TE0320 - MICROWAVE COMMUNICATION LAB

Laboratory Manual

DEPARTMENT OF
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1. STUDY OF MICROWAVE COMPONENTS

AIM

To study the microwave components in detail.

RECTANGULAR WAVE GUIDE

Wave guides are manufactured to the highest mechanical and electrical standards and mechanical tolerances.

L and S band wave guides are fabricated by precision brazing of brass-plates and all other wave guides are in extrusion quality.

W.G. sections of specified length can be supplied with flanges, painted outside and silver or gold plated in side.

SPECIFICATIONS X Band

EIA No. : WR - 90
Frequency : 8.2 - 12.4 GHZ
Width : 2.286cm Height : 1.1016cm Width : 2.54 cm
Height : 1.27cm ± Tol. (µm) : 7.6 Material : Brass/Copper.

FIXED ATTENUATORS

Series 5000 fixed Attenuators are meant for inserting a known attenuation in a wave guide system. These consists of a lossy vane inserted in a section of wave guide, flanged on both ends. These are useful for isolation of wave guide circuits, padding and extending the range of measuring equipments.
Fixed Attenuators are available for 3, 6 or 10 dB attenuation values, but any attenuation value between 0 and 30 dB can be provided.

**SPECIFICATIONS**

Model No: X-5000 / Frequency: 8.12 - 12.4 GHz / Attenuation (dB): 3, 6, 10 / Calibration Accuracy: ± 0.2 dB / Average Power: 2 W / Max VSWR: 1.10 / Max Insertion Loss (dB): 0.2 / WG Type: WG – 90 / Flange Type (UG/U): 39.

A precision built probe carriage has a centimeter scale with a vernier reading of 0.1 mm least count and a dial gauge can be mounted easily if precise readings are required.

Model No. : X - 6051  
Freq (Ghz) : 8.2 - 12.4  
Max Residual VSWR : 1.01  
WG type (WR-) : 90  
Flange Type (UG-/U) : 39

**TUNABLE PROBE**

Model 6055 Tunable probe is designed for use with model 6051 slotted sections. These are meant for exploring the energy of the EF in a suitably fabricated section of wave guide.

The depth of penetration into a wave guide - section is adjustable by the knob of the probe. The tip pick up the RF power from the line and this power is rectified by crystal detector, which is then fed to the VSWR meter or indicating instrument.

Model No. : X6055 / Freq (Ghz) : 8.2 - 12.4 / Output Connector : BNC(F) / Detector : IN23.
WAVE GUIDE DETECTOR MOUNT (TUNABLE)

Model 4051 Tunable Detector Mount is simple and easy to use instrument for detecting microwave power thru’a suitable detector. It consists of a detector crystal mounted in a section of a Wave guide and shorting plunger for matching purpose. The output from the crystal may be fed to an indicating instrument. In K and R bands detector mounts the plunger is driven by a micrometer.

Model No.    :  X - 4051  
Freq. Range (Ghz)   :  8.2 - 12.4  
O/P Connector   :  BNC (F)  
Wave guide type (WR-) :  90  
Flange Type (UG/U)  :  39  
Detector   :  IN23

KLYSTRON MOUNT

Model 2051 Klystron mounts are meant for mounting corresponding Klystrons such as 2K25, 723A/B, 726A or RK - 5976 etc.

These consists of a section of wave guide flanged on one end and terminated with a movable short on the other end. An octal base with cable is provided for Klystron.

Model No. : X – 2051/ Freq. Range (GHz)  8.2 - 12.4/ WG Type (WR-) : 90  
Flange Type (UG-/U): 39

CIRCULATORS

Model 6021 and 6022 are T and Y types of three port circulators respectively. These are precisely machined and assembled to get the desired specifications. Circulators are matched three port devices and these are meant for allowing Microwave energy to flow in clockwise direction with negligible loss but almost no transmission in the anti-clockwise direction.

Model No.    :  X - 6021  
Frequency Range (Ghz)   :  8.6 - 10.6 or 10.2 - 12.2  
Min. Isolation (dB)  :  20  
Max. Insertion Loss (dB) :  0.4  
Max. VSWR   :  1.20
SLIDE SCREW TUNERS

Model 4041 slide screw tuners are used for matching purposes by changing the penetration and position of a screw in the slot provided in the centre of the wave guide.

These consists of a section of wave guide flanged on both ends and a thin slot is provided in the broad wall of the Wave guide. A carriage carrying the screw, is provided over the slot. A VSWR upto 20 can be tuned to a value less than 1.02 at certain frequency.

Model No. : X – 4041/ Freq. Range (Ghz) : 8.2 - 12.4/WG Type (WR-) : 90
Flange type (UG/U) : 39

MULTIHOLE DIRECTIONAL COUPLERS

Model 6000 series Multihole directional couplers are useful for sampling a part of Microwave energy for monitoring purposes and for measuring reflections and impedance. These consists of a section of Wave guide with addition of a second parallel section of wave guide thus making it a four port network. However the fourth port is terminated with a matched load. These two parallel sections are coupled to each other through many holes, almost to give uniform coupling; minimum frequency sensitivity and high directivity. These are available in 3,6,10,20 and 40dB coupling.

Model No. : X - 6003
Frequency Range (Ghz) : 8.2 - 12.4
Coupling (dB) : 3,10,20,40
Directivity (dB) : 35
Wave guide type (WR-) : 90
Flange type (UG/U) : 39

E PLANE TEE

Model 3061 E - plane tee are series type T - junction and consists of three section of wave guide joined together in order to divide or compare power levels. The signal entering the first port of this T - junction will be equally dividing at second and third ports of the same magnitude but in opp. phase

Model No. : X - 3061
Frequency Range (Ghz) : 8.2 - 12.4
WG Type (WR-) : 90
Flange Type (UG/U) : 39
H - PLANT TEE

Model 3065 H - Plane Tee are shunt type T - junction for use in conjunction with VSWR meters, frequency - meters and other detector devices. Like in E-plane tee, the signal fed through first port of H - plane Tee will be equally divided in magnitude at second and third ports but in same phase.

