ELEC 453/6391 Microwave Engineering

Experiment #3

X-Band Waveguide Circuits: Doppler Radar and Interferometer

This lab consists of two short experiments, both using waveguide circuits at X band. The first circuit is a Doppler radar and measures the speed of movement of a swinging tennis ball. The second is a waveguide interferometer, and is used to measure the input impedance of waveguide components. There is one setup for each experiment, so you will spend half the lab session on one of the experiments and then exchange with the other group of students and spend the second half of the lab session on the other experiment.

You must do the Items 1.3 and 2.3, the Preliminary Exercises, before coming to the laboratory.

1. Doppler Radar

1.1 Equipment

- Gunn diode source: Macom voltage controlled oscillator transceiver MA87728-M01
- 8 volt DC power supply
- Caswell X-101 ferrite isolator
- HP X752C 10-dB directional coupler.
- HP X281A waveguide to coaxial transition
- Waveline 654 matched load.
- Two X-band waveguide stands
- HP5347A Power Meter and Frequency Counter, with HP8481A thermocouple sensor head (300 mW max for the power meter; 7 dBm max for the frequency counter)
- Weinschell Engineering Company model 532-10 coaxial attenuator (10 dB)
- 20 dB directional coupler, 15 inch flexible waveguide, FXR X621A H-plane tee, HP X485B tunable detector mount with 1N23 crystal.
- E & M Labs X234LT circulator, 10.7 to 11.7 GHz
- Omega 438 X band pyramidal horn, approx. 13.5 by 11.2 cm
- Tektronix TDS 340 storage scope
- tennis ball, foil, string, ruler, masking tape, wood block

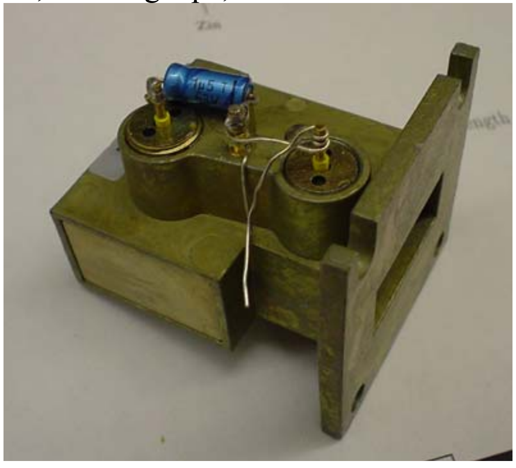

Figure 3.1 The Gunn diode oscillator.

1.2 Introduction

This lab makes use of X-band waveguide components that operate from 8 to 12 GHz. The internal waveguide dimensions are 0.9 by 0.4 inches. The 10.5-GHz microwaves for the Doppler radar are generated by a *Gunn diode*[1], named after the British physicist J. Gunn. It is a GaAs or InP device which exhibits a negative resistance characteristic. The Gunn diode is packaged as an X-band waveguide component, shown in Figure 3.1, and is sometimes informally called a "Gunn flange". The Gunn diode itself is mounted in a resonant cavity and is coupled to an X-band waveguide with an iris. The Gunn diode oscillates at the resonant frequency of the cavity. The Gunn Diode is powered by a D.C. voltage source, called the "bias voltage", in the range $6 \le v_G \le 10$ volts DC. Compared to a klystron tube, the Gunn is inexpensive ($30 for the Gunn diode itself, in quantity), reliable, and easy to operate. However, the operating frequency drifts with temperature, and its AM and FM noise performance is inferior to a klystron. Also, compared to tubes, the power output of semiconductor devices is low. The "Gunn flange" generates about 10 mW in the frequency range 10.0 to 10.6 GHz.

We can change the resonant frequency of the cavity in which the Gunn diode is mounted by putting a small post in the resonant cavity. The "Gunn flange" in Fig. 3.5 uses a varactor diode for the post. By applying a reverse bias or "tuning voltage" between 1 and 20 volts DC to the varactor, we can tune the operating frequency of the Gunn oscillator, by changing the resonant frequency of the cavity. By modulating the tuning voltage with an audio signal, we can produce an FM signal. But for this experiment we will not apply a voltage to the varactor. In Fig. 3.5 the input terminal of the varactor is grounded with a small length of wire.

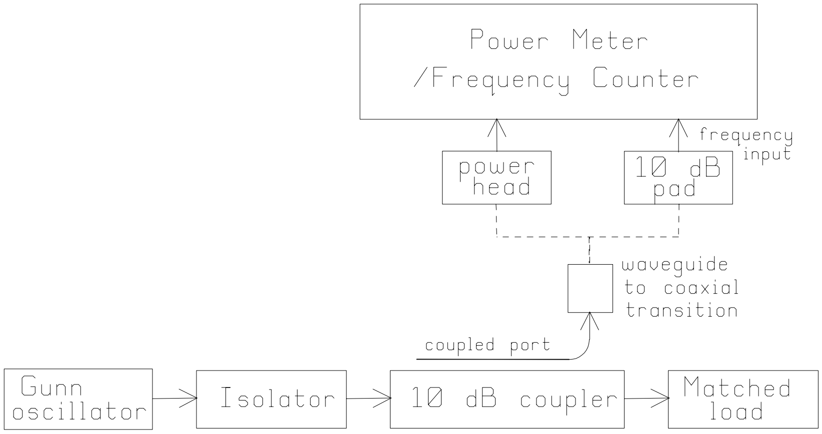

Fig. 3.2(a) Block diagram of the setup for measuring the frequency and power output of the Gunn oscillator.

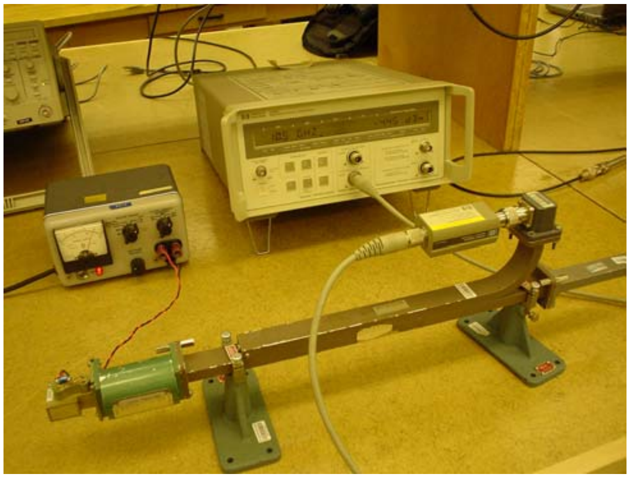

Fig. 3.2(b) Photo of the power measurement setup.

Fig. 3.2(c) The thermocouple head.

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[1] Pozar (3rd edition) Section 12.5

Frequency and Power Output of the Gunn Flange

Figure 3.2(a) is a block diagram of the setup for measuring the frequency of the Gunn oscillator and its power output. The measurement uses a modern HP5347A power meter and frequency counter, shown in Fig. 3.2. The figure shows the “Gunn flange” at left, powered by a DC voltage source. The Gunn flange is connected to a ferrite isolator[2], which permits propagation only in one direction: from the Gunn oscillator to the coupler. This suppresses reflections from the circuit back into the Gunn source, and also reduces “frequency pulling”, i.e., changes in the oscillation frequency due to impedance mismatch of the load. The isolator is connected to a directional coupler, which delivers most of the input power to its output port, which is terminated with a waveguide matched load. The signal at the “coupled” port is 20 dB down from the forward-traveling wave in the coupler. The coupled port is connected either to the HP8481A thermocouple head, shown in Fig. 3.2(c), or to the frequency counter input of the power/frequency meter, via a 10 dB attenuator.

