Telecommunications
Microwave

Microwave Variable-Frequency Measurements and Applications

Courseware Sample

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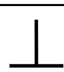
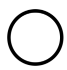
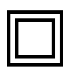
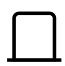
Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
⚠ DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
⚠ WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
⚠ CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign , indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
3∼	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

Foreword

The Lab-Volt Microwave Technology Training System With LVDAM-MW, Model 8091, is a complete microwave training system including data acquisition and instrumentation that allows students to perform experiments in microwave principles and practices.

This Student Manual, *Microwave Variable-Frequency Measurements and Applications*, is a continuation of the basic principles learned in *Microwave Fundamentals*. It demonstrates the operation of variable-frequency oscillators. You will learn how to control and measure the operating frequency of a voltage-controlled RF oscillator, using the Lab-Volt software Data Acquisition and Management for Microwave systems (LVDAM-MW®). You will learn how to perform frequency modulation and demodulation of microwave signals to convey useful information, such as data or music, over a microwave link.

The Instructor Guide *Microwave Variable-Frequency Measurements and Applications* provides answers to all procedure steps and review questions found in the exercises of this manual.

> **Note:** *Detailed information about how to set up and use the instruments of the LVDAM-MW software can be found in the Lab-Volt User Guide "Microwave Data Acquisition and Management", part number 85756-E. Additional information about using these instruments can be found in the Help section of this software. Information about the instruments used to control or monitor the Frequency Meter of the Voltage-Controlled RF Oscillator (VCO), Model 9511, are provided in the Parameter Settings section of the Help.*

Safety with RF Fields

When studying microwave systems, it is very important to develop good safety habits. Although microwaves are invisible, they can be dangerous at high levels or for long exposure times. The most important safety rule when working with microwave equipment is to avoid exposure to dangerous radiation levels.

The radiation levels in the Microwave Technology Training System are too low to be dangerous, so that this system allows safe operation in a classroom laboratory. To develop good safety habits, however, you should, whenever possible, remove the power from the Gunn Oscillator before placing yourself in front of the transmitting antenna. Your instructor may have additional safety directives for this system.

WARNING!

For your safety, do not look directly into the waveguides or Horn Antennas while power is being supplied to the Gunn Oscillator.

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Extracted from

Student Manual

Exercise 1

Microwave Frequency Measurements

EXERCISE OBJECTIVES

When you have completed this exercise, you will be familiar with three methods of measuring microwave frequencies: slotted-line, prescaler, and resonant cavity frequency measurements.

DISCUSSION

Slotted-Line Frequency Measurements

When the impedance of the load is not equal to that of the waveguide, an impedance mismatch occurs. In this case, not all the received energy is absorbed by the load. Instead, part of this energy is reflected back toward the source.

Figure 1-1 shows the waves traveling along a waveguide when the load end is in the short-circuit condition. The incident wave is completely reflected at the load end. The reflected and incident waves travel through each other, but in opposite directions, thereby combining vectorially. This results in the creation of a standing wave along the waveguide.

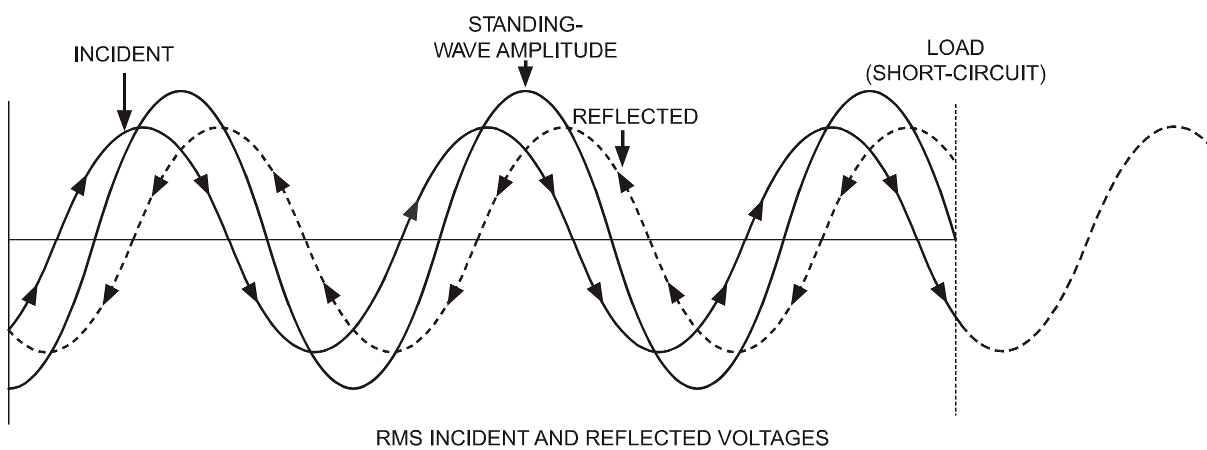


Figure 1-1. Creation of a standing wave along a short-circuited waveguide.