Model No.    : X - 3065
Frequency Range (GHz) : 8.2 - 12.4
WG Type (WR-)        : 90
Flange Type (UG-/U)    : 39

MAGIC TEE

Model 3045 E - H Tee consists of a section of wave guide in both series and shunt wave guide arms, mounted at the exact midpoint of main arm. Both ends of the section of wave guide and both arms are flanged on their ends. These Tees are employed in balanced mixers, AFC circuits and impedance measurement circuits etc. This becomes a four terminal device where one terminal is isolated from the input terminal.

Model No.    : X - 3045
Frequency Range (Ghz) : 8.2 - 12.4
WG Type (WR-)        : 90
Flange Type (UR-/U)    : 39

MOVABLE SHORT

Model 4081 movable shorts consists of a section of waveguide, flanged on one end and terminated with a movable shorting plunger on the other end. By means of this noncontacting type plunger, a reflection co-efficient of almost unity may be obtained.

Model No.    : X - 4081
Frequency Range (GHz) : 8.2 - 12.4
WG Type (WR-)        : 90
Flange Type (UG-/U)    : 39
MATCHED TERMINATION

Model 4000 are low power and non-reflective type of terminations. It consists of a small and highly dissipative taper flap mounted inside the centre of a section of wave guide. Matched Terminations are useful for USWR measurement of various waveguide components. These are also employed as dummy and as a precise reference loads with Tee junctions, directional couplers and other similar dividing devices.

Model No. : X - 4000, Freq. Range (Ghz) : 8.2 - 12.4 Max VSWR : 1.04
Avg Power : 2W, WG Type (WR-) 90,
Flange Type (UG-/U) : 39

PYRAMIDAL WAVEGUIDE HORN ANTENNA

Model 5041 pyramidal Wave guide Horn antenna consists of waveguide joined to pyramidal section fabricated from brass sheet. The pyramidal section shapes the energy to concentrate in a specified beam. Wave guide horns are used as feed horns as radiators for reflectors and lenses and as a pickup antenna for receiving microwave power.

Model No. : X - 5041
Frequency Range (Ghz) : 8.2 - 12.4
Max VSWR : 1.20
WG Type (WR-) : 90
Flange Type (UG-/U) : 39

GUNN OSCILLATORS

Model 2151 Gunn Oscillators are solid state microwave energy generators. These consists of waveguide cavity flanged on one end and micrometer driven plunger fitted on the other end. A gunn-diode is mounted inside the Wave guide with BNC (F) connector for DC bias. Each Gunn oscillillator is supplied with calibration certificate giving frequency vs micrometer reading.

Model No. : X - 2152, Freq : 8.2 - 12.4 Ghz,
Min output power : 10 MW
WG Type (WR-) : 90 Flange Type (UG-/U) : 39
PIN MODULATORS

Model 451 pin modulators are designed to modulate the cw output of Gunn Oscillators. It is operated by the square pulses derived from the UHF(F) connector of the Gunn power supply. These consists of a pin diode mounted inside a section of Wave guide flanged on it’s both end. A fixed attenuation vane is mounted inside at the input to protect the oscillator.

Model No.    : X - 451
Frequency Range (Ghz) : 8.3 - 12.4
Max RF Power  : 1W
WG Type (WR-)        : 90
Flange Type (GHz)      : 39

GUNN POWER SUPPLY

Model X-110 Gunn Power supply comprises of an regulated DC power supply and a square wave generator, designed to operate Gunn-Oscillator model 2151 or 2152, and pin modulators model 451 respectively. The DC voltage is variable from 0 - 10V. The front panel meter monitors the gunn voltage and the current drawn by the Gunn diode. The square wave of generator is variable from 0 - 10V, in amplitude and 900 - 1100 Hz in frequency. The power supply has been so designed to protect Gunn diode from reverse voltage application over transient and low frequency oscillations by the negative resistance of the Gunn-diode.

SPECIFICATIONS

Amplifier Type   : High gain tuned at one frequency
Frequency        : 1000 Hz ± 2%
Sensitivity      : 0.1 microvolt at 200 for full scale
Band width       : 25 - 30 cps
Range            : 70dB min in 10 dB steps
Scale selector   : Normal Expand
Gain control     : ‘Coarse’ & ‘Fine’
Mains power      : 230V, 50Hz
ISOLATORS

The three port circulators Model 6021 may be converted into isolators by terminating one of its port into matched load. These will work over the frequency range of circulators. These are well matched devices offering low forward insertion loss and high reverse isolation.

Model No. : X - 6022
Frequency Range (GHz) : 8.6 - 10.6 or 10.2 - 12.2
Min Isolation (dB) : 20
Max Insertion Loss (dB) : 0.4
Max VSWR : 1.20

RESULT

Thus all the microwave components were studied in detail.
REVIEW QUESTIONS

1. What is microwave?
2. Mention the frequency band for a millimeter wave.
3. List some of IEEE microwave frequency bands.
4. List some of characteristic feature of microwave.
5. List some of the application of microwave technology.
6. Draw a simple microwave system.
7. What are waveguide ’Tees’?
8. List the basic type of waveguide tees.
9. What is an isolator?
10. What is a circulator?
11. What is a directional coupler?
12. What is velocity modulation?
13. Mention the Principle used in Klystron?
14. When the o/p power of reflex klystron maximum?
15. What is meant by attenuator?
2. MODE CHARACTERISTICS OF REFLEX KLYSTRON

AIM

To study the Mode Characteristics of Reflex Klystron.

APPARATUS REQUIRED:

Klystron Power Supply, Klystron with mount, Isolator, Frequency meter, Variable Attenuator, Slotted section with Probe carriage, CRO, Movable Short.

