ELEC 453/6391 Microwave Engineering

Experiment #1

Impedance Measurement Using a TEM Slotted Line

Notes:
1.You must do the Item 3, the Preliminary Exercise, before coming to the laboratory.
2.Bring a diskette to the lab so that you can take your data away with you.

1. Equipment

Bench #1 (Along the back of the room)

- Agilent E4438C RF Oscillator
- Wavetek `182A audio oscillator
- HP 805A TEM slotted line (0.5-4 GHz) and 1N23 crystal detector
- HP 415 SWR meter, oscilloscope, two BNC cables, BNC tee
- Loads: short circuit load, matched load, VSWR 2:1 load, VSWR 1.2:1 load.
- N-type tee with either two 50-ohm loads or two 75-ohm loads.

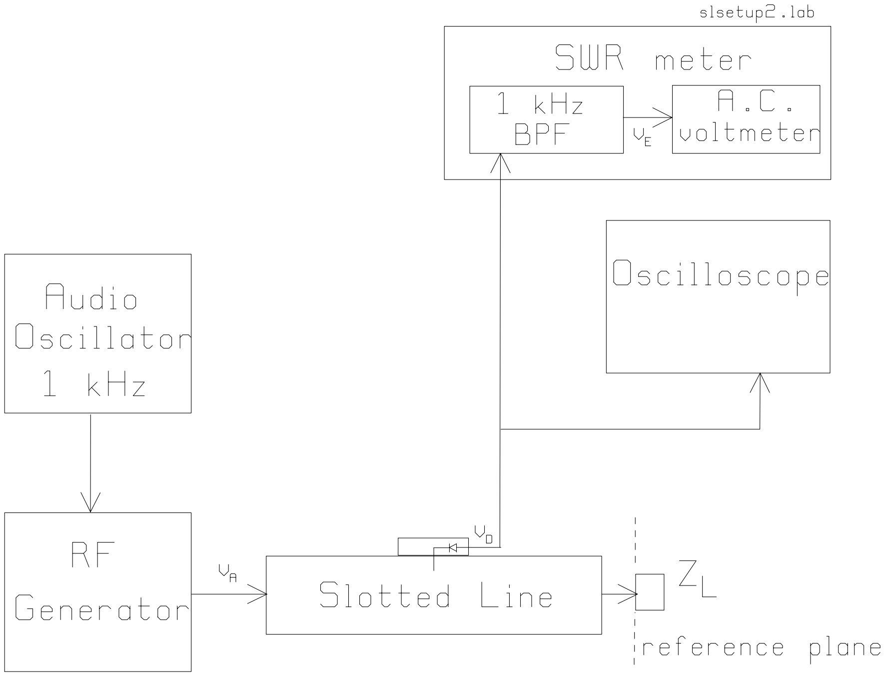

Figure 1.1 Block diagram of the setup.

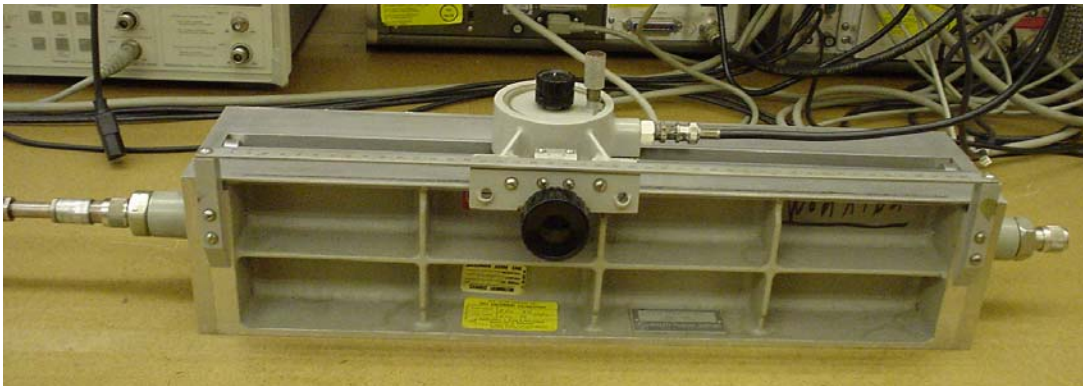

Figure 1.2 The HP 805A slotted line.

