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UNIVERSITY OF TECHNOLOGY, JAMAICA

SCHOOL OF ENGINEERING

MODULE: Microwave Systems

- Lab 1 -

Introduction to Microwave Waveguides and

Measurement of Source Frequency and Wavelength

Report:

1. Your reports should be submitted individually and should include the measurements and calculations made.
2. The Discussion of your report should also include the relevance of waveguides, wavemeters, and real applications of their use.
3. The report should be submitted on or before Wednesday February 14, 2012, and marks will be deducted for late submission.

INTRODUCTION OF A MICROWAVE WAVEGUIDE BENCH AND MEASUREMENT OF SOURCE FREQUENCY AND WAVELENGTH

ASSIGNMENT 1

CONTENT

In this first assignment a basic microwave measurement bench is set up to measure frequency and guide wavelength.

The waveguide bench comprises a Gunn-diode oscillator source, two resistive vane attenuators, a cavity wavemeter, a waveguide slotted line diode detectors and a resistive load termination.

The frequency of the microwave source is measured using the cavity wavemeter. The guide wavelength l_g is the wavelength of the microwave signal propagating in the waveguide. This is measured using a diode detector-probe unit to sample the standing waves set up in the slotted line when terminated in a short-circuit.

EQUIPMENT REQUIRED

Quantity	Identifying letter	Component description
1	---	Control console
2	A	Variable attenuators
1	B	Slotted line
1	D	Cavity wavemeter
1	K	Resistive termination
1	M	Diode detector
1	P	X-band microwave source
1	S	Probe detector assembly
1	R	Short-circuit plate

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OBJECTIVES

When you have completed this assignment you should

- Be familiar with some basic microwave waveguide components and know their use
- Know how to measure frequency using a cavity wavemeter
- Know how guide wavelength λ_g is measured using a slotted line
- Understand the meaning of cut-off wavelength and frequency
- Use the general relationship for waveguides of:

$$\frac{1}{\lambda_g^2} = \frac{1}{\lambda^2} - \frac{1}{\lambda_c^2}$$

to calculate guide wavelength, cut-off wavelength and free space wavelength and frequency.

KNOWLEDGE LEVEL

No prior specialist knowledge is required to carry out this assignment. Basic concepts of waves, wavelength and frequency should be known. You should also be familiar with reading a micrometer. To assist in understanding the measurements taken in the assignment it would also be useful to appreciate

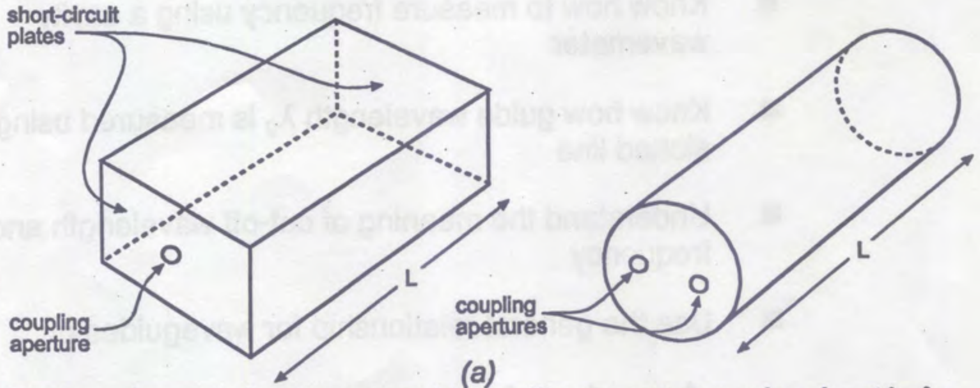
- The nature of electromagnetic waves as being composed of oscillating electric and magnetic fields
- The action of a diode in rectifying alternating current and in microwaves in detecting microwave signals for measurement of field strength and power
- That waves in a closed environment can resonate, e.g. in a cavity when the cavity length is a whole number of half-wavelengths
- Certain types of waves, known as modes, can exist in waveguide structures and are characterised by their own particular wave pattern of electric and magnetic field

INTRODUCTION OF A MICROWAVE WAVEGUIDE BENCH AND MEASUREMENT OF SOURCE FREQUENCY AND WAVELENGTHASSIGNMENT 1

INTRODUCTION

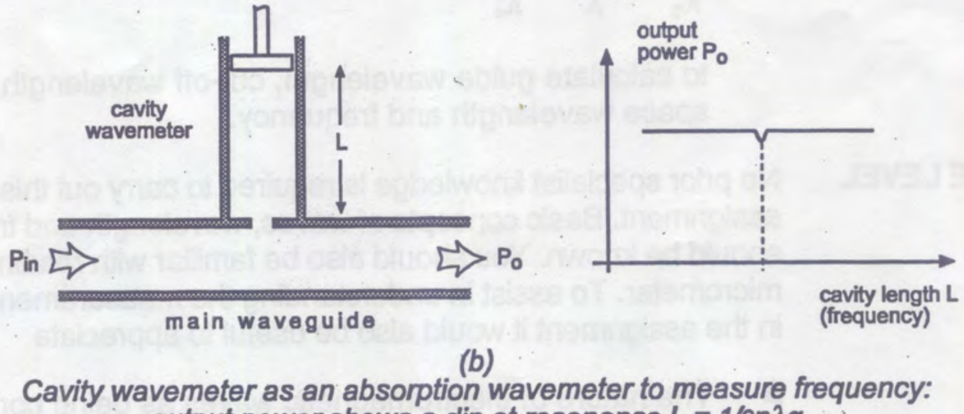
(a) MEASUREMENT OF SOURCE FREQUENCY USING A CAVITY WAVEMETER

Frequency in a microwave system can be measured using electronic counter techniques or by means of a cavity wavemeter.



(a)

Rectangular and circular waveguide cavities: resonance when L = 1/2nλg



(b)

Cavity wavemeter as an absorption wavemeter to measure frequency: output power shows a dip at resonance L = 1/2nλg

Fig 2.1.1 Cavity Wavemeters

The principle of operation of the cavity wavemeter is based on the fact that very high Q-resonances can be obtained in metal waveguide cavities. Such cavities are usually of uniform circular or rectangular cross-section and resonate when their axial length equals an integral number of half guide wavelength, i.e. with reference to figure 2.1.1(a) when:

L = ‰n λ_g

where L = axial length of cavity

n = 1,2,3...., the order of resonance

λ_g = guide wavelength of resonating mode

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Figure 2.1.1(b) illustrates a practical way of using a cavity as an absorption-type wavemeter. The cavity length L may be varied by altering the position of the short-circuit plunger. Off resonance the cavity absorbs little or no power from the main waveguide transmission system. However, at resonance considerable power is coupled into the cavity and this results in a corresponding dip observed in the main transmitted power. L at resonance can be very accurately determined. Knowing L, the type of resonant mode and the order of resonance enables the exciting frequency, the source frequency f, to be calculated. From theory:

$$f = \frac{C}{l} = 3 \times 10^8 \sqrt{\left[\frac{1}{l_g^2} + \frac{1}{l_c^2}\right]}$$

$$= 3 \times 10^8 \sqrt{\left[\left(\frac{n}{2L}\right)^2 + \frac{1}{l_c^2}\right]^{\frac{1}{2}}}$$

where

c = 3×10^8 m/s, the velocity of electromagnetic waves in free space

l_c = cut-off wavelength of mode resonant in the cavity

n = order of resonance: n = 1, 2, 3.....

More usually a calibration curve of frequency f versus L is provided. In high-quality wavemeters a cylindrical spiral scale measuring plunger position is calibrated to read frequency direct as illustrated in figure 2.1.2

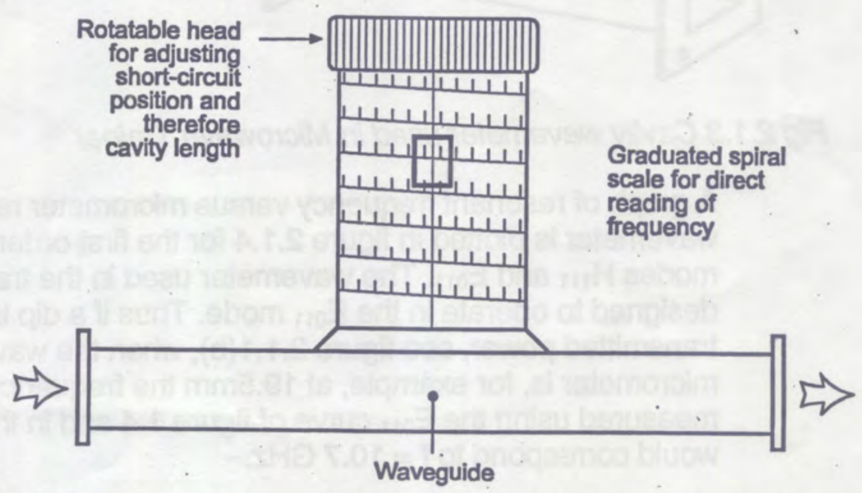

Fig 2.1.2 Cavity wavemeter calibrated for direct reading frequency

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A diagram of the wavemeter used in the microwave trainer is sketched in figure 1.3. The cavity consists of circular waveguide of diameter D = 28.3mm. Its length can be adjusted to be a maximum of approximately 22mm. Over the X-band frequency range the cavity can only support two modes, the H_{11} and the E_{01}, whose cut-off wavelengths are given respectively by:

$$H_{11} : l_c = 1.71\ D\ ;\ E_{01} : l_c = 1.31\ D$$

so for the case of the wavemeter where D = 28.3 the values of cut-off wavelength and frequency are:

$$H_{11} : l_c = 48.4\text{mm}\ ,\ f_c = 6.2\ \text{GHz}$$

$$E_{01} : l_c = 37.1\text{mm}\ ,\ f_c = 8.1\ \text{GHz}$$

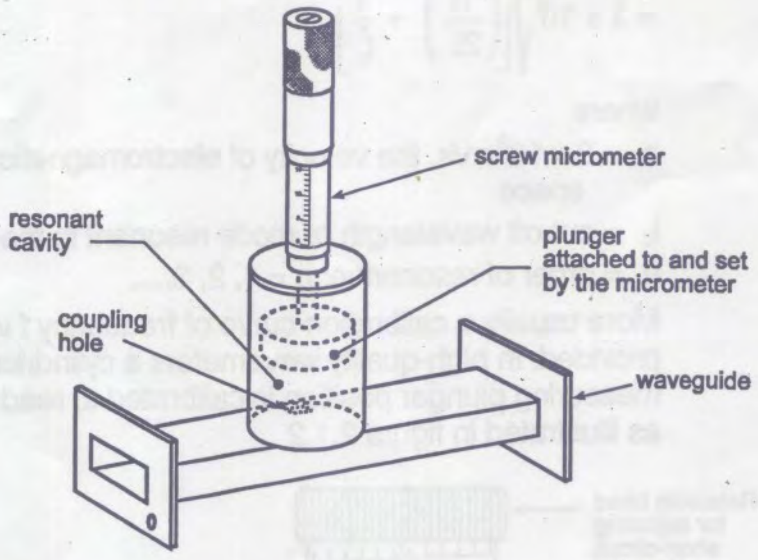

Fig 2.1.3 Cavity wavemeter used in Microwave Trainer

A graph of resonant frequency versus micrometer reading for the wavemeter is plotted in figure 2.1.4 for the first order resonant modes H_{111} and E_{011}. The wavemeter used in the trainer is in fact designed to operate in the E_{011} mode. Thus if a dip is found in the transmitted power, see figure 2.1.1(b), when the wavemeter micrometer is, for example, at 19.5mm the frequency can be measured using the E_{011} curve of figure 1.4 and in this case would correspond to f = 10.7 GHz.

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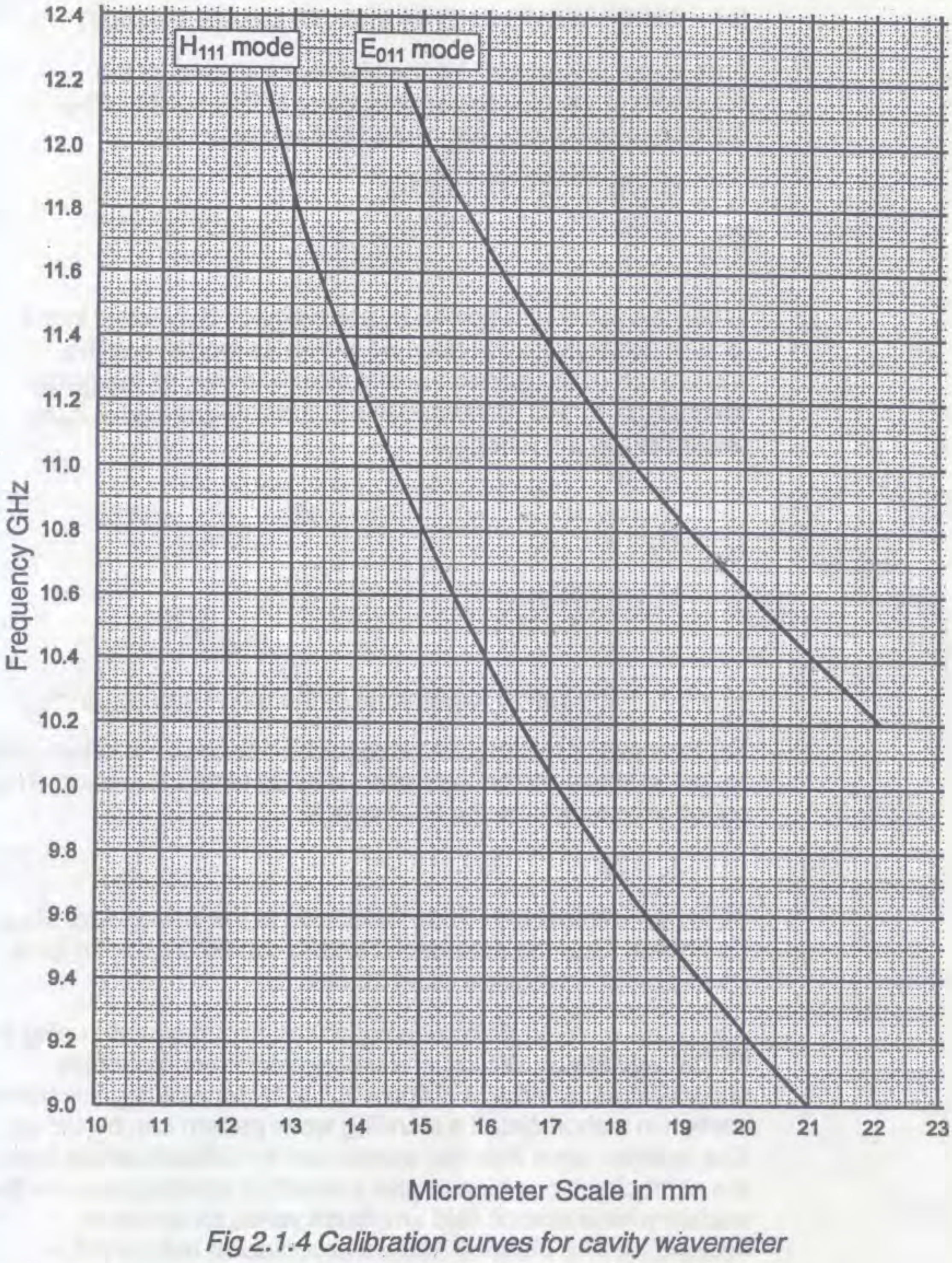

Fig 2.1.4 Calibration curves for cavity wavemeter

Diameter D = 28.3mm.
Note 0.00 point of micrometer scale corresponds to cavity length of 1.86mm and this offset is taken into account in the above graphs.

INTRODUCTION OF A MICROWAVE WAVEGUIDE BENCH AND MEASUREMENT OF SOURCE FREQUENCY AND WAVELENGTHASSIGNMENT 1

(b) GUIDE WAVELENGTH AND ITS MEASUREMENT

Free space wavelength l is the distance travelled by the wavefront of the electromagnetic wave in free space in the duration of one cycle. It is related to frequency f by:

$$f\lambda = c \quad , \quad c = 3\times 10^8 \, m/s$$

$$\lambda = \frac{c}{f}$$

When the waves are guided by a waveguide they travel in the form of distinctive wave patterns known as modes and the wavelength of the guided transmission is known as the guide wavelength λ_g. For rectangular and circular waveguides λ_g is related to l by the formulae:

$$\frac{1}{\lambda_g^2} = \frac{1}{\lambda^2} = \frac{1}{\lambda_c^2} \qquad (2)$$

$$\lambda_g = \frac{\lambda\lambda_c}{\sqrt{\left(\lambda_c^2 - \lambda_0^2\right)}} \qquad (3)$$

where λ_c = the cut-off wavelength of the mode propagating .

For the case of rectangular waveguides transmission is invariably limited to single-moded operation in its dominant H_{10} mode. The cut-off wavelength for the H_{10} mode is:

$$\lambda_c = 2a$$

where a = internal broadside dimension of the waveguide. Thus if f is known, λ can be determined and λ_g can be calculated for a given size of waveguide using formula 3.

The guide wavelength can be measured experimentally using the slotted waveguide section and probe-detector components shown diagrammatically in figure 2.1.5. By terminating the slotted section in a short circuit a standing wave pattern can be set up. The incident wave from the source and the reflected wave from the short-circuit combine to give a resultant standing wave in the section whose electric field amplitude varies as shown in figure 2.1.6 The distance between successive nulls is in the standing wave $\frac{1}{2}\lambda_g$ and can be measured very accurately. Thus guide wavelength can be determined experimentally to a high degree of accuracy.

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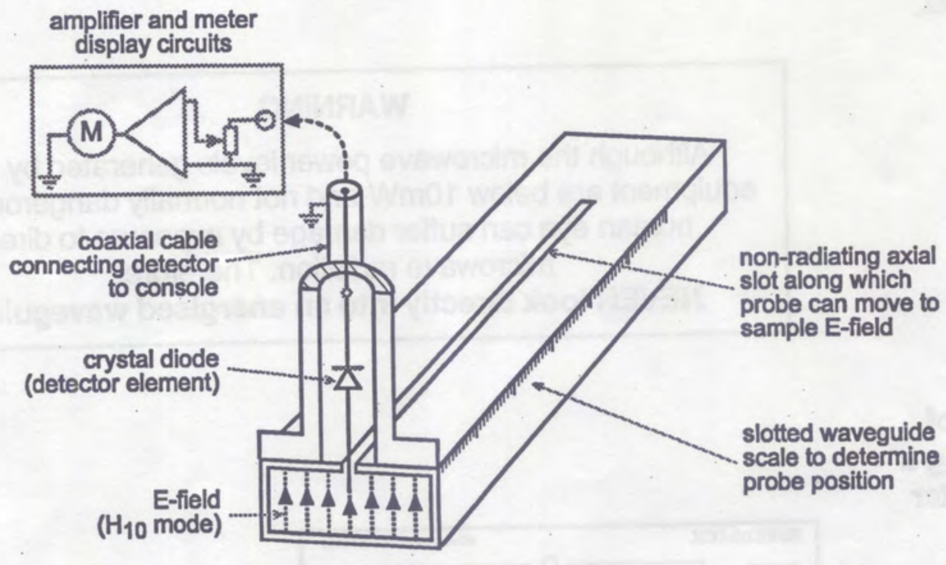

Fig 2.1.5

Diagrammatic sketch indicating main components of a waveguide slotted line and diode-probe detector for investigating standing waves in rectangular waveguide.