The power meter/frequency counter has separate inputs for power measurement and for frequency measurement. Both inputs present matched 50-ohm characteristic impedance. In general, a power meter measures small changes in the characteristics of a thermistor or thermocouple element that is heated up by the RF signal power. Since this is based on the heating effect, the device has a true RMS response. It is also broadband, so it gives the total power, both that in the signal and that in all the harmonics or sidebands that might be present. The thermistor can dissipate a maximum of 300 mW; any more and it burns out, and needs to be replaced, for $1500! This is why we use the 20-dB directional coupler: it limits the power input to the thermistor. Also, the frequency counter can dissipate even less power: only 7 dBm. So the circuit in Fig. 3.2 uses a 10-dB attenuator in series with the input, to ensure that the power input to the counter is small.

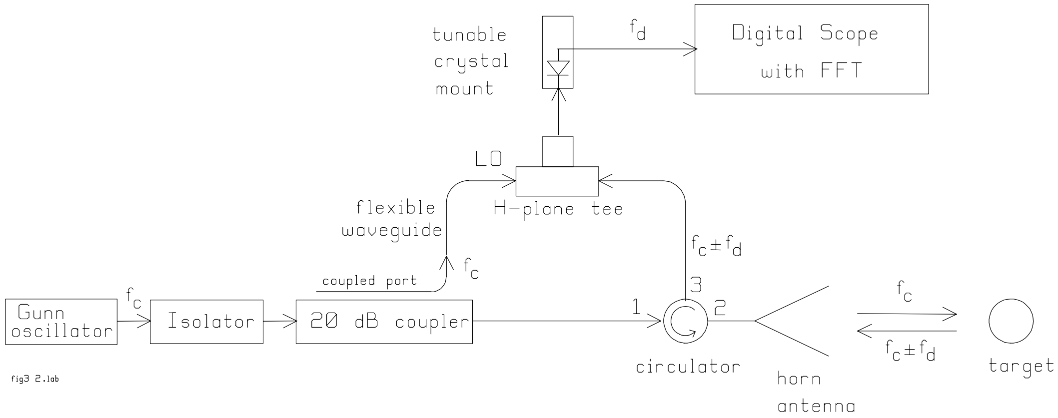

Fig. 3.3(a) Block diagram of the Doppler radar setup.

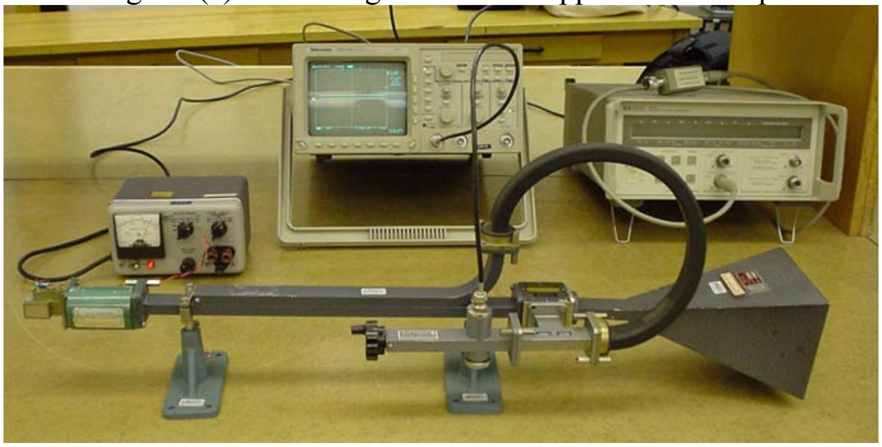

Figure 3.3(b) Photo off the Doppler radar setup.

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[2] Pozar Section 9.4

Doppler Radar Setup

Figure 3.3(a) is a block diagram of the Doppler radar[3] setup and Figure 3.3(b) shows the equipment, which is already assembled for you in the lab. All you have to do is to attach the Gunn flange and isolator, and connect the storage oscilloscope to the diode detector. The Gunn diode's signal at frequency f_c is radiated by the horn antenna. The signal is reflected by the target, which is a swinging tennis ball covered with aluminum foil. Because the target is moving, the frequency of the reflected signal is shifted by f_d, the Doppler frequency. The frequency is shifted upwards to $f_c + f_d$ if the ball is moving towards the horn, and downwards to $f_c - f_d$ if the ball is moving away. To "recover" the Doppler frequency f_d, a sample of the Gunn oscillator's frequency f_c is taken with a directional coupler and used as a "local oscillator" or LO. The LO signal at frequency f_c and the received signal at frequency $f_c \pm f_d$ are combined in a tee junction and then fed to a diode. The diode behaves as a mixer: the output is the difference between the LO frequency f_c and the frequency coming from the horn, $f_c \pm f_d$, so is at the Doppler frequency f_d. If the target were moving at constant speed, we could use a frequency counter to measure f_d. But as the tennis-ball target swings back and forth, it moves with a range of velocities towards and away from the horn antenna, so the returned signal contains a range of Doppler frequencies. In the circuit of Fig. 3.3, a digital storage oscilloscope is used to record the mixer output *as a function of time*, and then performs a Fourier transform to find the amplitude of the returned signal *as a function of frequency*.

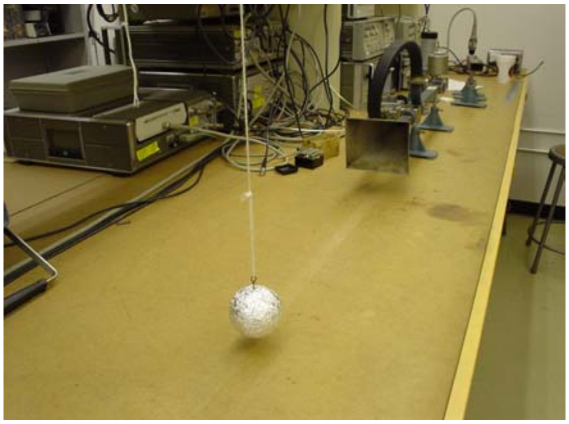

Figure 3.4 The foil-covered tennis ball swings in front of the horn antenna.

Doppler Frequency Shift

To test the Doppler radar, we need a target moving at a well-known, reproducible velocity. The "pendulum" of Fig. 3.4, made with a tennis ball at the end of a long string, is a good choice because elementary mechanics predicts the velocity, as follows. A pendulum swings with a horizontal displacement given by

$$x(t) = -A\cos\left(\sqrt{\frac{g}{\ell}}t\right)$$

where ℓ is the length of the pendulum in meters, t is time in seconds, and the acceleration of gravity is $g = 9.81$ m/s^2. So at $t = 0$, the displacement is $x(0) = -A$, and the tennis ball is furthest from the horn.

