho}$ = (Er)/(Ei) = ($\underline{Z}$-Zo)/($\underline{Z}$ + Zo)

where Er = reflected signal
EI = incident signal
$\underline{Z}$ = complex impedance at a given point.
The $\underline{\rho}$ evaluated at the load is,

$\underline{\rho}_L = (Z_L - Zo)/(Z_L + Zo)$

Then VSWR = S = Emax / Emin = [Ei] + {Er] / [Ei] - [Er]
Therefore $\underline{\rho}$] = (S–1)/(S–1)

3. Experiment Procedure



Setup diagram for SWR measurement

1. Set up the equipment as shown above.
2. Set the Gunn diode supply voltage to 7V. Do not exceed this value.
3. Set the variable attenuator to 10 dB.
4. Turn on the Gunn oscillator.
5. Apply the modulation signal to pin diode modulator.
6. Adjust the modulation freq for maximum meter deflection.

A. Measuring low and medium range SWR.

1. Move the probe of the slotted line and observe VSWR Vmax reading.
2. Completely disengage the probe of slide screw tuner. At this point, the VSWR indication should be small (less than 1.3).
3. Move the probe in slotted line until a maximum Vmax is observed on VSWR meter. Press the VSWR Vmax to 0 dB.
4. Move the probe to where a minimum Vmin is observed. Take the reading.
5. Repeat the above procedure with three different probe depths. The three different depths are required to be greater than the depth used in above procedure.

Probe depth (mm)				
VSWR				

Probe depth vs VSWR

B. Measuring high range SWR.

1. Maximize the depth of the probe of the slide screw tuner. Large depth of the probe is necessary for high VSWR measurements.
2. Move the probe along the slotted line until a minimum Vmin observed on the VSWR meter.
3. Set the VSWR Vmin to 3 dB. If necessary reduce the attenuation of the variable attenuator.
4. Move the probe along the slotted line until 0 dB is obtained on Vmax dB scale.
5. Record the position of the probe under the d1 column in table below.

Probe Penetration	d1 [mm]	d2 [mm]	1st min [mm]	2nd min [mm]	λg [mm]	SWR

Recording the 3dB measurement

6. Repeat the above procedure while moving the probe towards right and record the position of the probe under d2 column.
7. Repeat the measurement at three different probe depths.
8. Replace the slide screw tuner with shorting plate. Find the distance between two adjacent minimum. The guide wavelength is λg is twice of the distance.
9. Compute the SWR using the formula.

$$SWR = \{1+(1/\sin^2\pi(d1-d2)/\lambda g)\}^{1/2} = \lambda g/\pi(d1-d2)$$

C. Measuring high SWR using a calibrated attenuator

1) Maximize the probe depth of the slide screw tuner.
2) Move the probe along slotted line until a minimum is observed.
3) Set the variable attenuator to 10 dB. Call this value A1. Press the VSWR Vmax to 0 dB.
4) Move the probe along slotted line and adjust the attenuator until the same maximum value as in the previous step. Read the dB value, call this A2 and record it in table below.

Probe Penetration	A1 dB	A2 dB	SWR

SWR measurement using a calibrated attenuator

5) Calculate the SWR using the following formula
$$S= 10 * (A2- A1)/20$$
6) Repeat the procedure at different probe depths.

EXPERIMENT 7

IMPEDENCE MEASUREMENTS

1. Objectives:
Learn the smith chart and its application in determining unknown impedances

2. Theory:
In a transmission line with characteristic impedances of Zo, the reflection coefficient between the incident and the reflected signal is defined as

$$\underline{\rho} = (\underline{Z} - Zo) / (\underline{Z} + Zo)$$

Where $\underline{Z} = R + jX$ = load impedance connected to the line.
$\underline{\rho} = [\rho]\ \varepsilon^{j\theta}$ complex reflection coefficient.

The magnitude of $\underline{\rho}$ ([ρ]) is the ratio of the amp between the incident and reflected signal. The angle θ represents the angle of the rotation of the phase at the point of reflection.

The voltage at any point on transmission line is the vector sum of the incident and reflected waveforms. The resultant voltage waveforms are called standing wave pattern. In fact, when the two waveforms add in phase, it forms a peak at that point. Likewise, when the two waveforms add out of phase, a valley or a minimum voltage is observed at that point.

The voltage standing wave ratio VSWR is defined as
$VSWR = (Emax) / (Emin) = \{1 + (Er / Ei)\}/\{1 - (Er / Ei)\} = \{1 + [\rho]\}/\{1 - [\rho]\}$

The angle of rotation of the phase of the reflection coefficient at a distance "d" from the load is determined by

$$\theta = 2\pi\, d / \lambda g$$

The determination of the load impedance can be a three-step process:
1) Obtain data on the waveguide through well-defined measurements.
2) Determine the magnitude and phase of the reflection coefficient.
3) Calculate the load impedance.

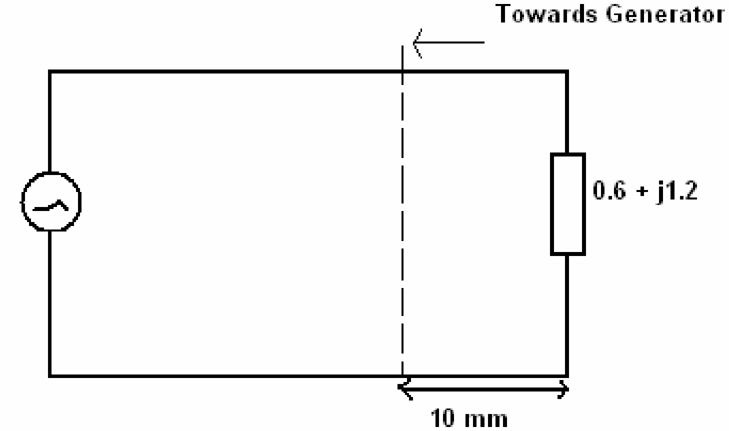
The smith chart is used for the third process of determining the load impedance at any point on the wave guide (or a transmission line in general) from known reflection coefficients.

The Smith chart is a graphical representation of the impedance transformation property of the length of the transmission line. The chart coordinates give the normalized resistance and reactance. They are normalized to Zo, the characteristic impedance of the waveguide. The VSWR circles are usually not included but can be constructed as needed with a compass centered on the center point of the chart. Notice that the distance scale on the outside periphery is normalized to the guide wavelength. Usually, the best way to learn smith chart is to try to solve actual problems.

Let's take a look on some problem.

Example: A waveguide is attached to a normalized load impedance of 0.6 +j1.2. The guide wavelength λg is 42 millimeters.

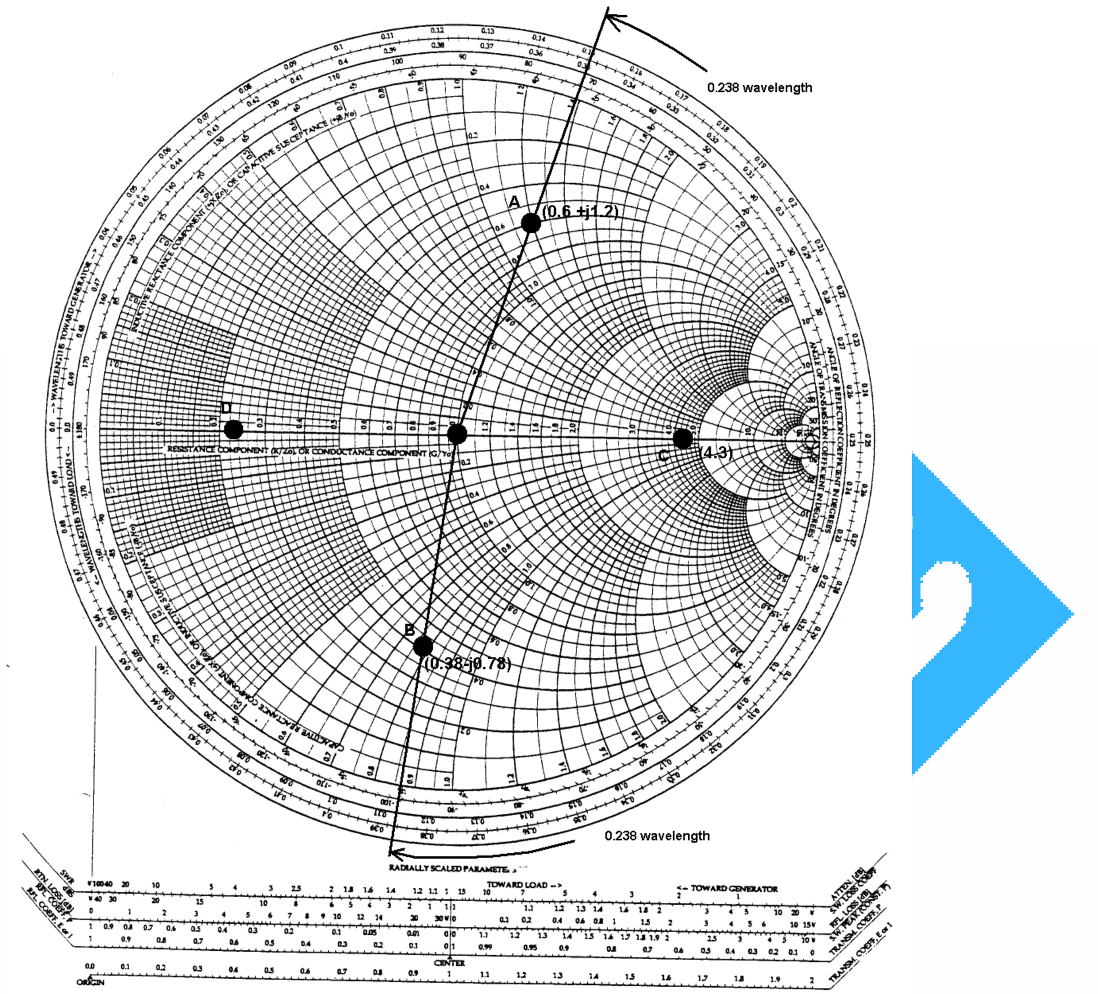
a. Find the impedance 10mm from the load.
b. Find the distance from the load where the first minimum of VSWR occurs.



Sample problem with the Smith Chart

Solution:
a. Refer to the smith chart as shown below.
1) Locate point A on the chart representing the load impedance of 0.6 + j1.2.
2) Draw the straight line from 0 to A. This line intersects the distance circle at 0.15λ towards generator. Traveling 10mm from the load is same as traveling 10mm/42mm= 0.238λ from the load.
3) Locate a point on the distance circle which is equal to 0.15 + 0.238λ= 0.388λ. Draw a straight line from the point to 0.
4) Draw a circle with radius 0A centered at 0. The impedance at point B represents the impedance of a point 10mm away from the load towards the generator. The normalized impedance of B is 0.38- j 0.78.

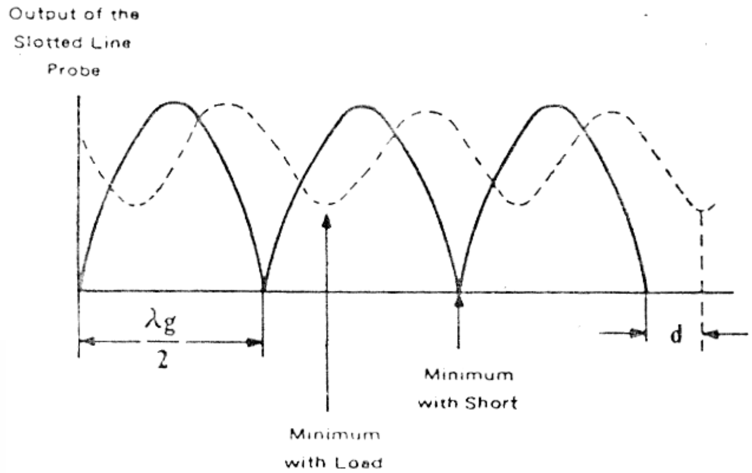
b. The VSWR of 4.3 at pt C is where the max of the VSWR pattern occurs. The first minima occurs at point D. The distance between point A and point D is
0.5λ - 0.15 λ = 0.35 λ



When the working on a determination of unknown impedance, it is necessary to establish a reference plane which the impedance can be related to. For example the input terminals of the unknown impedance can be a reference plane.

Once the reference plane is established the unknown impedance can be measured:

a. Connect the unknown impedance to a slotted line, then measure the VSWR and the position of minimum value.
b. Replace the unknown with a short at the output of the slotted line, then measure the distance between two adjacent minimum values. The distance obtained should be equal to 0.5λ of the guide wavelength.
c. Choose one of the minimum points as reference as shown below.

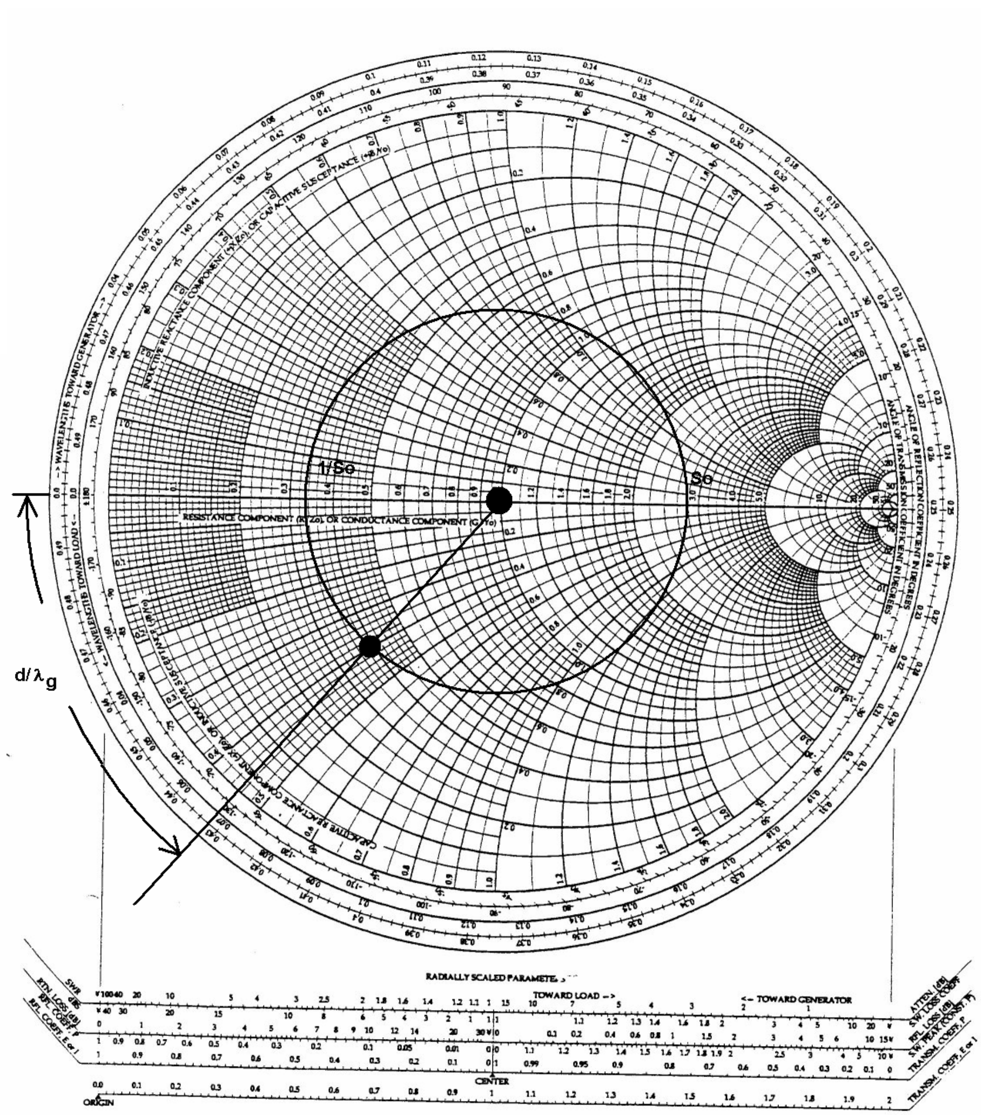


Fundamentals of Impedance Measurements

Draw a VSWR circle on the smith chart as shown below. The impedance at the voltage minima is 1/SWR. When a short is placed across the load, the min of VSWR moves towards the load. Therefore, the impedance at the load is determined by drawing a straight line from a point d/λg away from the zero of the outer most circle to the center of the VSWR circle. The intersection of the circle and the straight line represents the load impedance.

