<u>ANEXO C</u>

(Para responder la pregunta 13 de la guía No. 3, referente al experimento Philips II-3)

<u>Pregunta</u>: (Refiérase a las figuras a) y b) del anexo 3, aqui incluído) Asuma que la directividad de la copla es exactamente 40 dB y que la terminación usada tiene un ROE_v= 1.02. Demuestre que el valor de la directividad obtenida, para el esquema de la figura b) puede ser tan baja como 34 dB. (Ayuda: las dos ondas pueden sumarse en fase). ¿Cuál es el valor máximo de la direcividad para el mismo esquema?

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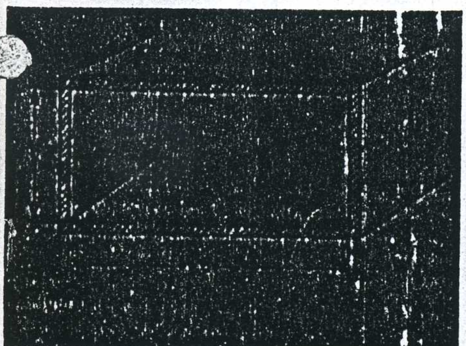
EXPERIMENTOS PHILIPS

Frequency, wavelength and attenuation measurements



Objective

To determine the relationship between frequency and wavelength in a rectangular waveguide and to measure attenuation.

Equipment

See also component description

1 Klystron power supply	PM 7812
1 Klystron mount with klystron 2 K25	PM 7011X
1 Ferrite isolator	PM 7045X
1 Variable attenuator	PM 7110X
1 Frequency meter	PM 7070X/ab
1 Standing wave detector	PM 7142X
1 Variable short	PM 7216X
1 SWR-meter	PM 7832
1 Termination	PM 7220X
2 Waveguide support	PM 7700 + 7701X

Theory

Frequency and wavelength

In Experiment 1 we have used the frequency meter to determine the oscillation frequency of the klystron. This method is very simple and no calculations are required. We will now calculate the frequency from the wavelength.

The following relationship can be proved:

$$c = f \cdot \lambda_0 \qquad \text{free space}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}} \qquad \text{air-filled hollow-pipe waveguide}$$

$$\lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2+\left(\frac{n}{b}\right)^2}} \qquad TE_{m,n} \text{ or}$$

$TM_{m,n}$-modes in rectangular waveguides where

- c = wave velocity in free space (velocity of light) $\approx 3 \cdot 10^8$ m/s
- f = frequency
- λ_0 = wavelength in free space
- λ_g = wavelength in waveguide
- λ_c = cutoff wavelength in waveguide
- a = broad dimension in waveguide, see figure 1
- b = narrow dimension in waveguide, see figure 1

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

$$\lambda_c = \frac{2}{\sqrt{\left(\frac{1}{a}\right)^2+\left(\frac{0}{b}\right)^2}} = 2a$$

Thus

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{2a}\right)^2}} = \frac{1}{\sqrt{\left(\frac{1}{\lambda_0}\right)^2-\left(\frac{1}{2a}\right)^2}}$$

or

$$\lambda_0 = \frac{1}{\sqrt{\left(\frac{1}{\lambda_g}\right)^2+\left(\frac{1}{2a}\right)^2}}$$

Finally we have

$$f = \frac{c}{\lambda_0} = c \cdot \sqrt{\left(\frac{1}{\lambda_g}\right)^2+\left(\frac{1}{2a}\right)^2}$$

The waveguide wavelength λ_g can be measured as twice the distance between two successive minima in the standing wave pattern. (Standing waves will be discussed in Experiment 3.)

The above formula

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

shows that the **waveguide wavelength is greater than the free space wavelength.** At the cutoff frequency, λ_g is infinitely long, which means that no field variations occur along the waveguide, i.e. no energy is propagated.

Attenuation

Attenuation at microwave frequencies is normally expressed in decibels, dB, defined as

$$\left(\frac{P_1}{P_2}\right)_{dB} = 10 \cdot \log \frac{P_1}{P_2} = 10\,(\log P_1 - \log P_2)$$

where P_1/P_2 is a power ratio.

The attenuator PM 7110X is a semi-precision attenuator, which in the experiments of this book mainly is used to set a convenient power level. The setting of the attenuator gives the ratio in dB between the power that would have reached the load if the attenuator was not in the system and the power when it is there. This is actually true only when the system is matched, i.e. no standing waves. (See Experiment 3.)

Experiment 3

SWR Measurements

EXPERIMENTOS PHILIPS

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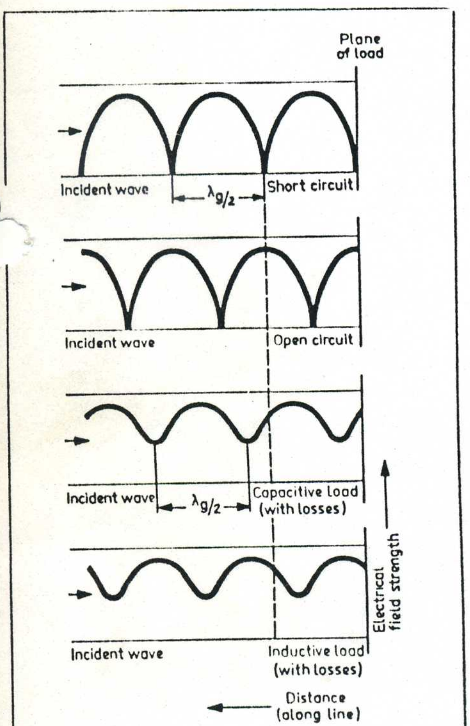


Figure 1. Standing waves on a lossless line

Objective

To become familiar with basic slotted line SWR measurements. Use of the SWR-meter.