The velocity of the pendulum is $v = \frac{dx}{dt}$ given by

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[3] Pozar Section 13.3

$$v(t) = A\sqrt{\frac{g}{\ell}}\sin\left(\sqrt{\frac{g}{\ell}}t\right)$$

The frequency of oscillation of the pendulum is $\sqrt{\frac{g}{\ell}}$ radians per second. The maximum velocity of the pendulum depends on the initial displacement A, on the acceleration of gravity, and on the length of the pendulum, ℓ, which is the length of the string. By starting the pendulum with a known displacement A, the velocity is also known. The Doppler frequency shift is

$$f_d(t) = 2\frac{f_c v(t)}{c}$$

where the velocity of the target is $v(t)$ and c is the speed of light in free space.

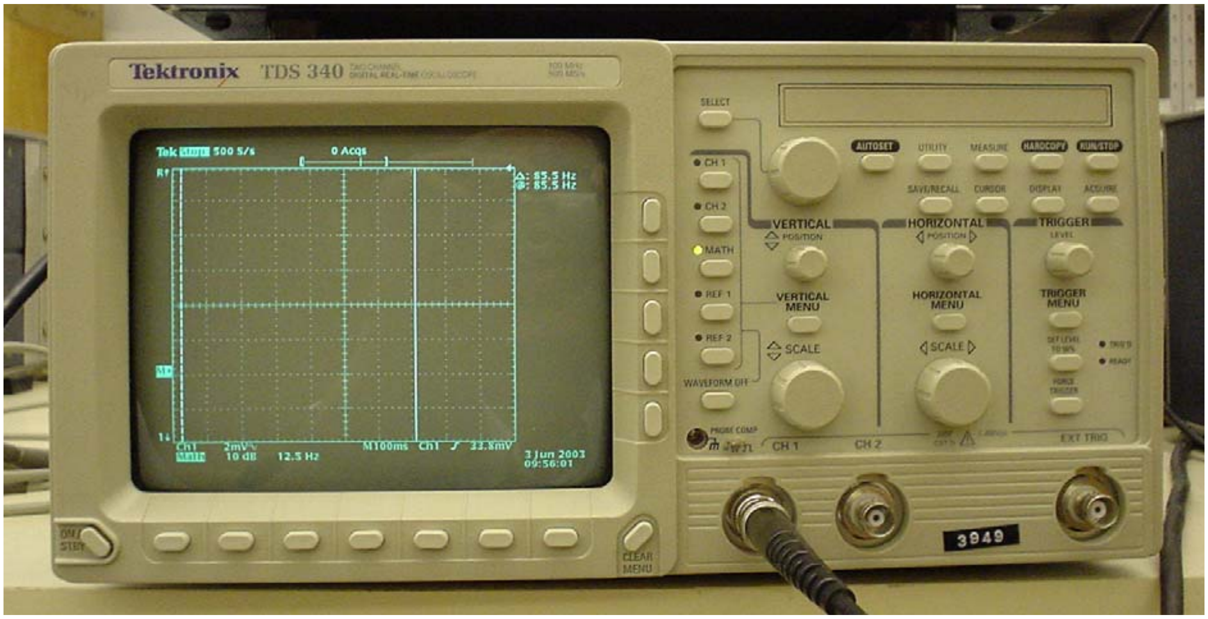

Figure 3.5 The Tektronix TDS340 storage oscilloscope.

Storage Scope

The Tektronix TDS340 digital real-time scope, Figure 3.5, is used to measure the Doppler signal. To use this instrument knowledgably, you need about two hours to study the manual! In the measurement, we will record the voltage at the crystal in Fig. 3.3 as a function of time on the storage scope, to get the lower trace of the display shown in Fig. 3.6. As the pendulum swings, it moves at velocities from zero to a maximum of $A\sqrt{g/\ell}$. Then the crystal voltage contains frequencies from 0 Hz to a maximum of $f_d = 2\frac{f_c}{c}A\sqrt{\frac{g}{\ell}}$ Hz, and indeed the lower trace in Fig. 3.6 shows a signal containing a range of frequencies. We will use the storage-scope's built-in Fourier Transform to find the frequency spectrum of this signal, shown by the top trace in Fig. 3.6, which shows the amplitude of the Doppler signal as a function of frequency. The spectrum shows increasing amplitude with frequency up to the maximum frequency of $f_d = 2\frac{f_c}{c}A\sqrt{\frac{g}{\ell}}$ Hz. Above this frequency, the spectrum rapidly falls to the noise level. The Doppler frequency corresponding to the maximum velocity is the frequency of the tallest peak in the spectrum shown in Fig. 3.6.

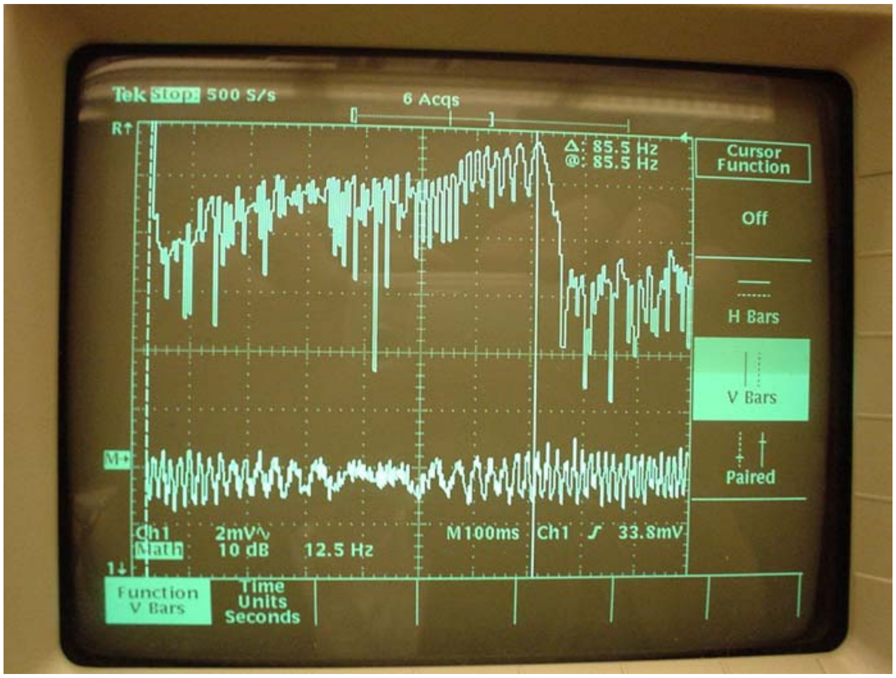

Fig. 3.6 The voltage of the diode detector as a function of time is shown at bottom, and the FFT of the diode voltage is shown at the top of the ‘scope display.

Figure 3.7 The circulator, H-plane tee, and diode detector.

Circulator, H-plane Tee, and Diode Detector

The Doppler radar setup of Figure 3.3(b) uses waveguide components that we have not encountered previously in the course. These are described in this section.