Figure 1-2 shows the conventional representation of the standing wave of voltage along the short-circuited waveguide.

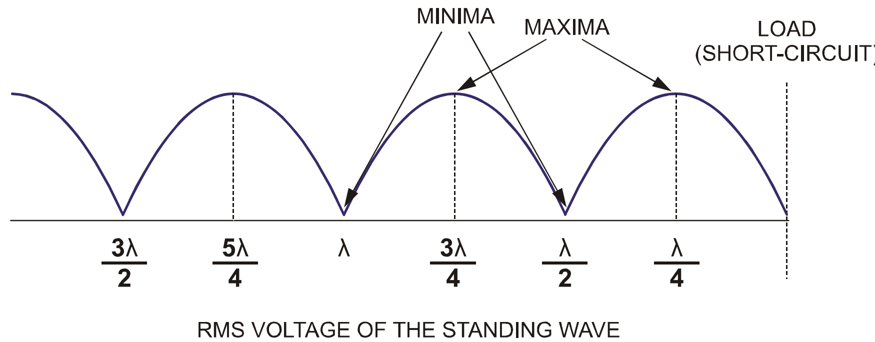


Figure 1-2. Conventional representation of the standing wave of voltage along the short-circuited waveguide.

When we examine Figure 1-2, the statements below can be inferred. These statements allow you to measure the frequency of a microwave signal propagating in a waveguide.

- A minimum invariably occurs at the load end of the waveguide.
- Minima also occur at every even multiple of $\lambda_g/4$ from the load end (λ_g being the wavelength of the propagating wave in the waveguide).
- Maxima occur at every odd multiple of $\lambda_g/4$ from the load end.

To measure the frequency of the microwave signal, the waveguide is coupled to a slotted line terminated by a short circuit. The slotted line is connected to a SWR meter. The microwave signal is amplitude-modulated with a 1-kHz square-wave signal to permit SWR measurements with the slotted line and SWR meter. Then, the following steps are performed:

1. Measure the distance between two successive minima. (Since minima are more sharply defined than maxima, measuring the distance between minima provides more accurate results).
2. Multiply the measured distance by 2 to obtain the wavelength of the signal in the waveguide, λ_g.
3. Calculate the frequency of the signal in the waveguide, f, using the following equation:

$$f = c\sqrt{\left(\frac{1}{\lambda_g}\right)^2 + \left(\frac{1}{2a}\right)^2} \qquad (1\text{-}1)$$

where
- c = velocity of propagation of the signal in free space ($3.0 \cdot 10^8$ m/s);
- λ_g = wavelength of the signal in the waveguide (m);
- a = width of the waveguide (m);
- f = frequency (Hz).

Figure 1-3 shows standing waves of voltage along a short-circuited waveguide for different frequencies of the guided signal. As the frequency is increased, the distance between two successive minima of the standing wave decreases.

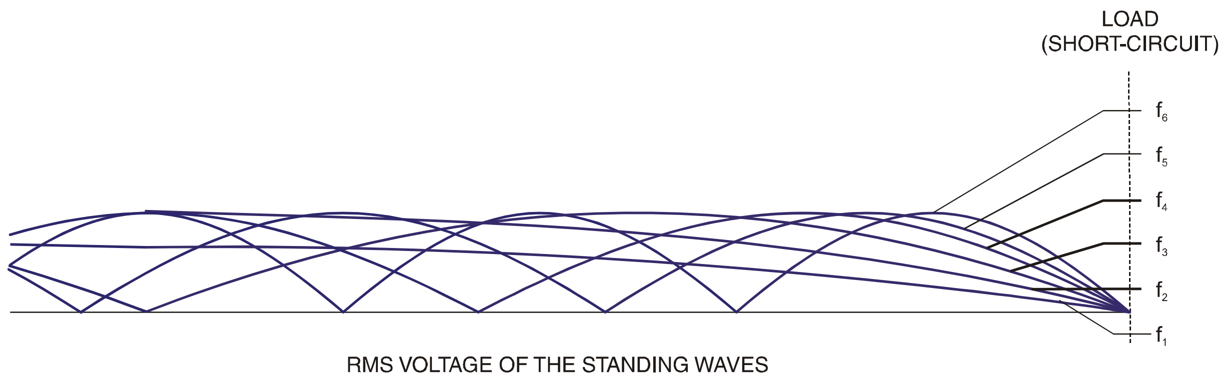


Figure 1-3. As the frequency of the guided signal is increased, the distance between two successive minima of the standing wave decreases.