Equipment

See also component description

- 1 Klystron power supply — PM 7812
- 1 Klystron mount with klystron 2K25 — PM 7011X
- 1 Ferrite isolator — PM 7045X
- 1 Variable attenuator — PM 7110X
- 1 Frequency meter — PM 7070X/ab
- 1 Standing wave detector — PM 7142X
- 1 Sliding screw tuner — PM 7151X
- 1 Termination — PM 7220X
- 1 Variable short — PM 7216X
- 1 SWR-meter — PM 7832
- 2 Waveguide support — PM 7700 + 7701X

Theory

The electromagnetic field at any point of a transmission line (e.g. a waveguide) may be considered as the sum of two travelling waves: the "incident wave" propagates from the generator, "the reflected wave" propagates toward the generator. The reflected wave is set up by reflection of the incident wave from a discontinuity on the line or from a load impedance not equal to the characteristic impedance of the line. The magnitude and phase of the reflected wave depends upon the amplitude and phase of the reflecting impedance. The magnitude also depends upon the losses on the line. On a lossy line the reflected (and incident) wave will be attenuated. If the line is uniform and infinitely long there will be no reflected wave. The same goes for a line of finite length which is matched, i.e. has a load equal to the characteristic impedance of the line.

The presence of the two travelling waves gives rise to standing waves along the line. The electrical (and magnetic) field varies periodically with distance. The maximum field strength is found where the two waves add in phase, and the minimum where the two waves add in opposite phase. Figure 1 shows the voltage standing wave patterns for different load impedances. The distance between two successive minima (or maxima) is half the wavelength on the transmission line.

The ratio between the electrical fields of the reflected and the incident wave is called the voltage reflection coefficient ϱ, being a vector, which means that its phase varies along the transmission line. If there are losses on the line, the amplitude of ϱ will also vary with position on the line.

The **Voltage Standing Wave Ratio** (abbrev.: VSWR or just SWR) on a transmission line is defined as the ratio between the maximum and the minimum field strength along the line.

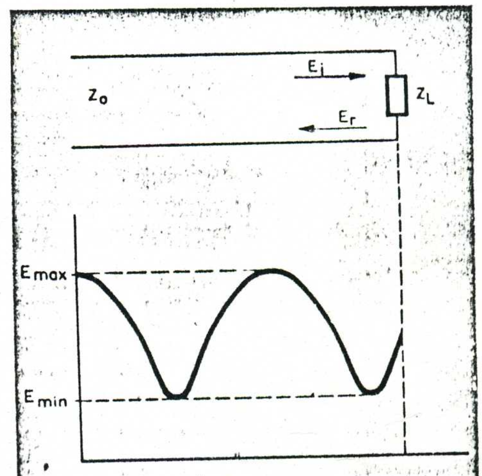


Figure 2. Standing waves

According to figure 2 it can be proved that:

$$\varrho = \frac{E_r}{E_i} = \frac{Z - Z_0}{Z + Z_0}$$

where Z is the impedance at a point on the line. E.g. at the load:

$$\varrho_L = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$S = \frac{E_{max}}{E_{min}} = \frac{/E_i/ + /E_r/}{/E_i/ - /E_r/}$$

$$/\varrho/ = \frac{S - 1}{S + 1}$$

The limits of $/\varrho/$ and S are:

	$/\varrho/$	S
Perfect match	0	1
Perfect mismatch	1	∞

Note: In British litterature the SWR is sometimes defined as Emin/Emax, which means that a perfect match corresponds to SWR = 0 and a complete mismatch corresponds to SWR = 1.

There are several methods for measuring SWR with a slotted line. In the slotted line a small part of the electric field is fed to a crystal detector via a probe (antenna) inserted in the waveguide. In the most straightforward method the SWR can be read directly on the SWR-meter PM 7832

Experiment 3

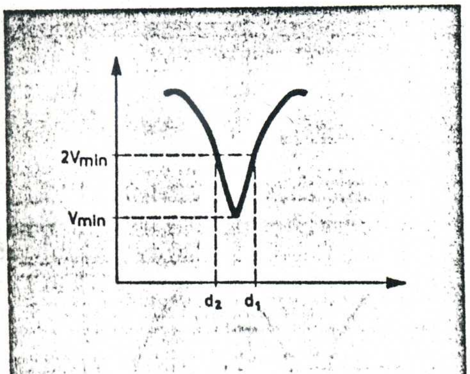


Figure 3. The "3dB-method"

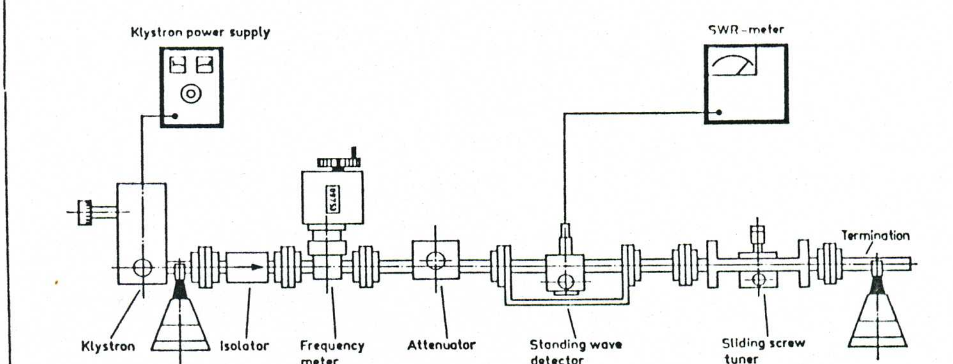


Figure 4. Measurement set-up in Experiment 3

connected to the crystal output. This method is accurate only when, a) the probe depth is small enough not to disturb the field in the waveguide, b) the crystal works in the "square-law" region, e.g. the output voltage is proportional to the input power. (about square-law, see SWR-meter description)

When the SWR is high, the probe depth must be increased if a reading is to be obtained at a voltage minimum. This will, however, cause a) field deformation when the probe is at a voltage maximum and perhaps b) so much power on the crystal that it does not work in the square-law region.

