ASSIGNMENT 1 BASICS OF FREQUENCY AND WAVELENGTH

CONTENT

The relationship between frequency and wavelength is described. The electric and magnetic field patterns in a rectangular waveguide are investigated. The cavity resonator is investigated and the wavelength of the signal in the guide is measured using a slotted line.

EQUIPMENT REQUIRED

Qty	Ident. letter	Description
1	–	Control Console
2	A	Variable Attenuator
1	B	Slotted Line
1	D	Cavity Resonator
1	K	Resistive Terminator
1	M	Diode Detector
1	P	X–Band Oscillator
1	S	Probe Detector Assembly

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OBJECTIVES

When you have completed this assignment you should:

- Know how to measure the wavelength of a signal in a rectangular waveguide, using a slotted line.
- Understand the meaning of the term cut–off frequency (f_c).

KNOWLEDGE LEVEL

Before you start this assignment you should:

- Know how to read a micrometer
- Understand what is meant by an electromagnetic wave.

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INTRODUCTION

The frequency f, velocity v and wavelength λ of any wave are related by the equation:

$$f\lambda = v$$

The velocity of an electromagnetic wave in free space is denoted by c. Its velocity in air is almost the same; the value being approximately:

$$c = 3 \times 10^8 \text{ m/s}$$

An electromagnetic wave passing through magnetic or dielectric material travels more slowly. Many microwave phenomena are frequency-dependent, or (amounting to the same thing) dependent on the relationship between a wavelength and some dimension of the apparatus in use.

When a waveguide is used to transmit the wave, there are other factors to consider. It turns out that the wavelength inside the guide is longer than that in free space. The reasons are discussed in Appendix A.

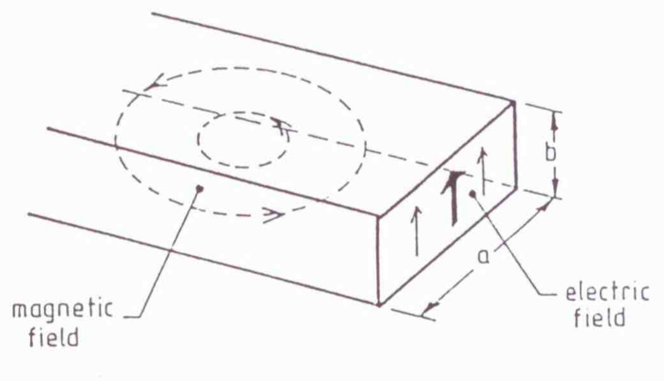
In a waveguide there is theoretically an infinite number of different modes, or field patterns, in which an electromagnetic wave can be transmitted. In general they are classified as:

Transverse electric (TE) or,

Transverse magnetic (TM).

Transverse electric indicates that the electric field is perpendicular to the direction of propagation.

Fig 1.1



Electric and Magnetic Fields in a Rectangular Waveguide

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Fig 1.1 illustrates the electric and magnetic field patterns for the mode used in the rectangular waveguides of the MWT530 experiments. This mode is called $TE_{1,0}$ mode. The figures indicate that the electric field is unidirectional, and there is no transverse magnetic field. Other modes have different number suffixes indicating the number of changes of field direction which occur in each transverse direction. A special mode called TEM has both electric and magnetic fields perpendicular to the direction of propagation. This mode of propagation occurs in free space and in coaxial lines.

Each mode has a critical frequency, called the *cut–off frequency, (f_c),* below which it cannot propagate energy, dependent on the waveguide dimensions. A waveguide is generally used over a range of frequencies such that only one mode can propagate, so that useful energy is not lost by conversion between different modes.

The cutoff frequency can be calculated for a rectangular waveguide as follows:

- For the $TE_{m,n}$ mode:

$$f_c = \frac{c}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2},$$

where a and b are the waveguide dimensions.

- For the $TE_{1,0}$ mode:

$$f_c = \frac{c}{2a}$$

In this assignment the source of microwave power will be an oscillator based on a *field-effect transistor* (FET). Its frequency of oscillation is determined by the resonance of the waveguide cavity in which it is mounted. This cavity is coupled to the external waveguide by a narrow slit to reduce the influence the external load has on the oscillator's built-in resonance. Other forms of microwave oscillator exist. The Gunn diode, a form of negative-resistance device, can be used at low powers. For higher powers, vacuum tubes, such as klystrons and magnetrons can be used. These use the finite speed of electrons travelling in a vacuum.

