الجامعة الإسلامية العالمية ماليزيا

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

KULLIYYAH OF ENGINEERING

DEPARTMENT OF ELECTRICAL & COMPUTER ENGINEERING

MICROWAVE LABORATORY
ECE 3203

EXPERIMENT NO.2

Measurement of Voltage and Standing Wave Ratio (VSWR).

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.

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

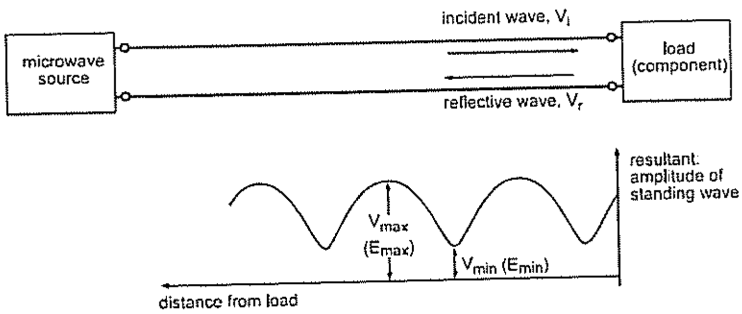

Figure 2-2-1: Standing Wave Pattern: VSWR S = V_{max}/V_{min} or E_{max}/E_{min}

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 penetrates 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.

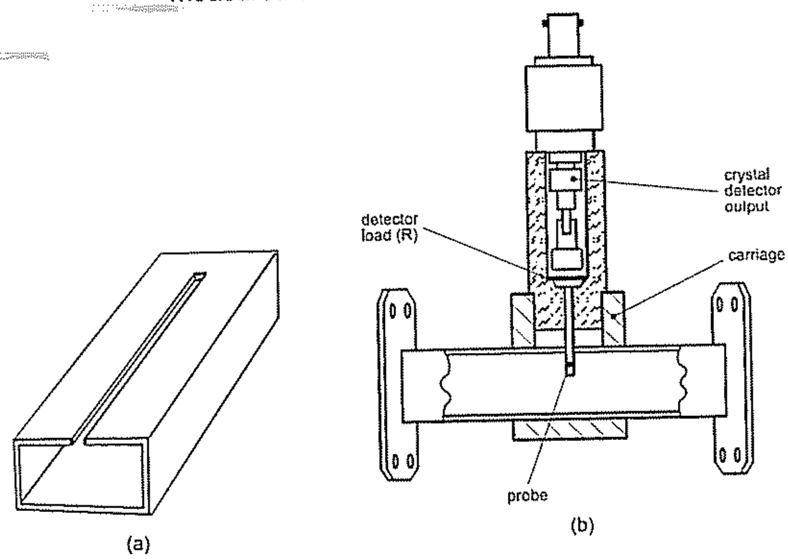

Figure 2-2-2: Slotted Waveguide and Diode Detector Probe Unit for Measuring Voltage Standing Wave Ratio

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

$$VSWR,\ S = \frac{E_{max}}{E_{min}}$$

minimum current are measured, we have:

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

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 4.6 mA and I_{min} at 3.2 mA

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

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 2-2-3 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

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

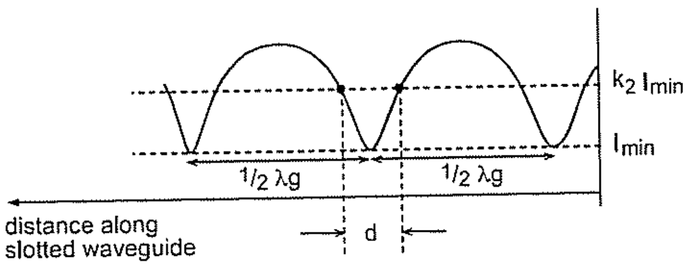

Figure 2-2-3: Plotting around the Field Minimum Method for Measuring High Values of VSWR

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.