Notice the line impedance equals the load impedance at λg/2, λg, 3λg/2 ...... from the load.

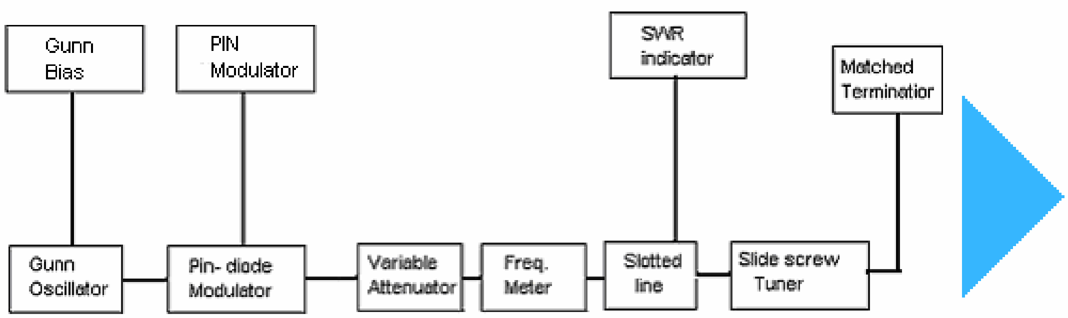
So far, the analysis assumed that the wave guide was loss less. In case the waveguide is lossy, any traces on the smith chart becomes a spiral rather than a circle. In a lossy line the SWR increases when the point of observation moves towards the load and decreases towards the generator.


1/So
So
d/λg
RESISTANCE COMPONENT (R/Zo), OR CONDUCTANCE COMPONENT (G/Yo)
RADIALLY SCALED PARAMETERS
TOWARD LOAD –>
<– TOWARD GENERATOR
CENTER
ORIGIN

3. Experiment Procedure:

A. Basic measurement.

1) Set up the equipment as shown below.
2) Completely unscrew the probe.
3) Turn on Gunn oscillator.
4) Apply 1 KHz mod signal to the pin diode modulator.
5) Measure the max & min values on VSWR meter.
6) Measure the frequency of the oscillator.



Setup diagram for SWR measurement

B. Impedance measurements

1) Press the VSWR Vmax to 0 dB.
2) Bring the probe of the slide screw tuner into the device such that the depth of the probe is approx 5mm.
3) Move the probe along the slotted line until a maximum Vmax is observed on the VSWR meter.
4) Press the VSWR Vmax to 0 dB.
5) Move the probe along the slotted line until min deflection is observed.

Probe Penetration (mm)	Load SWR S_L	Load min d_L (mm)	Short minima d_L (mm) d_{S2} (mm)	$\lambda g = 2(d_{s1} - d_{S2})$ (mm)	$d_L - (d_{S1}) / \lambda g$	Load Impedance
Frequency GHz						
2mm						
2mm						
2mm						
2mm						

Data recording table for the impedance measurement.

Note: In the following measurements, in case (d_L-d_{S1}) turns out to be positive, move the probe towards the generator. If the value is negative, move it towards the load. Also note that (d_L-d_{S1})/ λg is always les than 0.25

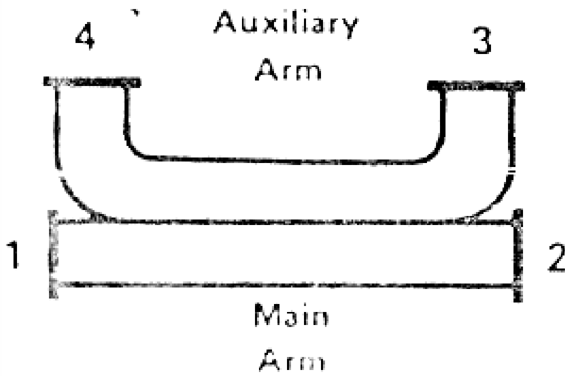
6. Remove the slide screw tuner and the matched termination from the setup. Place a shorting plate to the slotted line.
7. Obtain the distance d_{s1} and d_{s2} which corresponds to two adjacent min VSWRs. The guide wavelength λg is $2x(d_{S1}-d_{S2})$.
8. Repeat the procedure for two or more different probe depths

Experiment 8

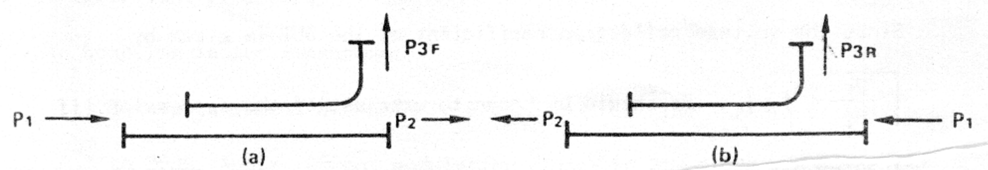
BASIC PROPERTIES OF A DIRECTIONAL COUPLER:

1. Objectives:
Learn the basic properties of a directional coupler coefficient including the coupling coefficient and the directivity.

2. Theory:
Directional coupler is shown in the fig's basically a sampling device is that it does not introduce reflections to the main systems The physical structure of a directional coupler can be thought of as a transmission line with one input port but two o/p ports. The directivity of the directional coupler allows energy coupling in one direction only.



The basic properties of the directional coupler are graphically presented in figure below. Notice that one end of the direction coupler contains a matched termination.

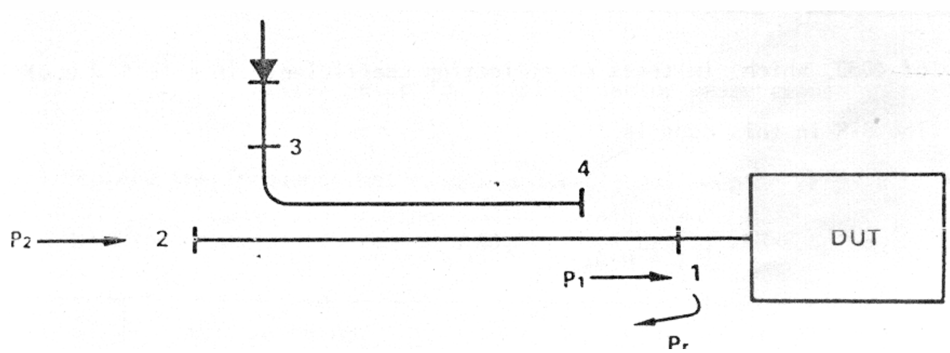


Sampling direction of a Directional Coupler
a. incident wave b. reflected wave.

The coupling coefficient and the directivity which are the most important figure of merit of a directional coupler is defined as following:

Coupling coefficient= 10 log(P1/P3F) (dB)

Directivity= 10 log (P3F/P3R)



Return Loss Measurements

When measuring return loss of a device the input signal is applied at the PORT2 and the device under test (DUT) is connected to port 1 then the return signal is picked up at PORT3.

The power at the detector when the coupling coefficient is C (or logC dB)
P3=Pr/C

Since the voltage reflection coefficient of the DUT is given by
$(Pr/P1)^{1/2} = \rho$

P1 should be known to make use of the expression. If the DUT is replaced by a short all the input power is reflected back, and therefore, P1 should appear at the PORT3. The actual power at port3 is equal to P1/C. The ratio of the two signals detected at the PORT3 is

$(P1/C) \times (C/Pr) = 1/(\rho)^2$

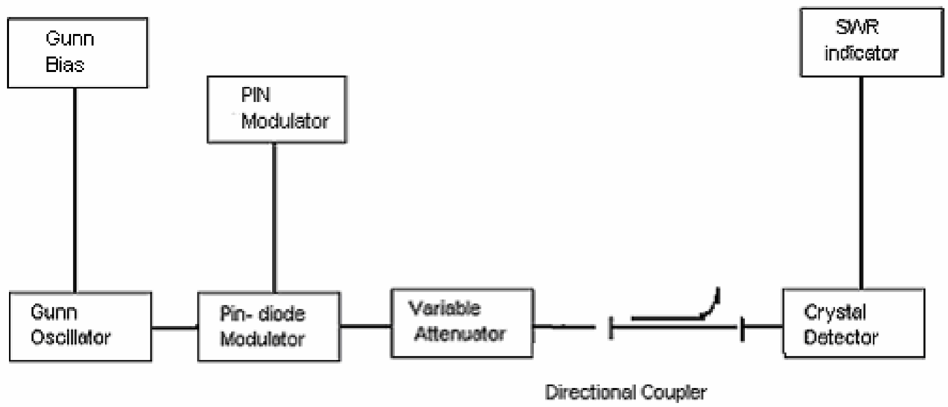
The ratio as expressed above is called return loss. The accuracy of the return loss measurement is dependent on the directivity of the coupler, which describes how much of i/p power at port 2 leaks to port3.
For example a directivity of 40 dB corresponds to a return loss of a 40 dB, which, in terms of reflection coefficient is 0.01

The SWR in this case is
SWR = (1+0.01)/(1- 0.01) = 1.02

4. Experiment Procedure

A Coupling factor measurements:

(1) Set up the equipment as shown below. Set the variable attenuator at 20 dB. Apply 1000Hz modulation signal to pin diode modulator and turn on to the Gunn oscillator. Press the VSWR Vmax to 0 dB. Use this value as reference.



INITIAL SETUP FOR COUPLING FACTOR MEASUREMENT

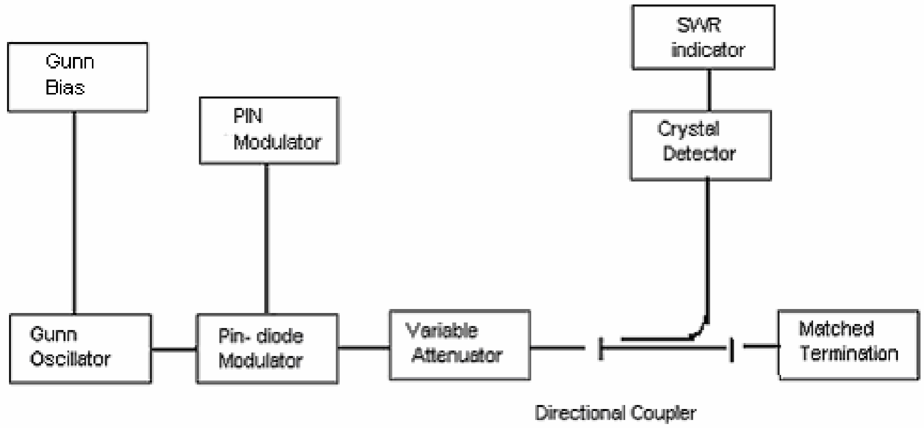
(2) Replace the freq meter with the directional coupler. Move the crystal detector to the auxiliary arm of the coupler.

A1 [dB]	A2 [dB]	A3 [dB}	A1-A2 [dB]	A4 [dB]	(A3-A4) + n*10 [dB]

Data for Coupling Factor Calculation.

(3) Adjust the variable attenuator until the same reference reading as in (1) is obtained

(4) Fill in the table above with attenuation of the attenuator. The coupling factor of the directional coupler is A1- A2



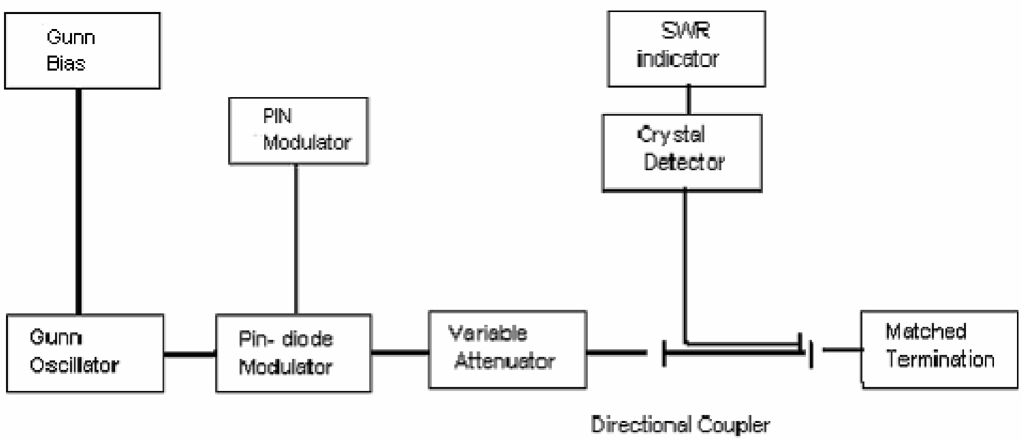
INITIAL SETUP FOR COUPLING FACTOR MEASUREMENT

B. Directivity measurements:

(1) Set the attenuator to 20 dB.

(2) Press the SWR Vmax to 0 dB. Read the SWR. Use this value as a reference. Record the attenuator setting.

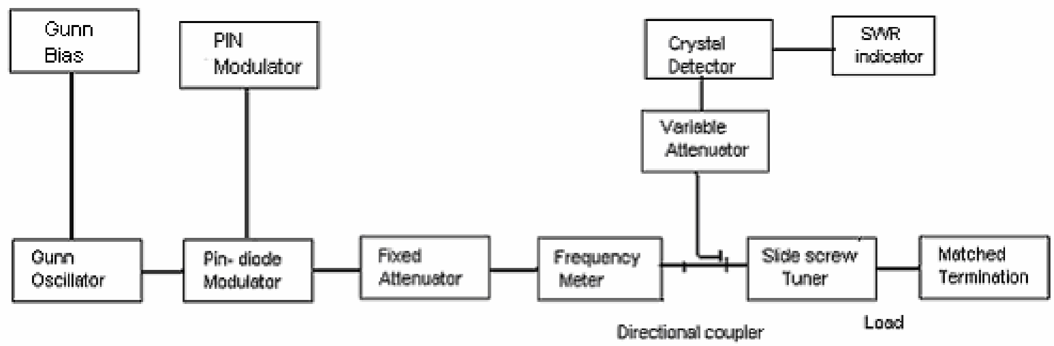
(3) Change the couplers orientation as shown below.



Setup diagram for directivity measurement

4) Reduce the attenuation until the same value in (2) i.e, 0dB is obtained. The directivity is (A3-A4 + n x 10) dB.

C. Return loss measurement of a load



SETUP FOR RETURN LOSS MEASUREMENT

1. Set up equipments as shown in figure above.
2. Set the probe depth of the slide screw tuner to 5mm.
3. Set the attenuator to 0 dB. A5. Press the SWR Vmax to 0 dB.Use this as reference.
4. Change the attenuator to maximum attenuation. Replace the load with a short.
5. Decrease the attenuator until the reference level in (3) is obtained. Record the attenuator position (A6).Add increased value to the position of the attenuator to get A6.
6. The return loss = (A6 – A5 + n X 10) dB

A5 [dB]	A6 [dB]	(A5-A6) + n X 10 [dB]	ρ	SWR

Data for return loss calculation

EXPERIMENT 9

ATTENUATION MEASUREMENTS:

1. Objectives:
Learn the attenuation measurement techniques of the microwave components.

2. Theory:
Although attenuation in general means reduction or decrease of something it specifically refers to the ratio between input to output power in microwave.

A (dB) = 10 log P1/P2
where P1 is the input power.
and P2 is the output power.