THEORY

Klystron is a microwave vacuum tube employing velocity modulation. These electrons move towards the repeller (ie) the electrons leaving the cavity during the positive half cycle are accelerated while those during negative half cycle are decelerated. The faster ones penetrate further while slower ones penetrate lesser in the field of repeller voltage. But, faster electrons leaving the cavity take longer time to return and hence catch up with slower ones. In the cavity the electrons bunch and interact with the voltage between the cavity grids.

It consists of an electron gun producing a collimated electron beam.

It bunches pass through grids at time the grid potentials is such that electrons are decelerated they give by energy. The electrons are then collected by positive cavity wall near cathode. To protect repeller from damage, repeller voltage is applied before accelerating voltage.

PROCEDURE

i) Assemble the components as shown in fig.
ii) After following the necessary precautions, the Klystron Power Supply is switched ON.
iii) To obtain peak voltage, the attenuator is positioned at it’s minimum attenuation.
iv) Vary the repeller voltage from it’s maximum negative value and increase it in steps on N and record output power and frequency.
v) The frequency is measured by tuning the basic frequency meter to have a dip in the output voltage each time.
vi) The frequency meter is detuned before measuring the output power each time.
vii) The mode characteristics of Reflex Klystron is plotted. (i.e. Output Voltage Vs Repeller voltage and Frequency Vs Repeller voltage)

BASIC PRECAUTIONS

1. During operation of Klystron, repeller does not carry any current and as such it may severely be damaged by electron bombardment. To protect repeller from such damage, the repeller negative voltage is always applied before anode voltage.
2. The repeller voltage should be varied in one direction to avoid hysteresis is in klystrons
3. The heater voltage should be applied first and cooling should be provided simultaneously after some time other voltages should be applied taking precaution(i).

4. While measuring power, the frequency meter should be detained each time because there is a dip in the output power when the frequency is tuned.

5. To avoid loading of the klystron an isolator/attenuation should invariably be used between klystron and the rest of the set-up.

**CALCULATIONS**

(i) Knowing mode top voltages of two adjacent modes, mode numbers of the modes is computed from the equation,

\[
\frac{N_2}{N_1} = \frac{V_1}{V_2} = \frac{(n+1)+3/4}{n+3/4}
\]

where

\(V_1\) and \(V_2\) are the values of repeller voltages required to operate the klystron in mode numbers \(N_1\) and \(N_2\).

(ii) Knowing mode number, transit time of each mode is calculated from

\[
t_1 = \frac{n + (3/4)}{f_{01}} = \frac{N_1}{f_{01}} \text{ seconds}
\]

\(f_{01} \rightarrow \) frequency of microwave operation in one mode.

(iii) ETR – Electronic tuning range i.e, the frequency band from one end of the mode to another is calculated by

\[
ETR = f_{1\text{max}} - f_{1\text{min}} \text{ for } N_1 \text{ mode (GHz)}
\]

\(f_{1\text{max}} - f_{1\text{min}} \rightarrow \) half power frequencies

(iv) ETS – Electronic tuning sensitivity

\[
ETS = \frac{f_{1\text{max}} - f_{1\text{min}}}{V_{1\text{max}} - V_{1\text{min}}} \text{ (MHz/V)}
\]

\(f_{1\text{max}}, f_{1\text{min}} \rightarrow \) half power frequency

\(V_{1\text{max}}, V_{1\text{min}} \rightarrow \) corresponding repeller voltages for a particular mode.
MODE CHARACTERISTICS OF REFLEX KLYSTRON

MODEL GRAPH:
<table>
<thead>
<tr>
<th>Mode</th>
<th>Frequency GHz</th>
<th>Repeller voltage V</th>
<th>Output Voltage (mV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9.84</td>
<td>140</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>9.85</td>
<td>150</td>
<td>325</td>
</tr>
<tr>
<td></td>
<td>9.875</td>
<td>160</td>
<td>275</td>
</tr>
<tr>
<td>2</td>
<td>9.895</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>9.87</td>
<td>100</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>9.85</td>
<td>90</td>
<td>175</td>
</tr>
<tr>
<td>3</td>
<td>9.85</td>
<td>60</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>9.88</td>
<td>70</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td>9.90</td>
<td>80</td>
<td>125</td>
</tr>
</tbody>
</table>
REVIEW QUESTIONS

1. List two basic configuration of Klystron tubes.
2. What is velocity modulation?
3. List down the characteristic of two cavity klystron amplifier.
4. Write a note on mode of oscillations.
5. Draw the reflex klystron modes.
6. Higher order mode occur at ____________ repeller voltage.
7. When the o/p power of reflex klystron maximum?
8. List the application of reflex klystron.
9. What is transit time?
10. Which mode number is most frequently used? Why?
3. IMPEDENCE MEASUREMENT

AIM

To measure the impedance of an unknown load using smith chart.

APPARATUS REQUIRED

Klystron Power supply, Klystron with mount, Isolator, Frequency meter, Variable attenuator, Slotted section, Movable Short, CRO.

THEORY

The simplest method for measurement of impedance at microwave frequencies is as follows. The unknown impedance is connected at the end of a slotted coaxial line. Microwave power is fed from the other end of coaxial line. Unknown impedance reflects a part of this power. This reflection coefficient is measured by probing the standing wave fields in the slotted line by a suitable arrangements. The reflection coefficient is given by

\[ P = \frac{Z_L - Z_o}{Z_L + Z_o} \]

\( Z_L \) - Load impedance at any point

\( Z_O \) - Characteristics impedance of waveguide at operating frequency

Thus if P is measured & \( Z_O \) is known, \( Z_L \) can be found. In general \( Z_L \) is complex, both magnitude and phase of P is needed. The magnitude of P may be found from VSWR measurement.

\[ |P| = \frac{VSWR - 1}{VSWR + 1} \]

The phase of P may be found by measuring the distance of first voltage minima from the load. Thus the measurement of impedance involves the measurements of VSWR and the distance of the voltage minima from the load. These measurements may be carried out by using a slotted line and probe arrangement.
PROCEDURE

1. Assemble the components as per the circuit diagram
2. After making initial adjustments, mode3 is set up for operations
3. The frequency of the excited wave is found by adjusting the frequency meter for a dip in the output meter. Thereafter detune the frequency meter slightly
4. The VSWR is found for the given load (horn), by measuring $V_{\text{max}}$ and $V_{\text{min}}$
5. With load - end short circuited, two successive minimas ($d_1$ and $d_2$)are found out by moving the probe carriage along the slotted waveguide line.
6. With load-end terminated with the given load, the first minima(x) is noted.
7. The given load is replaced with short-circuit, the second minima(y) is noted down.
8. Next the shift is found depending on whether it is towards the load or source.
9. The impedance of the unknown load is found using smith chart and verified using formula.