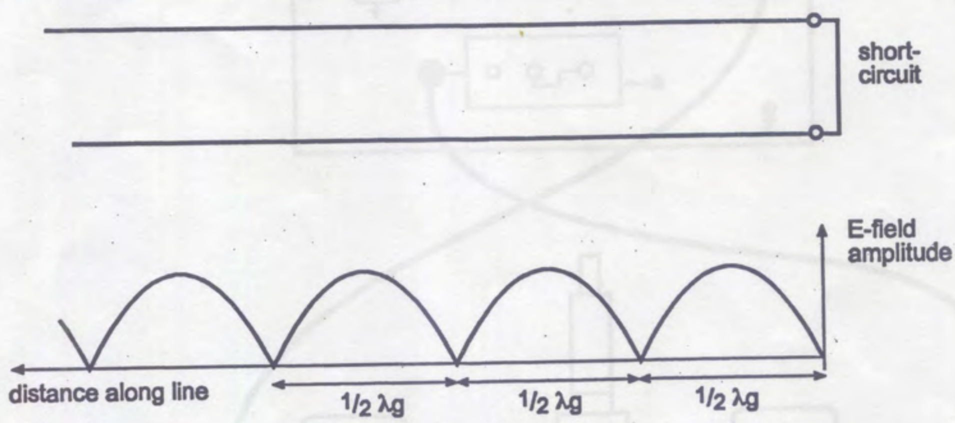

Fig 2.1.6

Standing wave electric field pattern on a short-circuited line; distance between successive null =$^1/_2\ \lambda g$

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EXPERIMENTAL PROCEDURE

WARNING

Although the microwave power levels generated by the equipment are below 10mW and not normally dangerous, the human eye can suffer damage by exposure to direct microwave radiation. Therefore:

NEVER look directly into an energised waveguide

(a) Measurement of frequency using a cavity wavemeter

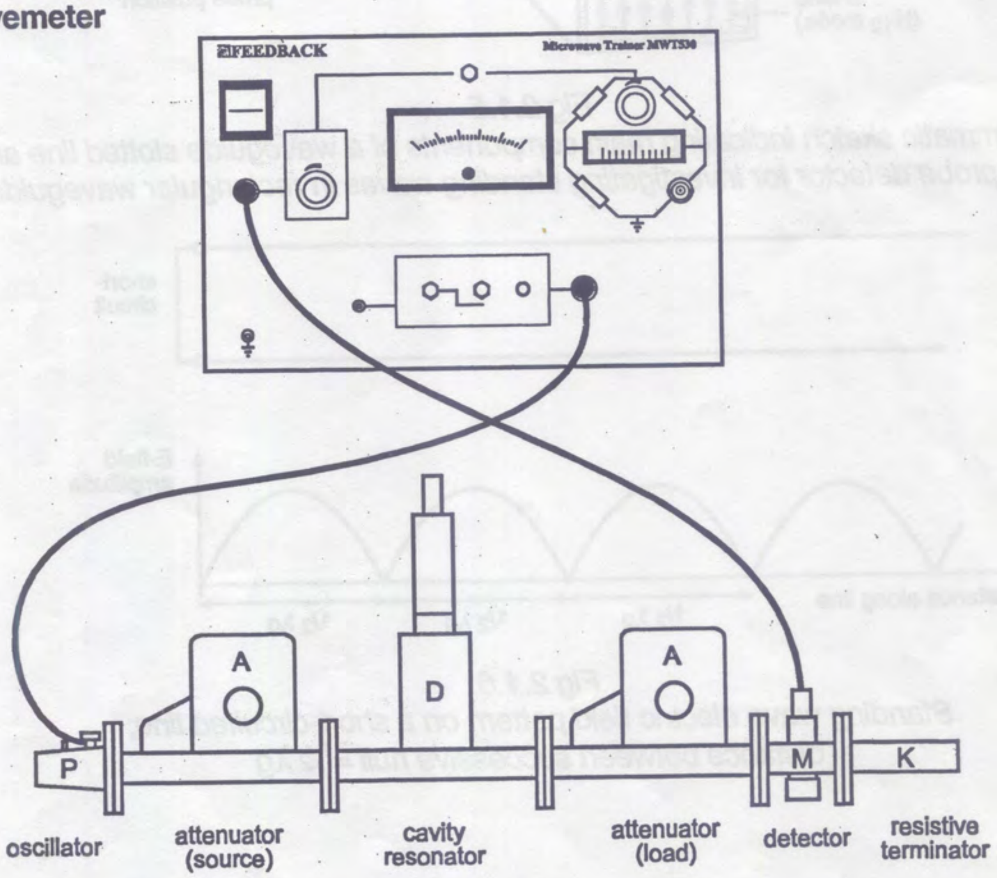

Figure 2.1.7

1. Set up the microwave components as shown in figure 2.1.7 with the switch positions on the control console initially as follows:

   main green power switch : off;

   amplifier and detector sensitivity control knob : to mid-position;

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meter switch : switch to detector output;

supply for X-band oscillator :

left-hand switch : switch to internal keying;

right-hand switch : off

2. Make sure the coaxial cables are also in place to connect the power supply for the X-band oscillator and to connect the diode detector output to the amplifier and detector input on the console.

3. Set the micrometer position of the cavity wavemeter fully out to a reading greater than 21mm. In this position the short-circuit plunger terminating the far end of the cavity is also fully out and the cavity is at its maximum length.

4. Set the angular position of the resistive vane for both attenuators at about 20°. At these settings the attenuators reduce the microwave power in the bench by the order of 10 dB and avoid possible diode-detector and display meter overload when we switch on.

5. Now switch on the main green power switch and the right-hand supply switch for the X-band oscillator to energise the bench.

6. Adjust the attenuator adjacent to the diode detector to give a meter reading on the console meter of about 4 mA. Note increasing the vane penetration reduces the microwave power transmitted in the system.

7. **Determination of frequency using the wavemeter**

Turn the micrometer thimble of the wavemeter very slowly clockwise to move the short-circuit plunger downwards and thus reduce the length of the cavity. Observe the meter deflection whilst this is being done.

Search for a position at which there is a sharp dip in the meter reading. Such a dip corresponds to a resonance at which power is absorbed by the wavemeter and so reduces the transmitted microwave power as detected by the diode-detector and observed on the meter.

Record the micrometer reading at this resonance and determine the frequency of the microwave signals using the E_{011} mode calibration curve of figure 2.1.4.

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NOTE

(i) The linear scale on the micrometer barrel of the wavemeter is graduated in 0.5mm intervals. The circular scale on the thimble is graduated 0 to 50 with each graduation representing a 0.01mm movement. Thus the vertical movement of the short-circuit and hence the cavity length and resonance position can be measured extremely accurately.

(ii) The design of the wavemeter is such that it resonates principally in the E_{011} mode and hence the curve for this mode should be used in figure 2.1.4.

(iii) At micrometer readings of the order of 15mm and below a number of deep over-lapping resonances may also be observed. These are termed "spurious" and should be ignored. They arise principally to leakage of energy past the plunger.

(b) Measurement of guide wavelength, λ_g

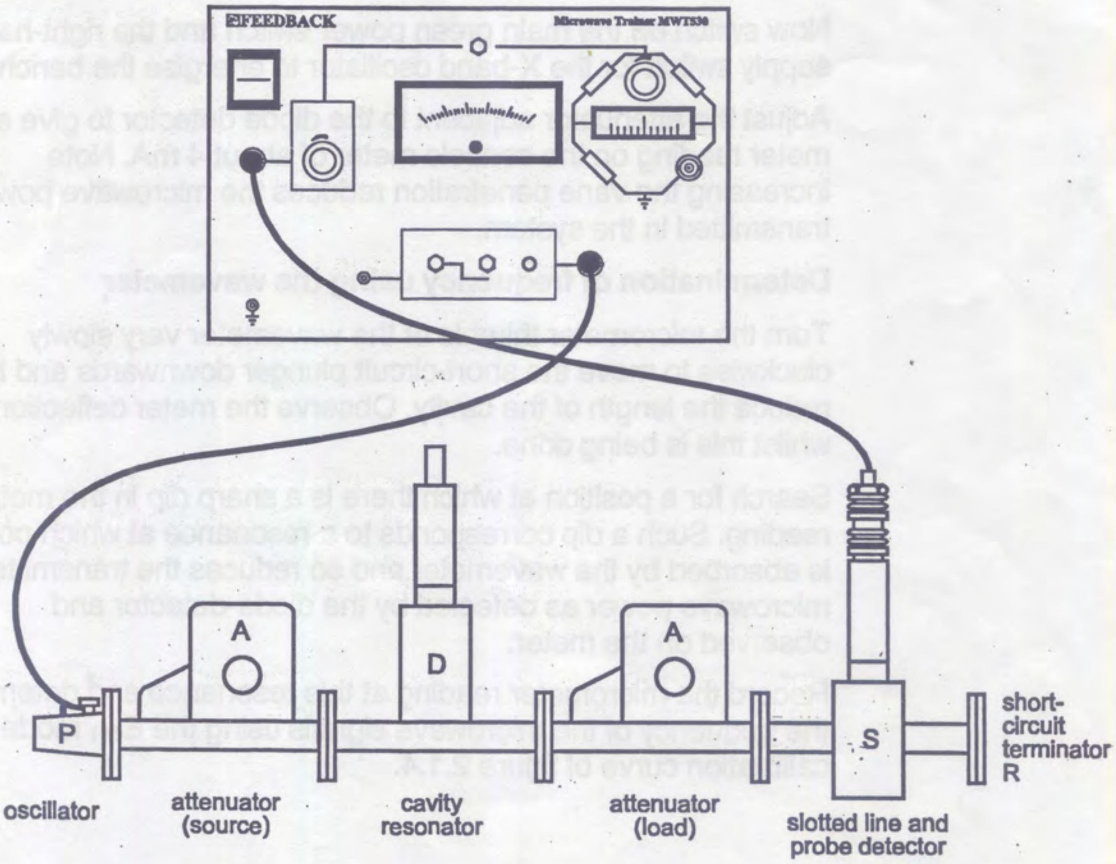

Figure 2.1.8

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1. The guide wavelength is measured using the waveguide slotted line component B fitted with one of the diode-detector/probe units S. This unit should be mounted so that its probe penetrates a short distance into the slot thereby allowing the electric field to be sampled. The depth of penetration is a compromise between obtaining reasonable coupling for the probe-detector to provide an observable meter reading without the probe causing undue disturbance of the field in the waveguide and thus invalidate the measurements. In practice a penetration depth of 1 to 2mm should suffice.