Fig. 3.3(b) shows that the “Gunn flange”, which generates the RF signal at frequency f_c, is connected to a ferrite isolator, and the isolator’s output port is connected to a directional coupler, which takes a sample of the signal to be used as the LO for the crystal mixer. The coupler’s output port is connected to a circulator[4], which is shown at the base of the horn antenna in Fig. 3.7. The circulator allows the same antenna to be used to transmit the signal f_c to the tennis-ball “target”, and to receive the reflected signal at $f_c \pm f_d$. The directional coupler delivers power at f_c to port #1 of the circulator, which routes all of this power to port #2, where the horn is connected, and (ideally) none of the power to port #3. The horn radiates the power, and some is reflected back into the horn, at frequency $f_c \pm f_d$. The reflected signal is delivered by the horn to port #2, and the circulator routes all of this power to port #3,

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[4] Pozar Section 9.6

and (also ideally) none to port #1. Port #3 of the circulator is connected to one side of the tee, and the coupled port of the directional couple is connected with a flexible waveguide to the other side of the tee. The tee takes the difference between the two signals[5] and delivers it to the crystal detector.

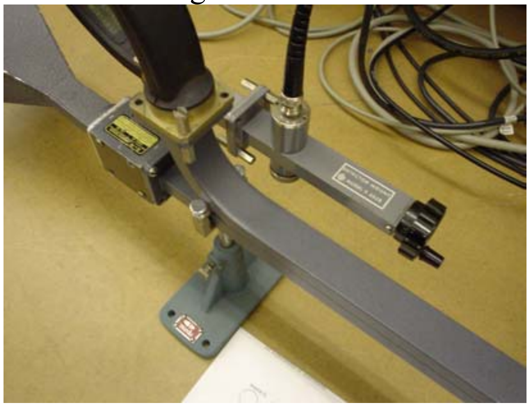

Fig.3.8 The directional coupler and the crystal mount.

The detector mount shown in Fig. 3.8 contains an RF diode or “crystal”, with its output on a BNC connector, and a sliding short, which can be moved by turning the black knob. Moving the short lets you put a maximum in the standing-wave pattern inside the crystal mount at the location of the diode, and so get the maximum output from the crystal. The crystal behaves as a square-law mixer[6], which has two frequencies at the input, f_c from the directional coupler, and $f_c \pm f_d$ from the circulator. The mixer forms signals at the sum frequency and the difference frequency. The difference frequency is the Doppler frequency f_d. The output of the crystal is carried via a BNC cable to the digital storage oscilloscope. The storage ‘scope records the output signal from the mixer as a function of time and then takes the Fourier transform to find the frequency content, as described above.

1.3 Preliminary Exercise

Answer this question before you come to the lab. The lab demonstrator will check that you have answered the preliminary exercise before he permits you to do the experiment.

Suppose that the tennis ball target is moving toward the horn antenna at a constant velocity v m/s, and that the radar operates at frequency f_c Hz. Explain the “Doppler Effect” and derive the formula for the Doppler shift frequency, $f_d = 2\frac{f_c v}{c}$, where c is the speed of light.

1.4 Procedure in the Laboratory

First, we will measure the frequency and power output of the Gunn flange. The setup in Fig. 3.2 has been assembled for you; all you have to do is to attach the Gunn flange and isolator to the directional coupler with 6-32 nuts and bolts. For this experiment, use 8 volts DC to power the Gunn oscillator. Be careful, you can blow the Gunn diode if you apply more than +10 V as a bias voltage, or get the polarity wrong. After you turn on the 8-volt bias voltage you should l**et the equipment warm up for 20 minutes.** Otherwise the frequency will drift.

Be careful never to exceed the power-input limit of the power meter, as a blown sensor head is costly. The HP8481A thermistor sensor head can operate at 10 mW or 10 dBm, but will blow at 300 mW. The frequency counter input can dissipate even less power, only 5 mW or 7 dBm. So a 10 dB

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[5] Pozar Section 7.2 and Fig. 7.5

[6] Pozar Section 12.6

attenuator is used in series with the frequency-counter input. Follow the instructions printed on top of the HP5347A power meter/counter to set it up for power measurement.

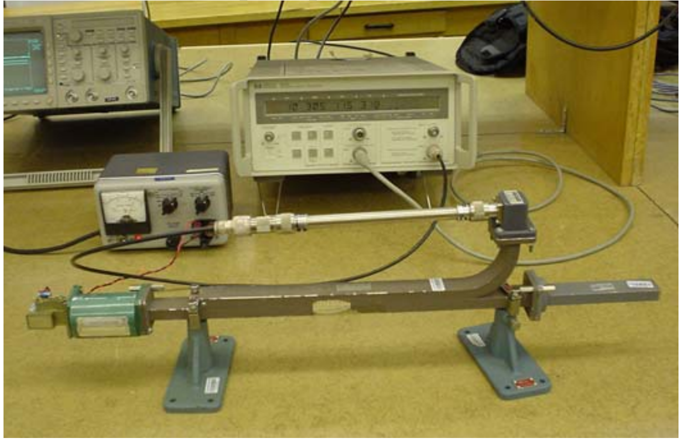

Fig. 3.9 The setup for the measurement of the frequency of the Gunn flange.

1.4.1 Frequency/Power Measurement

In the setup of Fig. 3.2, the coupled port of the directional coupler is connected to a waveguide-to-coaxial transition. Connect the 10-dB coaxial attenuator to the transition and use an adapter and a coaxial cable to connect the output of the pad to the frequency counter input, as shown in Fig. 3.9. Press the "input 1 key" and read the frequency, which is the oscillation frequency of the Gunn diode in its resonant cavity. Then calibrate the power meter, by following the instructions on top of the power meter:

1) Press the "Calibrate/Store Frequency" key to save the frequency and start the calibration procedure.
2) Connect the thermistor head to the "output" connector on the power meter. This provides a reference power level of 1 mW.
3) Press the "input dBm/Watt" key.
4) Press the "zero" key and wait about 15 seconds for zeroing to occur.
5) Press the "Calibrate" key to complete the calibration sequence; you are ready measure the power.

Then connect the thermistor head directly to the waveguide to coaxial transition, Fig. 3.2(b), and read the power flowing out of the branch of the directional coupler. Calculate the Gunn oscillator's power output, knowing that the insertion loss of the isolator is 0.4 dB, and that the coupling coefficient for the directional coupler is 10 dB. Record your data in Table 1.4.1 in Section 3.

1.4.2 Doppler Shift Measurement

Attach the Gunn flange and the ferrite isolator to the input of the Doppler radar, and connect the 8-volt power supply, as shown in Fig. 3.3(b). Turn on the D.C. power. With the tennis-ball at rest, set up the Doppler radar with the horn about 1 meter from the ball. We will swing the ball with a maximum displacement of about $A = 1$ m. Make sure that the horn is aimed directly at the tennis ball. Connect the output of the diode detector to the "Channel 1" input of the storage oscilloscope, with a BNC cable. Set the TDS 340 storage 'scope for DC coupling (Push "Ch 1" then "vertical menu" then the "DC" soft key).

To tune the probe mount, move your hand back and forth in front of the horn at a frequency of about 4 Hz. Press "autoset" on the scope to get a reasonable amplitude and time base setup. Keep waving your hand and adjust the black tuning knob to get the maximum output from the detector.

Change the scope to AC coupling (Push "Ch 1" then "vertical menu" then the "AC" soft key.) Swing the tennis ball with an initial displacement of about 50 cm to get a Doppler-shifted signal, and once again press "autoset". Look for a signal on the scope screen. Then set the time base to 100 mS/div (Push the "horizontal menu" key then turn the "horizontal scale" knob. The setting is displayed at the bottom of the screen: set it to 100 mS/div). Put the "Ch 1" trace in the bottom half of the screen by pushing "Ch 1" then adjusting the vertical position knob.