Insertion loss, although it has mathematically the same expression, has completely different meaning. While attenuation is introduced in the system on purpose, insertion is an undesirable situation. The insertion loss is happening due to non-ideal physical components in the system.

In microwave wave-guides two different measurements method are popular: power ratio or RF substitution.

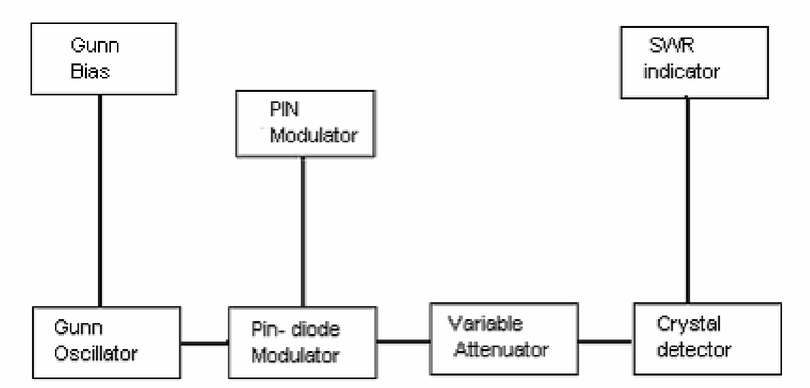
a. Power ratio method
The power ratio method is simply taking the power measurement with and the microwave detector operates at different power level in each case, causing errors due to the non-linearity of the device. Therefore the measurements results needed to be compensated. For example, when the output power of the detector is maintained at less then 1 milli watt level, about 0.3-dB compensation is necessary for up to 20 dB attenuation.

b, RF Substitution method.
The error associated with the detector in the above method is eliminated in the RF substitution method by first measuring the output power with the DUT then replacing the DUT with the calibrated variable attenuator. By properly adjusting the variable attenuator to the same power level as before attenuation of the DUT then, is simply the amount of attenuation of the variable attenuator. So far, in both methods, we are based on the assumption that the errors due to impedance mismatch are insignificant. Sometimes the SWR itself introduces a small amount of errors.
The MWL components are designed with less than ± 0.5 dB of error rate.

3. Experiment Procedure:

a. Preliminary Adjustment.

Set up equipment as shown below

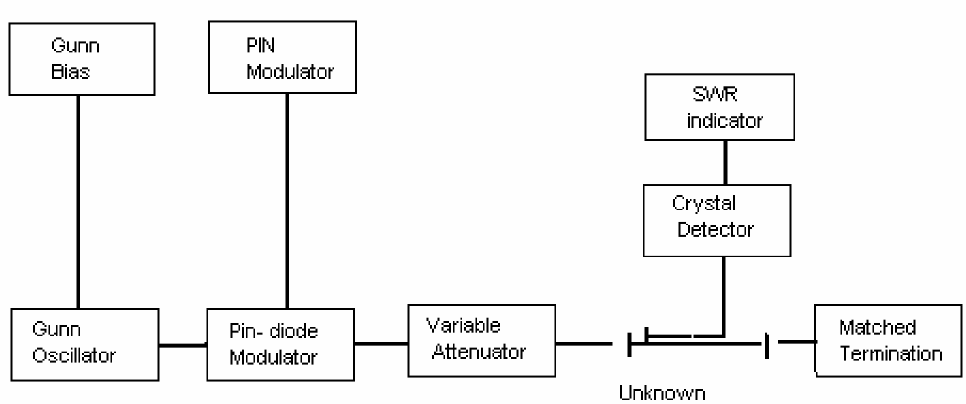


SETUP FOR PRELIMINARY ADJUSTMENT

1. Turn the power supply on.
2. Apply 1000Hz modulation to the PIN diode.
3. Adjust the pulse repetition rate for the maximum Vmax on the VSWR meter.

b. Measurement using power ratio method

1. Set the variable attenuator to 20 dB.
2. Press the VSWR Vmax to 0 dB
3. Using a directional coupler add a matched termination to the set up as shown below.
4. Obtain the reading of the VSWR meter. Calculate the actual coupling of the directional coupler.
5. Repeat step (2), (3) and (4) with the attenuator set at 15 and 10 dB respectively.
6. Repeat the above experiment using fixed attenuators.



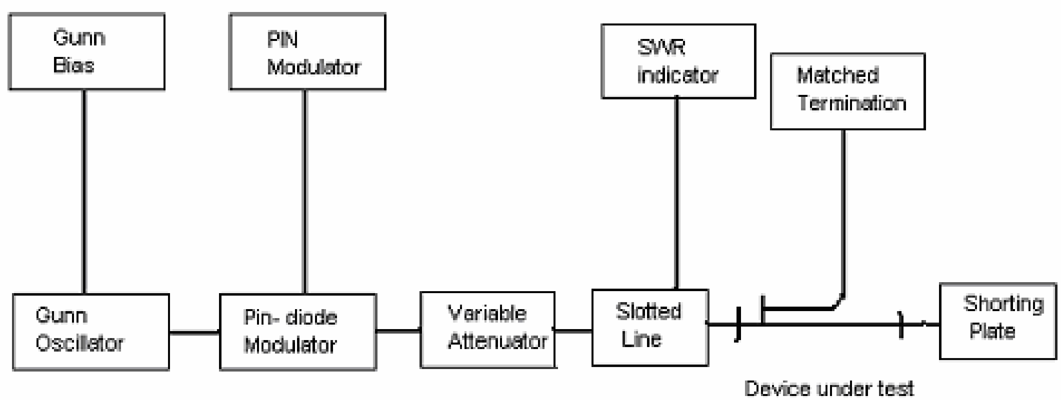
MEASURING ATTENUATION USING THE POWER RATIO METHOD

c. Measurement using RF substitution method.

1. Connect the crystal detector to the PIN diode modulator.
2. Set the variable attenuator to 20 dB. Press the VSWR Vmax to 0 dB.
3. Insert the directional coupler and connect the crystal detector to the auxiliary arm of the directions coupler. Without altering the SWR indicator setting, adjust the variable attenuator until the SWR indication is same as before. Record the attenuator setting. This is the actual value of attenuation of directional coupler in this case.
4. Repeat the above experiment using a fixed attenuator as a DUT

d. Measurements of low values of attenuation.

1. Set up the equipment



Setup diagram for the measurement of low values of attenuation

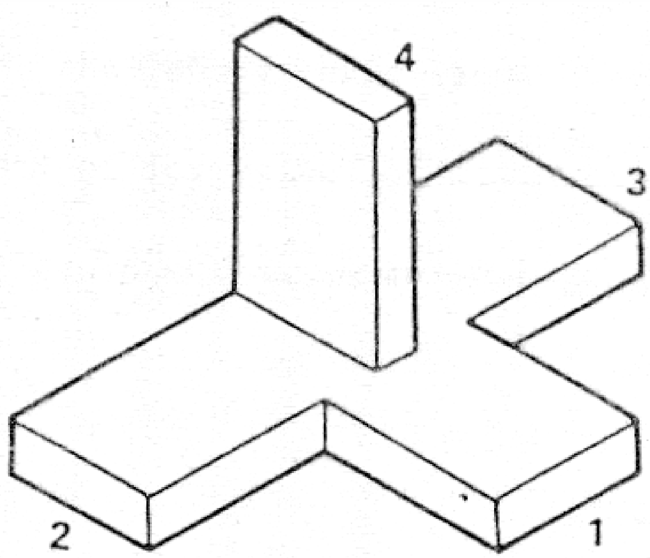
2. Set the variable attenuator to 20 dB.
3. Measure the input SWR of the device under test (a directional coupler in this case).
4. Determine the attenuation using the following expression.
   A= 10 log (SWR+1)/(SWR –1)

EXPRIMENT 10

STUDY OF A WAVEGUIDE HYBRID – TEE

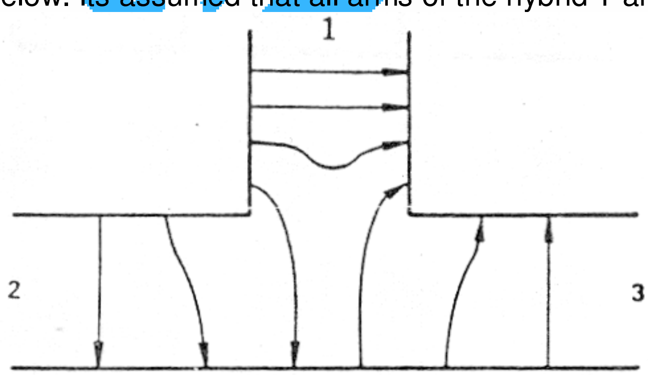
1. Objectives
Understand the basic principle of hybrid tee
Learn the measurement methods of hybrid –T characteristics

2. Theory
A hybrid –T is basically a microwave version of hybrid coil of the type commonly used in telephone repeater circuits.



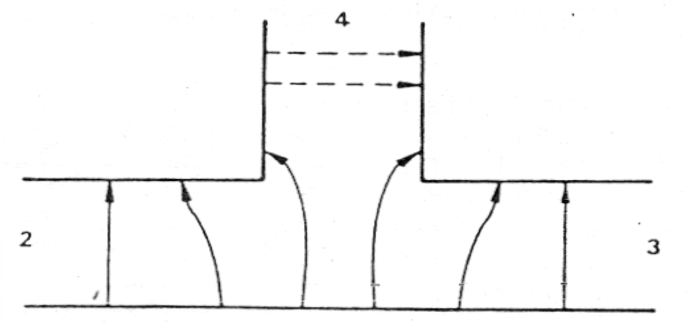
Waveguide Hybrid Tee

When the bridge circuits is properly matched by external impedances, the input signal applied at the port 1 appears at port 2 and port 3, but no signal appears at port 4. In the same manner when the input is applied at port4, then the signal appears at port2 and port3 but no signal appears at port1. The above input and output relationship can be described in terms of the field distribution inside of the hybrid-T. A view of the electric field, with the input applied at port1 is as shown below. Its assumed that all arms of the hybrid T are properly matched.



Electric field with input field applied at port 1

The field is an even symmetry about the mid plane. If the input is applied at the port 4 the signal splits equally to port 2 and port3 but no part of the signal enters port1.

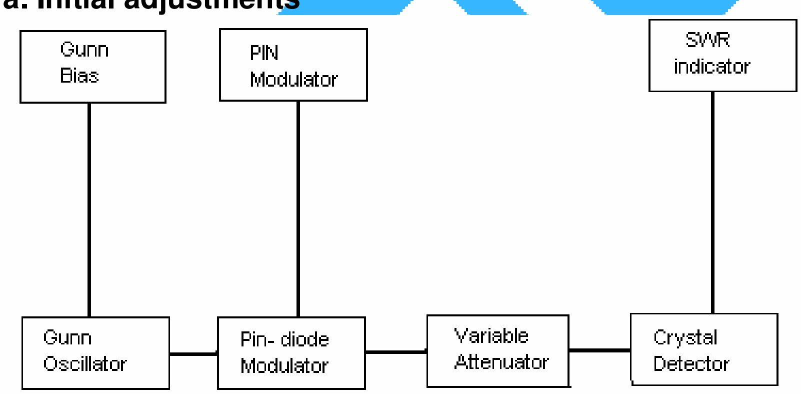


Electric field with input field applied at port 4

In figure above a side view at the junction of the hybrid-T is shown when the input signal is applied at the port4 in TE10 mode. The reason for no coupling to port 1 is due to the reciprocity and the symmetry of electric and magnetic field. The signal divides equally to port2 and port3 but the phase is 180 deg out of phase. **Arm1 is sometimes referred to as H- arm because it is in the plane of the magnetic field. Arm4 is referred as E-Arm for the similar reason**. Another place where the inputs can be applied to arm2 and arm3 at same time. In this case, the vector sum of the two inputs will appear at arm 1. At arm4 the vector difference of the inputs will appear.

3. Experiment Procedure:

a. Initial adjustments

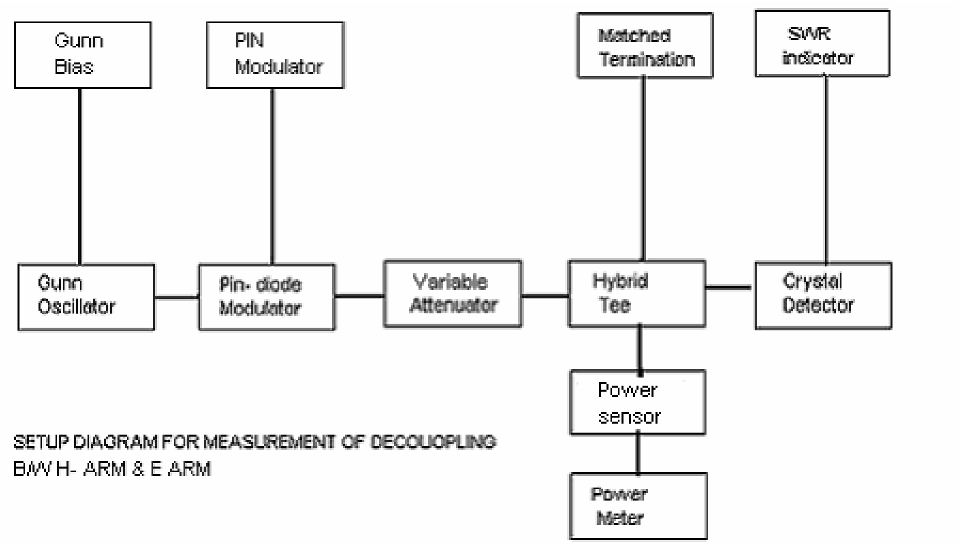


INITIAL SETUP DIAGRAM

(1) Set up the equipment.
(2) Apply 7 V to the Gunn oscillator.
(3) Apply modulation voltage to the pin diode modulator.

Adjust the offset voltage and the pulse freq of the square wave generator to obtain max deflection on the SWR indicator

B. Measurement of decoupling b/w H-arm and E-arm



SETUP DIAGRAM FOR MEASUREMENT OF DECOUOPLING
B/W H- ARM & E ARM

(1) Set the equipments
(2) Set the attenuator to 20 dB (A1)
(3) Remove the detector & connect the variable attenuator to arm1.
(4) Connect matched termination and power meters to arm2 and arm3 and connect the detector to arm4. Keep the power meter at off position.
(5) Record the result as below.

Attenuation of the variable attenuator		Variations of the SWR meter gain (in 10dB steps)	Decoupling A1-A2 + (nX10)
A1 (dB)	A2 (dB)	n steps	(dB)

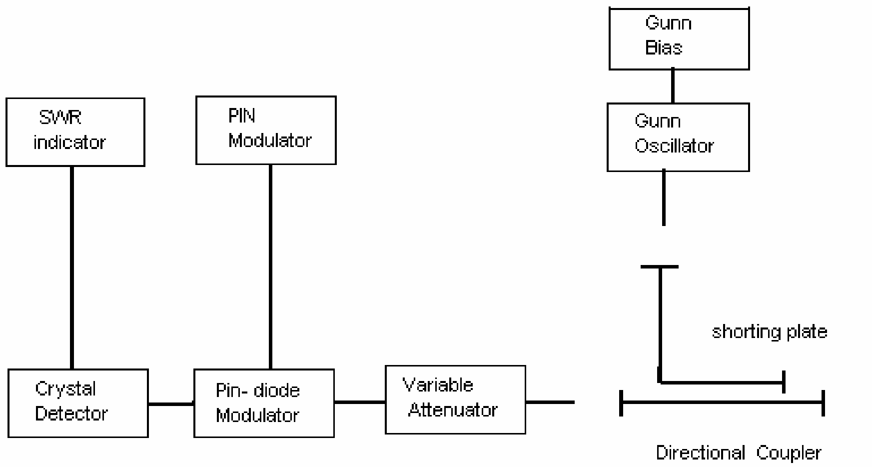
C. Measurement of insertion loss of Hybrid-T.