2. Connect the equipment as shown in figure 2.1.8 with the slotted waveguide section terminated in the metal plate R acting as a short-circuit.

3. Set the switch positions on the control console as follows:

   green power switch : off;

   meter switch : to detector output;

   left-hand switch of supply for X-band oscillator : to internal keying;

   right-hand oscillator switch : off.

   Check also the coaxial cables are correctly connected :

   oscillator output cable on console to microwave source;

   probe-detector unit cable to input of amplifier-detector on the console.

4. Now switch on power and oscillator and adjust attenuators and if necessary the sensitivity control on the console to obtain a detector reading. Move the probe to locate a position of maximum field and re-adjust sensitivity control and/or attenuators to provide a meter reading close to full scale, say 4 mA.

5. Starting from zero on the slotted-line scale move the probe along the slotted waveguide section and locate and record the positions of electric field nulls. It should be possible to locate 3 consecutive nulls:

   $x_1 =$

   $x_2 =$

   $x_3 =$

RICARDO FREEMAN

INTRODUCTION OF A MICROWAVE WAVEGUIDE BENCH AND MEASUREMENT OF SOURCE FREQUENCY AND WAVELENGTHASSIGNMENT 1

The guide wavelength:

$\lambda_g = 2\,(x_2 - x_1) \quad =$

$\quad = 2\,(x_3 - x_2) \quad =$

$\quad = (x_3 - x_1) \quad =$

6. The waveguide used in the Microwave Trainer is standard WG16 whose internal dimensions are

broad dimension $a = 0.9$ inch = 22.86mm

narrow dimension $b = 0.4$ inch = 10.16mm

The cut-off wavelength for the dominant mode, the H_{10} mode is

$$\lambda_c = 2a$$

$$= 2 \times 22.86\text{mm} = 45.72\text{mm for WG 16}$$

Using the result of formula (3) and the above value of λ_c determine the guide wavelength λ_g at the source frequency, f = 10.7GHz. Compare with the experimentally determined value.

SUMMARY

In this assignment two important parameters have been measured and a number of basic microwave components have been used. Frequency has been measured using a cavity wavemeter and guide wavelength has been measured experimentally using a waveguide slotted line. The relationship between free space wavelength l has also been introduced and used to determine guide wavelength.

UNIVERSITY OF TECHNOLOGY, JAMAICA

SCHOOL OF ENGINEERING

MODULE: Microwave Systems

\- Lab 2 -

Measurement of Voltage ~~and~~ Standing Wave Ratio (VSWR)

Report:

1. Your reports should be submitted individually and should include the measurements taken and any calculations made.
2. The discussion of your report should also include the derivation of the formulas used to determine the VSWR mathematically and should explain the relevance of different VSWR values to practical applications.
3. The report should be submitted on or before Wednesday February 21, 2012, and marks will be deducted for late submission.

MEASUREMENT OF VOLTAGE AND STANDING WAVE RATIO (VSWR)

ASSIGNMENT 2

CONTENT

In this assignment the measurement of voltage standing wave ratio (vswr) of waveguide components is undertaken using a waveguide slotted-line and probe detector. Voltage standing wave ratio, invariably abbreviated to vswr, is one of the fundamental parameters used in specifying component performance. It quantifies the degree of mismatch a component presents to the waveguide feed line.

EQUIPMENT REQUIRED

Quantity	Identifying letter	Component description
1	---	Control console
2	A	Variable attenuators
1	B	Slotted line
1	S	Probe-diode detector
1	P	X-band source
1	K	Resistive termination
1	N	Waveguide horn

OBJECTIVES

When you have completed this assignment you should:

- Know the definition of voltage standing wave ratio and its relation to reflection coefficient
- Know how to measure vswr using a slotted line and probe-detector
- Know the method used to measure high values of vswr

KNOWLEDGE LEVEL

No prior specialist knowledge is required to carry out this experiment, although completion of assignment 1 would be a distinct advantage.

MEASUREMENT OF VOLTAGE AND STANDING WAVE RATIO (VSWR) — ASSIGNMENT 2

INTRODUCTION

When a component is connected into a transmission line system it will cause reflection at the junction between the line and the component unless it is correctly matched or a matching unit is used.

The reflected wave from the component and incident wave from the source set up a standing wave pattern in the feed line as illustrated in figure 2.2.1

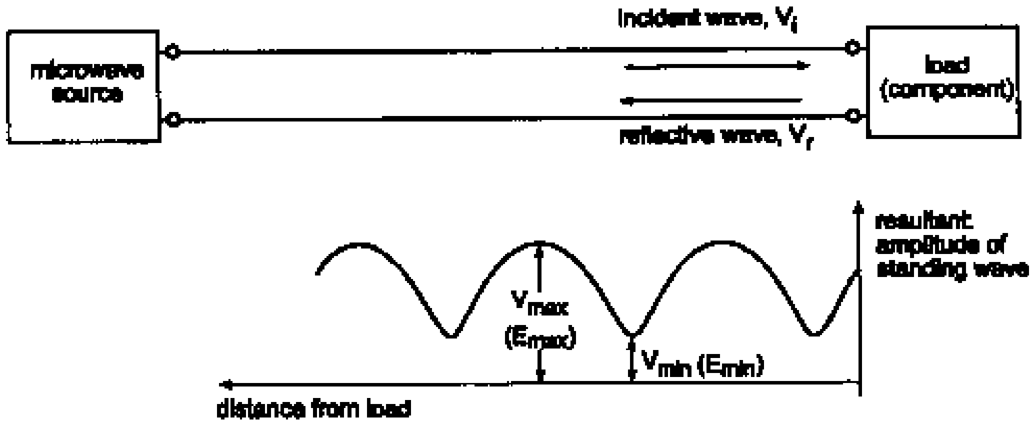


Fig 2.2.1. Standing wave pattern: vswr $S = V_{max}/V_{min}$ or E_{max}/E_{min}

Standing waves cause undesirable effects. They can give rise to very high values of voltage/electric field strength in the waveguide and this can cause breakdown in high-power systems. Reflection caused through the mismatch between the line and component reduces the amount of power that can be transferred below optimum and can adversely affect the efficiency of a communications or radar system. Power can be wasted in a transmitter by being reflected, for example, at the antenna input. Likewise, power can be lost by mismatch reflection at an antenna-receiver station.

The voltage standing ratio, vswr, is universally used to quantify the degree of mismatch. It is denoted by the letter S and defined as:

$$S = \frac{V_{max}}{V_{min}} = \frac{E_{max}}{E_{min}}$$

where V_{max}, E_{max} = voltage or electric field strength at a position of field maximum

V_{min}, E_{min} = voltage or electric field strength at a position of field minimum

There is an important relation between vswr, S, and reflection coefficient G:

$$G = V_r/V_i$$

where V_i = incident wave voltage or electric field amplitude

V_r = reflected wave amplitude

and since $V_{max} = V_i + V_r = V_i\,(1 + G)$

$V_{min} = V_i - V_r = V_i\,(1 - G)$

$$S = \frac{V_{max}}{V_{min}} = \frac{1 + \Gamma}{1 - \Gamma}$$

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

The table below provides a useful guide to the relationships of vswr, reflection coefficient G and power reflected due to mismatch.

vswr S	Reflection coefficient Γ	% power reflected Γ^2%	Comment
1.0	0	0	System matched
1.05	0.048	0.22	Very good match
1.5	0.2	4.0	Fair, just acceptable
2.0	0.33	11.1	Poor match, not usually acceptable
5.0	0.67	44.4	Reject, faulty, unacceptable

The voltage standing wave ratio produced by a waveguide component may be measured using a slotted waveguide section and a diode detector probe. The slotted section is inserted in the waveguide system to provide a means of sampling the standing wave electric field pattern produced by reflection from the component under consideration. The slotted section consists of waveguide with a narrow axial slot cut in the centre of its broad face as indicated in figure 2.2.2(a). A narrow slot in this position is non-radiating and causes negligible distortion to the waves within the waveguide. Coupling to the electric field is made by a probe which panetrates a small distance through the slot as illustrated in figure 2.2.2(b). The probe is connected in series with a crystal diode detector and the unit contained in a carriage that may be moved along the slot so enabling the field at different axial positions to be measured. The diode detector rectifies the sampled microwave signal and the rectified current is measured on a DC milliammeter.