RESULT

The impedance of an unknown load was measured and using a smith chart and the value was found out.
IMPEDANCE MEASUREMENT

Klystron Power Supply

Klystron with Mount

Isolator

Frequency Meter

Variable Attenuator

Slotted Section with Probe Carriage

Movable short/load

Tunable probe

CRO
OBSERVATIONS

\[ V_{\text{max}} = 32 \text{ mv}; \ V_{\text{min}} = 20 \text{ mv} \]

\[ \text{VSWR} = \frac{V_{\text{max}}}{V_{\text{min}}} = 1.6 \]

\[ d_1 = 9.68 \text{ cm} \quad d_2 = 11.74 \text{ cm} \]

\[ \lambda = 2(d_1 d_2) = 4.12 \text{ cm} \]

\[ X = 14 \text{ cm} \quad Y = 11.74 \text{ cm} \]

\[ \frac{X - Y}{\lambda} = 0.5485 \]

FORMULA

\[
Z_o = \frac{120\pi}{\sqrt{1 - \left(\frac{f_c}{f_o}\right)^2}}
\]

\[
Z_L = Z_o \left[ \frac{1 - j(V\text{SWR}) \text{Lan}(\beta L)}{V\text{SWR} - j\text{Lan}(\beta L)} \right]
\]

\[ \beta L = \left( \frac{XNYL}{\lambda} \right) \times 360^\circ \]

\[ f_c \quad \rightarrow \quad \text{Cutoff frequency} \]

\[ f_c = \frac{c}{\lambda_c} \quad ; \quad \lambda_c \rightarrow \text{cut off wavelength} \]

\[ \lambda_c = 2a \quad ; \quad a \rightarrow \text{broad dimension of waveguide} \]

\[ f_o = \frac{C}{\lambda} \]
REVIEW QUESTIONS

1. What are the types of methods used in microwave frequencies to measure impedance?
2. Relationship between S & P.
3. Under which case the impedance will be
4. How will you measure the impedance of the unknown load in the microwave setup bench
5. What are the application of smith chart.
4. DIRECTIONAL PATTERN OF HORN ANTENNA

AIM

To obtain directional pattern of a Horn Antenna.

APPARATUS REQUIRED

Klystron Power Supply, Klystron with mount, Isolator, Frequency meter, Fixed Attenuator Detector, Parabolic Reflector, CRO.

THEORY

A horn antenna may be regarded as a flared out or opened out wave guide. A wave guide is capable of radiating radiation into open space provided the same is excited at one end and opened at the other end. However, the radiation is much greater through wave guide than the 2 wire transmission line. To overcome reflection and diffraction in the wave guide, the mouth of the waveguide is opened out which assumes the shape of a electromagnetic horn. If the wave guide is terminated by any type of horn, the abrupt discontinuity existed is replaced by a gradual transformation, then all the energy incident in forward direction in the waveguide will now be radiated, provided the impedance matching is proper. This improves directivity and reduces diffraction. If flaring is done only in one direction, then sectorial horn is produced. If flaring is done along both the walls, then pyramidal horn is obtained. By flaring the walls of the circular waveguide, a concial horn is formed. The fields inside the waveguide propagate in the same manner as in free space, but on reaching the mouth of the waveguide, these propagating fields continue to propagate in the same general direction but also starts spreading laterally and the wave front eventually becomes spherical. However this may be treated as transition region where the change over from the guided propagation to free space propagation occurs. Since the waveguide impedance & free space impedance are not equal, hence to avoid standing wave ratio, flaring of walls of waveguide is done which besides matching of impedance also provide concentrated radiation pattern(greater directivity and narrower beam width. It is the flared structure that is given the name electromagnetic horn radiator. The function is to produce a uniform phase front with a larger aperture in comparison to waveguide and thus directivity is greater. If flare angle is very large, the wavefront on the mouth of the horn will be curved rather than plane. This will result in non-uniform phase distribution over the aperture, resulting in increased beam width and reduced directivity, and vice versa occurs if the flare angle is very small. The directivity of the horn antenna is given as \( D = \frac{7.5}{\lambda^2} \) where \( A \) area of horn mouth opening. Horn antennas are extensively used at microwave frequencies under the condition that power gain needed is moderate.

Precautions

1. Power flowing out of horns may damage retina of the eye so do not see directly inside the horn antenna
DIRECTIONAL PATTERN OF HORN ANTENNA

Gain in dB

0°

Angle in Degrees

270°

180°

90°
INPUT VOLTAGE $V_T = 330\text{mv}$

<table>
<thead>
<tr>
<th>Angle (degree s)</th>
<th>$V_R$ (mv)</th>
<th>Gain (dB) = $20 \log (V_R/V_T)$</th>
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<tr>
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<td>Clock wise</td>
<td>Anticlock wise</td>
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<tr>
<td>0</td>
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<td>60</td>
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<td>-18.11</td>
<td>-18.32</td>
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<tr>
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<td>11</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>-29.5</td>
<td>-30.3</td>
</tr>
</tbody>
</table>

PROCEDURE

1. Setup the equipments as shown in fig. Keeping the axis of both antennas in same axis line
2. Energize the microwave source, and set mode 3 determine input power at transmitting antenna end by connecting detector mount.
3. Connect the transmitting antenna back. Turn the receiving horn to the left in 5° steps upto atleast 60° and note the corresponding voltage.
4. Repeat the above step but this time turning the receiver to the right and notedown the readings.
5. Draw a relative power pattern ie, o/p vs angle.
6. From diagram 3 dB beam width is determined.

