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KULLIYYAH OF ENGINEERING

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

MICROWAVE LABORATORY
ECE 3203

EXPERIMENT NO.1

(Introduction of a Microwave Waveguide Bench and Measurement of Source Frequency and Wavelength)

Assignment 1
Introduction of a Microwave Waveguide Bench and Measurement of Source Frequency and Wavelength

CONTENT

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

The waveguide bench comprises a FET Dielectric Resonant Oscillator (DRO) 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

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

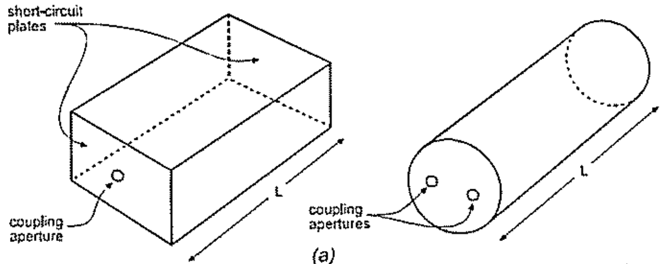
No prior specialist knowledge is required to carry out this assignment. Basic concepts of waves, wavelength and frequency should be known. You should also be familiar with reading a micrometer. To assist in understanding the measurements taken in the assignment it would also be useful to appreciate

- 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

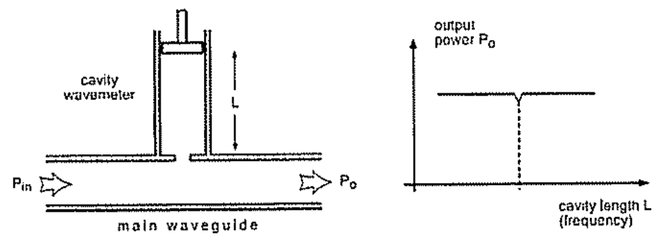
INTRODUCTION

(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 $L = 1/2 n\lambda g$



(b)
Cavity wavemeter as an absorption wavemeter to measure frequency: output power shows a dip at resonance $L = 1/2 n\lambda g$

Figure 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:

$$L = \frac{1}{2} n \lambda_g$$

where L = axial length of cavity

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

λ_g = guide wavelength of resonating mode

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:

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

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

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.

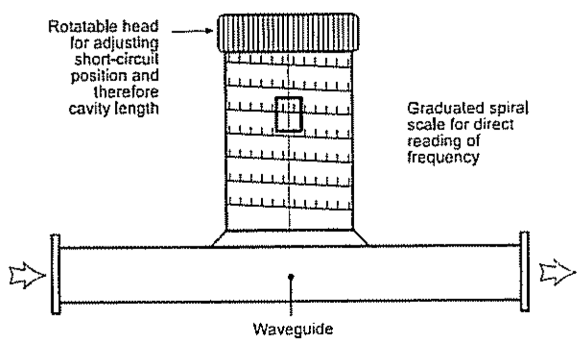


Figure 2-1-2: Cavity Wavemeter Calibrated for Direct Reading Frequency

A diagram of the wavemeter used in the microwave trainer is sketched in Figure 2-1-3. The cavity consists of circular waveguide of diameter D = 28.3 mm. Its length can be adjusted to be a maximum of approximately 22 mm. 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:

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

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

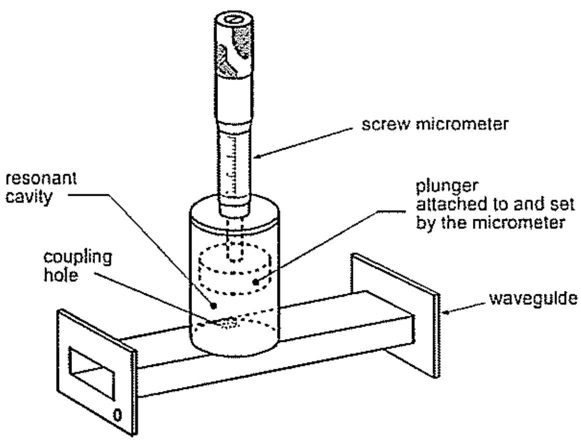


Figure 2-1-3: Cavity Wavemeter used in Microwave Trainer

A graph of resonant frequency versus micrometer reading for the wavemeter is plotted in Figure 2-1-4 for the first order resonant mode 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 11.2 mm the frequency can be measured using the curve of Figure 2-1-4 and in this case would correspond to f = 10.4 GHz.