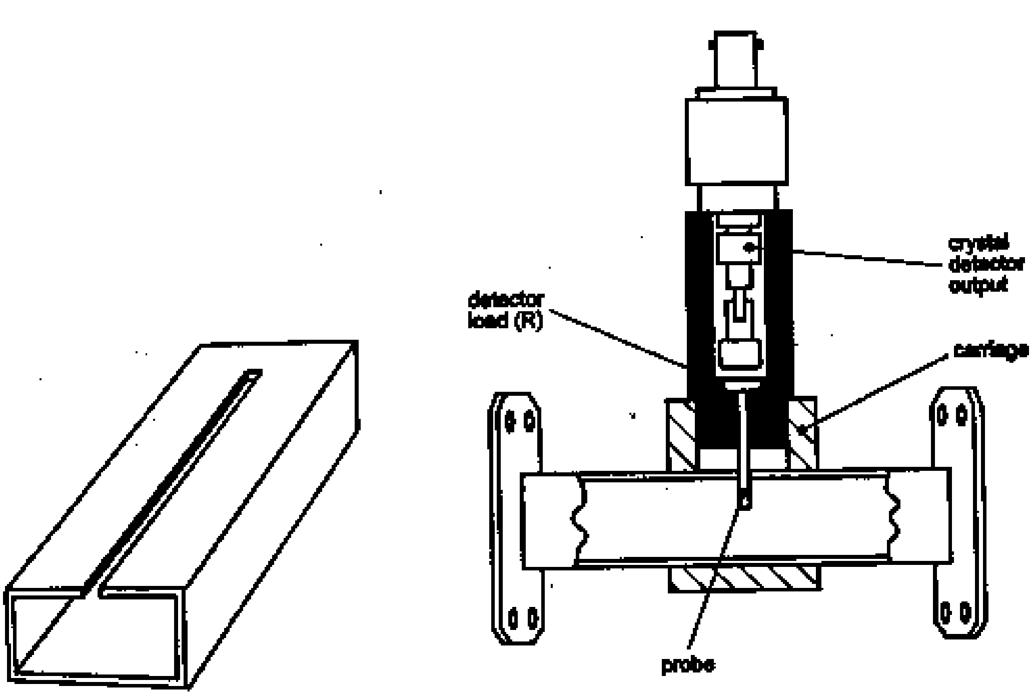


Fig 2.2.2 Slotted waveguide and diode detector probe unit for measuring voltage standing wave ratio

For small currents the diode-detector obeys a square law such that the detected current is proportional to the square of the electric field induced in the probe. Thus, if the values of maximum and minimum current are measured, we have:

$$\text{vswr, } S = \frac{E_{max}}{E_{min}}$$

$$\text{so } S = \frac{E_{max}}{E_{min}} = \frac{\sqrt{I_{max}}}{\sqrt{I_{min}}} = \sqrt{\frac{I_{max}}{I_{min}}}$$

where I_{max} = current measured at field maximum E^2_{max}

where I_{max} = current measured at field maximum E^2_{min}

for small current conditions

e.g. if I_{max} is measured at 4.6mA and I_{min} at 3.2mA

$$S = \frac{E_{max}}{E_{MIN}} = \sqrt{\frac{4.6}{3.2}} = \sqrt{1.44} = 1.2$$

MEASUREMENT OF VOLTAGE AND STANDING WAVE RATIO (VSWR)

ASSIGNMENT 2

Voltage standing wave ratio can be measured without knowledge of the diode-detector characteristics by using a precision attenuator. The probe is moved to a position of minimum and the value of the attenuator attenuation A_1 dB noted which gives a convenient current reading on the meter for reference. The probe is then moved to locate a position of maximum and the attenuator adjusted to provide the same reading as obtained with the minimum. Suppose the new attenuation value is to be A_2, then:

$$\text{attenuation added} = A_2 - A_1$$
$$= 10 \log (E^2_{max}/E^2_{min})$$
$$= 20 \log (E_{max}/E_{min})$$
$$= 20 \log S$$

so $S = \text{antilog}_{10} (A_2 - A_1)/20$ or $10^{(A2 - A1)/20}$

For large values of vswr, typically $S > 3$, E_{min} and therefore the detector current will become very small and the ratio E_{max} to E_{min} increasingly difficult to measure accurately. For these cases a method based on locating the minimum and determining the distance between points either side of the minimum at which the field is a constant factor, k say, times the minimum value. With reference to figure 2.3 and assuming a square law for the diode detector, the vswr may be evaluated from the formula

$$S = \frac{\sqrt{\left[k^2 - \cos^2 (\pi d/\lambda g)\right]}}{\sin\left(\frac{\pi d}{\lambda g}\right)}$$

where d = distance between points where

electric field, $E = k\, E_{min}$

detector current, $I = k^2\, I_{min}$

l_g = guide wavelength

$k^2 = I/I_{min}$

It is common practise to choose $k^2 = 2$ so

d = distance between points where detector current equals 2 I_{min}

and in this case the formula for S reduces to

$$S = \sqrt{1 + \frac{1}{\sin^2\left(\frac{\pi d}{\lambda g}\right)}}$$

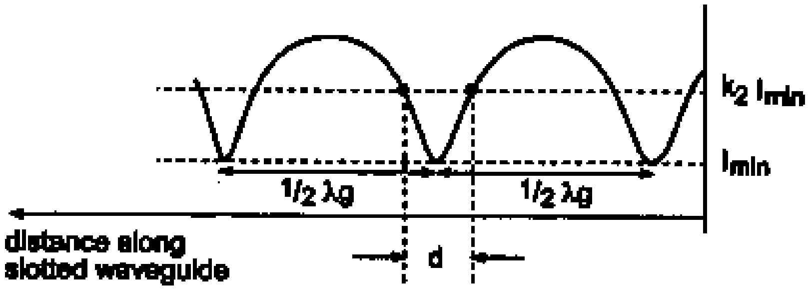


Fig 2.2.3 Plotting around the field minimum method for measuring high values of vswr

e.g. If d = 1.5 mm and l_g = 35.5 mm

pd/lg = 0.133 rad or 7.61°

so:

$$S = \sqrt{\left[1 + \frac{1}{\sin^2 7.61}\right]} = \sqrt{[1 + 57.1]} = 7.6$$

EXPERIMENTAL PROCEDURE

WARNING

Never look into an open-ended waveguide system
microwave radiation can cause harm

1. Set up the equipment as shown in figure 2.2.4 with the resistive termination component connected to the slotted line section. The depth of penetration of the probe of the diode detector into the slotted line should be set at approximately 1 to 2 mm.

Our first task is to measure the vswr of the resistive termination component.

MEASUREMENT OF VOLTAGE AND STANDING WAVE RATIO (VSWR)

ASSIGNMENT 2

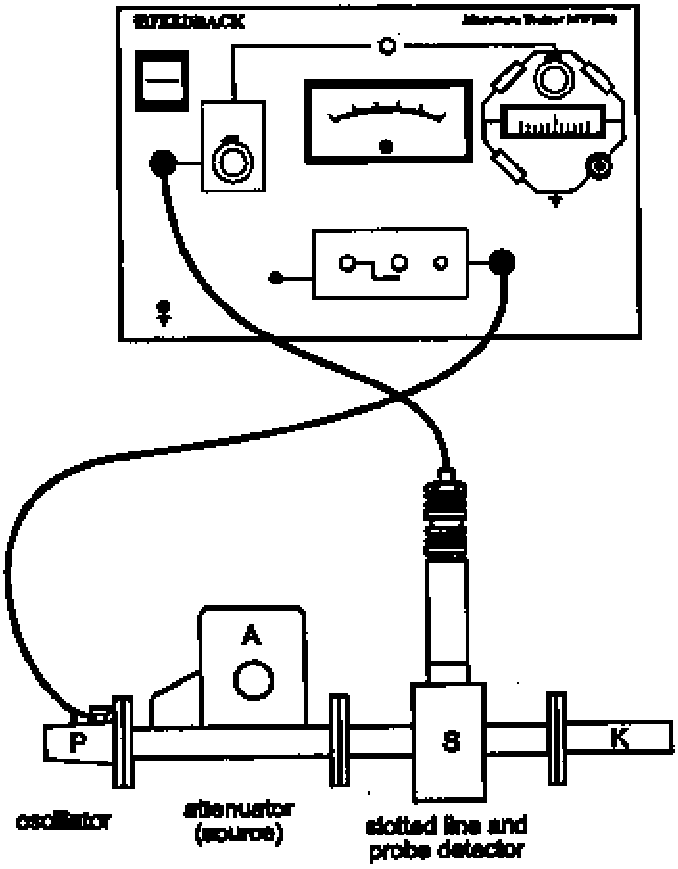


Figure 2.2.4 Experiment set up to measure vswr resistive load

2. Set the switch conditions on the console as follows:

amplifier and detector: switch to detector output

amplifier and detector sensitivity control: turn to mid-position supply for X-band oscillator:

left-hand keying switch: switch to internal keying

right-hand switch: initially off

Now switch on the console power supply, the main green switch, and energise the microwave bench by switching the right-hand X-band oscillator switch on

3. Set the attenuator at about 25° to provide a reasonable level or attenuation in the system. This is good practice since attenuation between the microwave oscillator and the equipment it drives helps reduce detuning of the oscillator due to reflected signals.

MEASUREMENT OF VOLTAGE AND STANDING WAVE RATIO (VSWR) **ASSIGNMENT 2**

Move the probe-detector unit along the slotted line to locate a position of electric field maximum. Adjust the detector sensitivity of the amplifier and detector on the console and, if necessary, the attenuator setting to obtain a meter reading close to full-scale deflection.

Record the detector current I_{max} corresponding to E_{max}.

4. Now move the probe-detector unit away from the maximum and locate accurately the position of the adjacent minimum.

Record the detector current I_{min} corresponding to E_{min}.

5. Using the results: I_{max} = I_{min} =

Calculate for the resistive load termination:

the vswr $S = \frac{E_{max}}{E_{min}} = \sqrt{\frac{I_{max}}{I_{min}}} =$

the reflected coefficient,

$$|\Gamma| = \frac{S-1}{S+1} =$$

the % of power reflected,

$$100|\Gamma|^2 = \quad \%$$

the return loss,

$$10 \log \frac{P_r}{P_i} = 20 \log |\Gamma| = \quad dB$$

where Pr, Pi = reflected and incident powers, respectively

6. **Measurement of vswr for the horn antennas**

Remove the resistive load termination and connect one of the horn antennas. Measure its vswr by measuring I_{max} and I_{min} as described in steps 2 and 3. Repeat with the second horn.

