ASSIGNMENT 2 MEASUREMENT OF VOLTAGE STANDING WAVE RATIO

CONTENT

Voltage Standing Wave Ratio (VSWR) is described and two methods of measuring it are investigated.

EQUIPMENT REQUIRED

Qty	Ident. Letter	Description
1	–	Control Console
2	A	Variable Attenuator
1	B	Slotted–line
1	P	X–Band Oscillator
1	R	Short–circuit Terminator
1	S	Probe Detector Assembly

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Chapter 3 Assignment 2

OBJECTIVES

When you have completed this assignment you will:

- Be able to explain the meaning of Voltage Standing Wave Ratio.
- Know two methods of measuring VSWR and when to use them.

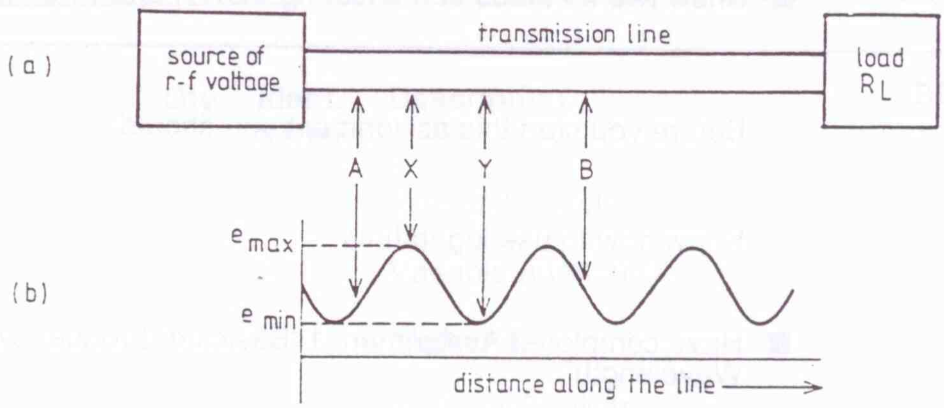
KNOWLEDGE LEVEL

Before you start this assignment you should:

- Know how to use logarithms.
- Have completed Assignment 1 'Basics of Frequency and Wavelength'

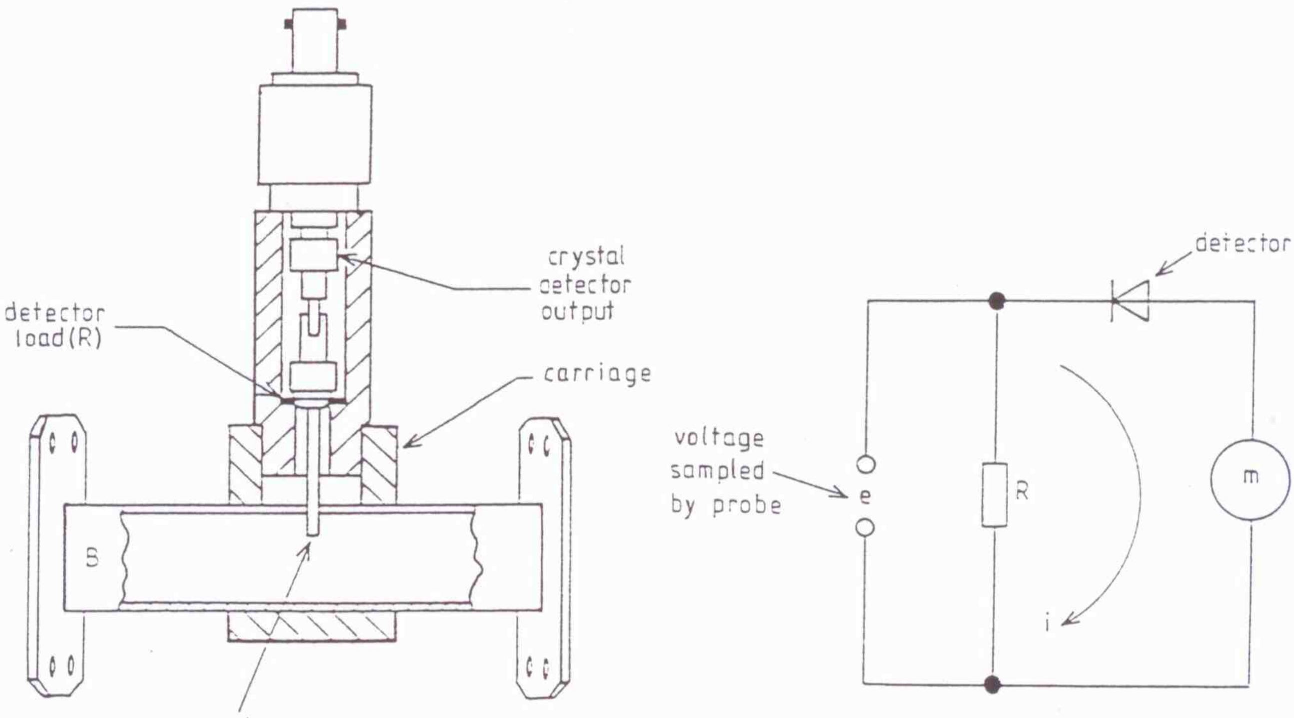
Chapter 3 Assignment 2

Fig 2.1



Voltage Distribution along a Transmission Line.