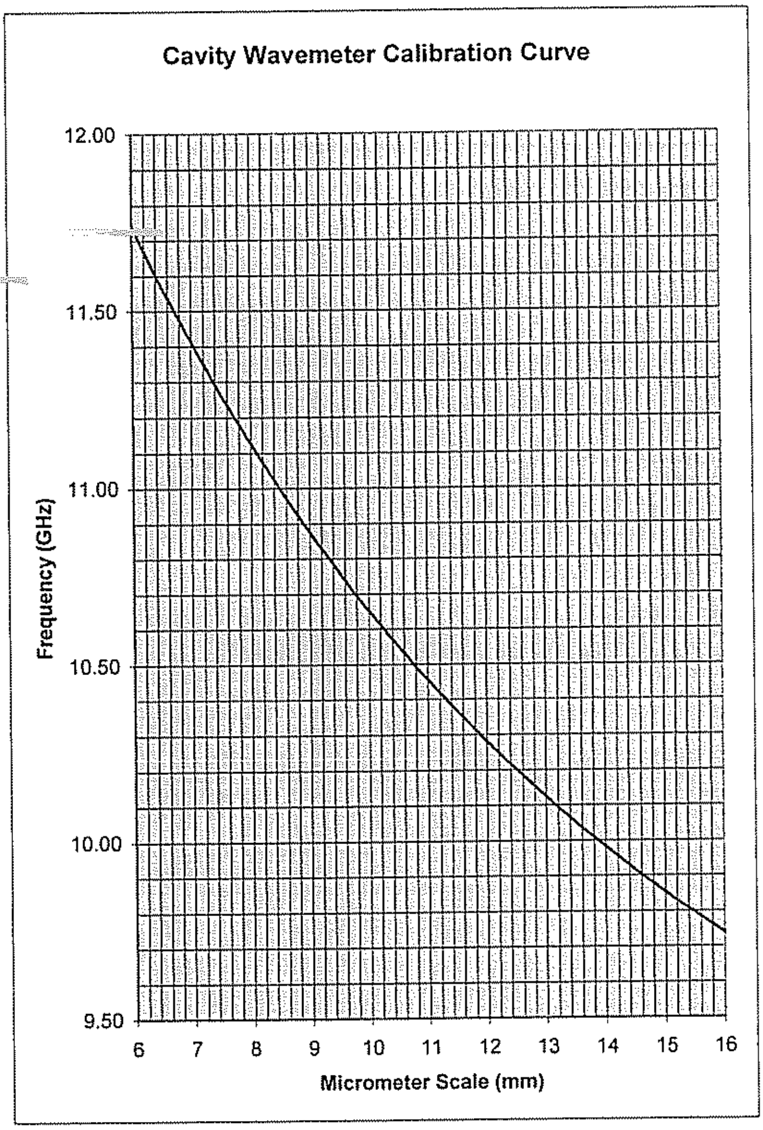


Figure 2-1-4: Calibration Curves for Cavity Wavemeter

Diameter D = 28.3 mm.
Note 0.00 point of micrometer scale corresponds to cavity length of 11.63 mm and this offset is taken into account in the above graph.

(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.

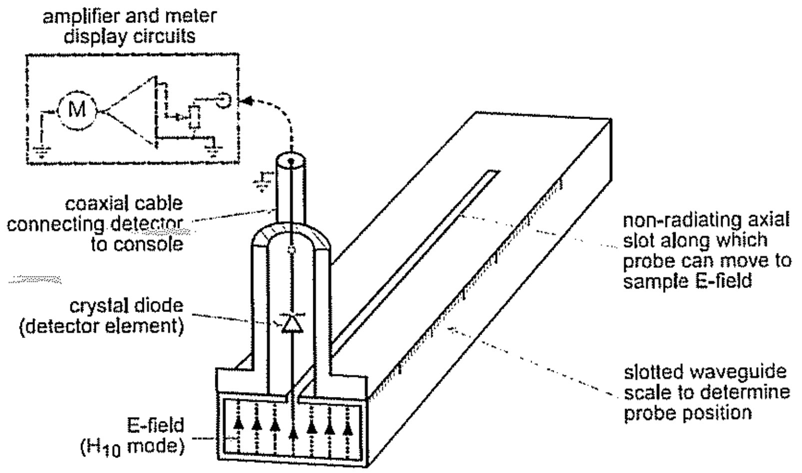


Figure 2-1-5

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

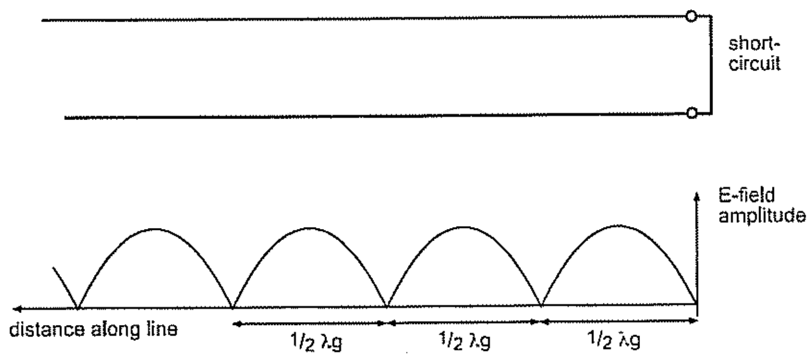


Figure 2-1-6

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

EXPERIMENT PROCEDURE

WARNING:

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

NEVER look directly into an energised waveguide.