Prescaler Frequency Measurements

A **prescaler** is an electronic circuit that divides the frequency of a signal by a precise amount. Prescalers increase the maximum frequency that conventional frequency counters can measure, thereby eliminating the need for high-cost microwave frequency counters.

Figure 1-4 shows the block diagram of the Lab-Volt Voltage-Controlled RF Oscillator, Model 9511.

> **Note:** *The intended input signals for the Lab-Volt Voltage-Controlled RF Oscillator are those produced at the RF OSCILLATOR SUPPLY AND CONTROL OUTPUT of the Data Acquisition Interface, Model 9508. These signals are applied to the Voltage-Controlled RF Oscillator via a DB-9 connection.*

- The VCO produces a sinusoidal signal whose frequency can be varied by varying the DC voltage applied to the internal frequency control input. The nominal variation range is 9.6 to 10.6 GHz. This range can be wider and vary slightly from one VCO to another.

- A directional coupler directs most of the VCO output signal to a single-pole, double-throw (SPDT) switch. This switch, when on (which is the normal condition), directs the VCO output signal to the PCB-to-waveguide transition, where the signal is launched into the waveguide.

- The VCO output signal can be on/off-modulated before it is launched into the waveguide to permit SWR measurements with the slotted line. This is performed by applying a 1-kHz square-wave signal to the SPDT switch. This signal repeatedly toggles the switch between the two contact points (which are connected to the PCB-to-waveguide transition and to the termination load respectively). This pulses the VCO output signal launched into the waveguide at a 1-kHz frequency.

- The directional coupler also directs a small portion of the VCO output signal to the prescaler. The prescaler divides the frequency of the signal by 64, and the resulting prescaler output signal is available at the BNC output of the Voltage-Controlled RF Oscillator, in the form of a square-wave signal. Varying the frequency of the VCO output signal from 9.6 to 10.6 GHz causes the frequency of the prescaler output signal to vary from 150 to 165.6 MHz.