Fig 2.2



Slotted–line Detector and Typical Circuit.

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INTRODUCTION

The electromagnetic field at any point of a transmission line (such as a waveguide) can be considered as the sum of two travelling waves, one travelling in each direction.

When a continuous wave (the 'incident wave') reaches a discontinuity in the transmission line, a portion of it (the 'reflected wave') is reflected back down the line. Usually we are trying to send r.f power from some source to a load. Consequently, any power that is reflected cannot enter the load. Often, therefore, we try to avoid reflections.

When reflection does occur, the incident and reflected waves will reinforce each other in some places, and in others they will tend to cancel each other out. The stationary pattern of larger and smaller amplitudes is called a 'standing wave'. The ratio between the largest and smallest amplitudes is called the 'standing wave ratio'. Usually the voltage amplitude is the one considered, so that the Voltage Standing Wave Ratio (VSWR) is defined as:

$$VSWR = \frac{e_{max}}{e_{min}}$$

Note that if there is no reflection, the VSWR becomes 1.

Fig 2.1 shows at (a) a signal source and load connected by a transmission line. If the load is not exactly matched to the line, the standing wave pattern shown at (b) is produced.

The instrument most commonly used to measure VSWR is a slotted length of waveguide section in which the electric field can be sampled by a movable probe. Fig 2.2 (a) shows the construction. A small probe, connected to a diode detector, extends through the slot in the waveguide wall to sample the voltage on the line. The probe and detector are mounted on a carriage which can be moved along to sample the voltage at different points along the line.

If the slotted line matches the remainder of the line, it can be inserted without introducing further reflections. Suppose that it extends between A and B in fig 2.1. Then e_{max} and e_{min} can be measured at points X and Y respectively. Note that absolute measurements are not required, but only a ratio.

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Most microwave detectors, including the diode detector, have a square-law characteristic, $i = ke^2$, where i is output d.c current, e is the r.f voltage on the line and k is a constant introduced by the detector and the probe coupling. What is actually measured therefore is the ratio of maximum to minimum current, from which the VSWR is obtained as follows:

$$\frac{i_{max}}{i_{min}} = \frac{ke^2_{max}}{ke^2_{min}}$$

$$= \left(\frac{e_{max}}{e_{min}}\right)^2$$

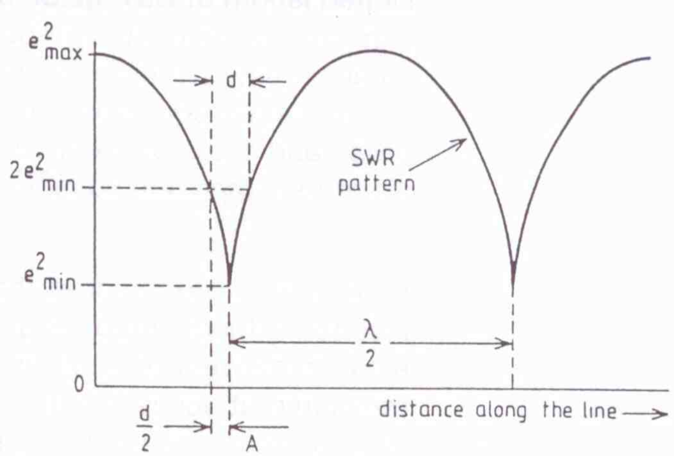
$$= (VSWR)^2$$

$$\therefore VSWR = \sqrt{\frac{i_{max}}{i_{min}}}$$

The preceding method is perhaps the simplest one, and is often referred to as the 'direct' method. It is satisfactory so long as accurate measurements of the relative values of e_{max} and e_{min} can be made. But when e_{max} becomes very large the detector can no longer be relied on to have a predictable characteristic

On the other hand if e_{min} is very small, the probe may have to penetrate so far into the field to get a measurable reading, that the field is distorted, changing the VSWR. Consequently for values of VSWR greater than about ten, the 'double minimum' method is usually employed.