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The FET Oscillator can be supplied with d.c from the MWT530 power supply, but in this and other assignments using the Diode Detector, the supply can be square-wave modulated or 'keyed' by repeated switching of the supply. This enables a simple a.c amplifier to increase a weak detector signal to the power level required for an indicating meter.

The Cavity Resonator to be used in this experiment has a cavity which is coupled to the waveguide by a small coupling hole (see fig 1.2). Because the hole is small it can normally absorb only a tiny fraction of the energy passing along the waveguide. That tiny amount of energy, once through the hole, bounces about between the walls of the cavity. It cannot escape except through the hole.

If a wave bouncing back to the hole and a wave entering reinforce each other, the strength of the wave will build up progressively to a large amplitude. This is a form of resonance. If the amplitude is large enough, even the small fraction of it which leaks back into the waveguide through the hole will have a significant effect, as we shall see. By making the size of the cavity variable, the resonant frequency can be varied. So, by adjusting the cavity size to the point where the cavity affects transmission of a particular signal, it can be resonated at the frequency of the signal.

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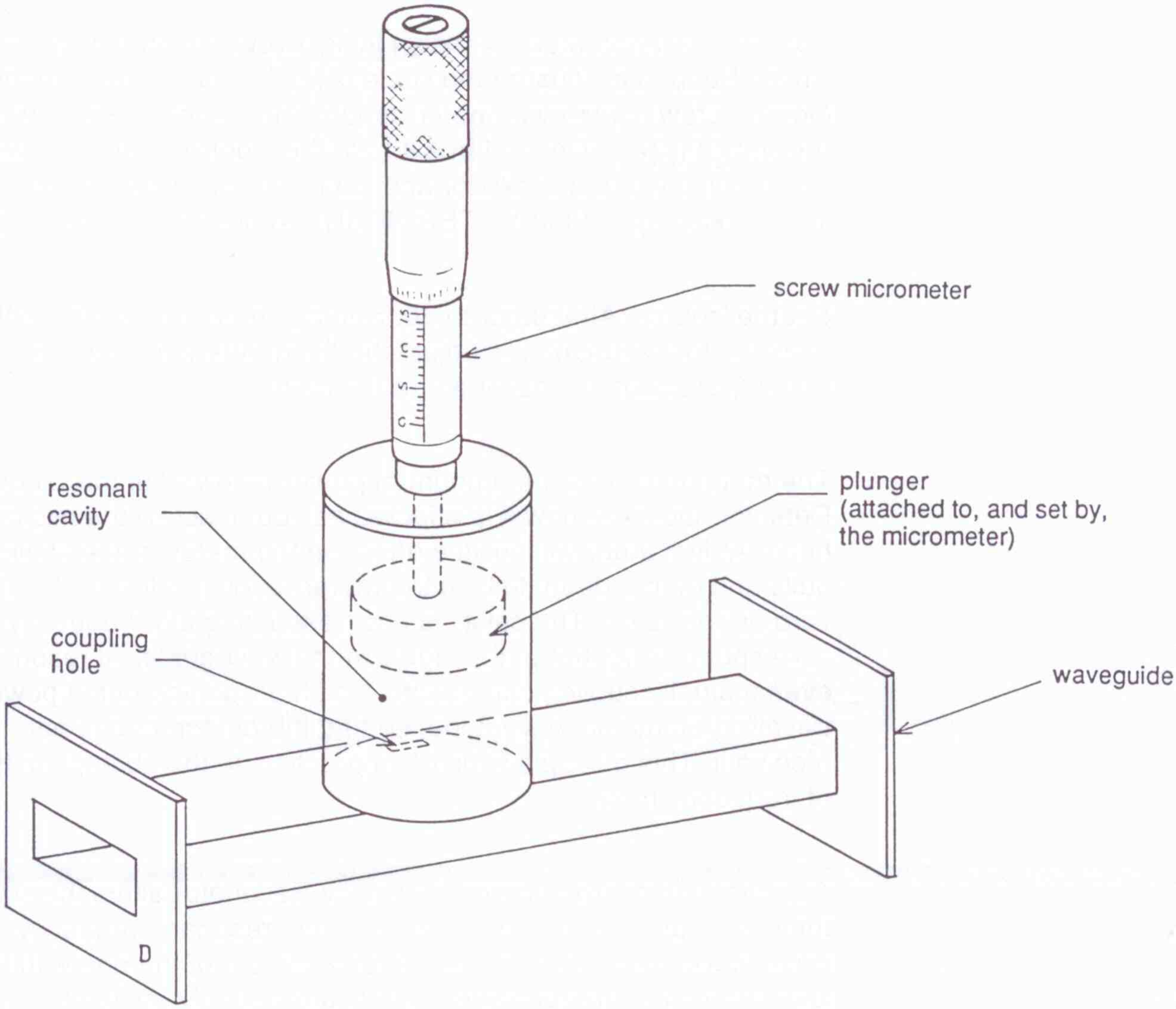
Fig 1.2