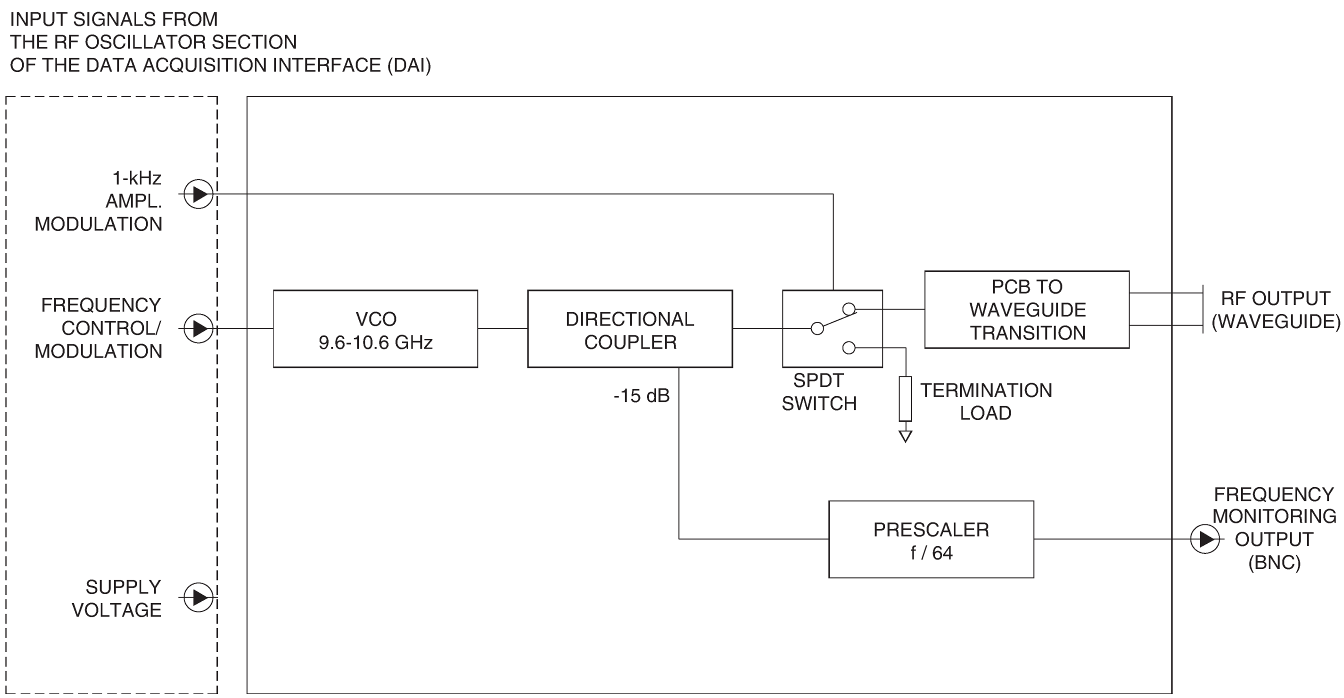


Figure 1-4. Block diagram of the Lab-Volt Voltage-Controlled RF Oscillator.

Resonant Cavity Frequency Measurements

A **resonant cavity** is a section of waveguide, closed at both extremities, that is usually rectangular, cylindrical, or spherical in shape.

When a microwave signal at a particular frequency (the resonant frequency) enters the cavity, the cavity comes into resonance: it behaves like a tank circuit—a capacitor and an inductor in parallel.

At resonance, the wave is reflected back and forth in the cavity, producing standing waves that gradually intensify.

Resonant cavities can be used to measure the frequency of microwave signals. In that case, they feature a tuning mechanism used to vary the resonant frequency, and a means of detecting the signal level in the cavity. Usually, graduations on the tuning mechanism provide a direct indication of the tuned frequency.

Figure 1-5, for example, shows the Lab-Volt Resonant Cavity Frequency Meter. The cavity is coupled to the waveguide through a small hole in the wall of the cavity. Moving the plunger downward increases the capacitive component of the tank circuit reactance, thereby decreasing the resonant frequency. Conversely, moving the plunger upward decreases the capacitive component of the tank circuit reactance, thereby increasing the resonant frequency.

The tuning mechanism is a micrometer that is linked to the movable shorting plunger. The micrometer graduations indicate the position (depth) of the plunger within the cavity.

The plunger's position is read by referring to the linear scale on the sleeve and the annular scale on the tuning screw. The linear scale on the sleeve represents the variation range of the micrometer (that is, from approximately 0 to 10 mm). One full revolution of the tuning screw will move 0.5 mm on the linear scale of the sleeve. Read from the sleeve first, then add the fine adjustment from the tuning screw, taking the reading at the intersection of the tuning screw's scale and the sleeve's scale.

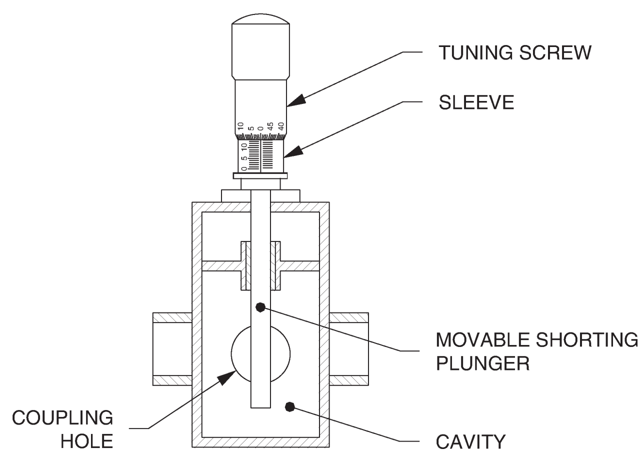


Figure 1-5. Resonant Cavity Frequency Meter with adjustable shorting plunger.

To measure the frequency of a microwave signal, the Resonant Cavity Frequency Meter is tuned until it resonates at the signal frequency. If a SWR meter is used as the indicator, resonance will reflect as a decrease (dip) in the signal level due to the storage of energy in the cavity at resonance.

Frequency Measurement Methods Compared

Slotted-line frequency measurements are sometimes cumbersome and often give less accurate results when compared to prescaler frequency measurements. High-Q resonant cavities usually provide very accurate results, on the order of ±0.1% of accuracy.

Frequency Control and Monitoring of the Lab-Volt Voltage-Controlled RF Oscillator with the LVDAM-MW Software

Connections

The LVDAM-MW software allows frequency control and monitoring of the Voltage-Controlled RF Oscillator, via the RF OSCILLATOR section of the Data Acquisition Interface (see Figure 1-6).