1. Connect the detector to the attenuator, which is set to 20 dB.
2. Remove the detector and the connect the arm(1) of the hybrid T to the attenuator.
3. Connect the matched termination and the power meters to arm3 and arm 4. Also connect the detector to arm2.
4. Decrease the attenuator (A4) until the same reference level as in (2) is obtained. The insertion loss between arm1 and arm2 is A3-A4.
5. For insertion loss between arm 1 and arm 3 repeat (4) and (5).
6. For insertion loss between arm 4 and arm 2 repeat (3), (4) and (5)
7. Record the results

Signal Path Arms	Variable Attenuator Attenuation		Insertion Loss (dB)
	A3 (dB)	A4 (dB)	
1-2	20		
1-3	20		
4-2	20		

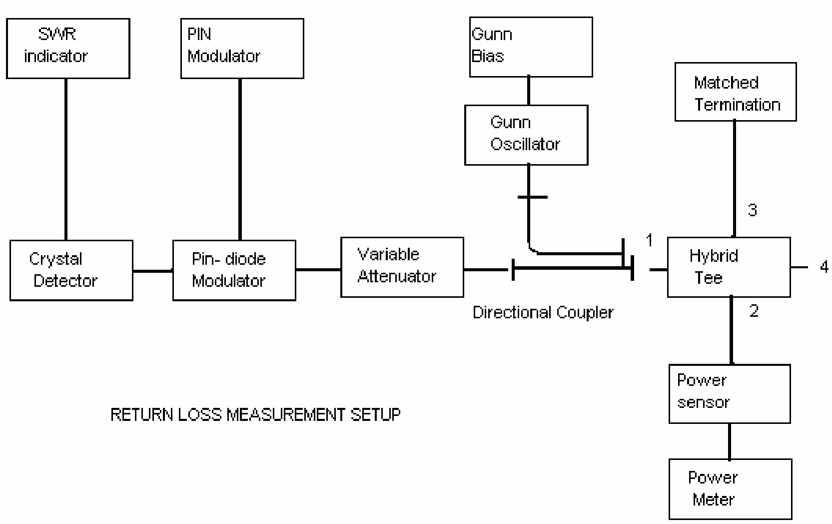
d. Return loss measurement of H-arm.

Set up the equipment as shown below:



Return loss measurement

1. Turn on the oscillator. Do not exceed 9V. Adjust the square wave output for the max modulation.
2. Set the variable attenuator to 20 dB (A5).
3. Set up the reference point as 0dB on the SWR indicator.
4. Remove the shorting plate. Connect arm1 to the directional coupler as shown below. Connect a matched termination to arm3. Leave arm 4 open. (Arm4 is the E plane T. Since the decoupling to arm 4 is almost 30-40 dB leaving it open should not affect the accuracy)
5. Increase the gain of the SWR indicator in 10 dB increments. Decrease the attenuation (A6) until the same level as in (4) is obtained. Record the results.
6. Repeat (5) and (6) using E-plane T (arm 4) instead of H- plane T(arm1).



RETURN LOSS MEASUREMENT SETUP

Object	Attenuation		Gain increase of the SWR Meter in 10dB steps A6-A5 + (nX10)	Return Loss	
	A5 dB	A6 dB		in dB	Absolute Value
Arm 1					
Arm 4					

Return Loss Measurement data

EXPERIMENT 11:

MEASUREMENT OF PHASE SHIFT OF A PHASE-SHIFTER

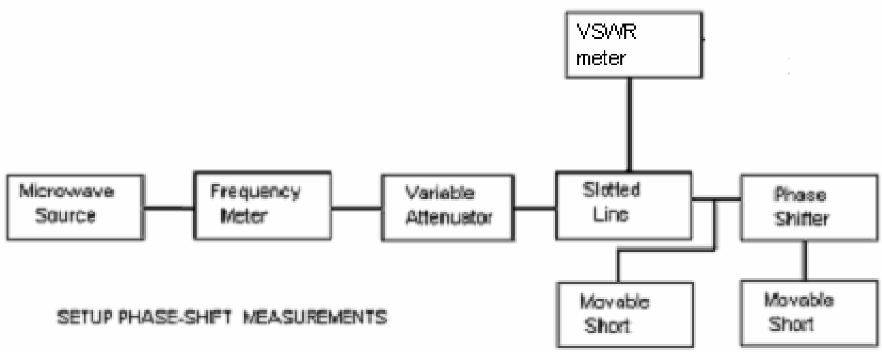
1. Objectives:
To study the phase-shifter.

2. Equipment required:
Microwave source, Isolator, Variable attenuator, Frequency meter, Slotted line, Tunable probe, Phase shifter, Movable short, VSWR meter.

3. Theory:

A phase shifter consists of a piece of waveguide and a dielectric material inside the waveguide placed parallel to the electric vector of TE10 mode. The phase changes as a piece of dielectric material is moved from the edge of the waveguide towards the centre of the waveguide

4. Experiment Procedure:
Set up the equipment in the figure.



1. First movable short is placed at the end of the slotted line.
2. Energize the microwave source for maximum output at particular frequency of operation.
3. Find out the λ_g with the help of the probe slotted line and VSWR meter. It is the twice the distance between two minima on the slotted line.
4. Find out the operating frequency of the frequency meter or by relation of λg.
5. Find out λ as
   $\lambda = c/f$ or
   $1 / \lambda^2 = 1 / \lambda_g^2 + 1 / \lambda_c^2$
6. Note and record a reference minima position on the slotted line. Let it is X.
7. Remove carefully the movable short from the slotted line.
8. Place the phase shifter to the slotted line with its micrometer reading zero and place the movable short to the other port of the phase shifter.
9. Find out a new minima position let it is Y.
10. Change the position of micrometer of phase shifter and find out the corresponding position of new minima, let it be y_i.

5. CALCULATION:

Since new minima are multiples of half wavelengths, from the short it should be possible to calculate the exact electrical length of the phase shifter.

For e.g. suppose at 10 GHz the reference minima is found at X= 16.08 cm. Suppose the phase shifter is two wavelengths long and placed on the line in the step 9, the new minima y = 14.90 cm is obtained. Short has apparently moved 16.08 - 14.90 = 1.18 cm. This can be written as

$\lambda\ (0.393) = (1.18)\lambda\ /\ 3$

The apparent movement is in the direction the short actually moved. It is added to the approximate half wave length in the phase shifter. The total electrical length is 2.393 wave lengths.
Multiply by 2π to give phase shift in radius by 360 deg.
Phase shift in above example
= 2π *2.393 radians
= $360 * 2.393$ degrees
The phase shift for other micrometer reading position can be found as above.

6. Observations:

Initial minima	New minima	Difference of minima's.
1.		
2.		
3.		

7. Conclusions and results:

The phase shifter can be used to match the propagation delay in feed networks for phased array antennas.

λ_g = 37.7mm@10.3 GHz= 360 deg
1 deg = 37.7/360= 0.105mm
or 1mm = 360/37.7 = 9.55 deg

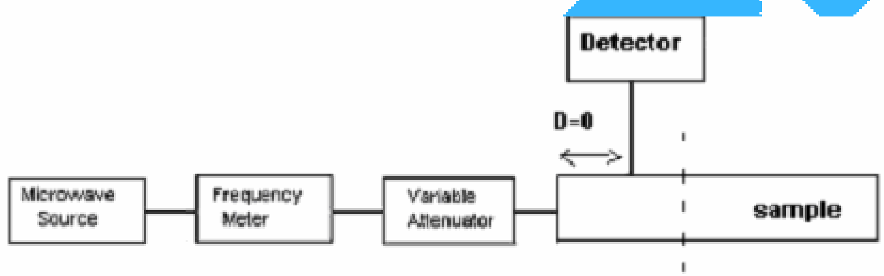
EXPERIMENT 12:

MEASUREMENT OF DIELECTRIC CONSTANT OF A HOMOGENEOUS MATERIAL

1. Objectives:
To determine the dielectric constant of an insulating material.

2. Equipment required:
Power supply, isolator, frequency meter, variable attenuator, detector mount, Waveguide containing sampling material

3. Theory:
It is useful to write the relative dielectric constant as:
$\varepsilon_r = \varepsilon\ (1 - j \tan\delta)$
The dielectric constant is not independent of frequency and stays constant over small portion of frequency spectrum.



Setup for dielectric measurements

Dielectric measurement method
The figure above, shows an empty short circuited waveguide with a probe located as voltage minimum Dr. The fig shows the same waveguide containing sample of length le with a probe located at new voltage minimum D. The sample is adjusted to short circuit
$\tan l_k (D_R - D - i_e) / k l_E = \tan l_k L_e K_e / K_e L_e$
All the quantities at the left hand is measurable. While right hand is of the form tan z /z
so that once the measurement have been performed the complex number Z= Ke le can be found by the solution of transcendental equation.

4. Procedure:
1. With no sample in short circuited lines find position of the voltage minima w.r.t. an arbitrary chosen reference.
2. With the help of slotted section and probe measure the guide wavelength by measuring the distance between two adjacent minima in slotted line.
3. Remove short circuit, inert the sample and replace the short circuit in such a manner that it touches the end of the sample.
4. Measure D_R, the position of minima in slotted line.
5. Measure the VSWR (r) in the slotted line.
6. Repeat the steps 1 to 5 with sample having different lengths.

5. Observations and Calculations:

6. Conclusions and results:

RESISTIVITY AND PERMITTIVITY

MATERIAL	PERMITTIVITY	LOSS TANGENT
Aluminum Oxide	10	0.0001
Bakelite	4.9	
Polystyrene	2.56	0.0016
Polyethylene	2.25	
Quartz	3.78	0.0001
Teflon	2.08	0.00037
Sapphire	9.3-11.7	0.0001
Beryllium	6.6	0.0001
Ferrite/Garnet	13-16	0.0002
Silicon	12	0.001
GaAs	13.1	0.0006

RELATIVE PERMEABILITY

Nickel	50
Cast iron	60
Cobalt	60
Ferrite	1,000
Silicon iron	4,000
Mu metal	20,000
Super Malloy	100,000

OHMIC LOSSES

Skin depth is defined as the distance from the conductor surface to the point where the current density falls to 1/e of its value at the surface.

	Au	Ag	Cu	Al
• Skin depth (2GHz)	1.7	1.4	1.5	1.9
• Skin depth (10GHz)	0.77	0.63	0.66	0.86 microns
• Surface resistivity	3	2.8	2.6	3.3

EXPERIMENT 13:

RADIATION PATTERN AND THE GAIN OF WAVEGUIDE HORN ANTENNA

1. Objectives:
To measure the polar pattern and the gain of the waveguide horn antenna.

2. Equipments Required:
Gunn power supply, Gunn oscillator, Pin modulator, Frequency meter, Variable attenuator, Detector mount, horn antenna, VSWR meter, and Accessories, Manual antenna rotator

3. Theory:
If a transmission line propagating energy is left open at one end, there will be radiation from this end. In case of a rectangular waveguide this antenna presents a mismatch of about 2:1 and it radiates in many directions.

The radiation pattern of an antenna is a diagram of field strengths or more often the power intensity as a function of aspect angle at a constant distance from the radiating antenna. An antenna pattern is three dimensional. An antenna pattern consists of several lobes, the main lobe, side lobe and back lobe. The major power is concentrated is the main lobe. and side lobe is normally to keep as low. as possible**.**

3 dB Beam Width
The angle between the two points on a main lobe when the power intensity is half the power intensity is half the maximum power intensity.
When measuring the antenna pattern , it is normally most interesting to plot the pattern far from the antenna.
Far field pattern is achieved at the maximum distance of $2D^2/\lambda o$ (For rectangular horn antenna)

Antenna measurements are mostly made with unknown antenna as receiver.
There are several methods to measure the gain of antenna. One method is to compare the unknown antenna with a standard gain of antenna. Another method is to use two antennas, one as transmitter and other as receiver from following formula gain can be calculated.

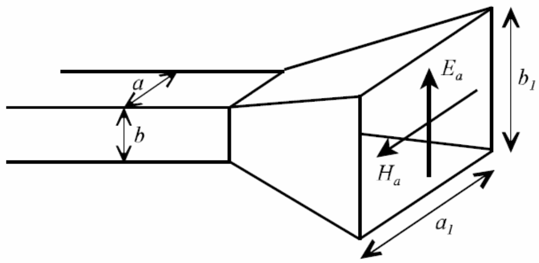
$P_r = P_t \lambda o\, G_1 G_2 / (4\pi S)^2$

P_t = transmitted power.
P_r = Received power.
λo = Free space wavelength.
$G_1 = G_2$= Gain of transmitting and receiving antennas.
S = Radial distance between two antennas.
If both transmitting and receiving antennas are identical having Gain G

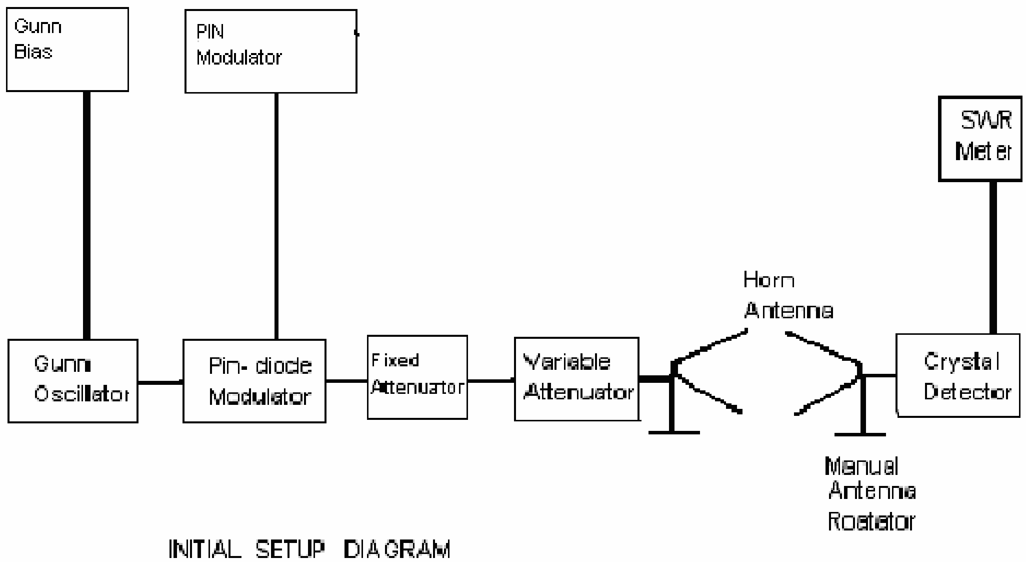
$P_r = P_t \lambda o\, G^2 / (4\pi S)^2$

$G = 4\pi S / \lambda o * (Pr / Pt)^{1/2}$

Pyramidal Horn



4. Procedure:



Gain and Pattern measurements

1. Set up the equipments as shown above.
2. Keep the horn at distance of 1m in line with waveguide. Press the Vmax to 0db at VSWR meter.
3. Obtain maximum Vmax value in VSWR meter with variable attenuator.
4. Replace the transmitting horn by detector mount and press the Vmin to get db reading.
5. Calculate the difference in db between the power measured between last two steps.
6. Rotate the horn antenna in steps of 5 degree and plot the dB level readings in SWR meter on a chart provided at back of manual. From the chart arrive at 3dB beamwidth and front to back ratio etc.

5. Observations:

The gain of antenna was measured to be around 15dB. The 3dB beamwidth was found to be around 45 degrees and front to back ratio was 25dB.

EXPERIMENT 14:

STUDY OF CIRCULATORS AND ISOLATORS

1. Objectives:
To study isolators and Circulators

Equipments Required:
Microwave source, Isolators, Circulators, Frequency meter, Variable Attenuator, Slotted line, Tunable probe, Detector mount, VSWR meter, Test isolation and circulation and Accessories.