Fig 2.3



Double–minimum Method

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The principle is illustrated in fig 2.3, in which the detector output (proportional to field strength squared) is plotted against position. The probe is moved along the line to find the minimum value of signal. It is then moved either side to determine two positions at which twice as much detector signal is obtained. The distance d between these two positions then gives the VSWR according to the formula:

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

Another way of overcoming the problem of a large VSWR is to use a calibrated attenuator. The minimum signal is measured with a minimum value of attenuation. The maximum value is then found, and sufficient attenuation is introduced to reduce the detector reading to the same value as before. (This completely removes any doubts about the detector's characteristics). The VSWR is then simply the volt ratio corresponding to the change of attenuation. Thus if the attenuator is calibrated in dB,

$$A_2 - A_1 = 20 \log \text{VSWR}$$

$$= 10 \log_{10}\left[1 + \frac{1}{\sin^2\left(\frac{\pi d}{\lambda}\right)}\right]$$

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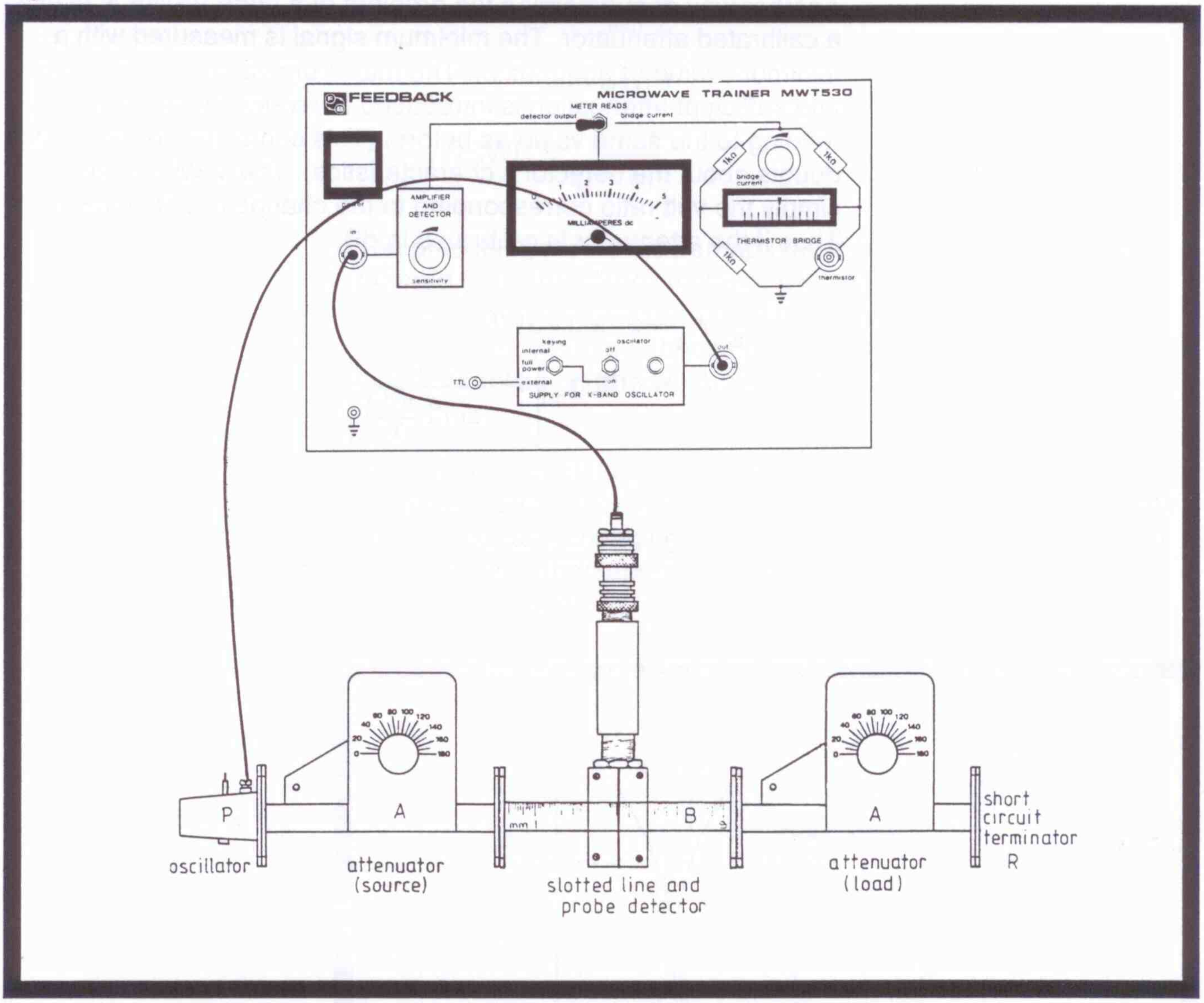
EXPERIMENTAL PROCEDURE

REMEMBER **NEVER look into an energised waveguide**

Connect the apparatus as shown in fig 2.4. On the Control Console, switch on the supply to the oscillator and set its left-hand switch for internal keying. Make sure that the meter is switched to read the detector output.