Cavity Resonator

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EXPERIMENTAL PROCEDURE

WARNING NEVER look directly into an energised waveguide.

Although the r.f power levels in this equipment are low and not normally dangerous, the human eye is especially susceptible to damage by microwave radiation.

Connect the apparatus as shown in fig 1.3.When attaching the Cavity Resonator, ensure the scale is positioned for easy reading. Gently screw in the micrometer head of the Cavity Resonator until resistance is felt. (Do not force it.) On the Control Console, switch on the supply to the oscillator and set its left-hand switch for internal keying; set the METER READS switch to 'detector output'

Set the 'source' Attenuator to 20. Set the sensitivity control of the amplifier to maximum and adjust the 'load' Attenuator until a reading of about 3 is obtained on the meter.

The meter indicates the amount of power received at the Diode Detector. Observe how it is affected as you unscrew the micrometer head. At first there will be little effect on the meter, some shallow nulls and then a deep null; i.e the meter reading will sharply fall to zero or near zero. The cavity is now resonating at a frequency corresponding to that of the signal in the waveguide. At resonance, even a small coupling can absorb a high proportion of the power travelling along the waveguide, so that the detector does not receive it. This principle is used, in practice, in the absorption type of frequency meter.

Adjusting the micrometer of the Cavity Resonator alters the size of the cavity, and consequently its minimum resonant frequency. Every cavity has many modes of resonance, but the one with the lowest resonant frequency is usually most simply related to its dimensions.

Find and record the micrometer setting which gives the lowest meter reading.

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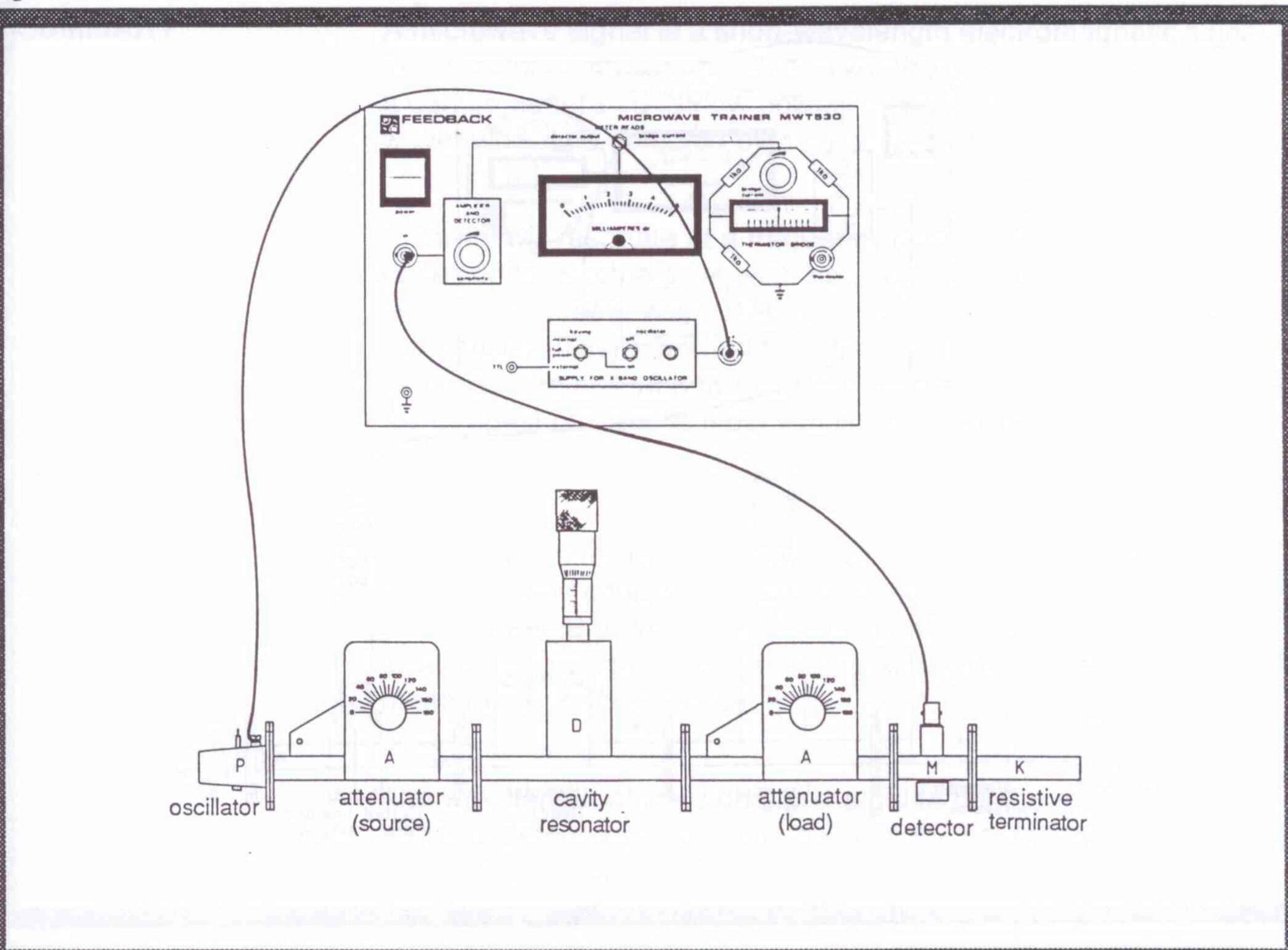
NOTE:

The micrometer barrel is graduated at half-millimetre intervals, with one turn of the screw advancing the plunger by one half-millimeter.

Unsrew the micrometer, again watching the meter. The reading will increase more or less to its original value, then dip a few times more as the whole lenght of the micrometer is unscrewed, thus illustrating the many modes of resonance possible in the cavity.

Fig 1.3



. To be useful as a frequency meter the cavity would need to be calibrated, preferably at several frequencies, so that the relationship between micrometer setting and frequency is known. Suppose that you were using a frequency meter calibrated in this way. How would you avoid getting a false reading from one of the secondary nulls?

Although the MWT530 has no means of altering the frequency of its microwave source, the wavelength of the signal in the waveguide can be measured using the slotted line.

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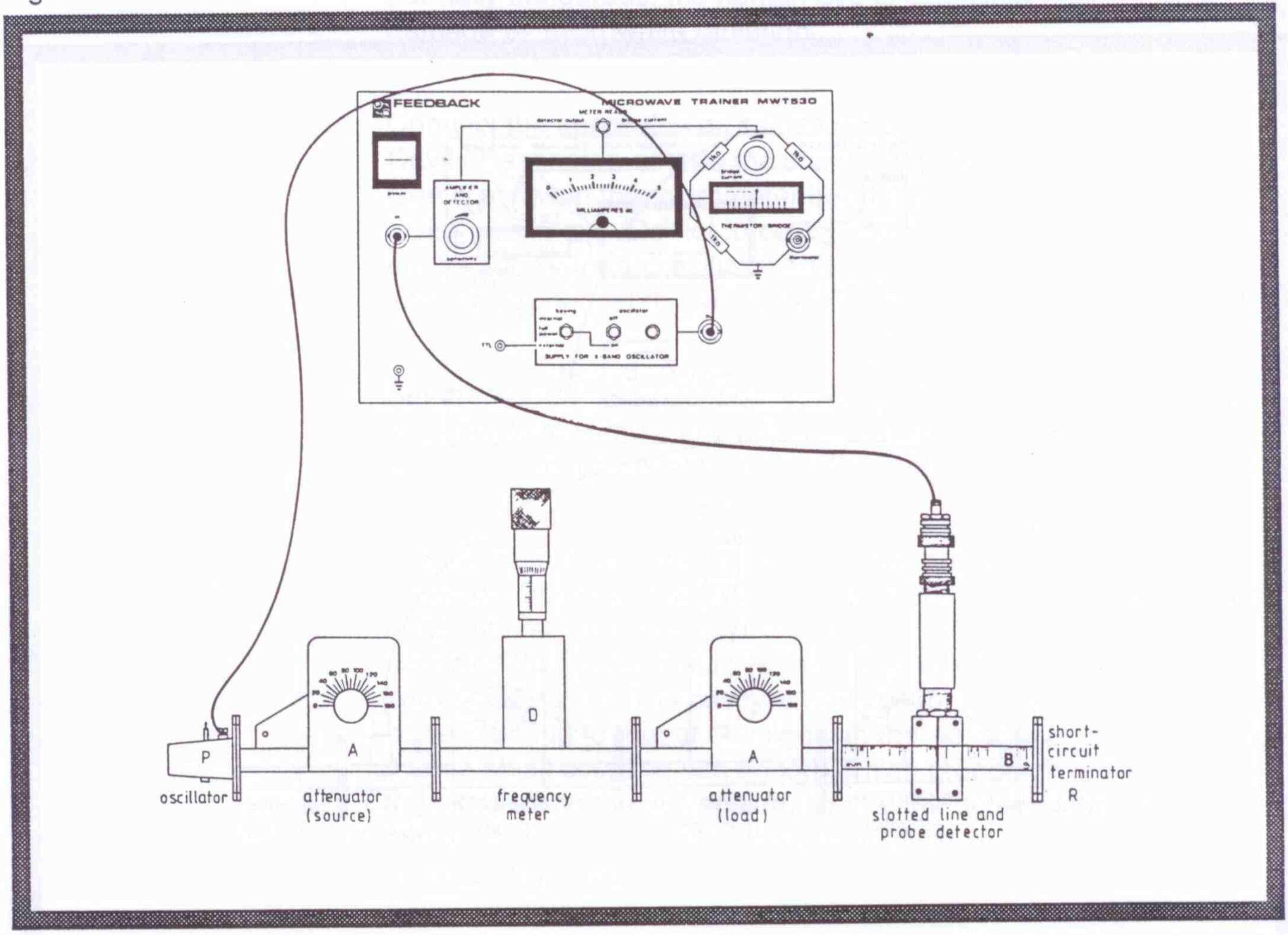
Remove the Diode Detector and Resistive Terminator and connect the components as shown in fig 1.4, ensuring that the probe of the Slotted-line Detector is projecting no more than about 1mm into the slotted line.Connect its waveguide assembly where the Diode Detector was, and add a blanking plate to short-circuit the microwave.

Fig 1.4



Adjust the depth of penetration of the probe into the slotted-line and both attenuators to obtain full-scale deflection (fsd).

Use the Slotted-line Detector to find two successive positions at which the signal reaches a sharp null. Note each position carefully against the scale on the waveguide.

These nulls arise because the signal from the microwave oscillator travels along the guide to the short-circuited end. Its energy cannot be absorbed by the short-circuit, so the signal is reflected back along the guide. There are thus two waves; the original, or 'incident' wave, and the 'reflected' wave travelling in the opposite direction. There are places where their electric fields will be in phase, and other places where they will tend to cancel each other.