3. Theory:
a. Isolator:
The isolator is a two port device with small insertion loss in forward direction and a large isolation in reverse attenuation. The third port is terminated in a matched termination.

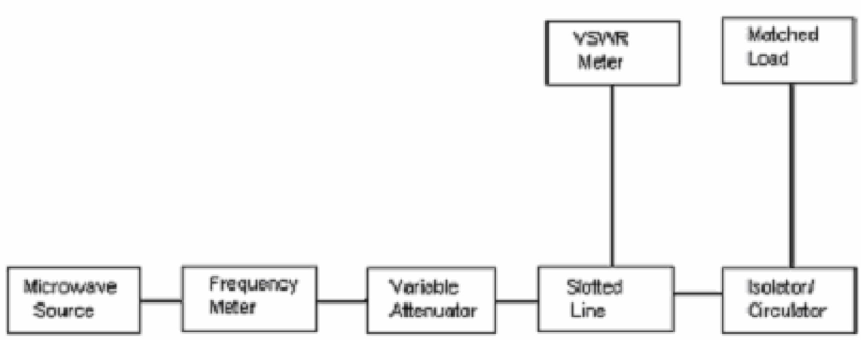
b. Circulator:
The circulator is a three port junction that permits transmission in say only clockwise direction. A wave incident in port1 is coupled to port2 only; a wave incident at port2 is coupled to port3 only and so on.

Some parameters of isolator and circulator:
a. Insertion loss: The ratio of the power supplied by a source to the input port to the power detected by the detector in the coupling arm i.e. output arm with other port terminated to the matched load is defined as insertion loss or forward loss.

b. Isolation: It is the ratio of the power fed in the input arm and the power detected at not coupled port with other port not terminated in the matched load.

c. Input VSWR: The input VSWR of an isolator or circulator is the ratio of the voltage max. to the voltage minimum of the standing wave existing on the line and the others have matched termination.

3. Procedure:



Measurement of VSWR of isolator or circulator

a. Input VSWR Measurement

1. Setup the equipments as shown above.

2. Connect the isolator or circulator in the direction of flow of energy. The input port is towards the gunn and the output port is connected to matched termination.
3. Energize the microwave source for 10GHz of frequency.
4. With the help of the slotted line, probe and VSWR meter, find out SWR of the isolator or circulators described earlier for low and medium SWR measurements.
5. The above procedure can be repeated for other frequencies.

b. Measurement of insertion loss and isolation

1. Remove the isolator or circulator from slotted line. Connect the detector at end of slotted line. The output of the detector mount should be connected to VSWR meter.
2. Energize the microwave source for maximum output for a particular frequency of operation say 10GHz. Tune the detector mount for maximum output in the VSWR meter.
3. Set any reference level of a power in VSWR meter with the help of a variable attenuator. Let it be P_1.
4. Carefully remove the detector mount from slotted line without disturbing and position of the set up. Insert the isolator / circulator between slotted line and detector mount. Keeping input port to the slotted line and detector mount.
5. Record the reading in the VSWR meter. Let it be P_2.
6. Compute insertion loss on P_1-P_2 in dB.
7. For measurement of isolation, the isolation or circulator has to be connected reverse, the output port to the slotted line and detector to input port with other port is terminated by matched termination after setting a reference level without isolator or circulator in the set up as described in insertion loss measurement. Let same P_1 level is set.
8. Record the reading of VSWR meter inserting the isolator or circulator as given in step 7. Let it is P_3.
9. The same experiment can be done for the other ports of the circulator. Always terminate the unused port of the circulator.
10. Repeat the above experiment for other frequencies when needed.

Conclusions and Results: The insertion loss for circulator/isolator was found to be 1dB and isolation was measured to be 20dB at frequency of 10GHz.

EXPERIMENT 15:

STUDY OF COAX TO WAVEGUIDE TRANSMISSION.

1. Objectives:
To study Coax to waveguide transmission and find its SWR.

2. Equipments Required:

3. Theory:
Transitions between the TEM coaxial mode and the TE_{10} mode in rectangular guide are frequently used in microwave equipment. In designing such a transition, it is necessary that it be shaped to encourage the desired mode conversion. One such configuration is shown in Fig. The coaxial line is connected to the broad wall of the waveguide with its outer conductor terminating on the wall. The center conductor protrudes into the guide and terminates on the opposite wall. As the TEM wave enters the waveguide section, the electric field lines follow the conducting walls as shown. Also with the TEM magnetic loops in the horizontal plane, they are favorably oriented for conversion to magnetic loop pattern of the of the TE10 mode.

From a circuit point of view, the function of the quarter wave shorted stub is provided an open circuit in shunt with the Z_o and Z_{01} lines is shown. One might be tempted to obtain the open circuit by $l_s = 0$. Unfortunately, this doesn't work since an open-ended waveguide is not electrically equivalent to an open circuit. It is, in fact, an excellent radiating antenna.

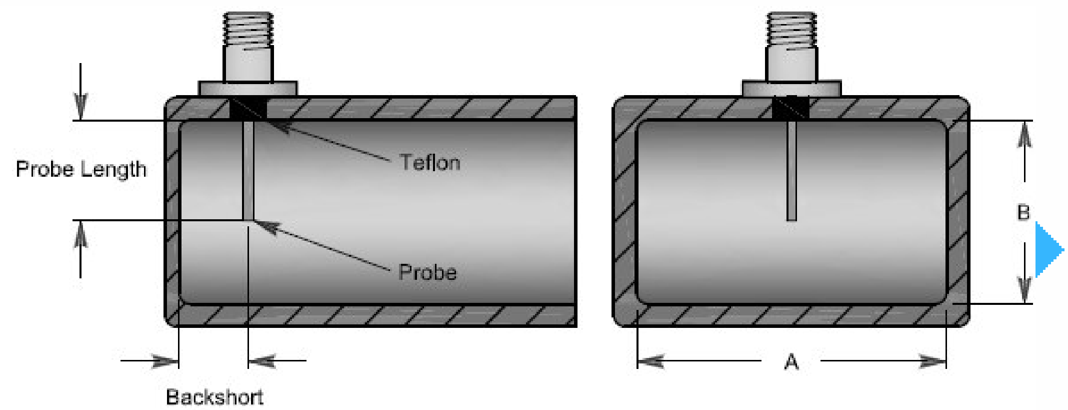
To achieve a low-SWR transition, the characteristic impedances of the coaxial line (20) and the rectangular waveguide (201) must be equal. In most cases, the coax impedance is 50 ohms while that of standard rectangular guide is several times larger.1 The waveguide impedance can be lowered by either reducing the guide height, as shown in the figure, or by using a ridge waveguide. Keep in mind that, unlike coaxial line, the characteristic impedance of waveguide is a function of frequency. Therefore, the two impedances can only be made equal at the design frequency. If a standard height output guide is desired, a quarter-wave transformer can be incorporated into the waveguide section.

Note that, unlike the output guide, the height of the shorted waveguide section (b_s) has not been reduced. With waveguide impedance proportional to height, this means 20s > 201, this results in a lower SWR over the useful waveguide band.

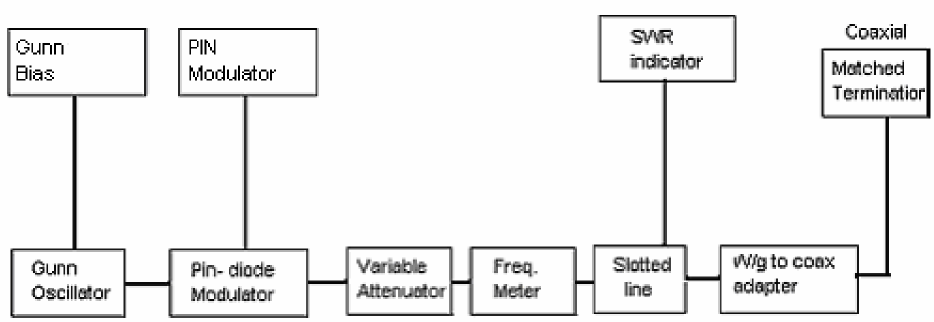
Figure shows side views of three other coax-to-waveguide transitions. In all cases, the transitions are made directly to standard height waveguide. The one shown in part a is useful in high-power applications and is known as a doorknob transition. The probe type shown in part b is widely used in test equipment. Note that the center conductor of the coaxial line extends part way into the waveguide section. It can be thought of as an antenna that radiates energy into the waveguide.2 The dielectric sleeve-probe combination provides the required transformation between coaxial and waveguide impedances. This technique results in an SWR of less than 1.25 over the useful frequency range of the rectangular waveguide.

An in-line transition is shown in part c of Fig. In this case, the center conductor 9f the coaxial line is bent so as to contact the broad wall of the wave-guide. The resultant loop encourages energy coupling between the coaxial and waveguide modes. The electric field conversion from TEM to TE10 is indicated in the figure. The orientation of the current-carrying loop is such that it converts the vertical plane of the TEM magnetic field (not shown) to a horizontally polarized magnetic loop as required for the TE10 mode. The loop dimensions are adjusted experimentally for best SWR.

The reader should keep in mind that the discontinuity created by a loop or probe produces higher-order modes. For instance, the ones in Fig. excite TM modes since they create a component of electric field parallel to the waveguide axis. By proper selection of guide dimensions, these higher-order modes can be attenuated while allowing the dominant mode to propagate. Impedance-matching methods are used to minimize the reactive effects associated with the localized higher modes.



Rectangular Waveguide Transition



Setup diagram for SWR measurement

The above setup can be used to measure SWR for coax to waveguide adapter. The coaxial matched termination is not provided.

Observations:
The waveguide to coax adapter can be used to connect waveguide to coax and vice versa

Conclusions and Results: The waveguide to coax adapter can be used to connect waveguide to coax and vice versa.

Experiment: 16

Microwave communications Link

1. Objectives: To establish a microwave communication link.

2. Equipments Required: Gunn diode, power supply, pin diode modulator, Horn antenna, Detector mount, power supply, C.R.O.

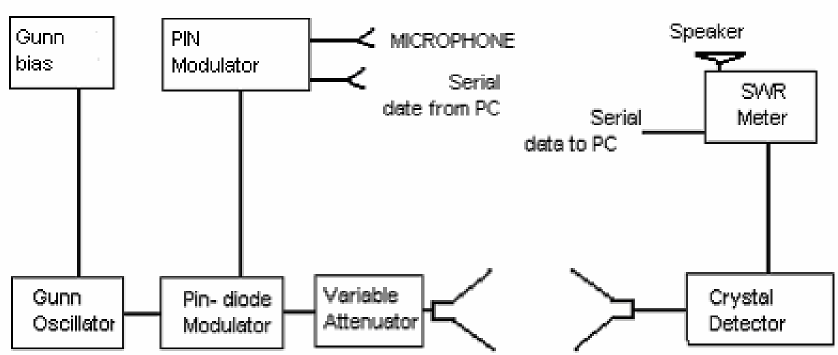
3. Theory: Microwave communication link are an important practical application of microwave technology and are used to carry voice, data, or television signals over distance ranging from intercity link to deep spacecraft.

4. Procedure:

1. Connect power supply to Gunn diode. A square wave is applied to the pin modulator, which in turn passes through the Horn antenna.
2. The microwave link is established between Horn antenna and Detector.
3. To the horn antenna a coaxial waveguide detector mount is attached for the detection of square waveform.
4. Through the detector mount the square waves is displayed on the C.R.O.
5. The SWR meter (Rx) provided has two inputs. One is tuned 1KHz input BNC (VSWR IN) at front panel which is used to read the SWR. The other is a broadband low noise input (IN AUDIO) BNC which can amplify a 20Hz-15KHz signal. This signal is then amplified and fed to comparators which convert the demodulated ASK data to digital waveform. This digital waveform is the converted to serial data for compatibility to PC serial port from USB (OUT at VSWR meter).
6. The Gunn power supply (Tx) has built in 1KHz square waveform for modulating the PIN diode for detecting by SWR meter (Rx). It has a microphone input jack for modulating on PIN diode. It also has a USB connector USB (IN), which converts an incoming serial data from PC serial port to a modulating signal from PIN diode. Press the USB button in Mod. Signal Menu. Adjust the DC Offset for PC communication.
7. After installing comdebug software from CD provided, kindly install CP210xVCPInstaller_x64 (Silicon labs Driver for USB) for Windows 7 64 bit. Connect the USB cable from GVM10 instrument to PC using USB-USB cable supplied and then, switch On the instrument. Open My Computer on PC, then Properties, then Hardware, then Device manager, and then click select ports (com & LPT) and then a new comport will appear: Silicon Labs CP210x USB to UART Bridge (COM2)).
8. In case Silicon Labs CP210x USB to UART Bridge (COM2) appears yellow, it means Silicon labs driver is missing and one needs to install the driver CP210xVCPInstaller_x64 form CD (supplied) for WIN 7 64 bit OS.
9. Connect the USB cables provided to PC and run the comdebug utility. Set up same baud rates at both Tx and Rx. The text typed into Tx window with the header space, space, space, space, enter, enter, message, enter would then be received at Rx window. Open terminal utility programs of Comdebug software in two different computers having one idle comport (virtual). Select com1 (If there are two comports in PC use the unused comport eg., com2) at each terminal. Or else use one PC having two com ports. Connect **Tx (TRANSMITTER) lead** (USB lead) at one of the PC(we will call it Tx PC i.e, PC connected at Tx (Gunn Bias Block) end) at say,

com1 and IN USB port of Tx. Connect **Rx (RECEIVER) lead** at OUT USB of Rx (VSWR meter Block) at comport of other PC (Rx PC). See if you are able to transfer data.