2. Introduction

Figure 1.1 is a block diagram of the equipment setup. The oscillator feeds the radio-frequency (RF) signal to the slotted line, shown in Figure 1.2, via a coaxial cable with N-type connectors. The RF signal is amplitude-modulated with a 1 kHz square wave. The other end of the slotted line is the "measurement port", and is terminated either with a short circuit for calibration, or with the unknown load impedance. The probe carriage can be moved along the slotted line and its position can be read from the scale with a precision of a tenth of a millimeter. The probe carriage has a small monopole that samples the electric field inside the slotted line. The base of the monopole is tuned with a short-circuited stub whose length is adjusted with the black knob on the probe carriage. The probe carriage contains a crystal detector which de-modulates the signal to recover the 1 kHz modulation. The output of the crystal is connected with a BNC cable to an A.C. voltmeter with a very narrow filter centered at 1 kHz, called an "SWR meter", shown in Fig. 1.3.

It is interesting to note that the HP805 slotted line of Fig. 1.2 can be used from 500 MHz to 4 GHz. This limit is determined by the probe matching network.

Figure 1.3 The HP 415 SWR meter.

SWR Meter

The probe in the slotted line picks up the E field and feeds the signal to a crystal detector. An RF voltage $v(t) = A\cos(\omega t)$ incident on a crystal detector will cause a diode current $i_D \propto A^2$. If this is connected to a detection circuit, the voltage would be $v_D \propto A^2$. Hence, the square root of the detector voltage is proportional to the RF amplitude[1], i.e. $A \propto \sqrt{v_D}$. In other words, a doubling the RF voltage amplitude A leads to a fourfold increase in the RF power and a fourfold increase in v_D. The HP415 SWR meter, shown in Figure 1.3, is calibrated to work with a "square law" detector, that is, a diode voltage that is proportional to the square of the amplitude, $v_D \propto A^2$. An SWR meter is essentially a bandpass filter at 1 kHz with a very narrow bandwidth, an audio amplifier, and a meter readout $A \propto \sqrt{v_D}$ that is proportional to the square root of the input voltage.

Fig. 1.4 shows the voltage at three points in the circuit of Fig. 1.1. The modulation turns the RF voltage up and down in amplitude, as shown by v_A at the input to the slotted line. The voltage across the crystal detector is v_B and is a messy square wave with a large noise component. It is a 1 kHz square wave with a DC offset, and is "noisy". The 1 kHz filter in the HP415 SWR meter has a very narrow bandwidth, centered about 1 kHz, so it rejects almost all the noise, leaving clean 1 kHz sine wave at v_E, which is the output of the filter. This greatly reduces noise problems in measuring small voltages because most of the noise power is rejected by the filter. You will find that the SWR meter is much better than an oscilloscope for taking voltage readings.

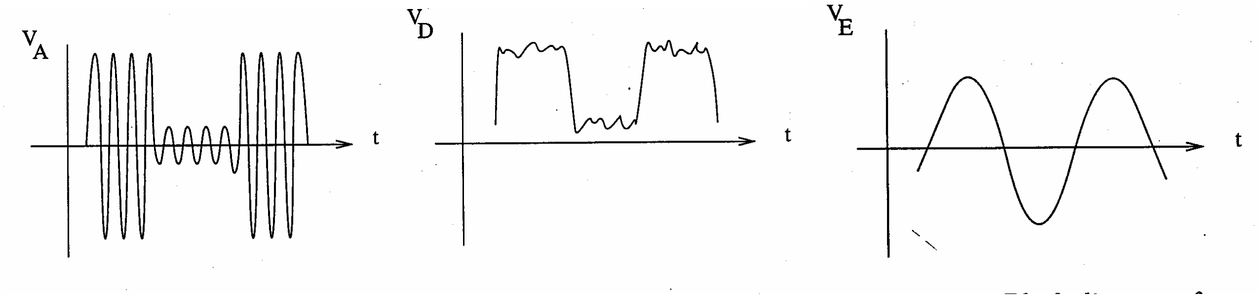

Figure 1.4 Voltage waveforms.