Set up the Fourier transform as follows. Push the "horizontal menu" key and select the "fit to screen off/on" soft key, and choose "off", to show 500 points on the screen. Then press the "math" soft key, and then the "FFT" soft key, which toggles between Channel 1 and Channel 2. Make sure "FFT Ch.1" is selected. Set the horizontal frequency resolution to 12.5 Hz using the "scale" knob below the "horizontal menu" button. Note that the horizontal frequency resolution appears at the bottom of the screen, third from the left, as in Fig. 3.6. Then swing the tennis ball and observe the time response on the Channel 1 trace. Let about two screens of data scroll by, then press the "run/stop" button at the upper right of the scope face, to freeze the time signal. The 'scope will compute the FFT. Move the FFT trace to the top half of the screen by pushing "math" and using the vertical position knob. The scope display should look like Fig. 3.6.

Read the frequency of the largest peak in the FFT by pushing "cursor" at the upper right of the scope face to get the cursor menu, then push the "V bars" soft key. Then use the knob near the upper right corner of the screen to move the vertical-bar cursor to the location of the largest peak, as in Fig. 3.6. The frequency is reported at the upper right hand corner of the screen, "@85.5 kHz" in Fig. 3.6.

When you are ready to take another measurement, push "run/stop" again so the scope will record data, then let two screens of data scroll by, and push "run/stop" once more to compute the Fourier Transform.

Swing the pendulum for several different amplitudes: $A = 20$ cm, 40 cm, 60 cm, 80 cm and 100 cm. Use the 'scope to take the FFT in each case and record the maximum Doppler frequency. Fill out Table 1.4.2 in Section 3. Measure and record the length of the string, ℓ, so that you can calculate the expected Doppler shifts.

2. X-Band Reflectometer

2.1 Equipment

The reflectometer shown in Figure 3.10(b) has been assembled for you, and consists of the following:

- HP 8672A 2-18 GHz synthesized signal generator
- 1 kHz 2V p-p audio oscillator
- HP X281 coax to waveguide transition
- RG 214U coax cable
- HP X750D 20 dB crossed-guide "Moreno" directional coupler
- HP X370C 10 db fixed waveguide attenuator
- Narda 950 180° hybrid (magic-T)
- Waveline 654 matched load
- Aircom tunable crystal mount
- HP 415E SWR meter
- HP X382A rotary vane variable attenuator
- HP X885A phase shifter
- three 90° H-plane elbows
- long 90° elbow
- FXR X64A, 10-inch flexible waveguide

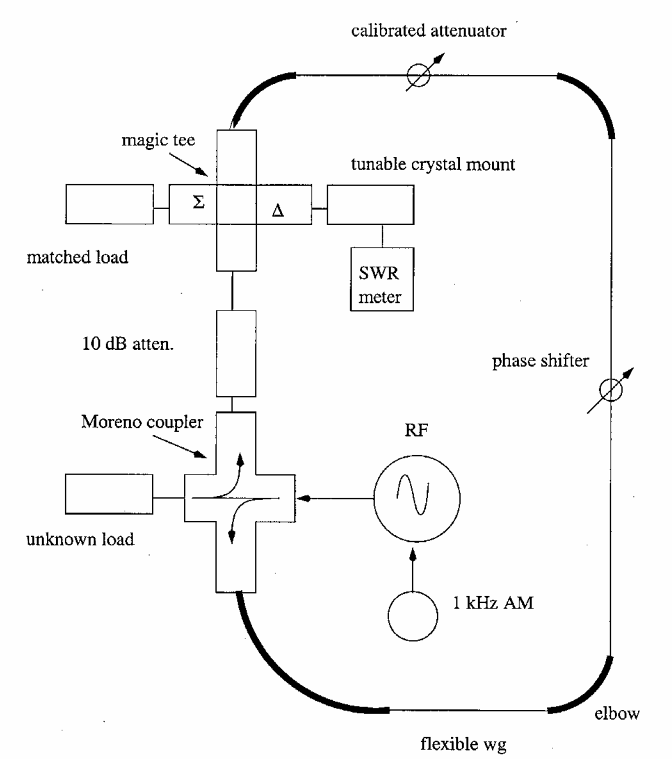

Figure 3.10(a) The X-band reflectometer setup.

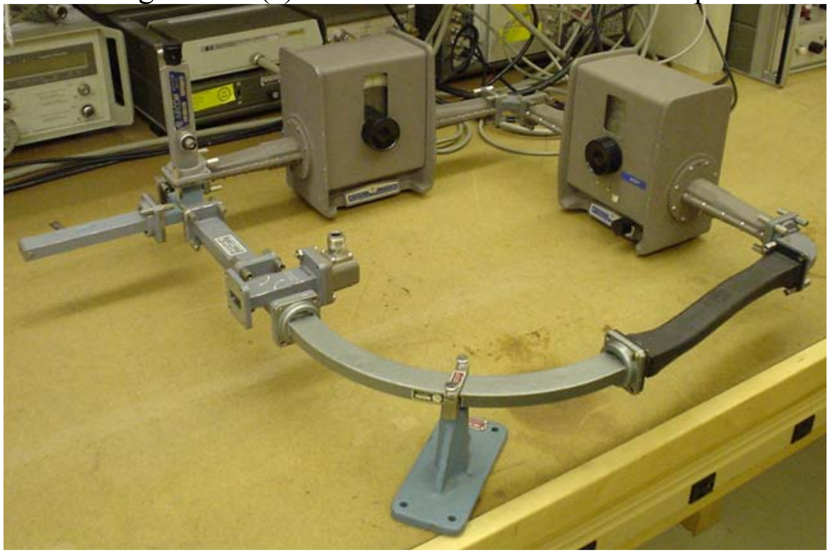

Figure 3.10(b) X-band reflectometer.

2.2 Introduction

A key problem in microwave engineering is the measurement of the reflection coefficient of a device. In Experiments 1 and 2, we measured the reflection coefficient of loads with coaxial N-type connectors. In this lab we will measure the reflection coefficient of X-band waveguide irises at about 10.5 GHz using the "reflectometer" shown in Figure 3.10. In Experiment 4, you will measure the same irises using a network analyzer.

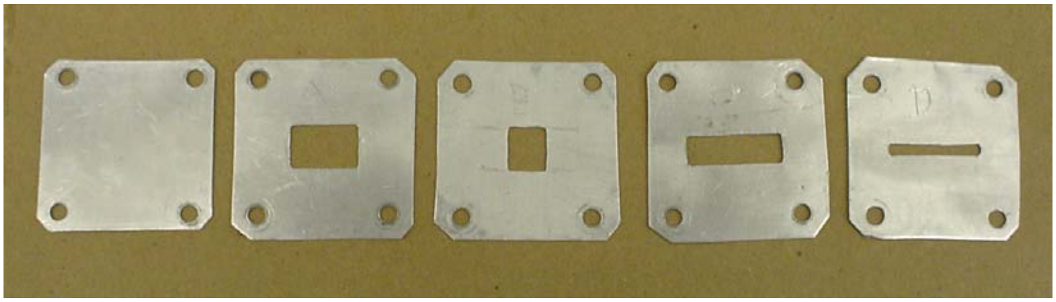

Figure 3.11 A waveguide shorting plate, and four waveguide irises.