One method to overcome the effect of probe loading is the **"3dB-method"**. In this method one measures the distances between the points where the crystal output voltage (proportional to the hf-power) is double the minimum. See figure 3. The SWR is given by

$$S = \sqrt{1 + \frac{1}{\sin^2 \frac{\pi (d_1 - d_2)}{\lambda_g}}}$$

where λ_g = waveguide wavelength.
When S is larger than about 10:

$$S = \frac{\lambda_g}{\pi (d_1 - d_2)} \quad \text{within a few percent}$$

The effect of detector variations from square-law is overcome in the **Calibrated-Attenuator method.** In this method the crystal output at a maximum is made equal to the output at a minimum by means of an attenuator placed between the generator and the slotted line. The difference in the attenuator settings (A_2—A_1) dB gives the SWR = S. (A_1 is the attenuator setting at a minimum)

$$A_2 - A_1 = 20 \log S$$

The accuracy here is determined by the accuracy of the attenuator (a precision attenuator such as PM 7101X is recommended) and the probe loading effect.

Procedure

1. **General**

1.1 Set up the equipment as shown in figure 4.

1.2 Set the variable attenuator at 20 dB.

1.3 Press the 40 dB button on the SWR-meter and switch on the instrument. Bandwidth selector: 20 Hz.

1.4 Completely unscrew the probe of the sliding screw-tuner. (0 on the scale).

1.5 Adjust the probe depth of the standing wave detector to the red mark on the scale.

1.6 Energize the klystron for maximum output at 9.0 GHz. Modulate the reflector with 1000 Hz square wave.

1.7 Obtain a medium deflection on the SWR-meter.

1.8 Move the probe along the standing wave detector. It will be seen that the deflection changes very little, i.e. the transmission line is well matched.

2. **Measurement of low and medium SWR**

2.1 Increase the probe depth of the sliding screw tuner to 5 mm. Probe position: fixed.

2.2 Move the probe along the standing wave detector to a maximum.

2.3 Adjust the SWR-meter gain until the meter indicates 1.0 on the upper scale.

2.4 Move the probe to a minimum.

Note: Do not change anything else.

2.5 Read the SWR on the upper scale. Record on table I.

2.6 Repeat the steps 2.2—2.5 for the probe depths 3.7 and 9 mm on the sliding screw tuner.

Note: When the SWR is less than 1.3 the expanded scale can be used (red scale). To do so press the "Expand" button before performing the steps 2.3—2.5.
When the SWR is between 3.2 and 10, the next higher gain button can be pressed in step 2.4. The SWR will then be read on the second upper scale.

3. **Measurement of high SWR. The „3dB method" (Double minimum method)**

3.1 Set the probe depth on the sliding screw tuner to 9 mm. As seen in section 2 it will set up a high SWR.

3.2 Move the probe along the standing wave detector until a minimum is indicated.

3.3 Adjust the SWR-meter gain to obtain a reading of 3 dB (lower scale).

3.4 Move the probe to the left on the standing wave detector until full scale deflection is obtained (0 dB on lower scale). Note and record the probe position, d_1. Table II.

3.5 Repeat step 3.4 but this time move the probe to the right. Note and record d_2.

3.6 Replace the sliding screw tuner and the termination with the variable short. Measure the distance between two successive minima. Twice this distance is the guide wavelength λ_g.

3.7 Calculate the SWR as:

$$S = \sqrt{1 + \frac{1}{\sin^2 \frac{\pi (d_1 - d_2)}{\lambda_g}}} \approx \frac{\lambda_g}{\pi (d_1 - d_2)}$$

4. **Measurement of high SWR. The "Calibrated Attenuator method"**

Note: This method actually requires a precision attenuator e.g. PM 7101X. The attenuator PM 7110X used in the experiment is not ideal. However, it can well be used to demonstrate the principle.

4.1 Set the probe depth on the sliding screw tuner to 9 mm.

4.2 Move the probe along the standing wave detector until a minimum is indicated.

4.3 Adjust the waveguide attenuator to A_1 = 20 dB. Adjust the SWR-meter gain to obtain a deflection of 3 dB (lower scale).

4.4 Move the probe along the standing wave detector and "track" with the attenuator to keep the deflection "on scale". Find a maximum and adjust the attenuator to obtain the same deflection as in 4.3. Note and record the attenuator setting, A_2 dB.

4.5 Calculate the SWR as:

$$S = 10^{\frac{A_2 - A_1}{20}}$$

Table I The SWR-meter method

Sliding screw tuner probe depth in mm				
	3	5	7	9
SWR				

Table III The "Calibrated Attenuator method"

Step	4.3	4.4		4.5
	A_1 (dB)	A_2 (dB)	A_2—A_1 (dB)	SWR

Table II "The 3-dB method"

Step	3.4	3.5	3.6			3.7
	d_1 (mm)	d_2 (mm)	1:st min. (mm)	2:nd min. (mm)	λ_g (mm)	SWR

Questions

1. Try to explain why successive minima of a standing wave pattern are separated half a wavelength.
2. Figure 1 shows various standing wave patterns. The capacitive and inductive loads shown, have losses (resistive components). If no losses, what would the patterns look like?
3. Which probe depth gave the largest SWR?
4. With the probe depth 9 mm, three methods have been used. Do the results agree?
5. Which method do you think is most accurate in this case? (probe depth 9 mm).