- The SUPPLY AND CONTROL OUTPUT of the RF OSCILLATOR section provides signals for supply and control of the Voltage-Controlled RF Oscillator. This output must be connected to the DB-9 connector of the Voltage-Controlled RF Oscillator.
- The FREQUENCY MONITORING INPUT of the RF OSCILLATOR section is used to monitor the operating frequency of the Voltage-Controlled RF Oscillator. This input must be connected to the prescaler output (BNC connector) of the Voltage-Controlled RF Oscillator.
- The FREQUENCY MODULATION INPUT of the RF OSCILLATOR section can be used to frequency modulate the RF oscillator's output signal around the carrier frequency using a modulating signal that conveys information such as speech or music.

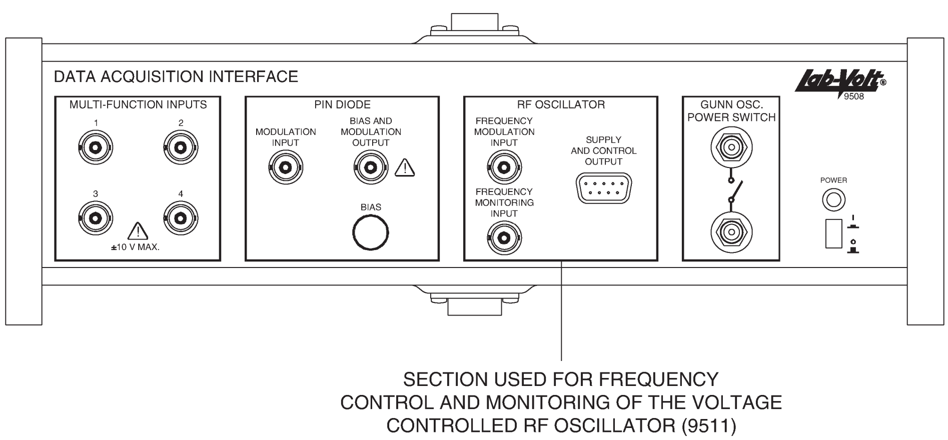


Figure 1-6. The Lab-Volt Voltage-Controlled RF Oscillator must be connected to the RF OSCILLATOR section of the Data Acquisition Interface.

Frequency monitoring and control

The frequency of the Voltage-Controlled RF Oscillator's output signal is indicated by the Frequency Meter of LVDAM-MW. To display this meter, select **Frequency Meter** from the **Instruments** menu, or click on the **Frequency Meter** icon of the Tool bar. The frequency of the Voltage-Controlled RF Oscillator's output signal is also displayed next to the **Frequency (GHz)** parameter of the Settings panel.

Note: *The Voltage-Controlled RF Oscillator must be properly connected to the Data Acquisition Interface, and the communications must be established between the Data Acquisition Interface and LVDAM-MW for the Frequency Meter to operate properly, otherwise the Frequency Meter will provide erroneous readings.*

Note: *The Frequency Meter is intended for use with the Voltage-Controlled RF Oscillator only. This instrument cannot be used to measure the frequency of the Gunn Oscillator's output signal (Lab-Volt Model 9501), which is fixed.*

The Voltage-Controlled RF Oscillator is controlled by using the parameters in the **RF Oscillator (VCO)** section of the LVDAM-MW Settings panel. Table 1-1 lists and describes these parameters.

PARAMETER IN THE RF OSCILLATOR (VCO) SECTION OF THE SETTINGS PANEL	DESCRIPTION
Frequency Control	Selects between the Automatic or Manual mode of control: – When the **Manual** mode is selected, the frequency of the RF oscillator's output signal is changed by changing the setting of the Control Voltage parameter. – When the **Automatic** mode is selected, the frequency of the RF oscillator's output signal is fixed. The control voltage is set to the default value of 1.5 V.
Frequency (GHz)	Displays the frequency of the RF oscillator's output signal.
Control Voltage (0-10 V)	Used to change the frequency of the RF oscillator's output signal. When the control voltage is varied from 0 to 10 V, the frequency of the RF oscillator's output signal passes from 9.6 to 10.6 GHz (typical). Note that the Frequency Meter of LVDAM-MW must be open to enable the Control Voltage field and permit adjustment of this voltage.
Amplitude Modulation	Used to perform on/off modulation of the RF oscillator's output signal with an internal 1-kHz square wave to permit SWR measurements with the Lab-Volt Slotted Line and the SWR Meter of LVDAM-MW.