Waveguide Irises

An "iris" is a small rectangular window between two sections of a waveguide. Fig. 3.11 shows a shorting plate for X-band waveguide, and four waveguide irises. The shorting plate is used to establish the location of the measurement plane, much as the coaxial short circuit was used in Experiments 1 and 2. An iris[7] behaves as an admittance $Y = jB$ connected across a waveguide. Waveguide filters[8] are made with irises of suitable size spaced along the length of a waveguide. There are two sample filters in the lab: one uses asymmetrical irises, and the other is made with posts instead of irises. The "tuning screws" permit precise alignment of the filter response with the desired pass band, and require considerable skill to adjust!

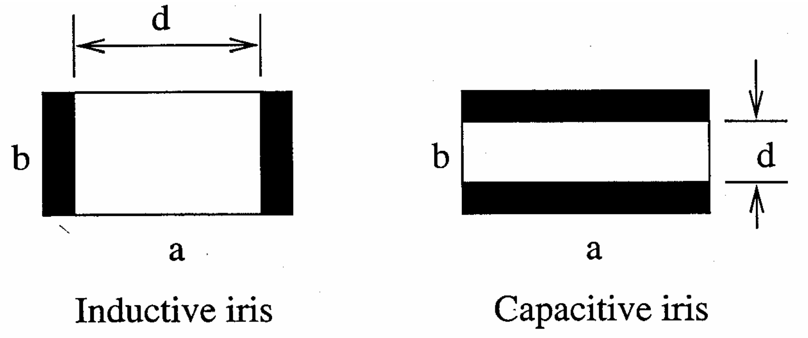

Figure 3.12 Dimensions for inductive and capacitive waveguide irises.

Collin[9] gives formulas that first appeared in Marcuvitz[10] for the susceptance of symmetrical inductive and capacitive irises as shown in Figure 3.12. For the symmetrical inductive iris of width d the susceptance is

$$B = \frac{-2\pi}{\beta a}\cot^2\left(\frac{\pi d}{2a}\right)\left(1+\frac{a\gamma_3 - 3\pi}{4\pi}\sin^2\frac{\pi d}{a}\right)$$

where

$$\gamma_3^2 = \left(\frac{3\pi}{a}\right)^2 - k^2$$

$$\beta^2 = k^2 - \left(\frac{\pi}{a}\right)^2$$

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[7] Pozar Section 4.6 and Fig. 4.22

[8] Pozar Chapter 8.

[9] R.E. Collin, "Foundations for Microwave Engineering", McGraw-Hill, 1966, pages 217-220.

[10] N. Marcuvitz, "Waveguide Handbook", McGraw-Hill 1951.

The waveguide dimensions are a and b, with $b \le a$. The iris width d is measured in the H-plane with $0 \le d \le a$. The free-space wave number is k and the wave number in the guide is β. For the symmetrical capacitive iris of height d

$$B = \frac{2\beta b}{\pi}\left(\ln\left(\csc\frac{\pi d}{2b}\right) + \left(\frac{2\pi}{b\gamma_2} - 1\right)\cos^4\frac{\pi d}{2b}\right)$$

where

$$\gamma_2^2 = \left(\frac{2\pi}{b}\right)^2 - k^2$$

The iris height d is measured in the E-plane with $0 \le d \le b$. Note that Collin's book has an error in the formula for γ_2! You will use these formulas to calculate the susceptance of each iris, and compare the "theoretical" value with your measurement.

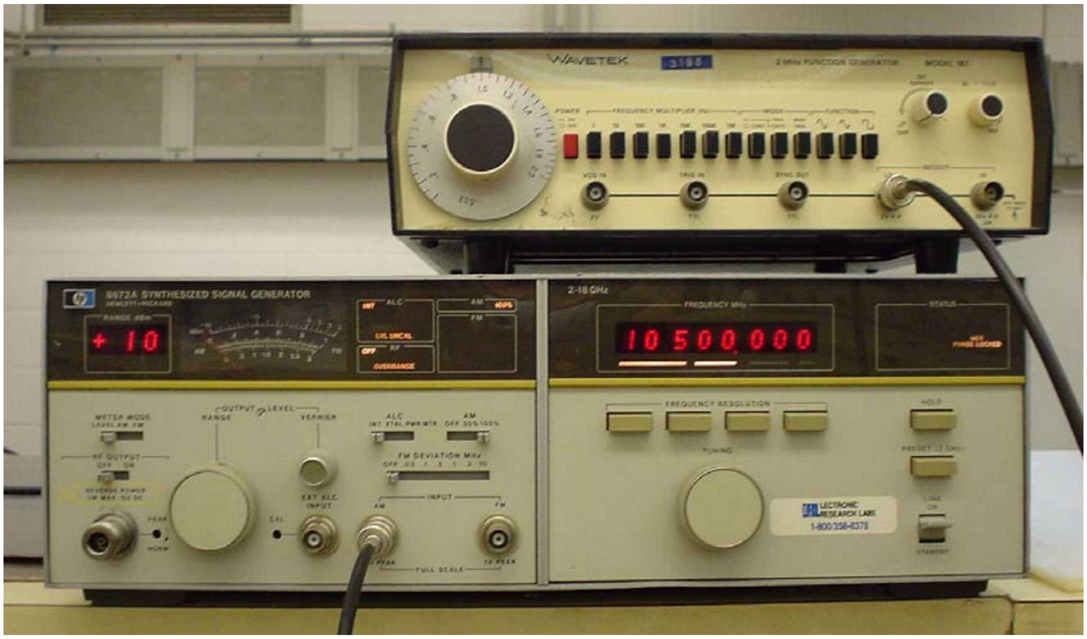

Fig. 3.13 The HP8672A synthesized signal generator.

HP8672 Synthesized Signal Generator

Fig. 3.13 shows the HP8672 synthesized signal generator. It operates from 2 to 18 GHz, with an output range of -120 to +3 dBm. It uses a Yttrium iron garnet (YIG) tuned oscillator[11] that is phase-locked to an internal 10 MHz crystal (also called time base). The frequency stability is dependent on the time base. An external audio oscillator is used to provide AM so that we can measure the signal strength with an SWR meter. Use a BNC cable to connect the low-level output of the audio oscillator to the external modulation input of the signal generator. The RF on/off switch on this oscillator is just above the N-type output connector, at left in Fig. 3.13. Keep the RF power off except when you are doing a measurement.