RESULT

Thus the directional pattern of the Horn antenna was obtained and the corresponding graph was drawn.
REVIEW QUESTIONS

1. List some of the types of antennas used in microwaves.
2. Why is a paraboloid preferred to horn at microwave frequencies?
3. Write the formula for directivity & power gain of horn antenna.
4. What are the different types of horn antenna used in microwave frequencies?
5. List some common features of horn antenna.
5. CHARACTERISTICS OF DIRECTIONAL COUPLER

AIM

To measure the performance of a Directional coupler and to determine the following:

i) Main line VSWR
ii) Auxiliaries line VSWR
iii) Insertion loss
iv) Coupling factor
v) Directivity

APPARATUS

Klystron power supply, Klystron with mount, Isolator, variable attenuator, slotted section, CRO, Directional Coupler, Matched termination.

THEORY

A directional coupler is a useful hybrid waveguide joint, which couples power in an auxiliary waveguide arm in one direction. It is a four-port device but one of the ports is terminated into a matched load. Ref figure 1.

Characteristics of a Directional Coupler

An ideal directional coupler has the following characteristics

i) If power is fed into port (1) the power is coupled in ports (2) and (3) i.e., power flows in the forward direction of the auxiliary arm port (3) but no power couples in port (4) i.e., in backward direction similarly power fed in (2) couples into ports (1) and (4) and not in (3).

ii) All the four ports are matched, i.e. if three of them are terminated in matched loads, the fourth is automatically terminated in a matched load.

iii) If power couples in reverse direction, power fed in (1) appears in ports (2) and (4) and nothing in (3), then such type of coupler is known as backward directional coupler. The conclusion is that in the auxiliary section the power is coupled in only one direction.

We will measure (i) main line and auxiliary line VSWR as a function of frequency, (ii) coupling coefficient as a function of frequency, (iii) directivity as a function of frequency, and (iv) the main line insertion loss as a function of frequency. These parameters are defined as follows:

(i) **Main Line VSWR**: The main line VSWR is the standing wave ratio measured looking into the main line input terminals when matched loads are placed at all the three other terminals. The main line VSWR will be the same for any orientation of the coupler in the transmission line.

(ii) **Auxiliary Line VSWR**: The auxiliary line VSWR is the standing wave ratio measured in the auxiliary line looking into the output terminal to which the detector is normally connected when matched loads are placed at all the three other ports or terminals.

DIRECTIONAL COUPLER AS A FOUR – PORT DEVICE
FIG 1

DIRECTIONAL COUPLER AS A THREE-PORT DEVICE:
UNDEIRECTIONAL COUPLER

FIG 1a
MAIN LINE VSWR MEASUREMENT

Klystron Power Supply

Klystron with Mount

Isolator

Variable Attenuator

Slotted Section

Main Line

Matched Termination

AUXILLARY LINE VSWR MEASUREMENT

Klystron Power Supply

Klystron with Mount

Isolator

Variable Attenuator

Slotted Section

Aux Line

Main Line

Matched Termination

Matched Termination

Tunable Probe

CRO
Insertion Loss (V1) Measurement

Klystron Power Supply

Klystron with Mount → Isolator → Variable Attenuator → Detector Mount → CRO
Directivity Measurement

Diagram:

- Klystron Power Supply
- Klystron with Mount
- Isolator
- Variable Attenuator
- Aux Line
- Main Line
- Detector Mount
- Matched Termination
- CRO
### Directional Coupler

#### VSWR Measurement

<table>
<thead>
<tr>
<th></th>
<th>$V_{\text{max}}$ (mv)</th>
<th>$V_{\text{min}}$ (mv)</th>
<th>VSWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Line</td>
<td>23</td>
<td>10</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>10</td>
<td>2.5</td>
</tr>
<tr>
<td>Aux Line</td>
<td>21</td>
<td>10</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>10</td>
<td>2.1</td>
</tr>
</tbody>
</table>

#### INSERTION LOSS & COUPLING FACTOR

- $V_1 = 2 \text{ V}$
- $V_2 = 1.5 \text{ V}$
- $V_3 = 0.5 \text{ V}$
- $L = 20 \log_{10} (V_1/V_2) \text{ dB} = 2.498$
- $C = 20 \log_{10} (V_1/V_3) \text{ dB} = 12.041$

#### Directivity

- Match P2, Input to P1 output at P3 Measures as $V_{13}$
- Reverse DCR, Match P1, Input to P2 output at P3, Note voltage as $V_{23}$

\[
D = 20 \log_{10} \left( \frac{V_{13}}{V_{23}} \right) \text{ dB}
\]

- $V_{13} = 0.5 \text{ V}$
- $V_{23} = 4 \text{ mV}$
- $D = 20 \log \left( \frac{V_{13}}{V_{23}} \right) = 41.93 dB$

(iii) Coupling: Coupling coefficient is the ratio of power supplied to the main line input ($P_1$) to the power output ($P_{AO}$) at the auxiliary line output. The coupling coefficient $C$ is usually expressed in decibels as a positive number.

\[
C = 10 \log_{10} \left( \frac{P_1}{P_{AO}} \right) \text{ Db}
\]

\[
C = 20 \log_{10} \left( \frac{V_1}{V_2} \right) \text{ dB}
\]
Main Line Insertion Loss: The main line insertion loss is the attenuation introduced in a transmission line by the insertion of the directional coupler. The auxiliary line of the coupler is assumed to be properly terminated. The main line insertion loss, \( L \) is given by

\[
L = 10 \log_{10} \left( \frac{P_1}{P_0} \right) \text{ db}
\]

\[
L = 20 \log \left( \frac{V_1}{V_2} \right) \text{ db}
\]