(a) Measurement of frequency using a cavity wavemeter

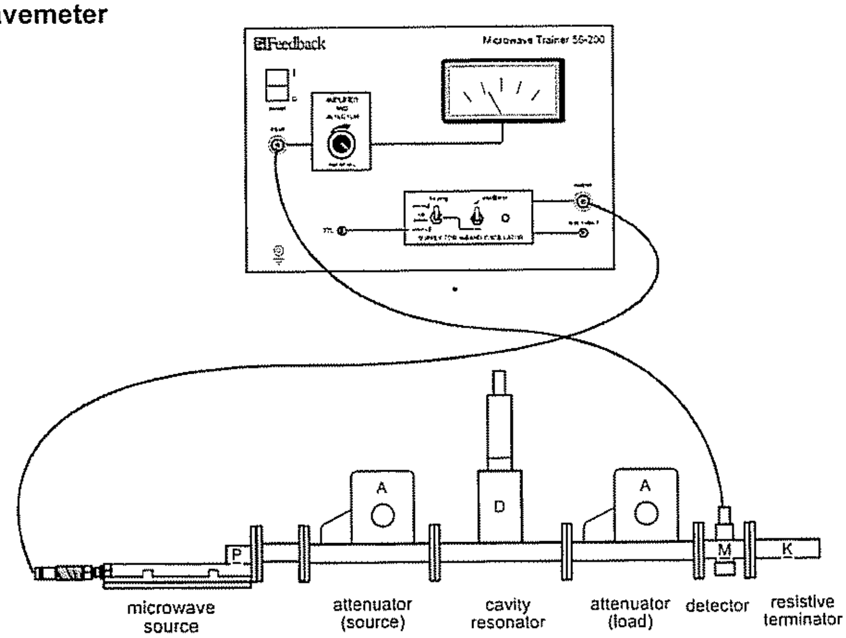


Figure 2-1-7

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;

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 15 mm. 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.

NOTE

(i) The linear scale on the micrometer barrel of the wavemeter is graduated in 0.5 mm intervals. The circular scale on the thimble is graduated 0 to 50 with each graduation representing a 0.01 mm 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 5 mm 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

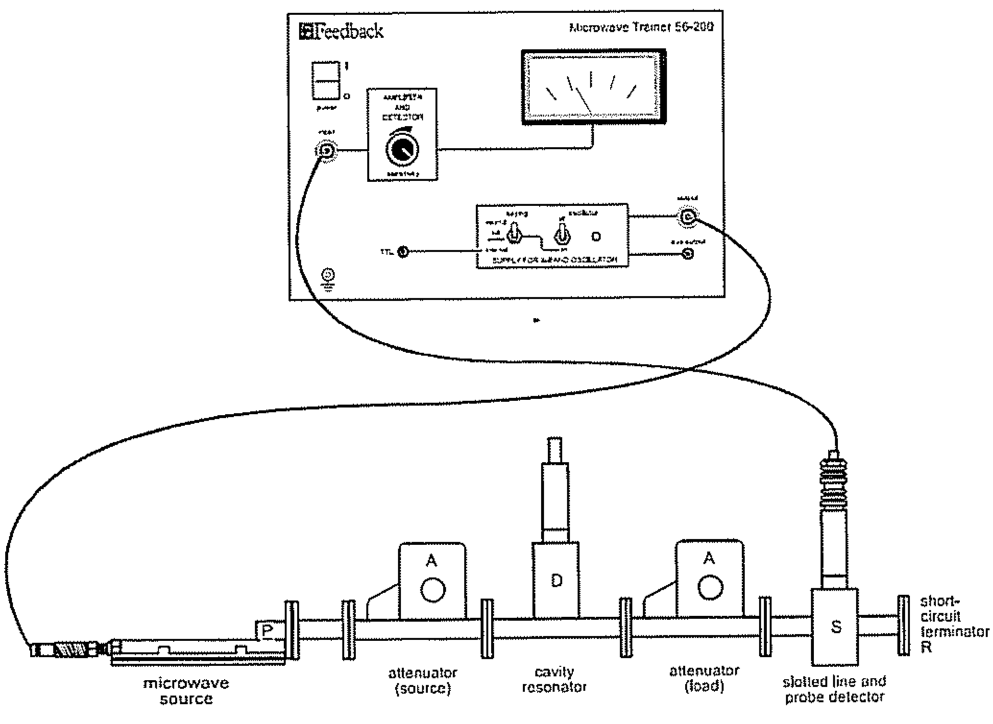


Figure 2-1-8

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 2 mm 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;

   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 =

The guide wavelength:

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

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

$$= (x_3 - x_1) =$$

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

broad dimension a = 0.9 inch = 22.86 mm

narrow dimension b = 0.4 inch = 10.16 mm

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 = 10.7 GHz. 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.

Notes