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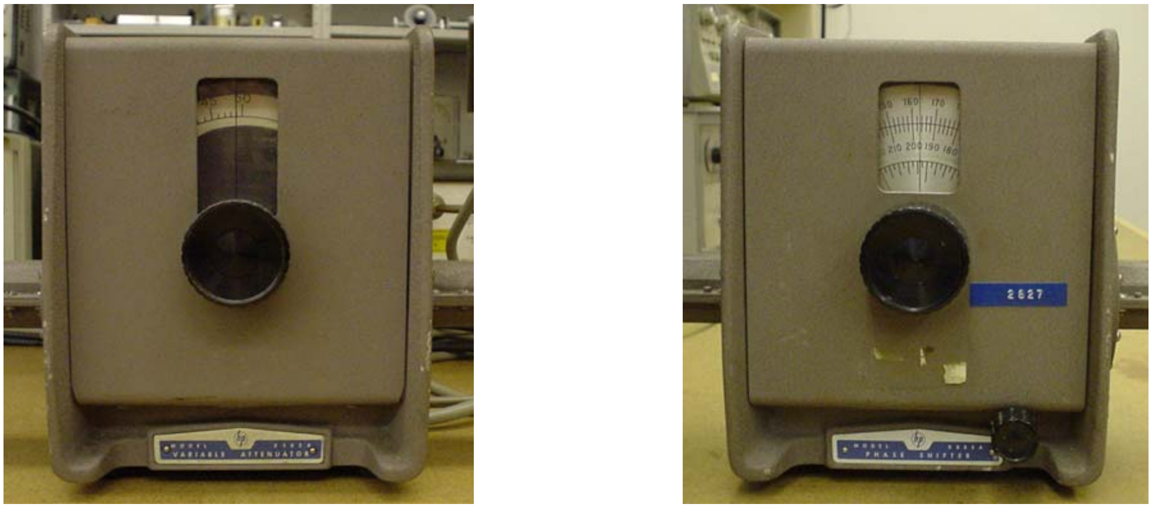
[11] Pozar Section 12.5



HP X382A rotary-vane variable attenuator HP X885A phase shifter

Figure 3.14 Variable attenuator and phase shifter.

Reflectometer Circuit

The reflectometer is a sensitive instrument for reflection coefficient measurement that was developed in the early days of microwave engineering. It uses the mechanical attenuator and mechanical phase shifter shown in Fig. 3.14 to adjust the amplitude and phase of the signal in the “test” channel equal to the amplitude and phase of the signal in the “reference” channel. We can deduce the reflection coefficient of the load from the settings of the attenuator and phase shifter as described below.

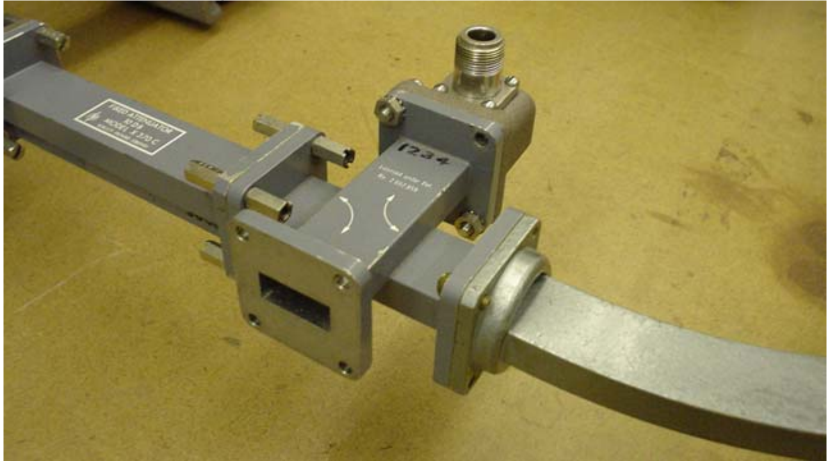


Figure 3.15 The Moreno coupler, with the waveguide “port” for the unknown load.

Figure 3.10(a) is a circuit diagram of the reflectometer. The source is the HP8672A synthesized signal generator and is amplitude-modulated with 1 kHz. The RF signal is routed from the generator on a coaxial cable connected to a coax-to-waveguide transition. The transition delivers the signal to a crossed-guide coupler or “Moreno coupler[12]”, Fig. 3.15, which is a waveguide implementation of the directional coupler used in Experiment 2. The “through” port is the open waveguide flange in Fig. 3.10(b) and Fig. 3.15, and is the “measurement port” where the shorting plate will be connected for calibration, and the unknown load for measurement. The Moreno coupler samples the signal from the RF generator, and delivers it to the “reference” channel for the reflectometer. The signal in the reference channel is routed with elbows and a flexible waveguide to the mechanical phase shifter and the mechanical variable attenuator. This lets us add any desired phase shift and attenuation to the reference

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[12] Pozar Section 7.9 and Figure 7.51.

channel. A 10 dB attenuator is used to connect the test channel to a "magic-T[13]" hybrid junction. Fig. 3.16 shows the magic-T, which has a matched load on the sum port, and a tunable crystal mount on the difference port. The magic-T takes the difference between the signal in the reference channel and the signal in the test channel and delivers it to the crystal mount. When the output of the magic-T is *zero*, the amplitude of the signal in the reference channel is equal to the amplitude in the test channel, and the phase of the signal in the reference channel is equal to the phase of the signal in the test channel. The crystal recovers the 1-kHz modulation from the RF signal and it is routed via a BNC cable to an SWR meter. Adjust the variable attenuator and the phase shift to get the minimum possible reading on the SWR meter; then the signal in the test channel is equal to the signal in the test channel.

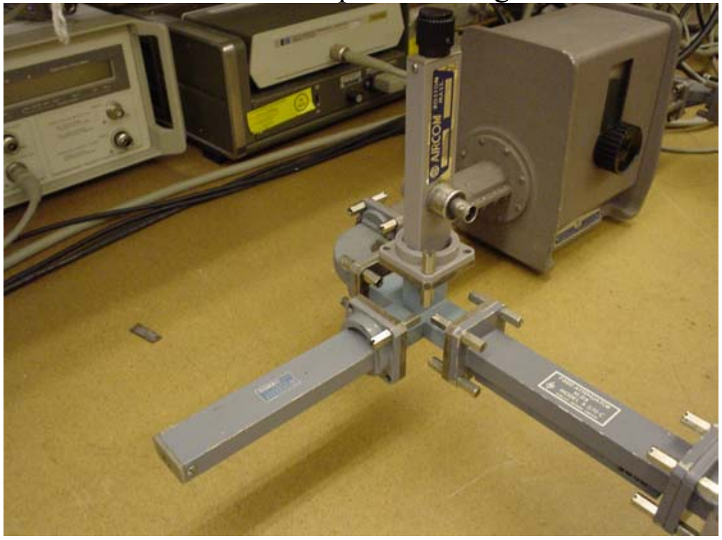

Figure 3.16 The Magic-T junction has a matched load on the sum port, and the crystal detector on the difference port.

Operating the Reflectometer

The reference channel in Fig. 3.10(b) includes the rotary-vane variable attenuator and the phase shifter of Fig. 3.14. By adjusting the black knobs, we can add any amount of attenuation and phase shift to the reference channel. The attenuator and phase shifter must be adjusted to null out the signal measured by the SWR meter, and then the reflection coefficient of the load can be found, as follows.

First establish the location of the "reference plane" by mounting a shorting plate on the measurement port. Adjust the phase shifter and attenuator until a null is observed on the SWR meter. Record the attenuator setting A_{ref} and phase shifter setting ϕ_{ref}. Because there is a 10 dB attenuator in the test channel, we expect the value of A_{ref} to be about 10 dB. Now remove the shorting plate and replace it with the unknown load. Again adjust the variable attenuator and phase shifter to obtain a null on the SWR meter, and read the attenuator setting A_{load} and the phase shifter setting ϕ_{load}. The reflection coefficient is $\Gamma = |\Gamma| \angle \theta$. The magnitude of the reflection coefficient is given by

$$|\Gamma| = \frac{A_{load}}{A_{ref}}$$

where A_{load} and A_{ref} are on a linear scale (not dB). The phase of the reflection coefficient is

$$\theta = \phi_{load} - \phi_{ref} + 180°$$

Note that you should read the *top* scale on the phase shifter.