Results and calculation of vswr

Horn 1	Horn 2
I_{max} =	I_{max} =
I_{min} =	I_{min} =
vswr = $\sqrt{\frac{I_{max}}{I_{min}}}$ =	vswr = $\sqrt{\frac{I_{max}}{I_{min}}}$ =

7. **Measurement of larger values of vswr: plotting around the minimum method**

The horn antenna presents a very good match to the waveguide and hence has a vswr quite close to unity. A component with a higher value of vswr can be simulated by using the second attenuator terminated by a short-circuit plate.

(i) Remove the horn and connect the attenuator terminated in a short circuit as shown in figure 2.5.

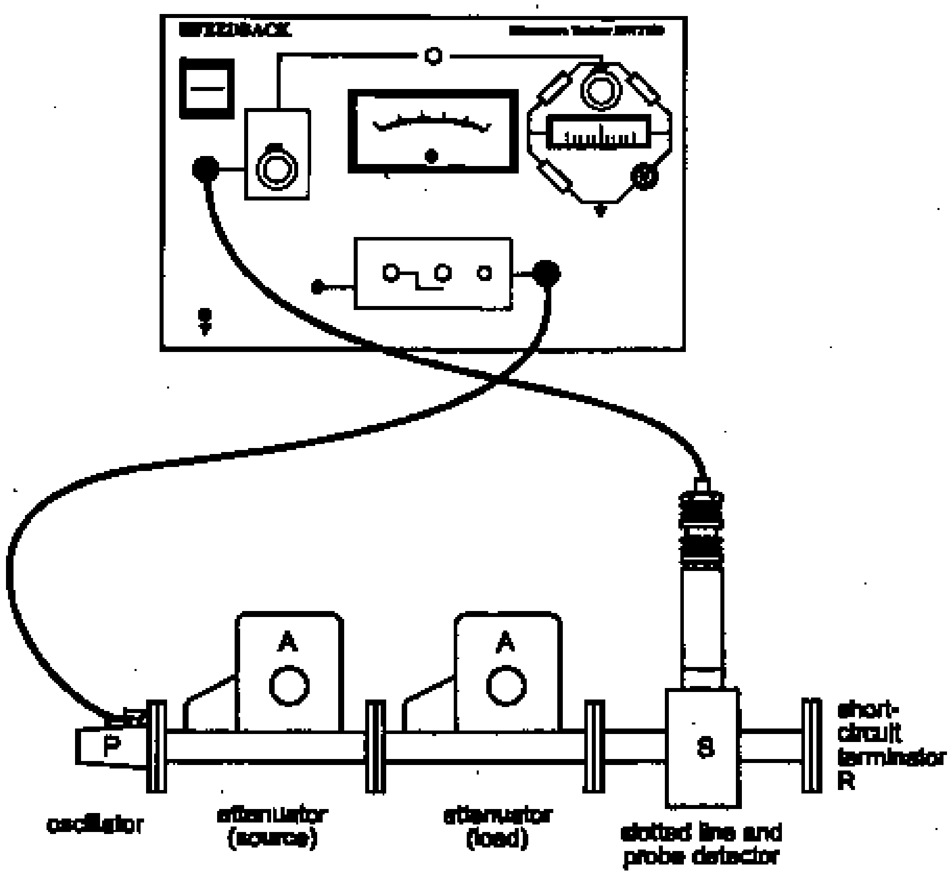


Figure 2.2.5

MEASUREMENT OF VOLTAGE AND STANDING WAVE RATIO (VSWR) **ASSIGNMENT 2**

(ii) Set the attenuator to 40° which provides a fairly low attenuation value (typically 2 to 3 dB).

(iii) Move the probe-detector along the slotted line section to locate an electric field minimum. Note the detector meter reading I_{min}.

(iv) Next move the probe-detector to the right until the detector meter registers twice the minimum current value, i.e. 2 I_{min} (corresponding to $k^2 = 2$). Record the probe-detector position on the slotted line scale, x_1 say.

(v) Now move the detector probe to the left through the minimum and locate the position where the detector meter current is again 2 I_{min}. Record the probe-detector position, x_2.

(vi) Measure the guide wavelength by finding the distance between successive minima and remembering: distance between successive minima = ½ l_g

(vii) **Results and calculation of vswr**

position where $I = 2\, I_{min}$: x_1 =

x_2 =

$d = x_1 - x_2$

l_g = 2 x distance between minima =

$$\text{vswr } S = 1 + \frac{1}{\sin^2\left(\frac{\pi d}{\lambda_g}\right)}$$

SUMMARY

The vswr of waveguide components has been measured using a waveguide slotted line to measure the ratio of maximum to minimum electric fields produced in the standing wave pattern set up by the components.

Components with a vswr close to 1 have very low reflection coefficient and present a good match to their waveguide feed.

A method for the measurement of large values of vswr based on determining the relative width about an electric field minimum has also been undertaken. Both methods assumed a square law for the diode detector. Measurements of vswr independent of the diode detector characteristics may be made by measuring the ratio E_{max}/E_{min} using a precision attenuator.

UNIVERSITY OF TECHNOLOGY, JAMAICA

SCHOOL OF ENGINEERING

MODULE: Microwave Systems

- Lab 3 -

Horn Antenna Investigations

Report:

1. Your reports should be submitted individually and should include the measurements taken and any calculations made.
2. The discussion of your report should include an explanation of the shape fo the radiation diagram obtained, and explain why certain this type of antenna may or may not be suitable for certain example applications (you are to think of at least four (4) different applications).
3. The report should be submitted on or before Wednesday March 28, 2012, and marks will be deducted for late submission.

HORN ANTENNA INVESTIGATIONS — ASSIGNMENT 6

CONTENT

A test bench is set up to investigate the radiation pattern of a rectangular waveguide pyramidal horn antenna. Polar radiation diagrams are plotted and the 3 dB beamwidth of the antenna is determined.

EQUIPMENT REQUIRED

Qty	Identifying Letter	Description
1	-	Control console
1	A	Variable attenuator
1	K	Resistive load termination
1	M	Diode detector
2	N	Horn antenna
1	P	X-band oscillator

OBJECTIVES

When you have completed this assignment you

- Will appreciated the directional radiation characteristics of a horn antenna and know how to plot its radiation pattern
- Know how to measure the beamwidth and gain of an antenna

KNOWLEDGE LEVEL

Before you start this assignment it would be an advantage

- To be familiar with the operation of the microwave bench
- Know that microwave signals can be detected using a diode detector and for low-level signals, that detected output is proportional to power
- To appreciate the role of antennas in the transmission and reception of radio waves

HORN ANTENNA INVESTIGATIONS — ASSIGNMENT 6

INTRODUCTION

Antennas are essential components in the transmission and reception of radio waves. In the microwave range highly directive antennas capable of producing the narrow beams required for the line-of-sight links and satellite communications can be designed. The horn antenna, whose radiation characteristics are investigated in this assignment, plays an important role as a radiator of microwave energy in its own right and also as a primary feed for reflector antennas employed in microwave radio links and radar.

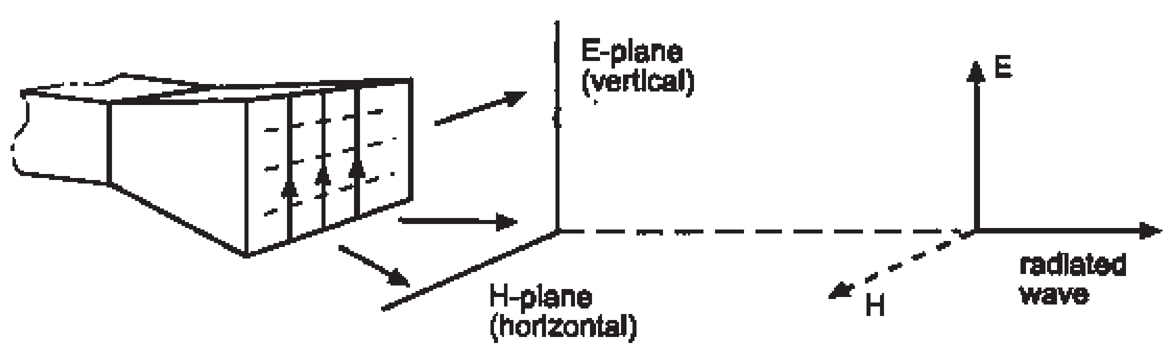
The directional characteristics of an antenna - the directions it radiates energy into space - can be visualised graphically by plotting radiated power density versus angular direction. These polar plots are known as far-field radiation diagrams, the latter qualifying the condition that measurements are taken at a sufficiently far distance from the antenna to represent the characteristics as dependent primarily on angular direction. Close to an antenna the radiation pattern is very complex and seldom used in practice. The far-field conditions are satisfied at distances,

$$r \geq 2D^2/\lambda$$

where D = largest antenna dimension

λ = transmitted wavelength

To fully describe the directional properties of an antenna two radiation diagrams are normally required: one in the horizontal plane, in the case of the horn antenna this would be the H-plane with respect to the horn sketched in figure 2.6.1, and one for the vertical plane, the E-plane in figure 2.6.1.



E = Electric field
H = Magnetic field

Figure 2.6.1 Pyramidal horn antenna

A typical radiation diagram for an antenna with directional radiation (and receiving) properties such as a horn or a parabolic reflector fed by a horn is shown in figure 2.6.2. The angular spread on the main beam between points where the power drops to one-half or by 3 dB from the maximum is known as the 3-dB beamwidth and is an important measure of an antenna's directivity. Not all radiation is confined to the main beam and subsidiary beams at lower power levels and known as side-lobes occur. side-lobes and spill-over radiation can cause interference in microwave radio systems and their levels must be carefully controlled by antenna designers.