10. Troubleshoot, if you are not being able to send data. Probable problems could be : 1) Mouse already connected to PC is not allowing com port to open – com port failed to open. Disconnect mouse, then restart PC. Open terminal utility using keyboard.2) See if transmitted signal is visible on CRO for a moment. Then try to receive at other com port.
11. Connect Tx lead from comport(Tx PC) to USB in of Tx & connect Rx lead from comport(Rx PC) to USB out of Rx. See if you are able to send data in a simple wireless link at programmed baud rate 9600bps. See what particular setting supports maximum and best data transfer. Select com port settings at **Tx** end, like , baud rate, data bits, parity and stop bit as **19,200, 8, N, 1**. Select com port settings at **Rx** end like, baud rate, data bits, parity and stop bit as **19,200, 8, N, 1**. Also see the effects of parity, data bits and stop bits settings.
12. After opening terminal utility window at Tx PC, type 4 times SPACE BAR in prompt window. Then type2 times ENTER. Then, type any message. Press enter once more after typing your message. Else, simply type any message. Now, click SEND below prompt window.
13. The message received at Rx end shall be displayed on REPLY window. The data send shall be accompanied by garbage data also. But message can be retrieved between two ENTER's (013). **If data is not transferred, change baud rates say, 9600, 4800 etc. on both ends or else adjust DC Offset from Gunn Power supply. If audio is not transferred using microphone adjust DC offset of gunn power supply.**



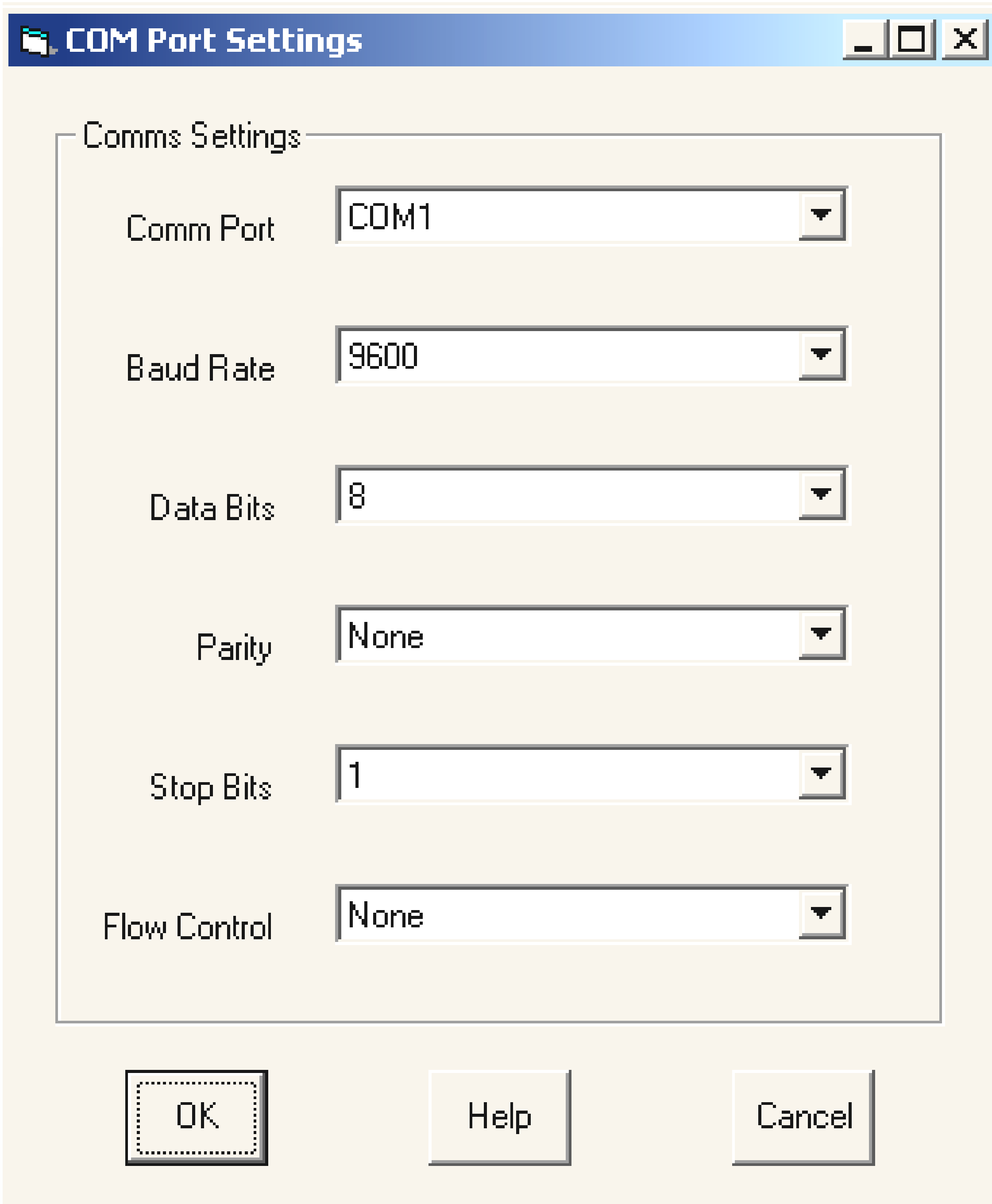
INITIAL SETUP DIAGRAM

Observations:

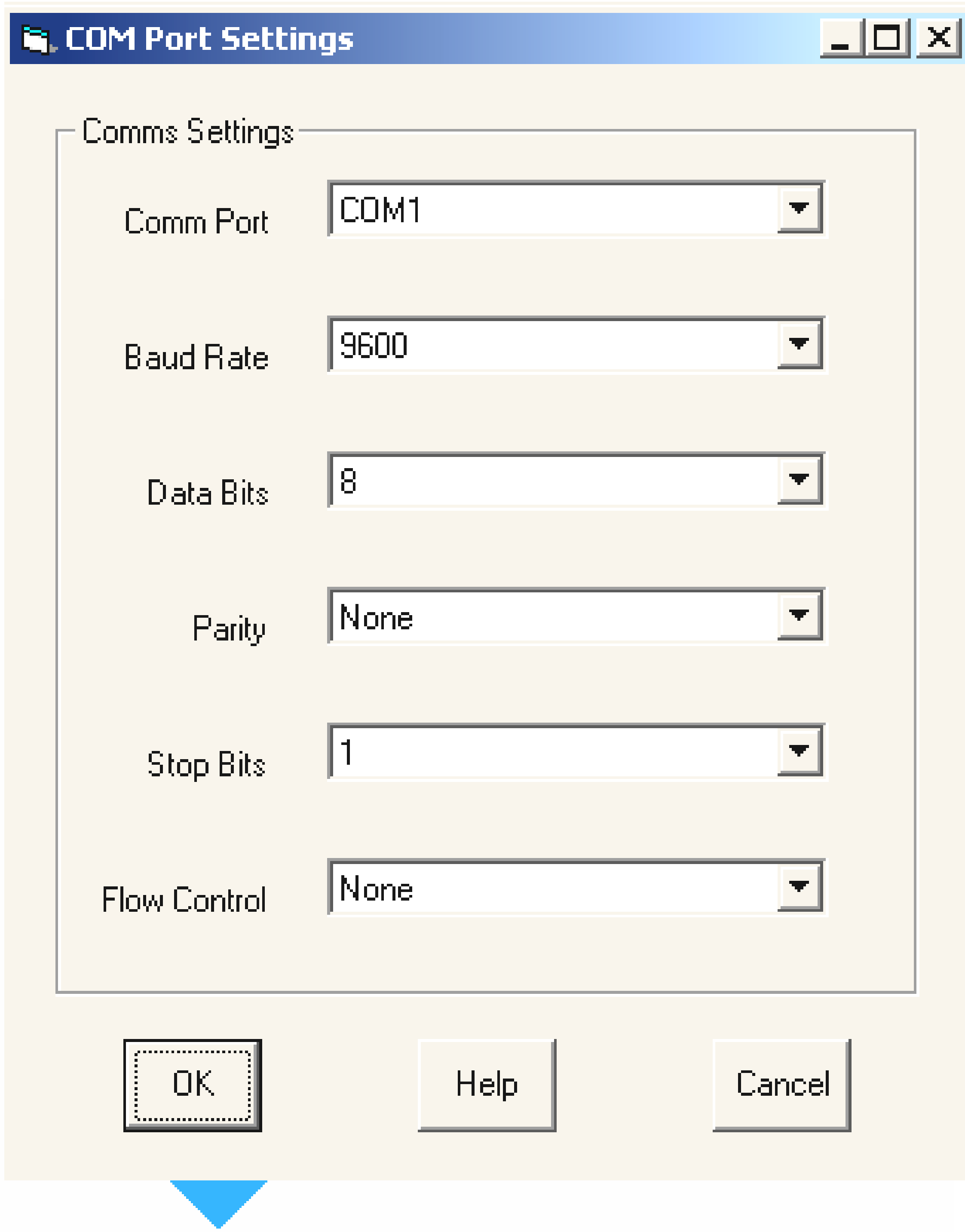
Due to inverse square law of microwave propagation, the received signal at detector decreases sharply. Due to Amplitude modulation the demodulated voice level or analog signal also decreases. The comparators in digital signal fail to detect the signal due to being indistinguishable from noise at larger distances. This is a drawback of using ASK or AM for communication. The other way is to use varactor diodes in Gunn oscillator and do an FM. One will have to use PLL FM demodulators to detect the signal in this case.

Conclusions and Results:

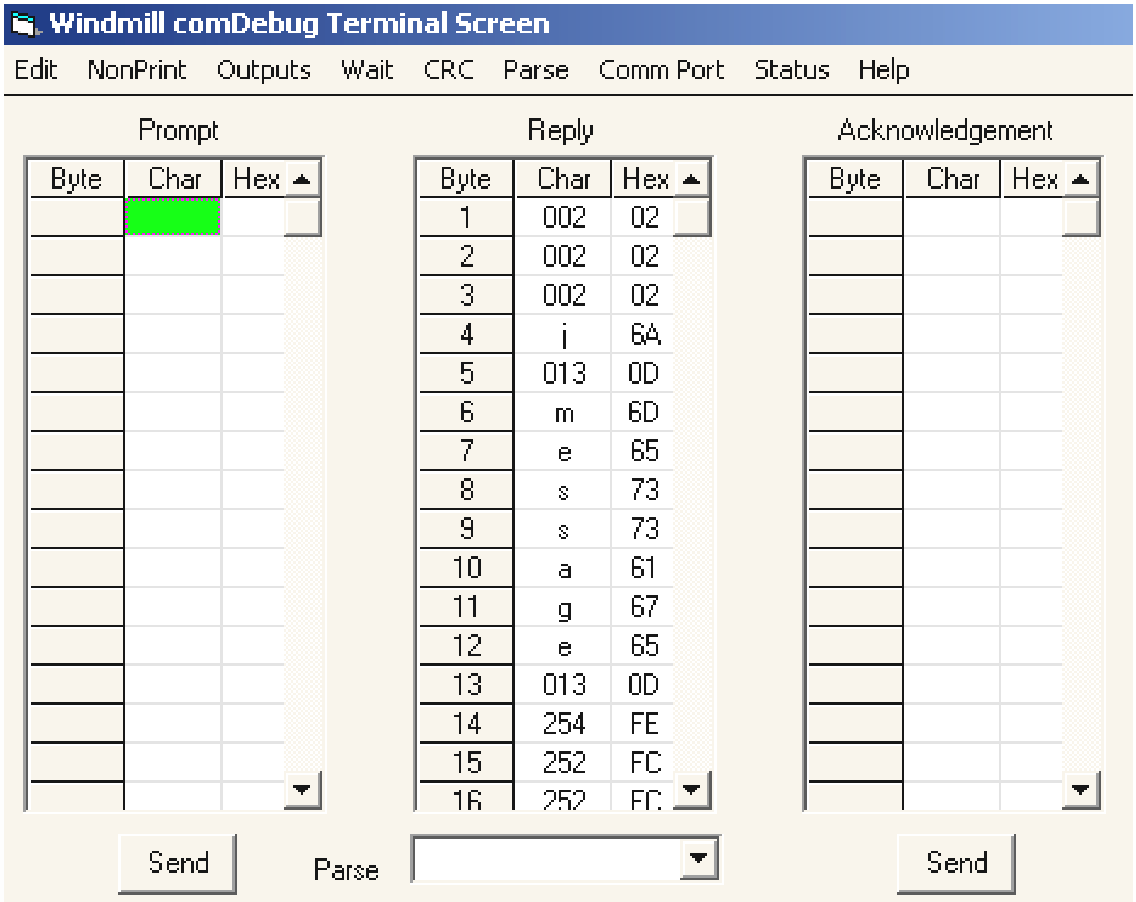
A microwave communication link can be established at X band. It can be used to transfer a square wave signal, Voice signal or PC serial data.



Select protocol – 9,600 or 19,200, 8, N, 1 at Tx end.



Select protocol – 9600 or 19,200, 8, N, 1 at Rx end.



Rx PC window

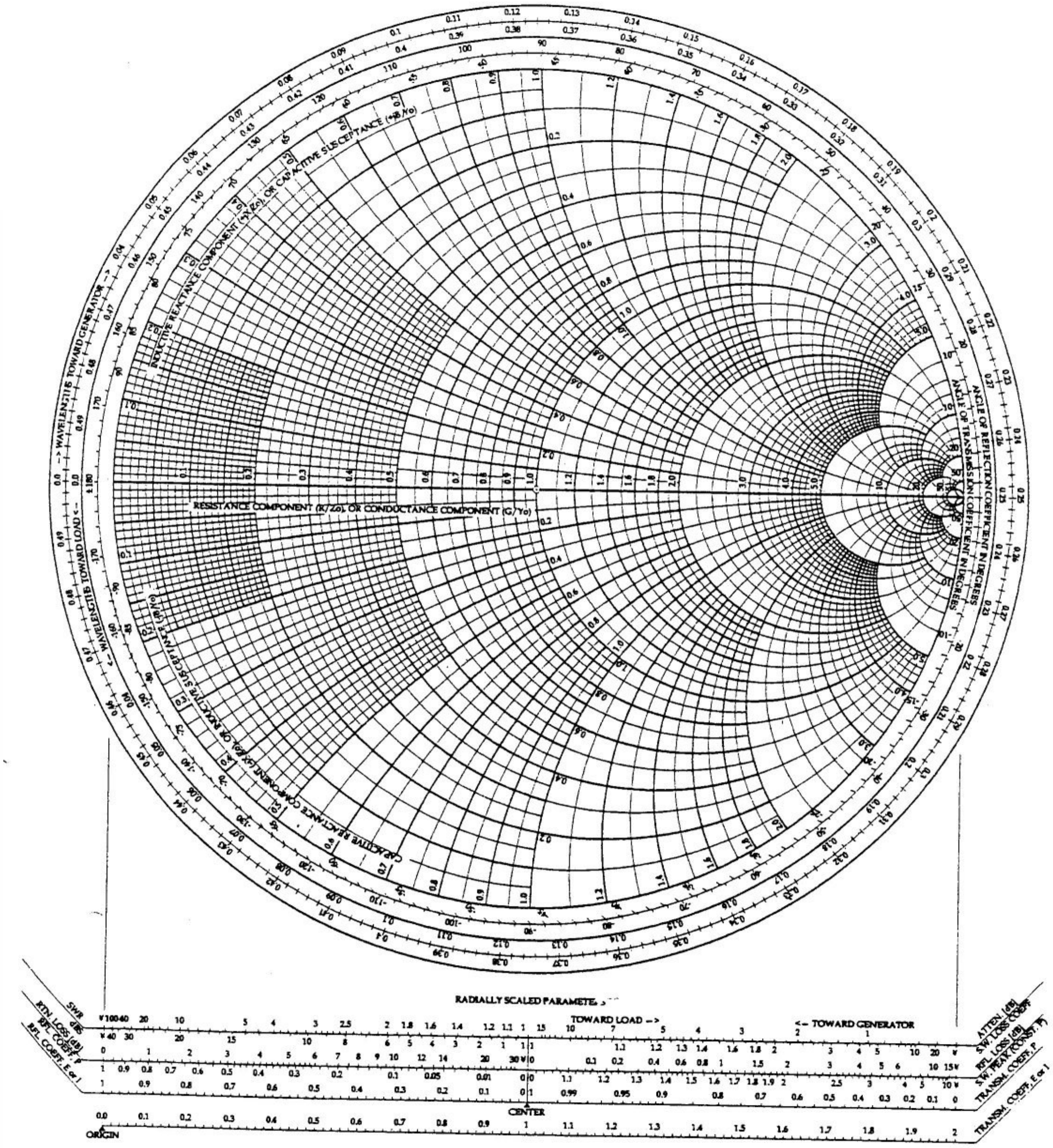
Actual Data sent is "message". The data received has actual transmitted data plus some garbage data. Correct is between first 013 and second 013.