Directivity: The directivity \( D \) is a measure of the discrimination property of a directional coupler between the waves traveling in the two directions in the main line. It is measured as the ratio of the two power outputs from the auxiliary line when a given amount of power is successively applied to each terminal of the main line. The other terminals or ports of the coupler not in use in the particular measurement are assumed to be terminated in matched loads.

\[
D = 10 \log_{10} \left( \frac{P_{A0}}{P_d} \right) \text{ db}
\]

\[
D = 20 \log \left( \frac{V_3}{V_4} \right) \text{ db}
\]

PROCEDURE:

**Main Line VSWR**

1. Setup the equipment as shown in fig, Terminating Port 2 and Port 3 with matched termination set modes
2. Move the slotted section and measure \( V_{\text{max}} \) and \( V_{\text{min}} \)
3. Calculate VSWR \( V_{\text{max}} \) and \( V_{\text{min}} \)

**Auxiliary –line VSWR**

1. Set up the equipment as shown in fig, terminating port 1 and port 2 set mode 3 with matched termination.
2. Move the slotted section and measure \( V_{\text{max}} \) and \( V_{\text{min}} \)
3. Calculate VSWR = \( V_{\text{max}} \) and \( V_{\text{min}} \)

**Insertion Loss and Coupling factor**

1. Set the equipment by connecting detector mount to the input end(without directional coupler).
2. Set mode 3 and observe the input voltage \( V_1 \). Do not alter till the end of the experiment.
3. Insert the directional coupler, terminate port 3 with matched termination.
4. Connect detector mount to port 2 and measure \( V_2 \).
5. Calculate insertion loss

\[
20 \log_{10} \left( \frac{V_1}{V_2} \right) \text{dB}
\]

6. To measure coupling factor, terminate port 2 with matched termination, connect detector mount to port 3 and measure \( V_3 \).
7. Calculate coupling factor
\[ C = 20 \log_{10} \left( \frac{V_1}{V_3} \right) \text{dB} \]

**Directivity**

1. Set up the equipment as shown in fig. Terminate port 2 with matched termination and connect detector mount to port 3.
2. Measure the voltage at port 3 and note it as \( V_{13} \).
3. Connect the directional coupler in reverse direction. i.e., port 2 – input, port 1 – matched termination, port 3 – detector mount.
4. Measure the voltage as \( V_{23} \).
5. Calculate directivity \( D = 20 \log \left( \frac{V_{13}}{V_{23}} \right) \) dB

**Calculations:**

Main Line VSWR = \( V_{\text{max}} / V_{\text{min}} \)

Auxiliary line VSWR = \( V_{\text{max}} / V_{\text{min}} \)

Insertion Loss \( L = 20 \log (V_1 / V_2) \) dB

Coupling factor \( C = 20 \log (V_1 / V_3) \) dB

Directivity \( D = 20 \log (V_3 / V_4) \) dB

**RESULT:**

The performance characteristics of directional coupler were determined.
REVIEW QUESTIONS

1. What is a directional coupler?
2. List the types of directional coupler.
3. Draw a basic directional coupler?
4. List the performance of a directional coupler.
5. Define the directivity ‘D’ of a directional coupler.
6. Define coupled factor C.
7. What is multihole directional coupler?
6. STUDY OF E PLANE, H PLANE AND MAGIC TEE

AIM

To determine isolations, coupling coefficients and input VSWR’s for E and H plane waveguide Tee and Magic Tee junctions.

APPARATUS REQUIRED

Klystron power supply, Klystron with mount, isolator, variable attenuator, slotted section, Magic Tee, Matched termination, detector mount, CRO.

THEORY

H Plane Tee

Fig 1(a) shows the sketch of an H plane tee. It is clear from the sketch that an auxiliary waveguide arm is fastened perpendicular to the narrow wall of a main guide, thus it is a three port device in which axis of the auxiliary or side arm is parallel to the planes of the magnetic field of the main of the main guide and the coupling from the main guide to the branch guide is by means of magnetic fields. Therefore, it is also known as H plane tee.

The perpendicular arm is generally taken as input and other two arms are in shunt to the input and hence it is also called as shunt tee. Because of symmetry of the tee; equivalent circuit of H plane, when power enters the auxiliary arm, and the two main arms 1 and 2 are terminated in identical loads, the power supplied to each load is equal and in phase with one another.

If two signals of equal amplitude and in same phase are fed into two main arms1 and 2, they will be added together in the side arm. Thus H plane tee is an ‘adder’.

E Plane Tee

Figure 2 and respectively show the sketch of the E plane tee. It is clear from the sketch of the E plane tee that an auxiliary waveguide arm is fastened to the broader wall of the main guide. Thus it is also a three port device in which the auxiliary arm axis in parallel to the plane of the electric fields of the main guide, and the coupling from the main guide to the auxiliary guide is by means of electric fields. Therefore, it is also known as E plane tee. It is clear that it causes load connected to its branches to appear in series. So it is often referred to as a series tee.

As indicated in fig, the two main guide arms are symmetrical with respect to the auxiliary guide arm. As such if power is fed from the auxiliary arm, it is equally distributed in the two arms 1 and 2 when they are terminated in equal loads. However as depicted in the field configuration, the power flowing out in arm 1 is 180 out of phase to the one in arm 2. As such this tee is known as ‘subtractor’ or ‘differencer’.