The directional coupler and it's use in reflectometer measurements

Objective

To measure coupling and directivity of a directional coupler and to measure the return loss of a test device.

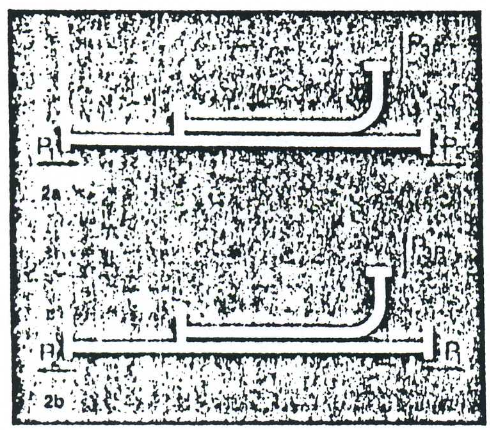
Equipment

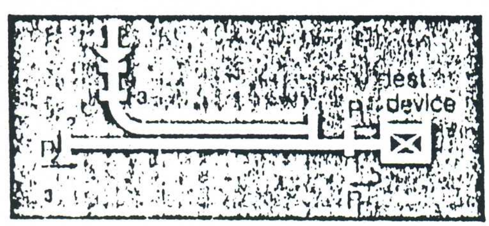
1	Gunn-oscillator power supply	PM 7813
1	Gunn-oscillator	PM 7015X
1	Modulator	PM 7026X
1	Ferrite isolator	PM 7045X
1	Variable attenuator	PM 7110X
1	Frequency meter	PM 7070X/ab
1	Directional coupler	PM 7241X
1	Termination	PM 7220X
1	Crystal detector	PM 7195X
1	Rotary vane attenuator	PM 7101X
1	Variable short	PM 7216X
1	Sliding screw tuner	PM 7151X
1	SWR-meter	PM 7832
2	Waveguide support	PM 7700 + 7701X

See also component description pages 20 etc

Theory

Some SWR-measurements with a standing wave detector (slotted line) have been treated in booklet I (1 : 3). The standing wave detector picks up and detects the field along a transmission line. This field is the sum of the incident and the reflected wave on the line. Instead of measuring the sum of the two waves it is possible to measure the two waves separately. A device which can separate two waves travelling in opposite directions is the *Directional Coupler*. A directional coupler in general consists of two transmission lines: the main arm and the auxiliary arm. These two arms are electromagnetically coupled to each other, so that energy entering port 1 in the main arm divides between port 2 and port 3, and nearly nothing comes out in port 4. See figure 1. On the other hand energy entering port 2 divides between port 1 and port 4.
To define the coupling and directivity we use figure 2. One of the ports of the





coupler is terminated with a built in matched load. Figure 2a shows the directional coupler in a transmission line with only a forward wave. In figure 2b there exists only a reversed wave on the line.

$$\text{Coupling factor (dB)} = 10 \log \frac{P_1}{P_{3F}}$$

$$\text{Directivity factor (dB)} = 10 \log \frac{P_{3F}}{P_{3R}}$$

Thus the coupling factor is a measure of how strongly coupled to each other the two arms are. The directivity is a measure of how good the separation between the incident and the reflected wave is.
There are many types of directional couplers. The one used in this experiment is a waveguide high directivity coupler in which a matched termination is built in.

When measuring the reflection from a test device the test signal is introduced through port 2, the test device is connected to port 1 and the reflected signal is detected at port 3. See figure 3.
Assume that the coupling factor is C (in dB 10 · log C). The power at the detector is then $P_3 = \frac{P_r}{C}$
Since the voltage reflection coefficient of the test item is $\sqrt{P_r/P_i} = /\varrho/$ it is necessary to know the power P_i. A common method is to replace the test item with a short, which reflects all the incident power, and to measure this at port 3. This power is then $\frac{P_i}{C}$. Thus, the ratio between the two signals detected at port 3 is $\frac{P_r}{C} \cdot \frac{C}{P_i} = /\varrho/^2$ = the *return loss* of the test item.
This ratio is normally measured with a precision variable attenuator inserted between the coupler and the detector. When measuring on the test device the attenuation is set to zero. When measuring on the short the attenuation is set to a value A dB which gives the same amount of detected signal as with the test device. A dB is then the return loss of the test device.
The accuracy of the return loss measurement is determined by how much of the incident power at port 2 "leaks" up into port 3, i.e. the directivity of the coupler. E.g. a directivity of 40 dB corresponds to a return loss of 40 dB meaning a voltage reflection coefficient of $\sqrt{10^{-4}} = 10^{-2} = 0.01$.
This means a SWR $= \frac{1 + 0.01}{1 - 0.01} = \frac{1.01}{0.99} = 1.02$.
Since the reflected wave from the test device and the "directivity" wave can add in any phase the uncertainty of the measured reflection coefficient is ± 0.01 (directivity 40 dB).

Example

Assume a directivity of 40 dB and a measured return loss of 14 dB. Thus $/\varrho/ = 0.2 \pm 0.01$ SWR = 1.47 — 1.53.

Procedure

1. General

1.1 Set up the equipment as shown in figure 4.

1.2 Set the rotary vane attenuator at 20 dB and the variable attenuator at approx. 10 dB.

1.3 Start the oscillator and tune it to 9.0 GHz (square wave modulated).

2. Measuring the coupling factor

2.1 Achieve a stable reference reading on the SWR-meter. (e.g. 3 dB on the lower scale). The rotary vane attenuator still at A_1 = 20 dB. Record on table I.