Table 1-1. Parameters used to control the Voltage-Controlled RF Oscillator in the RF Oscillator (VCO) section of the LVDAM-MW Settings panel.

Procedure Summary

In the first part of this exercise, you will measure the frequency of the Voltage-Controlled RF Oscillator's output signal for different voltages, using the Slotted Line and the SWR Meter. You will verify the validity of your results by comparing them to the frequency readings obtained with the Frequency Meter of LVDAM-MW.

In the second part of this exercise, you will perform frequency measurements by using the Resonant Cavity Frequency Meter. You will vary the frequency of the RF Oscillator's output signal over the nominal 9.6-10.6 GHz variation range. For each frequency adjustment, you will tune the Resonant Cavity Frequency Meter to resonance, then you will record the position of the cavity's plunger and the frequency of the signal produced by the RF oscillator. This will enable you to plot the calibration curve of the Resonant Cavity Frequency Meter (that is, the RF oscillator's output signal frequency as a function of the position of the Resonant Cavity plunger).

EQUIPMENT REQUIRED

Refer to the Equipment Utilization Chart, in Appendix D of this manual, to obtain the list of equipment required to perform this exercise.

PROCEDURE

Frequency Measurements with the Slotted Line

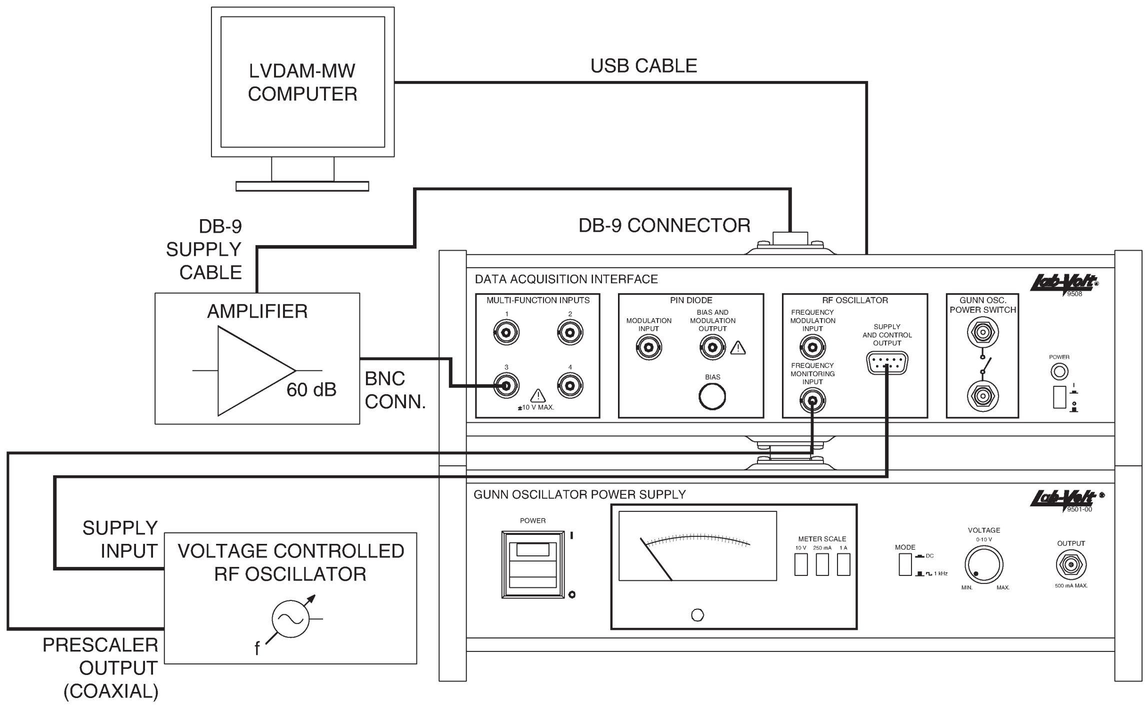
☐ 1. Make sure that all power switches are in the O (off) position. Set up the modules and assemble the microwave components as shown in Figure 1-7.

- Connect the Slotted Line, via the 60-dB Amplifier, to the analog input of the Data Acquisition Interface (DAI) dedicated to the SWR Meter of LVDAM-MW: MULTI-FUNCTION INPUT 3. The supply cable for the 60-dB Amplifier must be connected to the DB-9 connector on the top of the Data Acquisition Interface.