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H-PLANE WAVEGUIDE T-JUNCTION

Fig. 1

E-PLANE WAVEGUIDE T-JUNCTION

Fig. 2

E-H TEE OR MAGIC TEE

Fig. 3
Magic Tee
An interesting type of T junction is the hybrid tee, commonly known as ‘magic tee’ which is shown in fig. The device as can be seen from fig is a combination of the E arm and H plane tees. Arm3, the H arm forms an H plane tee and arm 4, the E arm, forms an E plane tee in combination with arms 1 and 2. The central lines of the two tees coincide and define the plane of symmetry, that is, if arms 1 and 2 are of equal length, the part of structure on one side of the symmetry plane shown by shaded area is the mirror image of that on the other. Arms1 and 2 are sometimes called as the side or collinear arms.

Magic of the MAGIC Tee
The name ‘magic Tee’ is derived from the manner in which power divides among various arms. If power is fed into arm3, the electric field divides equally between arms 1 and 2 and the fields are in phase. Because of symmetry of the T junction, no net electric field parallel to the narrow dimension of the waveguide is excited in arm 4. Thus no power is coupled in port 4. Reciprocity demands no coupling in port 3 if power is fed in 4.

Another property that results from the symmetry of the junction is, if power is fed in E or H arm, it is equally divided between arms 1 and 2.

Further, magic tee being combination of E and H plane tees, if power is fed from arms 1 and 2, it is added in H arm (3) while is subtracted in E arm (4).

A simple E-H tee has disadvantage of not being matched when seen from E and H arms when side arms are terminated in matched loads. The VSWR being > 2 the most commonly used method to reduce VSWR is to introduce discontinuity such as port iris in or near T junction to cancel out reflections occurring there in.

E Plane, H Plane Tee Parameter
a) Isolation
The isolation of a T junction is the ratio of power supplied from a matched generator to one of the arms, to the power coupled to a matched detector in any other arm when the remaining arm is terminated in a matched load.

Isolation between port 1 and 2 is
\[ I_{12} = 10 \log_{10} \frac{P_1}{P_2} \text{ dB}, \quad I_{12} = 20 \log_{10} \left( \frac{V_1}{V_2} \right) \text{ dB}, \]
And when matched load and detector are interchanged
\[ I_{13} = 10 \log_{10} \frac{P_1}{P_3} \text{ dB}, \quad I_{13} = 20 \log_{10} \left( \frac{V_1}{V_3} \right) \text{ dB}, \]
Similarly
\[ I_{31} = 10 \log_{10} \frac{P_3}{P_1} \text{ dB}, \quad I_{32} = 20 \log_{10} \left( \frac{V_3}{V_2} \right) \text{ dB}, \]
And when matched load and detector are interchanged,
\[ I_{33} = 10 \log_{10} \frac{P_3}{P_2} \text{ dB}, \quad I_{32} = 20 \log_{10} \left( \frac{V_3}{V_2} \right) \text{ dB}, \]
When arm 2 becomes the input, we will have other two values of isolation, \( I_{21} \) and \( I_{23} \). Due to reciprocity Property, \( I_{21} \) will be the same as \( I_{12} \). Therefore, we shall measure only the first four isolation coefficients.

b) Coupling coefficient
Corresponding to the values of isolation, we can compute
The coupling coefficient by the formula
\[ C = 10^{-\alpha/20} \]

Where \( \alpha \) is the attenuation in db between the input and detector arm when the third arm is terminated in a matched load. For example, the attenuation measured between arms 1 and 2 is 3 db when arm 3 terminated in matched load, that is, the coupling coefficient between arms 1 and 2,

\[ C_{12} = 10^{-\alpha/20} = 10^{-3/20} = 0.708 \text{ db} \]

c) **Input VSWR**

The are three values of input VSWR associated with a tee, one for each arm. The VSWR of any arm of a tee is the voltage standing wave ratio existing on a transmission line terminated by that arm of the tee when the other two arm of the tee are terminated in matched loads.

**Magic Tee Parameter:**

The basic properties and associated quantities to be measured for a magic tee are defined as follows:

a) **Input VSWR**

Corresponding to each port of a magic tee as load to the line, there is a value of VSWR. Thus there are four values of VSWR. VSWR is defined as the ratio of maximum voltage to minimum voltage of the standing waves existing on the line when one port of the tee terminates the line while other three ports are terminated in matched loads.

b) **Isolations**

The isolation between E-and H-arms is defined as the ratio of the power supplied by the matched generator connected to E-arms (port-4), to the power detected in H-arm (port-3) by a matched detector when collinear arms (1&2) are terminated in matched loads. It is expressed in db.

\[ I_{34} = 10 \log_{10} P_4/P_3, \quad I_{34} = 20 \log_{10} \left( \frac{V_4}{V_3} \right) \]

\( P_4 \) : power incident in port4 (E-arm)
\( P_3 \) : power detected in port3 (H-arm)

Similarly isolation between other ports may also be defined and measured.

c) **Coupling Coefficient:**

The voltage coupling coefficient from arm I to arm j is defined as \( C_{ij} = 10^{-\alpha/20} \)
Characteristics of E \& H Plane Tee

- Klystron Power Supply
- Klystron with Mount
- Isolator
- Variable Attenuator
- Slotted Section
- E/H Tee
- Detector Mount
- Matched Termination
- CRO
Characteristics of Magic TEE
### E-Plane and H – Plane

#### INPUT VSWR

<table>
<thead>
<tr>
<th>Nature of Tee</th>
<th>Load</th>
<th>( V_{\text{max}} ) (mv)</th>
<th>( V_{\text{min}} ) (mv)</th>
<th>VSWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>E – Plane</td>
<td>Ports</td>
<td>4</td>
<td>1.5</td>
<td>2.667</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>5</td>
<td>2.5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10</td>
<td>2.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>10</td>
<td>2.0</td>
<td>5.0</td>
</tr>
<tr>
<td>H – Plane</td>
<td>1</td>
<td>2.5</td>
<td>2.0</td>
<td>1.25</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.8</td>
<td>2.2</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>4.0</td>
<td>0.6</td>
<td>6.67</td>
</tr>
</tbody>
</table>