Impedance Measurement

To measure an impedance with the slotted line, we must first establish the position of the "reference plane", also called the "measurement plane", which is the connector at the measurement port of the slotted line. This is the "calibration" step. Put a short-circuit load on the measurement plane, which reflects the incident voltage and so sets up a standing-wave pattern on the slotted line with a null at the short circuit, and nulls at half-wavelength intervals from the short circuit. As you move the probe carriage along the slotted line, the SWR meter shows a large voltage at a maximum in the standing-wave pattern, and a very small voltage at a minimum in the pattern. Measure the position of one of the minima as precisely as possible. Then connect the unknown load to the measurement port. The load reflects some of the incident wave back towards the source, so there is a standing-wave on the line. Measure the voltage at a maximum in the standing-wave pattern. Then move the probe carriage to a minimum in the standing-wave pattern as precisely as possible. Measure the position of the minimum and the voltage at the minimum. The maximum voltage (in dB) minus the minimum voltage (in dB) is the "standing-wave ratio" or SWR, (in dB). Thus a complete measurement comprises: (i) the location of a minimum with a short-circuit load, z_{xc}; (ii) the location of a minimum with the unknown load, z_{load}; and (iii) the value of the SWR in dB. You can use the formulas given in the class notes to calculate the load impedance from these three values.

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[1] D.M. Pozar, "Microwave Engineering", 3rd edition, Wiley, 2005, Section 10.3, page 509.

The Smith Chart provides a quick method of finding the load impedance, as follows:

1) Draw the circle on the Smith Chart for the measured SWR value. The value of the unknown impedance lies somewhere on this circle.
2) The short-circuit's impedance is 0+j0 ohms. If $z_{load} > z_{xc}$, move around the Smith Chart from 0+j0 towards the generator through a distance of $(z_{load} - z_{xc}) / \lambda$. If $z_{load} < z_{xc}$, move around the Smith Chart from 0+j0 towards the load through a distance of $(z_{xc} - z_{load}) / \lambda$.

You can solve Pozar Example 2.4 (3rd edition) by using this method, for practice.

3. Preliminary Exercise

Answer these questions before you come to the lab. The lab demonstrator will check that you have answered these questions before he permits you to do the experiment.

1. At 750 MHz, the short-circuit load is attached to the measurement port of the slotted line of Fig. 1.2, and a minimum is found in the standing-wave pattern at 12.6 cm. Then an unknown load is put on the measurement port, and the SWR is measured as 9.4 dB, with a minimum in the standing wave pattern at 14.2 cm. Calculate the impedance of the unknown load. Show all the arithmetic and all details of the calculation.

2. Use the Smith Chart to solve exercise 1 and show that the answer is the same.

3. Run the "Slotted Line Calculator" program (SLcalc.exe) to check your answer. Run SLcalc by starting a "DOS window" on your computer. Make a directory for lab #1 (mkdir lab1) and change to that directory (cd lab1). Then fetch SLcalc.exe from the web and copy it to this directory. Start the program by typing "SLcalc" in the Dos window. Enter the frequency, the null positions and the SWR into the "spreadsheet" on the screen, and type F1 to calculate the impedance. Click here to fetch program SLcalc.exe from the web. Sorry but the utility programs for ELEC453 run under Microsoft Windows.

4. Procedure in the Laboratory

Figure 1.1 is a block diagram of the equipment setup. We need amplitude modulation or "AM", so we use a square wave oscillator to provide modulation frequency of 1 kHz. The first step is to select a square wave on the audio oscillator and adjust the frequency to 1 kHz. Connect the audio oscillator's output to the oscilloscope with a BNC cable, and adjust the frequency until you see a square wave on the 'scope screen with a period of 1 ms. The amplitude of the square wave should be 1 volt peak-to-peak. Then disconnect the 'scope.

Connect the audio oscillator's output to the signal generator's input jack. You will find detailed instructions for setting up the RF generator for amplitude modulation below. The RF generator's output is connected to the input port of the slotted line with a coaxial cable having N-type connectors. The output connector on the slotted line is the "measurement port" and is terminated with a short circuit for calibration, and with the unknown load for measurement.

The carriage on the slotted line contains a short antenna, a tuning stub, and a crystal detector. Connect the output of the detector with a BNC cable to a BNC tee. Connect the tee to the SWR meter, and to the oscilloscope. This lets you view the modulation on the scope screen. Set the selector knob on the HP415 SWR Meter to "high impedance crystal". Adjust the penetration depth of the probe on the slotted line's probe carriage to about halfway in. The frequency of the audio oscillator must be adjusted to match the pass band of the 1 kHz filter in the SWR meter as described below. Also, at each frequency the tuning stub on the probe carriage must be adjusted to get the maximum deflection of the needle.