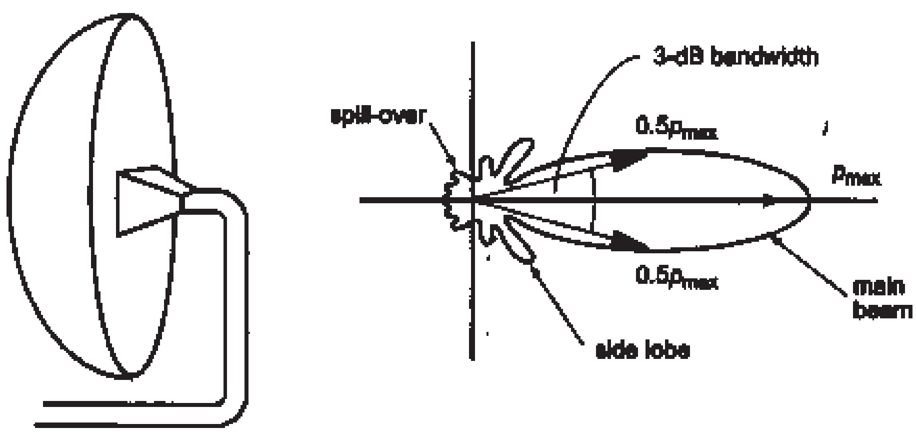


Figure 2.6.2 A typical radiation diagram for a directional microwave antenna

One of the most important parameters of an antenna is its gain. Antenna gain compares the power radiated in the direction of the main beam with that of a hypothetical antenna radiating equally in all directions. Antenna gain is defined as:

$$G = p/pi$$

where p = power density W/m^2 radiated by antenna in given direction

pi = power density radiated equally in all directions

$= P/4pr^2$

P = total power radiated

r = distance from antenna

$4pr^2$ = surface area of sphere radius r

HORN ANTENNA INVESTIGATIONS — ASSIGNMENT 6

For aperture type antenna such as horns and parabolic reflectors, gain is given by the formula:

$$G = \eta \frac{4\pi}{\lambda^2} A$$

where A = area of antenna aperture

η = aperture illumination efficiency (typically between 0.5 and 0.8)

Gain is very often expressed in decibels, dB:

G dB = 10 log (p/pi) dBi

The i qualifying, isotropic, the fact that the reference antenna radiates isotropically (equally in all directions). The product of antenna gain G and radiated power P is known as the effective isotropic radiated power normally abbreviated to EIRP:

EIRP = G x P

The power received in a line-of-sight radio link can be expressed in terms of transmitted power and antenna gains; the received power

$$P_R = P_T \; G_T \times \left(\frac{\lambda}{4\pi r}\right)^2 \times G_R$$

where P_T = transmitter radiated power

G_T = gain of transmitter antenna

G_R = gain of receiver antenna

l = wavelength

r = link distance

The above formula is extremely useful in power budget calculations for microwave radio links. It may also be used to measure experimentally the gain of an antenna. If P_R is measured for a given transmitted power and a reference antenna is used over a link of known length, G_T can be determined:

$$G_r = \frac{\left(\frac{P_R}{P_T}\right) \times \left(\frac{4\pi r}{\lambda}\right)^2}{G_R}$$

or in dB $$G_r\,dB = 10\log\left(\frac{P_R}{P_T}\right) + 20\log\left(\frac{4\pi r}{\lambda}\right) - G_R\,dB$$

EXPERIMENTAL PROCEDURE

WARNING!

Do **NOT** look directly into the transmitter antenna when taking measurements in this experiment.
Remember, although the power levels produced by the microwave source in the Trainer are low, microwave radiation can cause harm and and eyes are particularly sensitive.

1. Connect up the equipment as shown in figure 2.6.3. Switch the X-band source to internal keying and the meter to detector output

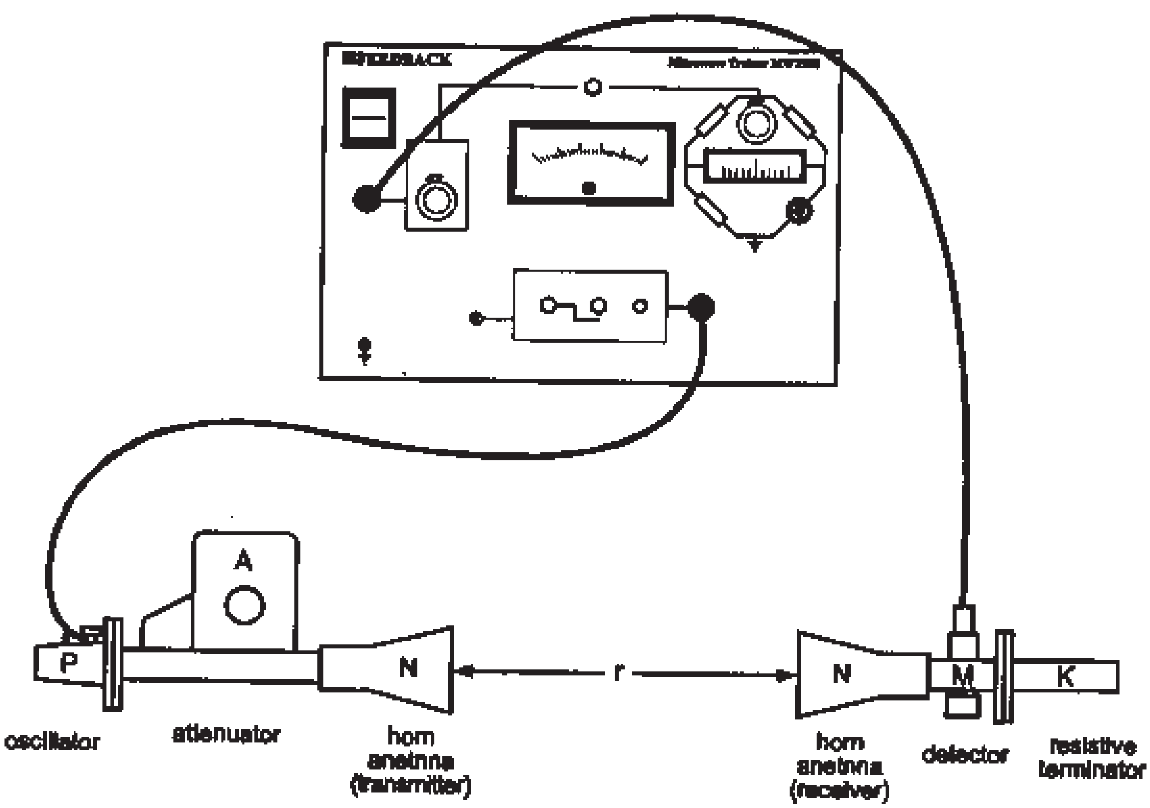


Figure 2.6.3

HORN ANTENNA INVESTIGATIONS **ASSIGNMENT 6**

2. Ensure that the distance r between transmitter and receiver horns is about 30 cm. This distance partially satisfies the conditions that measurements are taken in the far-field, whilst providing sufficient scope for the received signal levels to be detected. The far-field condition is

$$r \geq \frac{2D^2}{\lambda}$$

where D = maximum dimension of horn aperture = 8cm

λ = wavelength = 2.8cm for f = 10.7GHz

so $r = 2D^2/\lambda \cong 38\text{cm}$

Thus the condition is not quite satisfied. However, reasonably accurate results for plotting a radiation diagram can be obtained with r = 30cm. It is also important to ensure that the radio path between the antennas and their surrounds are free from obstacles, particularly metallic structures, which could cause reflections into the antennas and give rise to false results.

3. Switch on the console power supply and X-band oscillator source. Set the attenuator to a low attenuation setting, typically 40° on the attenuator scale, and turn the amplifier-detector control up to maximum sensitivity.

Align the antennas for the line-of-sight 0° position. In this position the transmitter antenna will be radiating directly in line with the receiver and correspond to maximum antenna gains and maximum received signal.

Adjust attenuator and detector-amplifier sensitivity to obtain a meter reading close to full scale deflection. Record this reading.

4. The radiation diagram for the transmitter horn can now be obtained by rotating the transmitter section from the 0° position through steps of 5°up to 40° either side of the 0° position.

Record measurement of received signal level as indicated on the detector meter in a table such as that given below.

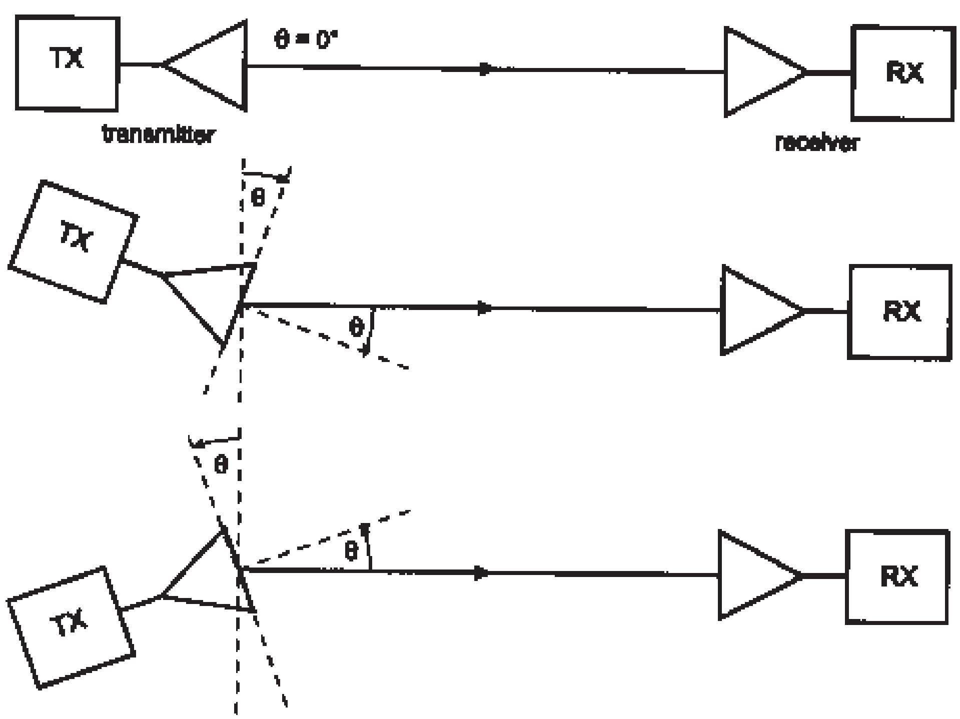
The angle of rotation Q° can be set by use of a protractor and aligning the edge of the transmitter horn at right angles to Q° direction as indicated in figure 2 6.4.