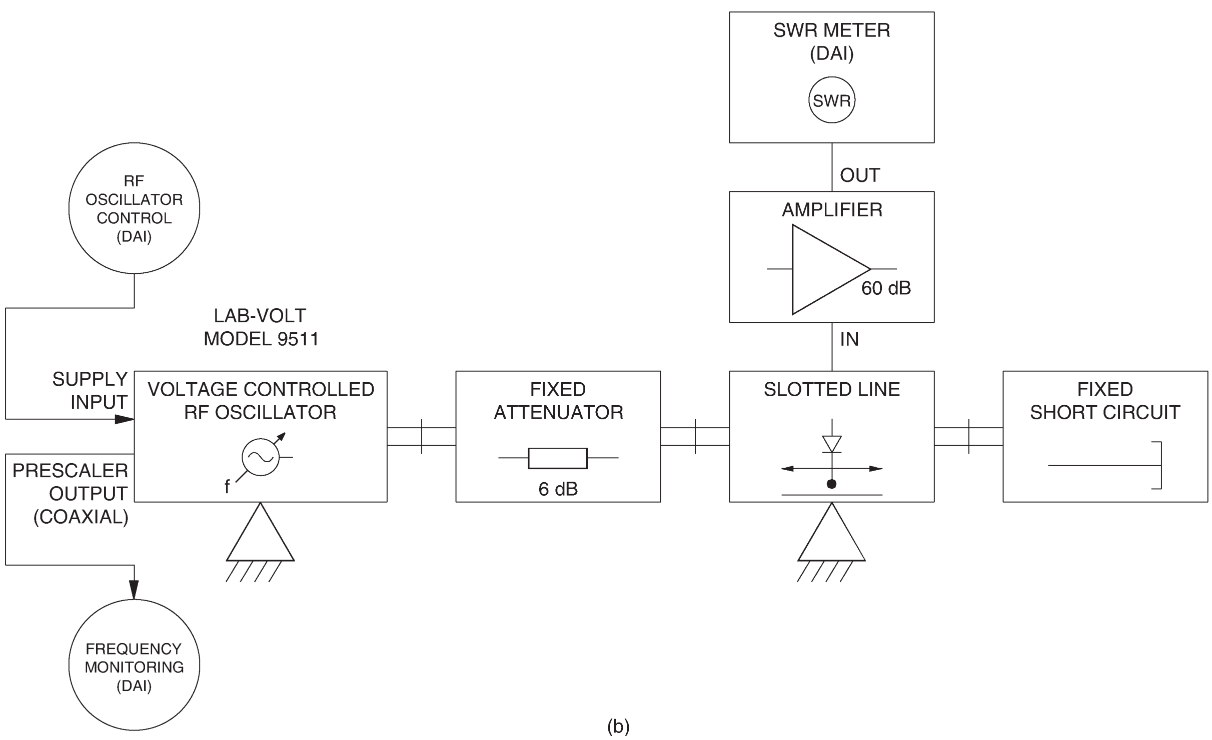
- Connect the supply cable (DB-9 connector) for the Voltage-Controlled RF Oscillator to the RF OSCILLATOR SUPPLY AND CONTROL OUTPUT of the Data Acquisition Interface. Connect the prescaler output (BNC connector) of the Voltage-Controlled RF Oscillator to the RF OSCILLATOR FREQUENCY MONITORING INPUT of the Data Acquisition Interface.

☐ 2. Turn on the Gunn Oscillator Power Supply and the Data Acquisition Interface (DAI) by setting their POWER switch to the "I" (ON) position.

Wait for about 5 minutes to allow the modules to warm up.



(a)



(b)

Figure 1-7. Computer and module arrangement (showing electrical connections to microwave components), and microwave setup.

☐ 3. Move the probe of the Slotted Line along the waveguide and set it over the 54.0-mm position. (The 54-mm mark on the waveguide scale intersects the rightmost ("0") mark on the carriage scale, as Figure 1-8 shows).