2.2 Move the rotary vane attenuator + the crystal detector to the auxiliary arm of the directional coupler. Connect the coupler to the variable attenuator.

2.3 Adjust the rotary vane attenuator to get the same reference reading as in 2.1.

2.4 Note and record the attenuator setting A_2 dB. Table I.

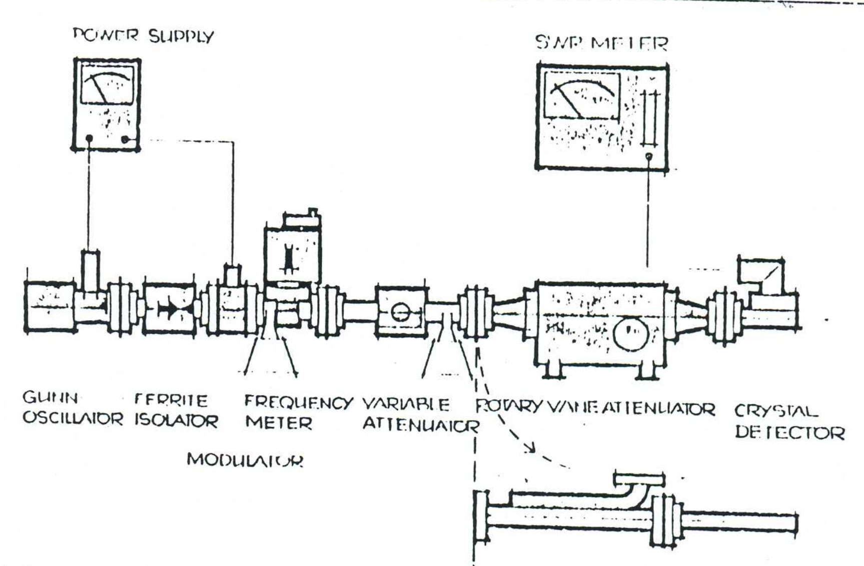
2.5 The coupling factor $C = A_1 - A_2$. Compare with the specification of the coupler: 10 dB ± 0.9 dB.

3. Demonstration of the directivity

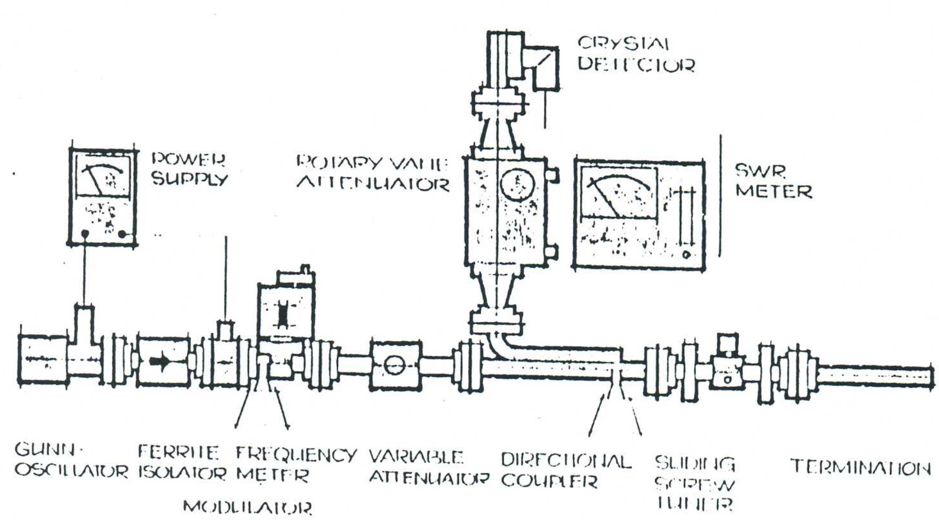
3.1 Set the rotary vane attenuator at 50 dB.

3.2 Achieve a reference reading on the SWR-meter. If necessary, to get a stable reading, decrease the attenuation of the rotary vane attenuator, A_3 dB. Record in table I.

3.3 Reverse the coupler in the set-up.



4. Set-up in Experiment 3 : 1 — 3 : 3



5. Set-up in Experiment 3 : 4

3.4 Decrease the rotary vane attenuator setting to a value A_4 that gives the same SWR-meter deflection as in 3.3. Note and record A_4.

3.5 The directivity D is (A_1 — A_4) dB. Compare with the specification: D > 40 dB.

te: The accuracy of this measurement is main- determined by the SWR of the termination. have assumed a perfect termination.

4. Measuring return loss of a test device

4.1 Set up the equipment as shown in figure 5. The variable attenuator at approx. 10 dB.

4.2 Set the probe depth on the sliding screw tuner to 5 mm. The test device is the sliding screw tuner + the termination.

4.3 Set the rotary vane attenuator at A_5 = 5 dB and obtain a reference deflection on the SWR-meter.

4.4 Set the rotary vane attenuator at max. and replace the test device with the short.

4.5 Decrease the attenuation to obtain the reference deflection. Note and record the attenuator setting A_6. Table II.

The return loss is (A_6 — A_5) dB.

4.7 Calculate the reflection coefficient, and the SWR. Record on table II.

4.8 If a standing wave detector is available, measure the SWR of the test device above and compare the results.

Table I Coupling and directivity factor

A_1 dB	A_2 dB	$A_1 - A_2$ dB	A_3 dB	A_4 dB	$A_3 - A_4$ dB

Table II Return loss

A_5 dB	A_6 dB	$A_6 - A_5$ dB	$\|\rho\|$	SWR

Questions

1. Suppose that the directional coupler in figure 3 has a coupling factor of 20 dB and a directivity factor of 40 dB.
   a. How many dB below P_2 is the unwanted signal at port 3?
   b. How much power (related to P_2) is dissipated in the load at port 4?
2. What are the answers of question 1 if the coupling factor is 40 dB and the directivity factor 20 dB?
3. Assume that the directivity to be measured in section 3 is exactly 40 dB and that the termination used has a VSWR = 1.02. Show that the value of the directivity obtained in step 3.5 could be as low as 34 dB. (Hint: the two waves could add in phase.) What would the maximum value be?