HORN ANTENNA INVESTIGATIONS

ASSIGNMENT 6

Angular direction Θ°	Diode detector meter reading I mA	Angular direction Θ°	Diode detector meter reading I mA
0°		0°	
+5°		– 5°	
10°		10°	
15°		15°	
20°		20°	
25°		25°	
30°		30°	
35°		35°	
40°		40°	

Table for logging radiation diagram results



5. Plot the polar radiation diagram of the horn antenna on polar graph paper, an example of which is shown below in figure 2 6.5. $\Theta°$ is the angular direction and I, the diode detector output current, is directly proportional to power for small signal levels. Thus a polar plot of I versus Θ represents the power radiation diagram.

From the radiation diagram determine the beamwidth between half-power point (3 dB) levels, that is the angle between points on the polar curve where the power drops to half of the maximum gain of the $\Theta = 0°$ position.

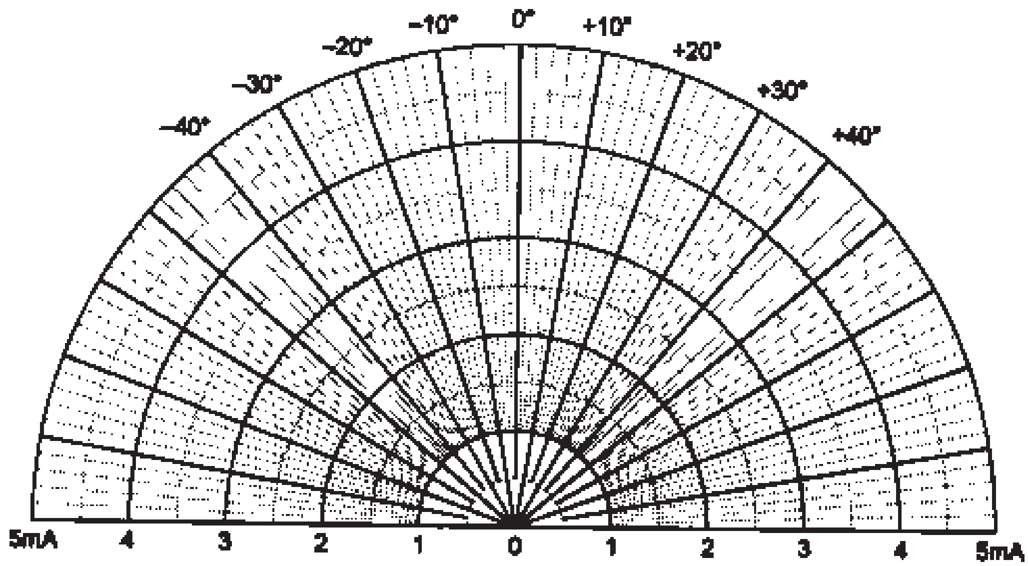


Fig 2 6.5 Polar graph paper for plotting radiation diagram

6. Interchange transmitter and receiver antennas so their respective roles are changed and repeat the experiment to obtain the radiation diagram of the second antenna. Compare the two diagrams and their 3 dB beamwidth.

7. The gain of an aperture type antenna is given by the formula:

$$G = \eta \frac{4\pi}{\lambda^2} A$$

where η = aperture efficiency

A = aperture area

Assuming that the aperture efficiency of the horn antenna is 60%, estimate the gain of the horns used in the experiment at the 10.7 GHz source frequency.

Half power points occur at -18° and +16°

so 3-dB beamwidth = 18 + 16 = 34°

Gain: dimension of horn aperture are:

7.3 cm x 4.8 cm

so Area A = 7.3 x 4.8 = 35.0 cm^2

and l = 3 x 10^8/10.7 x 10^9

= 0.028 m = 2.8 cm at f = 10.7 GHz

Hence estimate of gain using

$$G = \eta \frac{4\pi}{\lambda^2} A \quad \text{with } \eta = 0.60$$

$$= 0.6 \times 4\pi \times \frac{35}{2.8^2} = 33.7$$

or in dB 10 log G = 15.3 dBi

Gain using formula:

$$P_R = P_T \; G_T \times \left(\frac{\lambda}{4\pi r}\right)^2 G_R$$

and assuming $G_T = G_R = G$

provides

$$G = \sqrt{\left(\frac{P_R}{P_T}\right) \times \left(\frac{4\pi r}{\lambda}\right)}$$

$$= \sqrt{\left(\frac{0.05}{2}\right) \times \left(\frac{4\pi \times 0.5}{0.028}\right)} = 35 \text{ or } 15.5 \text{ dBi}$$

8. The gain of the antennas may be measured experimentally by determining:

P_T = total power transmitted

P_R = power received

or the ratio P_R/P_T

and utilising the formula:

$$P_R = P_T \; G_T \times \left(\frac{\lambda}{4\pi r}\right)^2 \; G_R$$

where G_T, G_R = gain of transmitter, receiver antennas which in our case can be assumed equal.

Outline how you would measure gain G of the horn antennas and calculate G for the case

P_T = 2.0 mW

P_R = 0.05 mW

r = 0.5 m

f = 10.7 GHz

SUMMARY

The radiation diagram of horn antennas has been investigated experimentally using a basic microwave test bench. The polar radiation diagram has been plotted and the 3dB beamwidth of the antenna determined. The measurements taken were in the H-plane and indicated the horn antenna to have a directive radiation pattern.

Angular direction Q°	Detector I mA	Angular direction Q°	Detector I mA
0°	4.0	0°	4.0
+ 10°	3.1	- 10°	3.1
+ 20°	1.4	- 20°	1.5
+ 30°	0.38	- 30°	0.4
40°	0	- 40°	0

Specimen Results

HORN ANTENNA INVESTIGATIONS

ASSIGNMENT 6

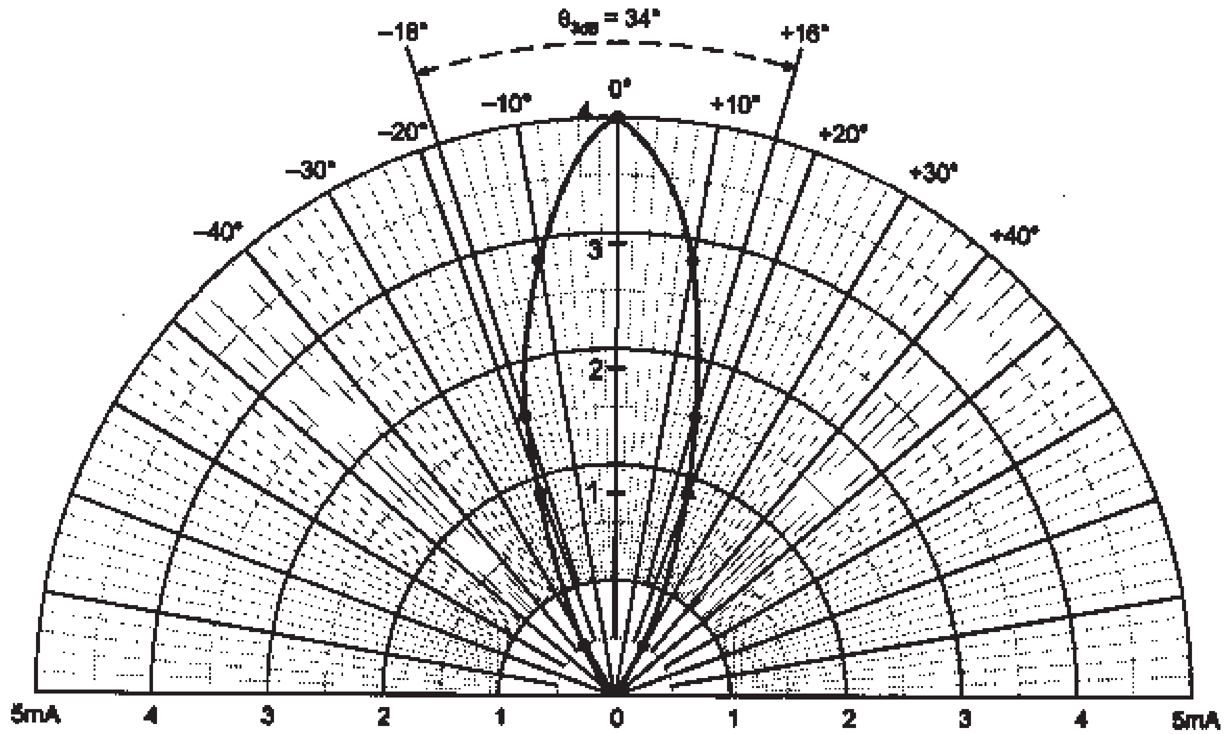


Fig 2.6.6 Radiation diagram for horn antenna