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[13] Pozar Section 7.8 and Figure 7.50

2.3 Preliminary Exercise

Answer this question before you come to the lab. The lab demonstrator will check that you have answered the preliminary exercise before he permits you to do the experiment.

The shorting plate is mounted on the measurement port of the reflectometer and to null the SWR meter, the phase shifter is adjusted to read A_{ref} =7.28 dB, ϕ_{ref} =266 degrees. Then iris A is mounted, backed by a matched load, and again the attenuator and phase shifter are adjusted to null out the SWR meter, and the settings are read as A_{load} =18.2 dB and ϕ_{load} =166 degrees. The frequency is 10.6 GHz What is the reflection coefficient of the load?. What is the impedance of the load? What is the susceptance of iris A?

2.4 Procedure in the Laboratory

Set the frequency of the generator to 10.6 GHz and the RF power to -5 dBm. Using the meter on the HP8672 to set the amplitude of the audio oscillator for 100% modulation.

Adjustment of the Modulation Frequency and the Crystal Mount

We need to adjust the frequency of the audio oscillator to match the narrow bandpass of the HP 415E SWR meter. Mount the shorting plate (backed by the matched load to provide mechanical support) on the test port of the reflectometer and turn on the RF power. Adjust the audio frequency for maximum deflection of the SWR meter's needle. You don't need to change the audio oscillator's frequency for the remainder of the experiment. Then tune the crystal detector mount for the largest possible deflection of the SWR meter. When you change the RF frequency, you must re-adjust the tuning of the crystal mount.

Reflectometer Calibration

We need to calibrate the reflectometer whenever we change the frequency. With the RF source set to 10.6 GHz, mount the shorting plate at the test port of the reflectometer and adjust the variable attenuator and phase shifter to null the signal on the SWR meter. Use your skill in adjusting the SWR meter from Experiment 1. Record the attenuator setting A_{ref} and phase shifter setting ϕ_{ref}. These are the "calibration values" the reflectometer for 10.6 GHz.

Measuring the Unknown Load

The load we want to measure is one of the irises backed by the waveguide matched load. Mount the unknown load on the test port. Adjust the attenuator and phase shifter to null the signal on the SWR meter. Record the attenuator setting A_{load} and the phase shifter setting ϕ_{load}. Then you can calculate the reflection coefficient using the formulas given above.

2.4.1 Matched Load Impedance Measurement

Calibrate the reflectometer at 10.6 GHz. Record your values in Table 2.4.1. Then mount the matched load on the measurement port. Measure the reflection coefficient of the matched load, and record your values in Table 2.4.1. Calculate the SWR of the matched load. This number is useful; it represents the threshold where useful measurements can be made. Pozar tells us that the SWR of a simple waveguide flange is "typically less than 1.03[14]". The match of a "matched load" cannot be better than the match of the associated waveguide flange.

2.4.2 Iris Impedance Measurement

Calibrate the reflectometer at 10.4 GHz, and measure the reflection coefficient for iris A. Record you data in Table 2.4.2. Repeat for irises B, C and D. Then re-calibrate the reflectometer for 10.5 GHz,

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[14] Pozar page 116

and measure the reflection coefficient for each of the four irises. Finally re-calibrate for 10.6 GHz, and measure the reflection coefficient. The result is the reflection coefficient at three frequencies for each of four irises.

Use the electronic calipers to measure the physical dimensions of the four irises, for later use. Record your data in Table 2.4.3. The inductive irises in Fig. 3.11 are narrow in the H plane and capacitive irises are narrow in the E plane.

3. Tables of Measured Data

Student name:	
Student I.D.:	
Lab Section:	
Lab Instructor's Signature:	

Table 1.4.1
Characteristics of the Gunn Oscillator

Frequency GHz	Measured Power Output dBm	Isolator Insertion Loss dB	Coupling Factor dB	Gunn Output Power dBm
		0.4 dB	10 dB	

Table 1.4.2
Doppler Frequency Shifts
Length of string = ______ cm

Initial Displacement cm	Doppler Shift Hz
20	
40	
60	
80	
100	

Table 2.4.1
Reflection Coefficient of the Waveguide Matched Load at 10.6 GHz

Case	Attenuator Setting (dB)	Phase Shifter Setting (degrees)	Reflection coefficient		SWR
			Magnitude (linear)	Angle (degrees)	
Shorting Plate			1	180	-
Matched Load					

Table 2.4.2
Reflection Coefficient of the Waveguide Irises

Frequency GHz	Case	Attenuator Setting (dB)	Phase Shifter Setting (degrees)	Reflection coefficient	
				Magnitude (linear)	Angle (degrees)
10.4	Shorting Plate			1	180
	Iris A				
	Iris B				
	Iris C				
	Iris D				
10.5	Shorting Plate			1	180
	Iris A				
	Iris B				
	Iris C				
	Iris D				
10.6	Shorting Plate			1	180
	Iris A				
	Iris B				
	Iris C				
	Iris D				

Table 2.4.3
Dimensions of the Irises

Iris	Width a	Height b
A		
B		
C		
D		

4. Questions to Answer in your Lab Report

Your lab report must include a signed “Expectations of Originality” form.

Your lab report must include the tables from Section 3, filled in with your data, and “signed off” by your lab demonstrator at the end of the lab session.

1) What is the frequency of the Gunn diode oscillator, f_c? What is the power output of the “Gunn flange”?
2) Make a table showing the initial displacement of the tennis ball A and the corresponding frequency f_d of the peak on the FFT display of the storage scope. For each initial displacement, calculate the maximum velocity of the tennis ball from elementary mechanics, $v_d = A\sqrt{g/\ell}$, and then calculate the theoretical Doppler shift, $f_d = 2\frac{f_c v_d}{c}$. Compare the theoretical and the measured Doppler shifts and comment on whether they agree or disagree.
3) What is the reflection coefficient of the X-band matched load at 10.6 GHz? What is the SWR with the matched load?

4) Make a table of the attenuator settings and phase shifter settings for the reflectometer. At each frequency, give the reference values with the shorting plate, and the values measured for each of the four irises. Use the reflection coefficient from the iris/matched load in each case to calculate the impedance of the iris backed by the matched load, and hence the susceptance of the iris. Your table has three frequencies and the susceptance of each of four irises at each frequency.
5) Calculate the susceptance of each iris at each of the three frequencies, using the formulas given above. Make a table showing the measured susceptance and the calculated susceptance. Are the measurements in agreement with the calculations?
6) Use the SMTHCHT program to graph the measured susceptance and the calculated susceptance of each iris at three frequencies. You will need to use the Notepad to prepare a “gam” file for each case, giving the reflection coefficient at three frequencies. Save your “gam” files because you will need them for Experiment 4.

Acknowledgement

Thanks to Ibrahem Abdalla for revising the instructions for this experiment.