#### ISOLATION AND COUPLING COEFFICIENTS

\( V_{\text{in}} = 1200\text{mV} \)

<table>
<thead>
<tr>
<th>Nature of Tee</th>
<th>Voltage (mv)</th>
<th>Isolation (Iij) dB</th>
<th>Coupling Coefficient ( C_{ij} = 10^{\frac{Iij}{20}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-Plane</td>
<td>I(^{\text{st}}) arm</td>
<td>2(^{\text{nd}}) arm 640</td>
<td>5.64</td>
</tr>
<tr>
<td></td>
<td>= 2(^{\text{nd}}) arm 500</td>
<td>7.604</td>
<td>( C_{13} = 0.533 )</td>
</tr>
<tr>
<td></td>
<td>3(^{\text{rd}}) arm</td>
<td>2(^{\text{nd}}) arm = 52 480</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>= 1(^{\text{st}}) arm = 48</td>
<td>( C_{31} = 0.366 )</td>
<td></td>
</tr>
<tr>
<td>H = Plane</td>
<td>I(^{\text{st}}) arm = 120</td>
<td>2(^{\text{nd}}) arm = 66 3(^{\text{rd}}) arm = 36</td>
<td>( C_{12} )</td>
</tr>
<tr>
<td></td>
<td>3(^{\text{rd}}) arm</td>
<td>2(^{\text{nd}}) arm = 54 1(^{\text{st}}) arm = 48</td>
<td>( C_{32} )</td>
</tr>
</tbody>
</table>

**Magic Tee**

**INPUT – VSWR** : All other ports terminated with matched load termination except for the load.

<table>
<thead>
<tr>
<th>Load</th>
<th>( V_{\text{max}} ) (mv)</th>
<th>( V_{\text{min}} ) (mv)</th>
<th>VSWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port 1</td>
<td>3.6</td>
<td>2</td>
<td>1.8</td>
</tr>
<tr>
<td>Port 2</td>
<td>3.2</td>
<td>1.2</td>
<td>2.667</td>
</tr>
<tr>
<td>Port 3</td>
<td>2.8</td>
<td>2.2</td>
<td>1.2727</td>
</tr>
<tr>
<td>Port 4</td>
<td>3.2</td>
<td>2.0</td>
<td>1.6</td>
</tr>
</tbody>
</table>

**ISOLATION AND COUPLING COEFFICIENTS**

- Generator to port \( i \)
- Detector mount to port \( j \) (\( V_{ij} \))
- All other ports terminated using matched termination
- \( I_{ij} = 20 \log (V_i / V_j) \)
- \( C_{ij} = 10^{-I_{ij}/20} \)
<table>
<thead>
<tr>
<th>Magic Tee orientation</th>
<th>Input Arm-I / Output arm-j</th>
<th>Vi (mv)</th>
<th>Vj (mv)</th>
<th>Iij (dB)</th>
<th>Cij</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1200</td>
<td>27</td>
<td>I_{12} = 32.95</td>
<td>C_{12} = 0.0225</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1200</td>
<td>700</td>
<td>I_{13} = 4.68</td>
<td>C_{13} = 0.58</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1200</td>
<td>600</td>
<td>I_{14} = 6.02</td>
<td>C_{14} = 0.5</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1200</td>
<td>24</td>
<td>I_{21} = 33.97</td>
<td>0.02</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>1200</td>
<td>640</td>
<td>I_{23} = 5.46</td>
<td>0.53</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1200</td>
<td>600</td>
<td>I_{24} = 6.03</td>
<td>0.51</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>1200</td>
<td></td>
<td>I_{34}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1200</td>
<td></td>
<td>I_{31}</td>
<td></td>
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<tr>
<td></td>
<td>2</td>
<td>1200</td>
<td></td>
<td>I_{32}</td>
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</tr>
<tr>
<td>4</td>
<td>3</td>
<td>1200</td>
<td></td>
<td>I_{43}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1200</td>
<td></td>
<td>I_{41}</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1200</td>
<td></td>
<td>I_{42}</td>
<td></td>
</tr>
</tbody>
</table>

Where $\alpha$ is the attenuation in db when I is the input and j the output arm.

Thus

$$\alpha (\text{db}) = 10 \log \frac{P_i}{P_j}$$

where $P_i$ is the power delivered to I arm by a matched generator and $P_j$ is the power detected by a matched detector in arm j.

In the case of magic tee, there are 12 coupling constants, one for each of the arms as an input to each of the other three arms as an output. However, if we have a perfectly matched detector and generator, $C_{ij} = C_{ji}$ and also the reciprocity desires $C_{12} = C_{21}$, $C_{32} = C_{31}$ and $C_{41} = C_{42}$.

**Procedure:**

**VSWR**

1. Setup the components as shown, with port 1 of tee(E-plane/H-plane/Magic Tee) towards slotted line and matched termination to other ports.
2. Energize the microwave source and set mode 3.
3. Calculate VSWR by measuring $V_{\text{max}}$ and $V_{\text{min}}$ by adjusting the slotted line carriage.
4. Similarly connect other arms and calculated VSWR as above.

**Isolation and Coupling Coefficient**

1. Remove the slotted line and Magic Tee/E/H Tee and connect the detector mount.
2. Energize the microwave source and set mode 3.
3. Note down the input voltage as $V_i$ (mv) (should not alter the setting)
4. Now connect the magic tee/E-Plane/H-Plane Tee.
5. Determine the corresponding voltages $V_j$ (mv) for each pair of ports by connecting one port to the source and measuring the output at other port while the remaining ports are connected to matched termination.
6. Determine the isolation and coupling coefficients for the given Tee.

**Result:**

Isolation, coupling coefficients and Input VSWR’s for E, H and magic tee determined.
REVIEW QUESTIONS

1. What are the several types of tees used in microwave communication?
2. What is the S.Matrix of H-plane Tee function.
3. What is a hybrid ‘T’ or magic ‘T’?
5. List some of the basic magic Tee parameters.