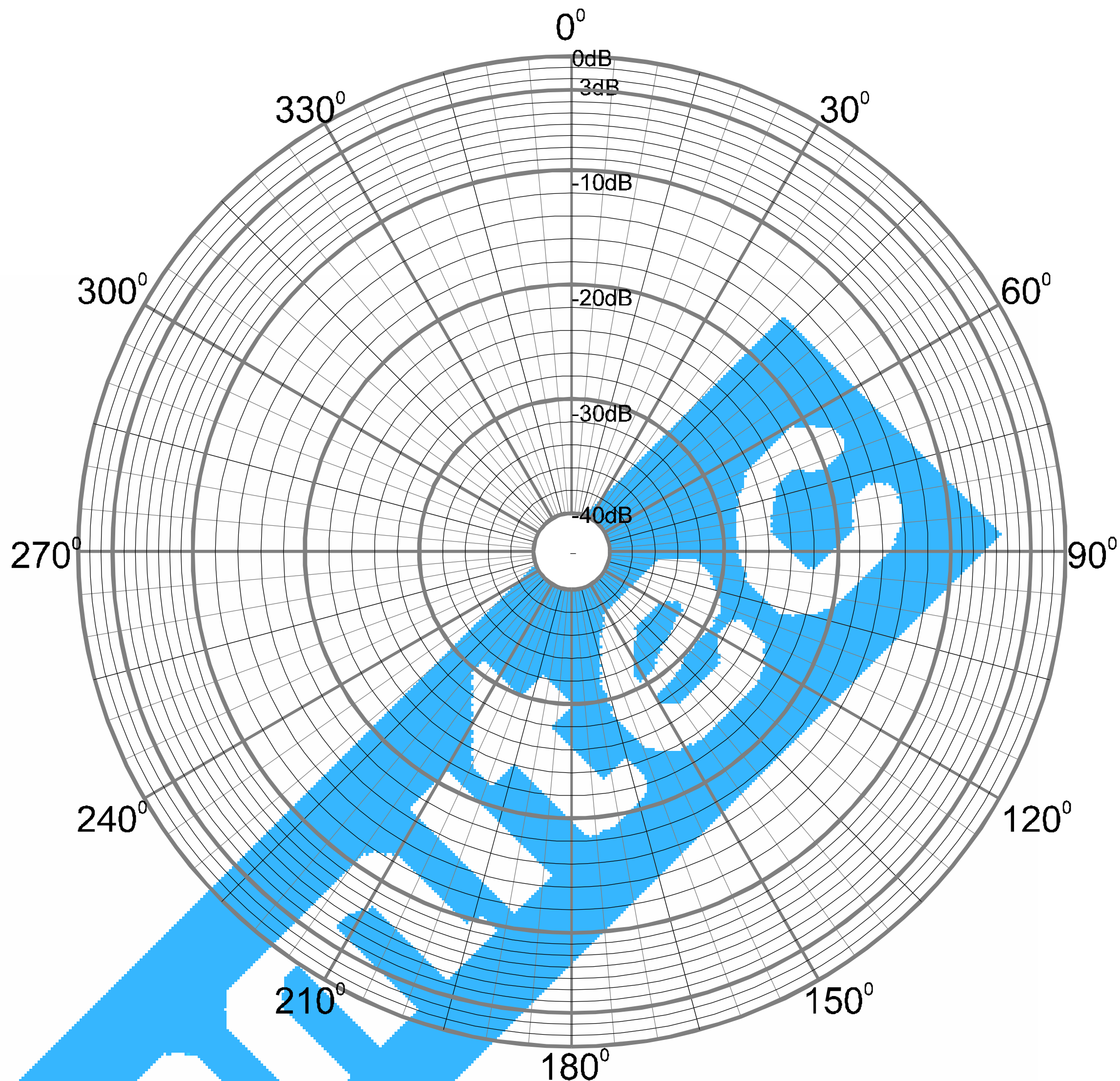
Guide to Data/ Voice communication
1. Keep the detector away by around 5-10cm from bench setup (gunn, + Pin + isolator only, remove other components if any) for link in air.
2. Connect Detector out to VSWR in and set for maximum signal by tuning Gunn Oscillator at around 10 Ghz.
3. Now, disconnect Detector from VSWR in and connect to Audio In.
4. Press the MIC button in Mod. Signal Menu speak at Microphone and listen to voice at VSWR meter Block's speaker.
5. If not adjust DC offset by Up & Down Key.

For data communication
1. Transfer data by connecting USB Transmitter (Tx) and receiver(Rx) lead directly by connecting the lead together without using equipment through BNC Tee connector. Set baud rate as 19,200, parity as None, Flow control as hardware and stop bits as 1 etc as shown in pics in expt.This ensures PC and ports are alright.

2. Connect detector to audio In (already done at step No. 3 above) and connect USB lead for receiver to USB at VSWR meter.
3. Similarly connect USB Tx lead at USB port at GVM10. Press the USB button in Mod. Signal Menu.
4. Make sure at Rx window the input window is clear. If you receive garbage data, clear window by clicking send button at Rx window. Always ensure Rx window is clear. It means Rx is not receiving Noise.
5. Once, Rx window is clear, send data from Tx window by clicking, 4 times space then 2 times enter, fill data data in between as shown in expt and end it by pressing another enter.
6. Now, if you don't receive data at Rx window you can adjust DC offset. Also, try to vary distance between isolator and detector and keep sending data by clicking send button at Tx window at PC. Remove garbage data at Rx window by clicking send button at Rx window everytime you send the data.

The Smith Chart





Antenna Polar Plot

(Linear radial scale)

SCALE FACTOR: 2mm=1dB

Conducted by:.. Checked by:..

POWER CONVERSION TABLE

System: 50 Ω

dBm	mW	dBmV	mV(RMS)	mVp	mVpp	uV(RMS)	dBuV
-130	1.00E-13	-83.01	7.07E-05	1.00E-04	2.00E-04	7.07E-02	-23.01
-129	1.26E-13	-82.01	7.93E-05	1.12E-04	2.24E-04	7.93E-02	-22.01
-128	1.58E-13	-81.01	8.90E-05	1.26E-04	2.52E-04	8.90E-02	-21.01
-127	2.00E-13	-80.01	9.99E-05	1.41E-04	2.83E-04	9.99E-02	-20.01
-125	3.16E-13	-78.01	1.26E-04	1.78E-04	3.56E-04	1.26E-01	-18.01
-124	3.98E-13	-77.01	1.41E-04	2.00E-04	3.99E-04	1.41E-01	-17.01
-123	5.01E-13	-76.01	1.58E-04	2.24E-04	4.48E-04	1.58E-01	-16.01
-122	6.31E-13	-75.01	1.78E-04	2.51E-04	5.02E-04	1.78E-01	-15.01
-121	7.94E-13	-74.01	1.99E-04	2.82E-04	5.64E-04	1.99E-01	-14.01
-120	1.00E-12	-73.01	2.24E-04	3.16E-04	6.32E-04	2.24E-01	-13.01
-119	1.26E-12	-72.01	2.51E-04	3.55E-04	7.10E-04	2.51E-01	-12.01
-118	1.58E-12	-71.01	2.82E-04	3.98E-04	7.96E-04	2.82E-01	-11.01
-117	2.00E-12	-70.01	3.16E-04	4.47E-04	8.93E-04	3.16E-01	-10.01
-116	2.51E-12	-69.01	3.54E-04	5.01E-04	1.00E-03	3.54E-01	-9.01
-115	3.16E-12	-68.01	3.98E-04	5.62E-04	1.12E-03	3.98E-01	-8.01
-114	3.98E-12	-67.01	4.46E-04	6.31E-04	1.26E-03	4.46E-01	-7.01
-113	5.01E-12	-66.01	5.01E-04	7.08E-04	1.42E-03	5.01E-01	-6.01
-112	6.31E-12	-65.01	5.62E-04	7.94E-04	1.59E-03	5.62E-01	-5.01
-111	7.94E-12	-64.01	6.30E-04	8.91E-04	1.78E-03	6.30E-01	-4.01
-110	1.00E-11	-63.01	7.07E-04	1.00E-03	2.00E-03	7.07E-01	-3.01
-109	1.26E-11	-62.01	7.93E-04	1.12E-03	2.24E-03	7.93E-01	-2.01
-108	1.58E-11	-61.01	8.90E-04	1.26E-03	2.52E-03	8.90E-01	-1.01
-107	2.00E-11	-60.01	9.99E-04	1.41E-03	2.83E-03	9.99E-01	-0.01
-106	2.51E-11	-59.01	1.12E-03	1.58E-03	3.17E-03	1.12E+00	0.99
-105	3.16E-11	-58.01	1.26E-03	1.78E-03	3.56E-03	1.26E+00	1.99
-104	3.98E-11	-57.01	1.41E-03	2.00E-03	3.99E-03	1.41E+00	2.99
-103	5.01E-11	-56.01	1.58E-03	2.24E-03	4.48E-03	1.58E+00	3.99
-102	6.31E-11	-55.01	1.78E-03	2.51E-03	5.02E-03	1.78E+00	4.99
-101	7.94E-11	-54.01	1.99E-03	2.82E-03	5.64E-03	1.99E+00	5.99
-100	1.00E-10	-53.01	2.24E-03	3.16E-03	6.32E-03	2.24E+00	6.99
-99	1.26E-10	-52.01	2.51E-03	3.55E-03	7.10E-03	2.51E+00	7.99
-98	1.58E-10	-51.01	2.82E-03	3.98E-03	7.96E-03	2.82E+00	8.99
-97	2.00E-10	-50.01	3.16E-03	4.47E-03	8.93E-03	3.16E+00	9.99
-96	2.51E-10	-49.01	3.54E-03	5.01E-03	1.00E-02	3.54E+00	10.99
-95	3.16E-10	-48.01	3.98E-03	5.62E-03	1.12E-02	3.98E+00	11.99
-94	3.98E-10	-47.01	4.46E-03	6.31E-03	1.26E-02	4.46E+00	12.99
-93	5.01E-10	-46.01	5.01E-03	7.08E-03	1.42E-02	5.01E+00	13.99
-92	6.31E-10	-45.01	5.62E-03	7.94E-03	1.59E-02	5.62E+00	14.99
-91	7.94E-10	-44.01	6.30E-03	8.91E-03	1.78E-02	6.30E+00	15.99
-90	1.00E-09	-43.01	7.07E-03	1.00E-02	2.00E-02	7.07E+00	16.99
-89	1.26E-09	-42.01	7.93E-03	1.12E-02	2.24E-02	7.93E+00	17.99
-88	1.58E-09	-41.01	8.90E-03	1.26E-02	2.52E-02	8.90E+00	18.99
-87	2.00E-09	-40.01	9.99E-03	1.41E-02	2.83E-02	9.99E+00	19.99
-86	2.51E-09	-39.01	1.12E-02	1.58E-02	3.17E-02	1.12E+01	20.99
-85	3.16E-09	-38.01	1.26E-02	1.78E-02	3.56E-02	1.26E+01	21.99
-80	1.00E-08	-33.01	2.24E-02	3.16E-02	6.32E-02	2.24E+01	26.99
-79	1.26E-08	-32.01	2.51E-02	3.55E-02	7.10E-02	2.51E+01	27.99
-78	1.58E-08	-31.01	2.82E-02	3.98E-02	7.96E-02	2.82E+01	28.99
-77	2.00E-08	-30.01	3.16E-02	4.47E-02	8.93E-02	3.16E+01	29.99

dBm	mW	dBmV	mV(RMS)	mVp	mVpp	uV(RMS)	dBuV
-76	2.51E-08	-29.01	3.54E-02	5.01E-02	1.00E-01	3.54E+01	30.99
-75	3.16E-08	-28.01	3.98E-02	5.62E-02	1.12E-01	3.98E+01	31.99
-74	3.98E-08	-27.01	4.46E-02	6.31E-02	1.26E-01	4.46E+01	32.99
-73	5.01E-08	-26.01	5.01E-02	7.08E-02	1.42E-01	5.01E+01	33.99
-72	6.31E-08	-25.01	5.62E-02	7.94E-02	1.59E-01	5.62E+01	34.99
-71	7.94E-08	-24.01	6.30E-02	8.91E-02	1.78E-01	6.30E+01	35.99
-70	1.00E-07	-23.01	7.07E-02	1.00E-01	2.00E-01	7.07E+01	36.99
-69	1.26E-07	-22.01	7.93E-02	1.12E-01	2.24E-01	7.93E+01	37.99
-68	1.58E-07	-21.01	8.90E-02	1.26E-01	2.52E-01	8.90E+01	38.99
-67	2.00E-07	-20.01	9.99E-02	1.41E-01	2.83E-01	9.99E+01	39.99
-66	2.51E-07	-19.01	1.12E-01	1.58E-01	3.17E-01	1.12E+02	40.99
-65	3.16E-07	-18.01	1.26E-01	1.78E-01	3.56E-01	1.26E+02	41.99
-64	3.98E-07	-17.01	1.41E-01	2.00E-01	3.99E-01	1.41E+02	42.99
-63	5.01E-07	-16.01	1.58E-01	2.24E-01	4.48E-01	1.58E+02	43.99
-62	6.31E-07	-15.01	1.78E-01	2.51E-01	5.02E-01	1.78E+02	44.99
-61	7.94E-07	-14.01	1.99E-01	2.82E-01	5.64E-01	1.99E+02	45.99
-60	1.00E-06	-13.01	2.24E-01	3.16E-01	6.32E-01	2.24E+02	46.99
-59	1.26E-06	-12.01	2.51E-01	3.55E-01	7.10E-01	2.51E+02	47.99
-58	1.58E-06	-11.01	2.82E-01	3.98E-01	7.96E-01	2.82E+02	48.99
-57	2.00E-06	-10.01	3.16E-01	4.47E-01	8.93E-01	3.16E+02	49.99
-56	2.51E-06	-9.01	3.54E-01	5.01E-01	1.00E+00	3.54E+02	50.99
-55	3.16E-06	-8.01	3.98E-01	5.62E-01	1.12E+00	3.98E+02	51.99
-54	3.98E-06	-7.01	4.46E-01	6.31E-01	1.26E+00	4.46E+02	52.99
-53	5.01E-06	-6.01	5.01E-01	7.08E-01	1.42E+00	5.01E+02	53.99
-52	6.31E-06	-5.01	5.62E-01	7.94E-01	1.59E+00	5.62E+02	54.99
-51	7.94E-06	-4.01	6.30E-01	8.91E-01	1.78E+00	6.30E+02	55.99
-50	1.00E-05	-3.01	7.07E-01	1.00E+00	2.00E+00	7.07E+02	56.99
-49	1.26E-05	-2.01	7.93E-01	1.12E+00	2.24E+00	7.93E+02	57.99
-48	1.58E-05	-1.01	8.90E-01	1.26E+00	2.52E+00	8.90E+02	58.99
-47	2.00E-05	-0.01	9.99E-01	1.41E+00	2.83E+00	9.99E+02	59.99
-46	2.51E-05	0.99	1.12E+00	1.58E+00	3.17E+00	1.12E+03	60.99
-45	3.16E-05	1.99	1.26	1.78	3.56	1.26E+03	61.99
-44	3.98E-05	2.99	1.41E+00	2.00E+00	3.99E+00	1.41E+03	62.99
-43	5.01E-05	3.99	1.58E+00	2.24E+00	4.48E+00	1.58E+03	63.99
-42	6.31E-05	4.99	1.78E+00	2.51E+00	5.02E+00	1.78E+03	64.99
-41	7.94E-05	5.99	1.99E+00	2.82E+00	5.64E+00	1.99E+03	65.99
-40	1.00E-04	6.99	2.24	3.16	6.32	2.24E+03	66.99
-39	1.26E-04	7.99	2.51E+00	3.55E+00	7.10E+00	2.51E+03	67.99
-38	1.58E-04	8.99	2.82E+00	3.98E+00	7.96E+00	2.82E+03	68.99
-37	2.00E-04	9.99	3.16E+00	4.47E+00	8.93E+00	3.16E+03	69.99
-36	2.51E-04	10.99	3.54E+00	5.01E+00	1.00E+01	3.54E+03	70.99
-35	3.16E-04	11.99	3.98	5.62	11.25	3.98E+03	71.99
-34	3.98E-04	12.99	4.46E+00	6.31E+00	1.26E+01	4.46E+03	72.99
-33	5.01E-04	13.99	5.01E+00	7.08E+00	1.42E+01	5.01E+03	73.99
-32	6.31E-04	14.99	5.62E+00	7.94E+00	1.59E+01	5.62E+03	74.99
-31	7.94E-04	15.99	6.30E+00	8.91E+00	1.78E+01	6.30E+03	75.99
-30	1.00E-03	16.99	7.07	10.00	20.00	7.07E+03	76.99
-29	1.26E-03	17.99	7.93E+00	1.12E+01	2.24E+01	7.93E+03	77.99
-28	1.58E-03	18.99	8.90E+00	1.26E+01	2.52E+01	8.90E+03	78.99
-27	2.00E-03	19.99	9.99E+00	1.41E+01	2.83E+01	9.99E+03	79.99
-26	2.51E-03	20.99	1.12E+01	1.58E+01	3.17E+01	1.12E+04	80.99
-25	3.16E-03	21.99	12.57	17.78	35.57	1.26E+04	81.99
-24	3.98E-03	22.99	1.41E+01	2.00E+01	3.99E+01	1.41E+04	82.99