Fig. 1.6 Agilent E4438C RF Oscillator

Setting up the Agilent E4438C RF Oscillator

The Agilent E4438C RF oscillator is shown in Fig. 1.6. Follow these instructions to set up the instrument:

1. To turn the instrument on, push the power button in the lower left corner below the screen and give it time to boot its software.
2. The buttons to the right of the screen are called "soft keys". Their meanings are listed at the right side of the screen, and change according to what buttons you have pushed.
3. Connect the "low" or 2-v peak-to-peak output of the audio oscillator with a BNC cable to the "EXT 1" input jack at the upper right-hand corner of the face of the instrument.
4. Select the AM Menu. You will find the "AM key" in the MENUS block, above and to the right of the big knob.
5. Choose external modulation by pushing the soft key labeled "AM SOURCE". Set to "EXT 1".
6. Set external coupling to "AC" using the soft key.
7. Set the AM Depth to 100% using the soft key. Press the "AM Depth" soft key and then type 100 on the keypad, then press the "%" soft key.
8. Set AM to "ON" using the 2nd soft key from the top.
9. Push "Frequency" above the knob and note the definition of the soft keys. Type the frequency on the number key pad. Push the "MHz" soft key to select MHz; verify that the correct frequency is reported on the screen.
10. Set the power to 0 dBm. Push "Amplitude" directly above the knob and note the definitions of the soft keys on the screen. Type in "0" on the keypad and then push the "dBm" soft key, to set the output power level to 0 dBm.
11. The RF on/off button is at the lower right near the RF output connector. See the note about RF on and RF off, below.

RF On/Off

You should keep the RF "off" most of the time to protect the RF oscillator against operating into a high impedance load by accident. This can damage some RF generators severely, especially costly, high-power generators! Also, if you were working with high-power RF equipment, there can be health hazards when you are exposed to strong RF fields. In our lab experiments, the power levels are extremely small so there is no risk. But it is good practice to keep the RF "off" most of the time, except when you need to excite the circuit to do a measurement. Make sure the RF is "off" when you are changing the load on the slotted line. Then turn the RF "on", make your measurement, and turn the RF "off" again.

Using the SWR Meter

The first step in using the SWR meter in Fig. 1.3 is to adjust the audio oscillator's frequency to precisely match the pass band of the HP 415's narrow filter. Put a short circuit termination on the measurement port of the slotted line. Set the RF generator's frequency to 750 MHz, the power to 0 dBm, and turn on the RF power. Set the HP 415's selector dial to "NORM", and set the gain to 30 dB. With the selector at "NORM", read the meter using the "10 to 0 DB" scale at the bottom of the face of the meter. Look for a deflection of the SWR meter's needle; you may have to roughly adjust the audio oscillator's frequency to see a deflection. Also, you may have to turn the black knob on the probe carriage to tune the probe. Then move the probe carriage to a maximum in the standing-wave pattern. Then finely adjust the frequency of the audio oscillator to obtain a maximum deflection of the needle on the SWR meter. This needs to be done only once at the beginning of your measurements.

Observer the voltage on the scope in the setup of Figure 1.1, which shows the waveform at the detector output, v_D in Figure 1.4. It has a D.C. component, which is proportional to the RF carrier power. Superimposed, you should see the 1 kHz modulation signal. If you have difficulty seeing a voltage on the 'scope, ask the demonstrator for help.

Note that you should keep the crystal voltage down to 100 mV or less. Use the 30 dB range or lower on the HP415. If the signal is too strong, the crystal will no longer obey a square law characteristic, and the SWR readings will be inaccurate. You can reduce the signal level by reducing the power output of the signal source, or by decreasing the probe penetration on the slotted line's probe carriage.

Calibration

Each time the frequency is changed, you need to calibrate the slotted line to establish the location of the "measurement plane" where the unknown load is to be connected in Fig. 1.1. Put the short circuit terminator on the measurement port. Set the frequency on the RF generator and turn the RF power. Don't adjust the probe penetration: it has been pre-set for you. Move the carriage to a maximum, and then adjust the tuning stub in the probe carriage by rotating the black knob to obtain a maximum deflection of the SWR meter. This needs to be repeated whenever you change the frequency of the RF oscillator. Then measure the position of a minimum in the standing-wave pattern as precisely as possible, following the procedure below.