Impedance Measurements. The Smith Chart.

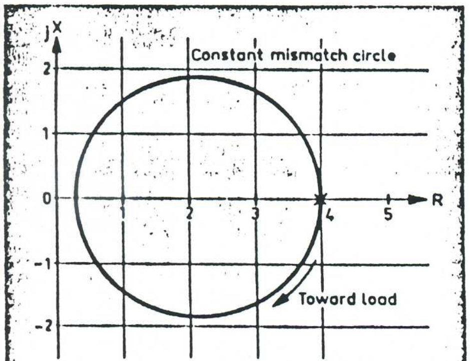


Figure 1. The reactance chart

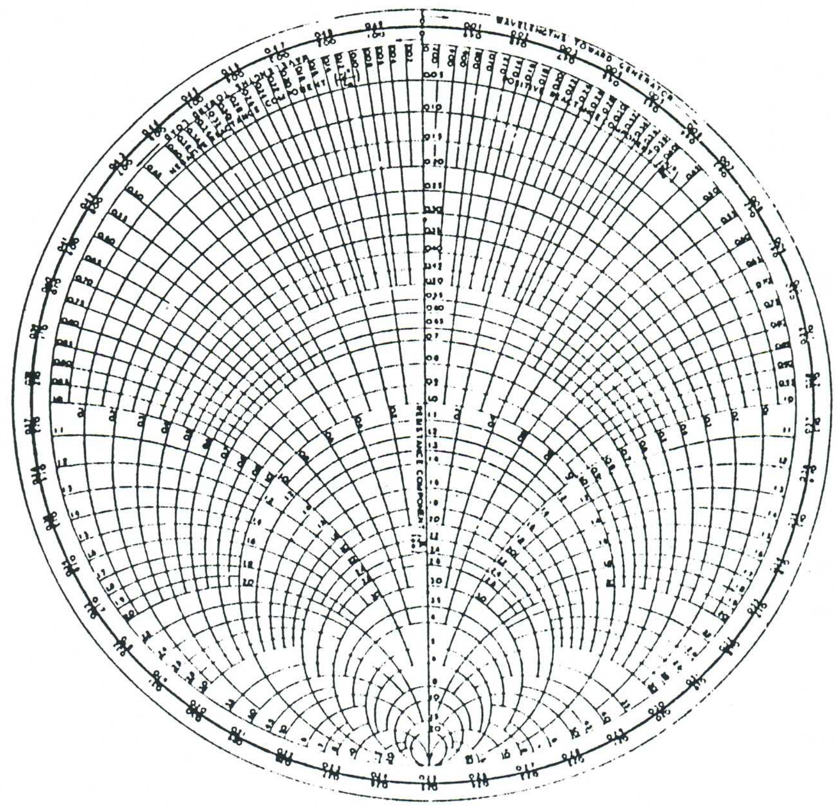


Figure 2. The Smith Chart

Objective

To become familiar with the Smith Chart and to measure an unknown impedance.

Equipment

See also component description

1 Klystron power supply	PM 7812
1 Klystron mount with klystron 2K25	PM 7011X
1 Ferrite isolator	PM 7045X
1 Variable attenuator	PM 7110X
1 Frequency meter	PM 7070X/ab
1 Standing wave detector	PM 7142X
1 Sliding screw tuner	PM 7151X
1 Termination	PM 7220X
1 Variable short	PM 7216X
1 SWR-meter	PM 7832
2 Waveguide support	PM 7700 + 7701X

Theory

In Experiment 2 we have studied the standing wave pattern. As we have seen it is the result of interaction between an incident wave and a reflected wave. In the matched case (i.e. no reflected wave) the ratio between the electrical and magnetic field is the same at all points along the line. This ratio is directly related to the characteristic impedance of the line, Z_0. If a reflected wave exists, the ratio is no longer the same along the line, i.e. the impedance level varies periodically.

The impedance at any point of a transmission line can be written in the form $R + jX$. The mathematical expression of the impedance at a particular point is not easy to use. One graphical approach is the rectangular reactance chart, figure 1. The scales are normalized to the characteristic impedance Z_0 of the line. If the line has a load resistance of $4\ Z_0$ the impedance along the line will be represented by points on the drawn circle (if the line is lossless). There are several disadvantages with this graphical presentation: it does not cover all impedance values out to infinity, the constant mismatch circles are not concentric etc. A much more useful chart is the Smith Chart, figure 2. It is a so called conformal transformation of the reactance chart.