Calculate the distance between the two null positions, which is $\frac{\lambda}{2}$ That is; half the wavelength in the waveguide.

SUMMARY

A microwave signal is a short-wavelength electromagnetic signal like a radio wave, characterised by a frequency and a wavelength. It can be generated (at low power) by an FET oscillator, guided by a waveguide, and detected by a suitable diode.

A Cavity will resonate at a frequency determined by its physical dimensions. Such a cavity can be used in resonant circuits and filters, much in the same way as an LC circuit is used at lower frequencies. There are many modes of resonance possible in a cavity but the one with the lowest resonant frequency usually gives the deepest null and is most simply related to the cavity dimensions.

An absorption frequency meter is an application of a resonant cavity, loosely coupled to the transmission path, which absorbs r.f. energy when the frequency of the signal is matched by one of the cavity's resonances. Such a component could be calibrated for measurement of frequency.

The wavelength of the signal in the guide can be measured by sliding a detector probe along a slot in the guide. This component is commonly called a "slotted line".

Chapter 3 Assignment 1 - Typical Results and Answers

Typically the micrometer reading giving the deep (and very sharp) null could be 10mm. (It would normally be expressed to several significant figures, e.g 10.02 mm).

Other nulls will be found. In a typical experiment the next two nulls occured at 14.86mm (less deep) and 13.7 to 14mm (quite deep but broadly spread over this 0.3mm–long region). Other nulls may be found, becoming increasingly erratic.

As these results show, selection of the correct null is essential. The micrometer should be screwed fully in to start with, then unscrewed carefully until the deepest null is found.