Put the RANGE-DB EXPAND switch on NORM (red center knob) and slide the probe carriage along to find a maximum in the standing-wave pattern. With the EXPAND switch on NORM, read the meter using the "10…0 DB" scale at the bottom of the meter, meaning -10 dB to 0 dB. With the probe carriage at a maximum, such the EXPAND switch to "0". Then you should read the meter on the scale at the very top, running from 2 to 0 DB (this really means -2 dB to 0 dB). You can read the meter precisely by lining up the needle with its reflection in the mirror on the meter's face. Adjust the GAIN and the VERNIER knobs so that the meter reads 0 dB at a standing-wave maximum.

To find a minimum precisely, set the "EXPAND" switch to "0" and adjust the gain so the maximum in the standing-wave pattern is 0 dB. Then slide the probe carriage a small amount towards toward a minimum in the standing-wave pattern; the needle moves from 0 dB towards -2 dB. Remember to read the "2…0 DB" scale at the top of the meter. When you hit -2 dB, add 2 dB of gain by moving the EXPAND switch from "0" to "2". The needle moves up from -2 dB to 0 dB. Move further towards the minimum until the needle drops by another 2 dB; add another 2 dB of gain; move again; and so forth until you have either found the standing-wave minimum or added 8 dB of gain. If this happens move the EXPAND knob from 8 dB back to 0 dB, and move the outer black knob from "30" to "40" to add a full 10 dB of gain. The needle returns to 0 dB (meaning 10 dB below the maximum since we added 10 dB of gain). Move the carriage further towards the minimum; add gain in 2 dB steps as required. With the short circuit load you may need to add as much as 30 dB of gain to find the standing-wave minimum, but you will find it very precisely. Turn off the RF power.

Measuring the Impedance of an Unknown Load

Replace the short circuit with the unknown load impedance. Turn on the RF power. To measure the load's SWR, the procedure is as follows. Set the NORM/EXPAND switch to NORM for "normal". Slide the probe to a place on the slotted line where the voltage is a maximum $V_{\max}$ and adjust the gain knob on the SWR meter so that it reads SWR=1.0 or zero dB. Then change the NORM/EXPAND switch to EXPAND. You may need to finely readjust the gain so that the meter reads 0 dB once again. On EXPAND, the range of the meter is 2 dB, so read the position of the needle on the -2 dB to 0 dB scale at the top of the meter.

Then move the probe carriage to find a minimum in the standing-wave pattern by the procedure described previously. Record the value of the SWR and the position of the minimum. Then turn the RF power off.

You need to use one of the methods that you learned in the Preliminary Exercise to calculate the impedance from the null positions with the short and the load, and the SWR of the load.

4.1 Standing-Wave Pattern with a Short Circuit

In this part of the experiment you will measure the standing-wave pattern with a short circuit load. Set the RF generator to 750 MHz and the power to 0 dBm. Put the short circuit load on the measurement port, and turn on the RF power. Set the RANGE-DB EXPAND switch to NORMAL and slide the probe carriage back and forth. You will observe large swings of the needle. Move the probe carriage to an SWR maximum, at $z_{\max}$, and tune the probe carriage by turning the black knob. With the switch on "NORMAL" you must read the "10…0 DB" scale at the bottom of the face of the meter. You get a lot more accuracy using the RANGE-DB EXPAND switch on the "0", "2", "4", "6" or "8" settings because you can read the "2…0 DB" scale at the top of the meter. So put the EXPAND on "0" and then adjust the SWR meter's gain to get a reading of 0 dB at a maximum in the standing-wave pattern. Measure the voltage in dB from the position of the maximum at intervals of 2 cm "towards the load" until you pass a minimum. Move the probe carriage gradually and watch the meter needle. When the meter needle falls to -2 dB, then add 2 dB of gain by moving the "expand" switch from "0" to "2", and the needle returns to 0 dB. Move the carriage gradually once again; the meter reading falls; and when it falls to -2 dB, move the "expand" switch to "4", and the needle returns to 0 dB. But don't touch the "GAIN VERNIER" controls, which are set to make the maximum in the standing-wave pattern equal to 0 dB! As you move the probe carriage, read the voltage in dB every 2 cm of distance. Write your data in Table 4.1 in Section 5 of these instructions. You will use this data to draw a graph of a measured standing-wave pattern in your lab report.