	The reactance chart	The Smith Chart
Constant resistance	Vertical lines	Circles tangent at the bottom
Constant reactance	Horizontal lines	Circle arcs starting from the bottom
Constant mismatch	Nonconcentric circles	Concentric circles about the point 1 + j0
Constant electrical distance from resistive load	Circle arcs through the point 1 + j0	Radial lines from the point 1 + j0

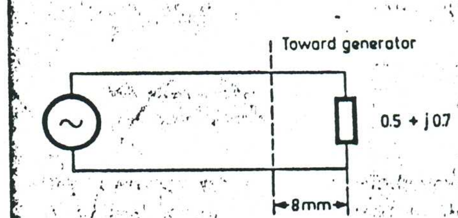


Figure 3. Illustration of the example

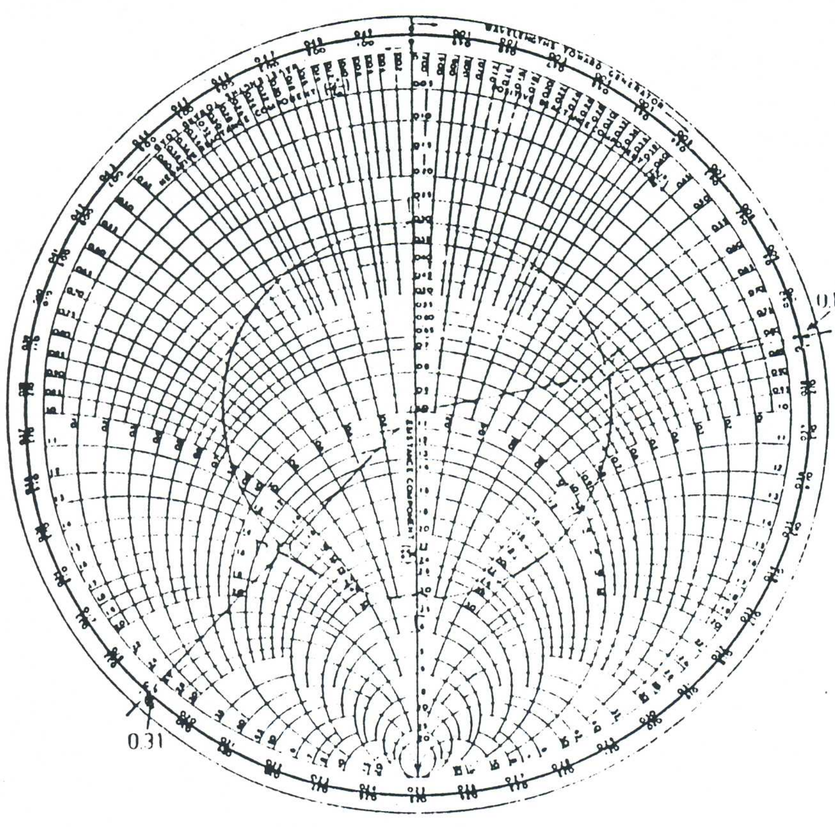


Figure 4

The scale on the outer edge of the Smith Chart indicates movement along the line normalized to the guide wavelength, i.e. distance along the waveguide/wavelength in the waveguide .

Normally the resistance- and reactance-scales are normalized to Z_0.

Example. Assume a lossless transmission line with a normalized load impedance of 0,5 + j 0,7. The guide wavelength is supposed to be 40 mm.

What is the impedance 8 mm toward the generator?

What is the SWR presented by the load?

How far from the load is the first minimum in the standing wave pattern?

For solution, see figure 4. Point A represents the load impedance 0.5 + j0.7. Draw the line OA. OA intercepts the outer scale "wavelengths toward generator" at 0.11. A movement 8 mm along the line corresponds to 0.2 wavelengths. ($^8/_{40}$ = 0.2) Draw a line from O out to 0.11 + 0.2 = 0.31 on the "wavelengths toward generator" scale. Draw a circle with radius OA and origin O. Point B represents the impedance at a point 8 mm toward the generator 1.4 - j1.4.

The SWR 3.2 is read directly at the point C. This point corresponds to a maximum

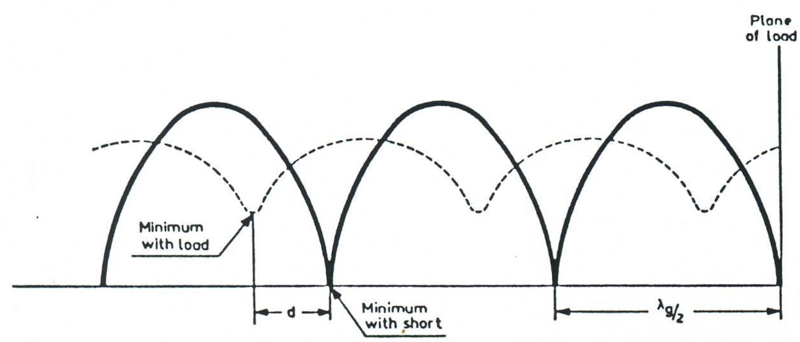


Figure 5. Illustration to impedance measurement

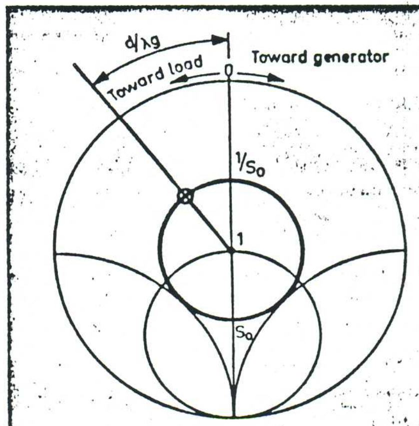


Figure 6

in the standing wave pattern. The first minimum occurs at point D, 0.50 — 0.11 = 0.39 wavelengths toward generator from A. 0.39 wavelengths = 15.6 mm.