dBm	mW	dBmV	mV(RMS)	mVp	mVpp	uV(RMS)	dBuV
-23	5.01E-03	23.99	1.58E+01	2.24E+01	4.48E+01	1.58E+04	83.99
-22	6.31E-03	24.99	1.78E+01	2.51E+01	5.02E+01	1.78E+04	84.99
-21	7.94E-03	25.99	1.99E+01	2.82E+01	5.64E+01	1.99E+04	85.99
-20	0.01	26.99	22.36	31.62	63.25	2.24E+04	86.99
-19	1.26E-02	27.99	2.51E+01	3.55E+01	7.10E+01	2.51E+04	87.99
-18	1.58E-02	28.99	2.82E+01	3.98E+01	7.96E+01	2.82E+04	88.99
-17	2.00E-02	29.99	3.16E+01	4.47E+01	8.93E+01	3.16E+04	89.99
-16	2.51E-02	30.99	3.54E+01	5.01E+01	1.00E+02	3.54E+04	90.99
-15	0.03	31.99	39.76	56.23	112.47	3.98E+04	91.99
-14	3.98E-02	32.99	4.46E+01	6.31E+01	1.26E+02	4.46E+04	92.99
-13	5.01E-02	33.99	5.01E+01	7.08E+01	1.42E+02	5.01E+04	93.99
-12	6.31E-02	34.99	5.62E+01	7.94E+01	1.59E+02	5.62E+04	94.99
-11	7.94E-02	35.99	6.30E+01	8.91E+01	1.78E+02	6.30E+04	95.99
-10	0.10	36.99	70.71	100.00	200.00	7.07E+04	96.99
-9	1.26E-01	37.99	7.93E+01	1.12E+02	2.24E+02	7.93E+04	97.99
-8	1.58E-01	38.99	8.90E+01	1.26E+02	2.52E+02	8.90E+04	98.99
-7	2.00E-01	39.99	9.99E+01	1.41E+02	2.83E+02	9.99E+04	99.99
-6	2.51E-01	40.99	1.12E+02	1.58E+02	3.17E+02	1.12E+05	100.99
-5	0.32	41.99	125.74	177.83	355.66	1.26E+05	101.99
-4	3.98E-01	42.99	1.41E+02	2.00E+02	3.99E+02	1.41E+05	102.99
-3	5.01E-01	43.99	1.58E+02	2.24E+02	4.48E+02	1.58E+05	103.99
-2	6.31E-01	44.99	1.78E+02	2.51E+02	5.02E+02	1.78E+05	104.99
-1	7.94E-01	45.99	1.99E+02	2.82E+02	5.64E+02	1.99E+05	105.99
0	1.00	46.99	223.61	316.23	632.46	2.24E+05	106.99
1	1.26	47.99	250.89	354.81	709.63	2.51E+05	107.99
2	1.58	48.99	281.50	398.11	796.21	2.82E+05	108.99
3	2.00	49.99	315.85	446.68	893.37	3.16E+05	109.99
4	2.51	50.99	354.39	501.19	1002.37	3.54E+05	110.99
5	3.16	51.99	397.64	562.34	1124.68	3.98E+05	111.99
6	3.98	52.99	446.15	630.96	1261.91	4.46E+05	112.99
7	5.01	53.99	500.59	707.95	1415.89	5.01E+05	113.99
8	6.31	54.99	561.67	794.33	1588.66	5.62E+05	114.99
9	7.94	55.99	630.21	891.25	1782.50	6.30E+05	115.99
10	10.00	56.99	707.11	1000.00	2000.00	7.07E+05	116.99
11	12.59	57.99	793.39	1122.02	2244.04	7.93E+05	117.99
12	15.85	58.99	890.19	1258.93	2517.85	8.90E+05	118.99
13	19.95	59.99	998.81	1412.54	2825.08	9.99E+05	119.99
14	25.12	60.99	1120.69	1584.89	3169.79	1.12E+06	120.99
15	31.62	61.99	1257.43	1778.28	3556.56	1.26E+06	121.99
16	39.81	62.99	1410.86	1995.26	3990.52	1.41E+06	122.99
17	50.12	63.99	1583.01	2238.72	4477.44	1.58E+06	123.99
18	63.10	64.99	1776.17	2511.89	5023.77	1.78E+06	124.99
19	79.43	65.99	1992.90	2818.38	5636.77	1.99E+06	125.99
20	100.00	66.99	2236.07	3162.28	6324.56	2.24E+06	126.99
21	125.89	67.99	2508.91	3548.13	7096.27	2.51E+06	127.99
22	158.49	68.99	2815.04	3981.07	7962.14	2.82E+06	128.99
23	199.53	69.99	3158.53	4466.84	8933.67	3.16E+06	129.99
24	251.19	70.99	3543.93	5011.87	10023.74	3.54E+06	130.99
25	316.23	71.99	3976.35	5623.41	11246.83	3.98E+06	131.99
26	398.11	72.99	4461.54	6309.57	12619.15	4.46E+06	132.99
27	501.19	73.99	5005.93	7079.46	14158.92	5.01E+06	133.99
28	630.96	74.99	5616.75	7943.28	15886.56	5.62E+06	134.99
29	794.33	75.99	6302.10	8912.51	17825.02	6.30E+06	135.99

dBm	mW	dBmV	mV(RMS)	mVp	mVpp	uV(RMS)	dBuV
30	1000.00	76.99	7071.07	10000.00	20000.00	7.07E+06	136.99

Units:

E or V = Volts (can use either, as per convention standards)
R = Ohms (impedence/resitance)
P = Power (Watts, dBm, mW, or W)
dB = decibel ratio (log_{10}) - all log's will be to base 10
W = Watts = (E.E)/R
u = micro = 10E-6 (for all units - E, R, P, or V)
m = milli = 10E-3 (for all units - E, R, P, or V)
dBm = decibel ratio of Watts W to one milliwatt
= $10log_{10}$ (W/mW)
dBuV = decibel ratio of Volts to one microvolt
= $20log_{10}$ {V/uV} or, for example, {E/uV}

Conversions for 50 ohm systems:

1. To convert dBm to dBuV add 107 dB: dBuV = dBm + 107 dB
2. To conver dBuV to dBm subtract 107 dB: dBm = dBuV - 107 dB

Proof:
Remember, 0 dBm = 1 mW (milliwatt) = 0.001 Watts

E = Square Root of (W x R) - assume R = 50 Ohms
Note: for dBm our reference will be 1 mW
E = Square Root (1mW* x 50 ohms) = 0.224 Volts
dBuV = 20 log_{10} (0.224 Volts/1uV*) = 107 dBuV
Therefore, 107 dBuV = 0 dBm in a 50 W system
Using this as the scale factor: dBm + 107 dB = dBuV
* Must be entered in Watts (0.001 or 1x10-3 W = 1 mW)
* Must be entered in Volts (0.000001 or 1x10E-6 V = 1uV)

VSWR = V_{max}/V_{min} = ($V_{forward}$ + $V_{reverse}$)/$V_{forward}$- $V_{reverse}$)

Reflection Coefficient = $V_{reverse}/V_{forward}$

The **return loss** of a load or S-Parameter S_{11} is the magnitude of the reflection coefficient expressed in decibels is also equal to difference between the incident power P_i (in dBm) and the reflected power P_r (in dBm),

Return loss = -20 x log [mag(Γ)] also $RL(\mathrm{dB}) = P_\mathrm{i}(\mathrm{dBm}) - P_\mathrm{r}(\mathrm{dBm})$ = S_{11}

$$\Gamma = \frac{VSWR - 1}{VSWR + 1} \qquad RL = -20\log\left[\frac{VSWR - 1}{VSWR + 1}\right] \qquad ML = -10\log\left\{1 - \left[\frac{VSWR - 1}{VSWR + 1}\right]^2\right\}$$

$$VSWR = \frac{1 + \Gamma}{1 - \Gamma} \qquad RL = -20\log(\Gamma) \qquad ML = -10\log\left(1 - \Gamma^2\right)$$

$$\Gamma = 10^{\frac{-RL}{20}} \qquad VSWR = \frac{1 + 10^{\frac{-RL}{20}}}{1 - 10^{\frac{-RL}{20}}} \qquad ML = -10\log\left[1 - \left(10^{\frac{-RL}{20}}\right)^2\right]$$

A good rule of thumb:
VSWR 1.5:1 = 14 dB Return Loss
VSWR 1.9:1 = 10 dB Return Loss
VSWR 3.0:1 = 6.0 dB Return Loss
VSWR 1:1 = Perfect Match
VSWR Infinity:1 = Short/Open Circuit

The mismatch of a load Z_L to a source Z_0 results in a reflection coefficient of:

$\Gamma=(Z_L-Z_0)/(Z_L+Z_0)$

For $Z_L<Z_0$: $VSWR=Z_0/Z_L$

For $Z_L>Z_0$: $VSWR=Z_L/Z_0$

Just Remember VSWR is always greater than 1. So mismatch of 50 Ohms to 75 Ohms system is VSWR 1.5:1.

THE EFFECT OF VSWR ON TRANSMITTED POWER

VSWR	VSWR (dB)	RETURN LOSS (dB)	TRANS. LOSS (dB)	VOLT. REFL. COEFF.	POWER TRANS. (%)	POWER REFL. (%)
1.00	.0	∞	.000	.00	100.0	.0
1.01	.1	46.1	.000	.00	100.0	.0
1.02	.2	40.1	.000	.01	100.0	.0
1.03	.3	36.6	.001	.01	100.0	.0
1.04	.3	34.2	.002	.02	100.0	.0
1.05	.4	32.3	.003	.02	99.9	.1
1.06	.5	30.7	.004	.03	99.9	.1
1.07	.6	29.4	.005	.03	99.9	.1
1.08	.7	28.3	.006	.04	99.9	.1
1.09	.7	27.3	.008	.04	99.8	.2
1.10	.8	26.4	.010	.05	99.8	.2
1.11	.9	25.7	.012	.05	99.7	.3
1.12	1.0	24.9	.014	.06	99.7	.3
1.13	1.1	24.3	.016	.06	99.6	.4
1.14	1.1	23.7	.019	.07	99.6	.4
1.15	1.2	23.1	.021	.07	99.5	.5
1.16	1.3	22.6	.024	.07	99.5	.5
1.17	1.4	22.1	.027	.08	99.4	.6
1.18	1.4	21.7	.030	.08	99.3	.7
1.19	1.5	21.2	.033	.09	99.2	.8
1.20	1.6	20.8	.036	.09	99.2	.8
1.21	1.7	20.4	.039	.10	99.1	.9
1.22	1.7	20.1	.043	.10	99.0	1.0
1.23	1.8	19.7	.046	.10	98.9	1.1
1.24	1.9	19.4	.050	.11	98.9	1.1
1.25	1.9	19.1	.054	.11	98.8	1.2
1.26	2.0	18.8	.058	.12	98.7	1.3
1.27	2.1	18.5	.062	.12	98.6	1.4
1.28	2.1	18.2	.066	.12	98.5	1.5
1.29	2.2	17.9	.070	.13	98.4	1.6
1.30	2.3	17.7	.075	.13	98.3	1.7
1.32	2.4	17.2	.083	.14	98.1	1.9
1.34	2.5	16.8	.093	.15	97.9	2.1
1.36	2.7	16.3	.102	.15	97.7	2.3
1.38	2.8	15.9	.112	.16	97.5	2.5
1.40	2.9	15.6	.122	.17	97.2	2.8
1.42	3.0	15.2	.133	.17	97.0	3.0
1.44	3.2	14.9	.144	.18	96.7	3.3
1.46	3.3	14.6	.155	.19	96.5	3.5
1.48	3.4	14.3	.166	.19	96.3	3.7
1.50	3.5	14.0	.177	.20	96.0	4.0
1.52	3.6	13.7	.189	.21	95.7	4.3
1.54	3.8	13.4	.201	.21	95.5	4.5
1.56	3.9	13.2	.213	.22	95.2	4.8
1.58	4.0	13.0	.225	.22	94.9	5.1
1.60	4.1	12.7	.238	.23	94.7	5.3
1.62	4.2	12.5	.250	.24	94.4	5.6

VSWR	VSWR (dB)	RETURN LOSS (dB)	TRANS. LOSS (dB)	VOLT. REFL. COEFF.	POWER TRANS. (%)	POWER REFL. (%)
1.64	4.3	12.3	.263	.24	94.1	5.9
1.66	4.4	12.1	.276	.25	93.8	6.2
1.68	4.5	11.9	.289	.25	93.6	6.4
1.70	4.6	11.7	.302	.26	93.3	6.7
1.72	4.7	11.5	.315	.26	93.0	7.0
1.74	4.8	11.4	.329	.27	92.7	7.3
1.76	4.9	11.2	.342	.28	92.4	7.0
1.78	5.0	11.0	.356	.28	92.1	7.9
1.80	5.1	10.9	.370	.29	91.8	8.2
1.82	5.2	10.7	.384	.29	91.5	8.5
1.84	5.3	10.6	.398	.30	91.3	8.7
1.86	5.4	10.4	.412	.30	91.0	9.0
1.88	5.5	10.3	.426	.31	90.7	9.3
1.90	5.6	10.2	.440	.31	90.4	9.6
1.92	5.7	10.0	.454	.32	90.1	9.9
1.94	5.8	9.9	.468	.32	89.8	10.2
1.96	5.8	9.8	.483	.32	89.5	10.5
1.98	5.9	9.7	.497	.33	89.2	10.8
2.00	6.0	9.5	.512	.33	88.9	11.1
2.50	8.0	7.4	.881	.43	81.6	18.4
3.00	9.5	6.0	1.249	.50	75.0	25.0
3.50	10.9	5.1	1.603	.56	69.1	30.9
4.00	12.0	4.4	1.938	.60	64.0	36.0
4.50	13.1	3.9	2.255	.64	59.5	40.5
5.00	14.0	3.5	2.553	.67	55.6	44.4
5.50	14.8	3.2	2.834	.69	52.1	47.9
6.00	15.6	2.9	3.100	.71	49.0	51.0
6.50	16.3	2.7	3.351	.73	46.2	53.8
7.00	16.9	2.5	3.590	.75	43.7	56.2
7.50	17.5	2.3	3.817	.76	41.5	58.5
8.00	18.1	2.2	4.033	.78	39.5	60.5
8.50	18.6	2.1	4.240	.79	37.7	62.3
9.00	19.1	1.9	4.437	.80	36.0	64.0
9.50	19.6	1.8	4.626	.81	34.5	65.5
10.00	20.0	1.7	4.807	.82	33.1	66.9
11.00	20.8	1.6	5.149	.83	30.6	69.4
12.00	21.6	1.5	5.466	.85	28.4	71.6
13.00	22.3	1.3	5.762	.86	26.5	73.5
14.00	22.9	1.2	6.040	.87	24.9	75.1
15.00	23.5	1.2	6.301	.88	23.4	76.6
16.00	24.1	1.1	6.547	.88	22.1	77.9
17.00	24.6	1.0	6.780	.89	21.0	79.0
18.00	25.1	1.0	7.002	.89	19.9	80.1
19.00	25.6	.9	7.212	.90	19.0	81.0
20.00	26.0	.9	7.413	.90	18.1	81.9
25.00	28.0	.7	8.299	.92	14.8	85.2
30.00	29.5	.6	9.035	.94	12.5	87.5

AMITEC ELECTRONICS LTD.

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