Measure the position of the minimum as precisely as possible and the voltage in dB at the minimum. Then return to the maximum, and measure the voltage in dB every 2 cm "towards the generator" until you pass a standing-wave minimum. Measure the position of the minimum as precisely as possible, and the voltage in dB at the minimum.

Since it is customary to set the maximum value of the standing-wave pattern to 0 dB, the standing-wave pattern can be described fully by two numbers: the SWR in dB, and the position of one minimum.

Graphing Your Data

RPLOT is a general-purpose graphing program that you can fetch from the course web site. You can graph the standing-wave pattern with RPLOT as follows. Use the Windows Notepad or a file editor, and type your data into a data file, say "swr.dat", with two columns. The first column is position in cm and the second column is voltage in dB. The run RPLOT and enter the name of the data file, "swr.dat" into the second box on the screen. Type F10 to graph your data. But don't use "tab" characters to separate the numbers in your data file because RPLOT does not work with "tabs". You can type a label for the x axis and y axis into RPLOT's main menu, and choose the range of the axes to make a good-looking plot. Use edit-copy to make a copy of the graph to the Windows clipboard. Then you can use the paste function in WORD to paste the graph into a "doc" file for your lab report.

4.2 Confidence Checks for Impedance Measurement

Make sure the RF power is off and disconnect the short-circuit load, and put the 2:1 load on the measurement port. Set the RF generator to 750 MHz and the power to 0 dBm, as before, and turn on the RF power. The 2:1 load has an SWR of 2 or 6 dB, corresponding to a reflection coefficient of 1/3 or -9.54 dB. Move the probe carriage to a maximum in the standing-wave pattern. Set the gain so the SWR meter reads 0 dB. Then find a standing-wave minimum by the procedure described above. Measure the position of the minimum and the SWR reading in dB at the minimum. Record you data in Table 4.2. Calculate the value of the load impedance. Use your load impedance value to calculate the expected reflection coefficient and then the SWR, and verify that you get approximately SWR=2.

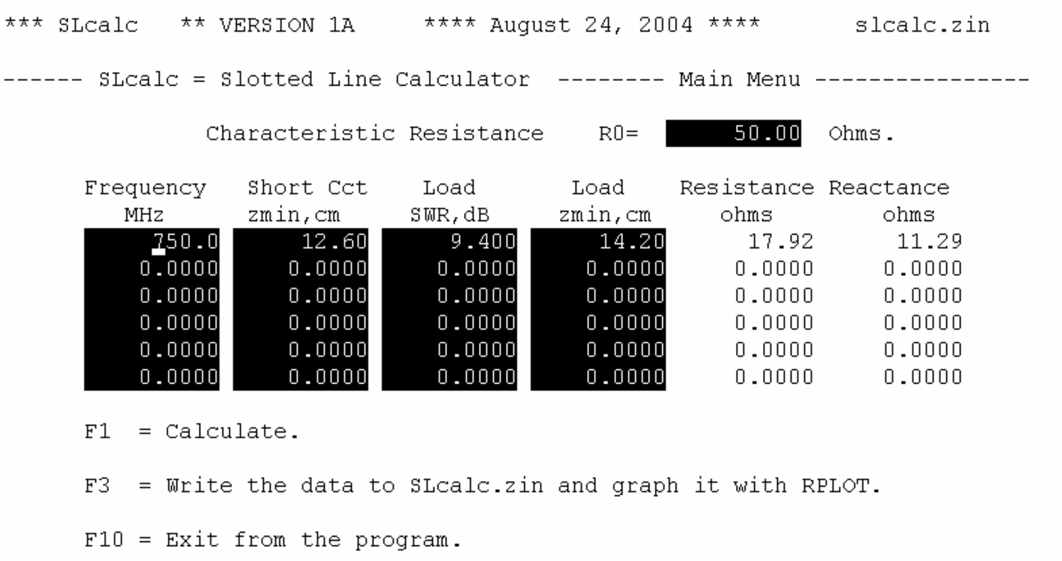
Repeat the experiment with the 1.2:1 load. Then repeat with the matched load. Record your data in Table 4.2. Using the matched load, move the probe carriage back and forth along the slotted line. Since the load is "matched", the voltage is more-or-less independent of the position of the probe carriage. If the match were truly perfect, the voltage would be perfectly independent of the carriage position, but in practice there will be a small mismatch and so a small variation in the voltage as the probe carriage is moved.