For comparison the SWR can be calculated as $\frac{1 + |\varrho|}{1 - |\varrho|}$ where $\varrho = \frac{\frac{Z}{Z_0} - 1}{\frac{Z}{Z_0} + 1}$

Z is the impedance at **any** point on the line, which corresponds to a point on the drawn circle. E. g. at point A:

$$\varrho = \frac{0.5 + j0.7 - 1}{0.5 + j0.7 + 1} = \frac{-0.5 + j0.7}{1.5 + j0.7}$$

$$|\varrho| = \sqrt{\frac{0.5^2 + 0.7^2}{1.5^2 + 0.7^2}} = 0.52$$

$$S = \frac{1 + 0.52}{1 - 0.52} \approx 3.2$$

When measuring an unknown impedance it is necessary to define a plane to which the impedance is related. The reference plane can for instance be at the input terminals of the unknown device. The measurement is performed in the following way:

The unknown device is connected to the slotted line and the SWR = S_0 and the position of one minimum is determined. After that the unknown device is substituted by a short circuit at the output terminals of the slotted line. Two successive minima are noted. Twice the distance between them is the guide wavelength. One of the minima is used as reference. Figure 5.

A circle corresponding to the measured SWR = S_0 is drawn on the Smith Chart. Figure 6.

$\frac{1}{S_0}$ is the impedance at a minimum. The impedance at the plane of the load input terminals is found on the S_0-circle $\frac{d}{\lambda_g}$ from the point $\frac{1}{S_0}$; toward load if the minimum when the short is connected is moved toward the load. Otherwise toward generator.

As can be seen from figure 5 the impedance along the line equals the load impedance at planes spaced $\frac{\lambda_g}{2}$, λ_g, $\frac{3}{2}\lambda_g$ etc. from the plane of the load.

Note: The transmission line is assumed to be lossless. If not, movement along the line will correspond to movement along a spiral shaped curve on the Smith Chart. This means that the SWR will decrease when distance from load increases.

Procedure

1. **General**
1.1 Set up the equipment as shown figure 7.
1.2 Completely unscrew the probe of sliding screw tuner. (0 on the sc
1.3 Energize the klystron at 9.0 G Modulation: square wave 1000
1.4 Obtain a medium deflection on SWR-meter, 40 dB-range. Bandwidth: 20 Hz.
2. **Impedance measurement**
2.1 Set the probe depth on the sli screw tuner to 5 mm. Probe position :fixed.
2.2 Move the probe along the stan wave detector to obtain maxin deflection on the SWR-meter.
2.3 Adjust the SWR-meter gain until meter indicates 1.0 on the u scale.
2.4 Move the probe on the standing w detector to a minimum. Note record the SWR = S_l, and the pr position d_l,. Table I.
2.5 Remove the sliding screw tuner the termination. Place the vari short at the slotted line output. plunger should be at the wavegu flange. (0 on the micrometer sc

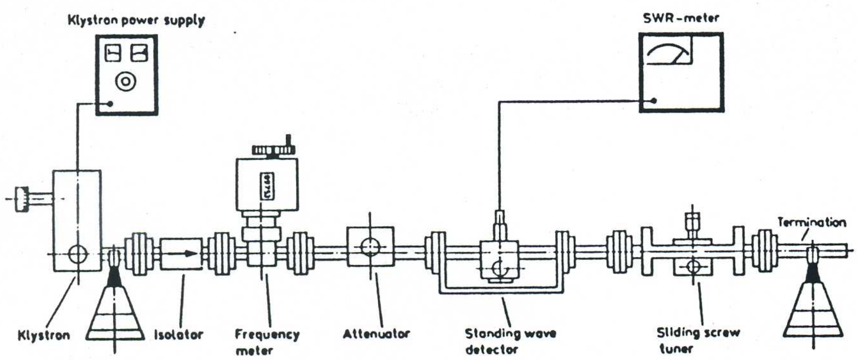


Figure 7 Set up in Experiment 4

2.6 Note and record the position of two successive minima, d_{S1} and d_{S2} (d_{S1} closest to d_L). Twice the distance $/d_{S1} - d_{S2}/$ is the guide wavelength.

Note: When close to a minimum increase the SWR-meter gain to get an accurate reading.

2.7 Calculate the guide wavelength λ_g and $\frac{d_L - d_{S1}}{\lambda_g}$

2.8 Draw a circle corresponding to the measured SWR = S_L on the Smith chart.

2.9 Locate the point $\frac{d_L - d_{S1}}{\lambda_g}$ on the scale
"Wavelengths toward load" if $(d_L - d_{S1}) > 0$
"Wavelengths toward generator" if $(d_L - d_{S1}) < 0$

2.10 Draw a line from the point 1 + j0 out to $\frac{/d_L - d_{S1}/}{\lambda_g}$ on the appropriate scale found in 2.9.

2.11 Note and record the load impedance at the interception between the S_L-circle and the line in step 2.10. The found impedance is the impedance of the sliding screw tuner + the termination at the input flange of the sliding screw tuner.

2.12 Repeat the steps 2.2 - 2.11 at 8.5 and 9.5 GHz.

Table I Impedance measurement

Step →	2.4		2.6		2.7		2.11
Frequency GHz	Load SWR S_L	Load min. d_L mm	Short minima d_{S1} mm	d_{S2} mm	$\lambda_g = 2./d_{S1} - d_{S2}/$ mm	$\frac{d_L - d_{S1}}{\lambda_g}$ (see note)	Load impedance
8.5							
9.0							
9.5							

Questions

1. Why is it necessary to relate the impedance of a load to a reference plane?
2. In the measurements the minima in the standing wave patterns are used for reference etc. Is it possible to use the maxima instead?
If so, why do we prefer the minima?
3. The load impedance measured in the Experiment is the impedance at the input flange of the sliding screw tuner. How is it possible to find the impedance at the plane where the probe is inserted?
4. Is the measured impedance frequency dependent?

Note: If $d_L - d_{SL}$ is positive: toward load
negative: toward generator
If $\frac{/d_L - d_{SL}/}{\lambda_g} > \frac{1}{2}$, this simply means an extra turn on the Smith Chart.