Fig 2.4



Set the right-hand (load end) Attenuator to minimum attenuation (vane fully outside the waveguide). Set the sensitivity control to maximum. Start with the left-hand Attenuator (source end) at about 20° from 0 (maximum attenuation).

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If the Detector carriage is now slid along the waveguide, the meter should move up and down. Adjust the source Attenuator so that the maximum reading of the meter is about full scale. If the source Attenuator is now set outside the range 20° to 60° open, the Detector probe may need adjusting. Slacken its locknut, and screw it in until a satisfactory reading is obtained. (It may be necessary to disconnect its lead if many turns are required).

The object is to get a full-scale reading (approximately) on the meter, with as little penetration of the Detector probe into the waveguide as possible, since the probe can upset the field in the waveguide. It is also desirable to have some attenuation between the microwave oscillator and the rest of the equipment, so that reflected signals shall not detune the oscillator.

Standing Wave Pattern (large VSWR)

Now slide the Detector along its slot. It should be possible to observe very sharp drops (minima) in the meter reading. The reason is that, since there is nothing to absorb the incident energy, it is, all (very nearly) reflected back. The reflected wave will therefore now almost exactly cancel the incident wave at places where their phases are opposite. Record, in a table headed 'Large VSWR' the maximum and minimum meter readings, and the scale position at which they occur. **Plot a graph of meter reading against position.**

Standing Wave Pattern (small VSWR)

Set the load Attenuator for maximum attenuation (vane fully in). Without making any other adjustments, repeat the experiment, recording the results in a further table headed 'Low VSWR'. Some variation of the meter reading may be seen, but it should not be very great. The load Attenuator absorbs much of the energy travelling towards the end of the transmission line, and, if the remainder is reflected from the end, the Attenuator absorbs most of that. Plot the resulting graph on the same axes as before, labelling the two graphs to distinguish them.

The VSWR is the ratio between the maximum and minimum values of field strength. Since the Detector operates on a square law, the VSWR can be calculated as

$$\sqrt{\frac{\text{maximum meter reading}}{\text{minimum meter reading}}}$$

Make this calculation for the small VSWR experiment. Try it also with the large VSWR (load Attenuator at zero). It will be found very difficult to get sensible readings.

Chapter 3 Assignment 2

Double-minimum Method for Large VSWR

In order to establish a suitable high value of VSWR, remove the short-circuit terminator from the load attenuator, and set that attenuator for minimum attenuation (vane fully out).

Set the source Attenuator to approx. 20°. Move the Detector to find a minimum. Adjust the Detector position very carefully to find the true minimum meter reading. **Record the minimum reading.**

Now move the Detector carefully to the left until the meter reading is double the minimum value. Record the position on the scale. Move the Detector past, the minimum position to the right, and again find where the meter reading is double the minimum value. Note the distance between the two positions giving the twice-minimum reading.

Calculation

In order to calculate the VSWR you will need to know the wavelength, λg, of the r.f signal passing along the waveguide. This can be read from your graphs as twice the distance between successive minima (or the distance between two minima separated by a third).

The VSWR is then calculated as:

$$\text{VSWR} = \sqrt{1 + \frac{1}{\sin^2\theta}}$$

$$\text{where } \theta = \frac{\text{distance between twice-minimum points}}{\lambda_g}$$

This formula is explained in Appendix B. Use it to calculate the high value of VSWR.

SUMMARY

In this assignment it was seen that:

If the end (or other discontinuity) of a waveguide does not absorb the incident energy, a standing wave is set up, which is a stationary pattern of field intensity which repeats cyclically as a detector moves along the transmission path.

The ratio $\left(\frac{\text{maximum intensity}}{\text{minimum intensity}}\right)$ is known as the VSWR.

When it is small (near 1), it can be measured directly Because normal detectors produce an output proportional to the square of field intensity, the square root of the ratio of detector outputs is taken.

For large values of VSWR, direct measurement of the ratio becomes impracticable. The double-minimum method is then useful.

Chapter 3 Assignment 2 - Typical Results and Answers

The graph of detector output against detector position, with the load attenuator vane fully out, should resemble fig 2.3, with the minima probably too small to measure.

When the load attenuator vane is put right in, the resulting graph should ideally be a horizontal straight line. In practice some variation in height will probably be found, giving a VSWR of typically 1.4.

Double Minimum Method

With source attenuator and detector adjusted to give a minimum of 1mA, readings of 2mA were obtained at 35mm and 46mm, i.e 11 mm apart. From the graph resembling fig 2.3, the wavelength in the guide was 36mm,

$$\text{so } \theta \text{ was } \frac{11}{36} = 0.3055 \text{ rad.}$$

The VWSR was therefore:

$$\sqrt{1+\frac{1}{\sin^2 0.3055}} = 3.47$$

(Note that if the direct-measurement method had been used, the ratio of meter readings would have been, possibly quite impractical)