4.3 Impedance of a "Tee-50" or "Tee-75" Load as a Function of Frequency

A "tee-50" load is made using an N-type tee junction and two 50-ohm loads. We expect the input impedance of this load to be approximately 25 ohms. Similarly, a "tee-75" load uses two 75-ohm loads on a tee. We use these "tee" load2 in lab 1 and lab 2. The lab demonstrator will give you one of the "tee" loads. Measure the impedance of the "tee" load at 650, 700, 750, 800, 850, and 900 MHz using the slotted line. Note that at each frequency you must retune the stub on the probe carriage, then:

1) put the short circuit on the measurement port and find the position of a standing-wave minimum; then
2) put the load on the measurement port, and measure the SWR, and the position of a standing-wave minimum

Record your data in Table 4.3.



```
*** SLcalc   ** VERSION 1A     **** August 24, 2004 ****       slcalc.zin

------ SLcalc = Slotted Line Calculator  -------- Main Menu ----------------

             Characteristic Resistance    R0=     50.00  Ohms.

      Frequency   Short Cct    Load       Load    Resistance Reactance
         MHz      zmin,cm     SWR,dB    zmin,cm     ohms       ohms
        750.0      12.60      9.400      14.20      17.92      11.29
       0.0000     0.0000     0.0000     0.0000     0.0000     0.0000
       0.0000     0.0000     0.0000     0.0000     0.0000     0.0000
       0.0000     0.0000     0.0000     0.0000     0.0000     0.0000
       0.0000     0.0000     0.0000     0.0000     0.0000     0.0000
       0.0000     0.0000     0.0000     0.0000     0.0000     0.0000

      F1  = Calculate.

      F3  = Write the data to SLcalc.zin and graph it with RPLOT.

      F10 = Exit from the program.
```

Fig. 1.7 The “spreadsheet” menu in program SLcalc.

There is a lot of arithmetic to do in converting the measured data to impedance values. To make the calculations easy, you can use the Slotted-Line Calculator program “SLcalc” to do the arithmetic. Fig. 1.7 shows the SLcalc “spreadsheet” menu. Enter your data in the boxes on the screen and type F1 to calculate the impedance. The screen’s “spreadsheet” accepts data for as many as six frequencies. Type F3 write a data file (called “slcalc.zin”) and then start program RPLOT to graph the data. When RPLOT starts, type F10 to draw the graph. SLcalc saves your data in file “slcalc.zin”. You can draw a Smith Chart showing your measured impedance as a function of frequency using program SMTHCHT with file “slcalc.zin” as the input file. You should RENAME the data file “slcalc.zin” to some convenient name such as “Lab_1_1.zin”, and SAVE it because you will need to use it in Lab 2 and Lab 5.

You can run the “slcalc” program on the “Darwin” computer in the lab. Log in with user name “Maxwell” and no password. Analyzing your data right in the laboratory is good practice: you can graph it immediately and if the resistance and reactance do not change smoothly with frequency, your data is in error and you can go back to the “bench” to verify your measurement. When you are confident that your data is correct, copy your “zin” data file to your diskette and take it home. Darwin is *not* connected to the internet so you cannot email the data file to yourself!

At home, you can download “slcalc.exe” from the course web site to analyze your data, if you have not done so in the lab. You can download the RPLOT program to graph the data. Also, download program SMTHCHT to plot your impedance data on a Smith Chart. The User’s Guide for SMTHCHT describes the format of the “zin” file.

Your lab group has a directory on Darwin, and you can save your data in that directory.

4.4 Impedance of a Resistor

What is the impedance of an ordinary carbon-composition resistor at radio frequencies in the high hundreds of MHz? The lab demonstrator will give you a resistor mounted on an N-type “bulkhead” connector. There are two resistors. One is a five-watt resistor with a beige body, of resistance 23.9 ohms at D.C. The other is a ½-watt resistor with a value of about 100 ohms at D.C. Measure the impedance of one of the resistors as a function of frequency from 650 to 900 MHz. Record your data in Table 4.4.