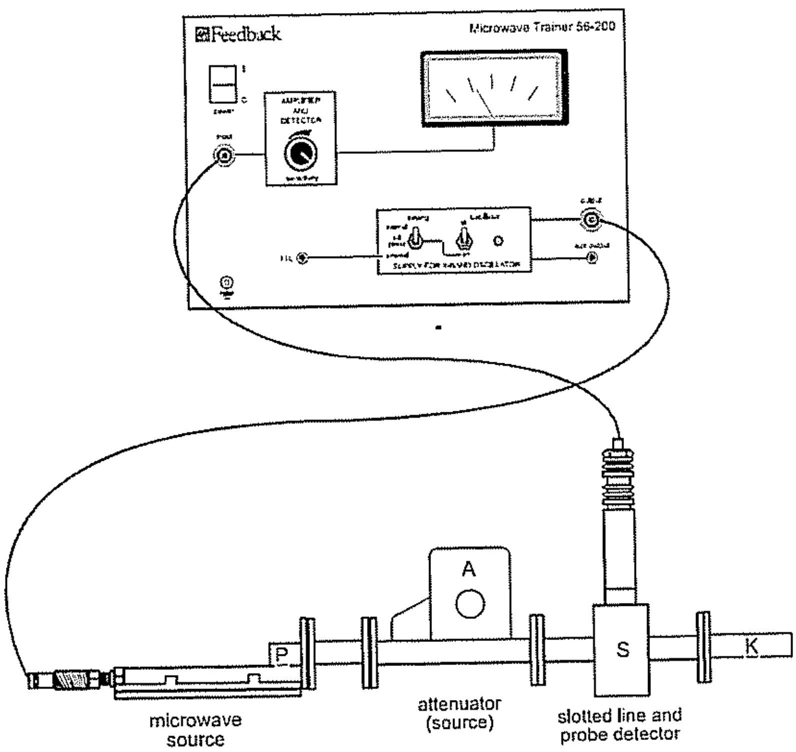

Figure 2-2-4: Experiment set up to Measure VSWR Resistive Load

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.

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,

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

the return loss,

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

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 2-2-5.

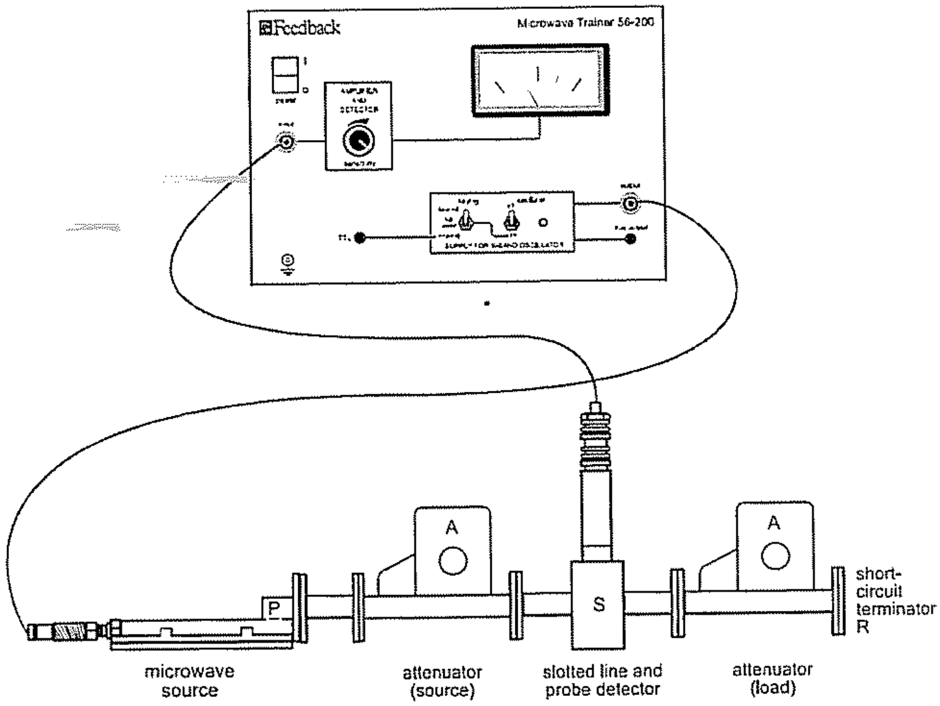

Figure 2-2-5

(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.

Notes