Note that some lab groups do experiment 2 first, then experiment 1. Make sure you measure the *same* resistor for experiment 1 that you did for experiment 2.

Use the slotted-line calculator program SLCALC to calculate the impedance from the slotted-line measurements and graph the impedance as a function of frequency. Save your “slcalc.zin” data file with a name such as “lab_1_2.zin” because you will need the data in Lab 2 and Lab 5 later in the course.

5. Tables of Data

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

Table 4.1
Standing-Wave Pattern Data for Part 4.1

Position of the Probe Carriage	Voltage on the SWR meter in dB
z_{max} = cm	0 dB
z_{max} +2= cm	
z_{max} +4=	
z_{max} +6=	
z_{max} +8=	
z_{max} +10=	
z_{max} +12=	
z_{min} = as precisely as possible	
z_{max} = cm (same as above)	0 dB
z_{max} -2= cm	
z_{max} -4=	
z_{max} -6=	
z_{max} -8=	
z_{max} -10=	
z_{max} -12=	
z_{min} = as precisely as possible	

Table 4.2
Confidence Checks

Case	Short-circuit load	Unknown Load		Impedance	
	Minimum (cm)	SWR (dB)	Minimum (cm)	R (ohms)	X(ohms)
2:1 load					
1.2:1 load					
Matched load					

Table 4.3
“Tee” Load Measurements

Frequency	Short Circuit Load	“Tee” Load		“Tee” Load Impedance	
f (MHz)	zmin (cm)	SWR (dB)	zmin (cm)	R (ohms)	X (ohms)
650					
700					
750					
800					

850					
900					

Table 4.4
Resistor Measurements

Frequency	Short Circuit Load	Resistor Load		Resistor RF Impedance	
f (MHz)	zmin (cm)	SWR (dB)	zmin (cm)	R (ohms)	X (ohms)
650					
700					
750					
800					
850					
900					

6. 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 5, filled in with your data, and “signed off” by your lab demonstrator at the end of the lab session.

Your lab report will consist of the answers to the following questions:

1) Use your voltage-as-a-function-of-position data to graph the standing-wave pattern for the short-circuit load. Plot the magnitude of the voltage on a *linear* scale as a function of position on the slotted line. What is the distance between the minima? Does it correspond precisely to half a wavelength at 750 MHz? Note that the speed of propagation on the slotted line is equal to the free-space speed of light. What is the standing-wave ratio with the short-circuit load, in dB? What is magnitude of the reflection coefficient for the short-circuit load?
2) With the slotted line terminated with a 50-ohm “matched” load, what is the SWR on the slotted line? Theoretically, it should be exactly 1, but the 50-ohm load is not perfect and the N-type connectors introduce some mismatch. What is your measured value for the impedance of the “matched” load?
3) With the slotted line terminated with the 2:1 load, what is your measured impedance for this load? Use your measured impedance to calculate the expected value of the SWR. Is the SWR equal to 2, as expected? Repeat for the 1.2:1 load.
4) Plot the resistance and reactance of the “tee” load as a function of frequency from 650 to 900 MHz. For the “tee-50”, we might expect that two 50-ohm loads in parallel would make a 25 ohm load. Why do the measured values differ from 25 ohms? For the “tee-75”, why to does the impedance differ from 37.5 ohms? You can use the transmission-line solver “TRLINE” to model the “tee” load and calculate its input impedance, and compare with your measured values.
5) Plot the resistance and reactance of the carbon-composition resistor as a function of frequency from 650 to 900 MHz. Are the measured values different from the D.C. resistance?
6) Consider measuring the impedance of the “tee” load at 750 MHz. Suppose you made a 1 cm error in measuring the position of the null with the “tee” load. What would be the error in the phase of the reflection coefficient? What would be the error in the impedance? Suppose the

measurement error were 1 mm. What would be the error in the phase of the reflection coefficient? In the impedance?

Some lab groups do experiment 2 before experiment 1. If your group has already done experiment 2, answer these questions:

7) Make a graph comparing the measured impedance of the “tee” load using the slotted line and the vector voltmeter. Plot resistance as a function of frequency, and plot the reactance as a function of frequency. Explain any differences between the impedance values measured by the two methods.
8) Make a graph comparing the measured impedance of the carbon-composition resistor, using the slotted line and the vector voltmeter.