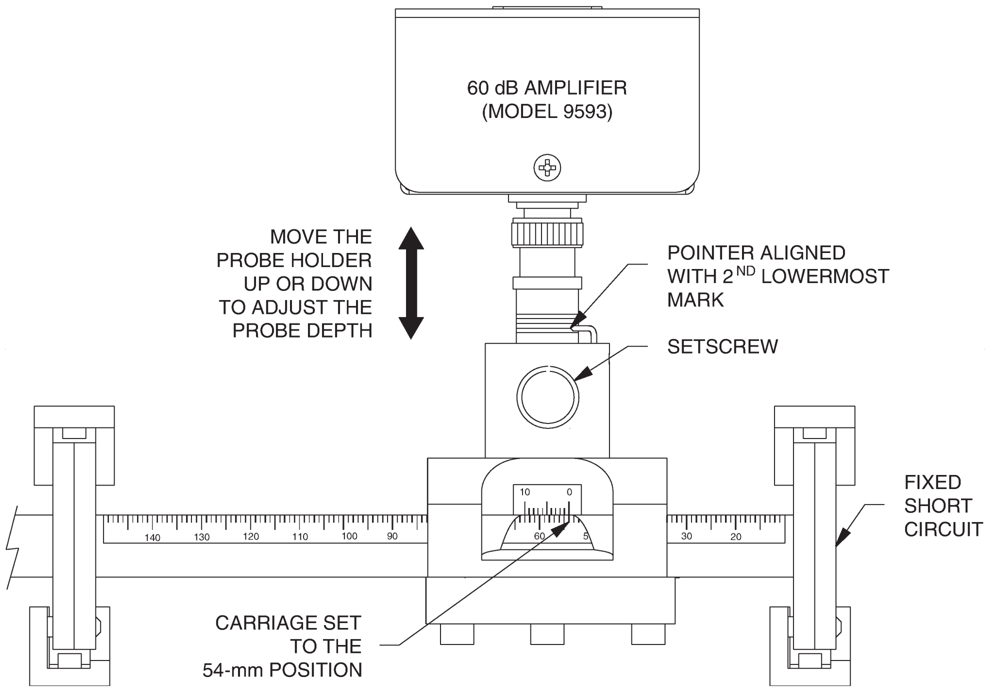


Figure 1-8. Locate the Slotted Line's probe over the 54-mm position and adjust the probe's depth to 1/3 of maximum (pointer aligned with the second lowermost mark).

☐ 4. On the Slotted Line, loosen the thumbscrew of the sliding carriage and partially withdraw the probe holder (by gently pulling up on the 60-dB Amplifier connected to the probe holder).

Adjust the depth of the Slotted Line's probe to approximately 1/3 of maximum (the Slotted Line's pointer must be aligned with the second lowermost mark, as Figure 1-8 shows); then tighten the thumbscrew.

> **Note:** *Particular attention must be paid to the adjustment of the probe depth inside the Slotted Line. If the probe penetrates too deep into the Slotted Line, the field distribution can be distorted, especially when the SWR is high. Moreover, the probe's crystal detector is then more likely to operate outside of its square-law region, causing the measurements to be erroneous.*

☐ 5. On the host computer, start the LVDAM-MW software. In the Application Selection window, make sure the Work in stand-alone box is unchecked, and click OK.

In the main window of LVDAM-MW, start the SWR Meter and set it to display decibels (dB) by clicking on its Mode Log button. Then, display the

Frequency Meter by selecting this instrument in the Instruments menu, or by clicking on the Frequency Meter icon of the Tool bar.

In the Settings panel of LVDAM-MW, make the following settings:

Function Input 3 . . . . SWR Meter
Gain Input 3 . . . . 0 dB
60 dB Ampli on Input 3 . . . . ON

> **Note:** *When the Lab-Volt 60-dB Amplifier, Model 9593, is used to amplify the Slotted Line's output signal, the field 60 dB Ampli on input 3 must be set to ON for the SWR Meter to provide valid readings.*

☐ 6. In the RF Oscillator (VCO) section of the Settings panel, make the following settings:

– Set the Frequency Control parameter to Manual. This enables the Control Voltage (0-10 V) parameter of the RF Oscillator (VCO) section, enabling you to adjust the control voltage applied to the VCO and, therefore, the frequency of the Voltage-Controlled RF Oscillator's output signal.

– Adjust the value of the Control Voltage parameter so that the frequency of the Voltage-Controlled RF Oscillator is 9.6 GHz. This frequency is indicated by the Frequency Meter.

– Set the Amplitude Modulation parameter to ON. This enables on/off modulation of the Voltage-Controlled RF oscillator's output signal with an internal 1-kHz square wave, enabling you to perform SWR measurements with the Slotted Line and the SWR Meter of LVDAM-MW.

☐ 7. Tune the frequency of the SWR Meter's amplifier: by using the cursor of the SWR Meter, scan through the frequency tuning range of this meter (from 900 to 1100 Hz) to find the frequency at which the Signal Level (indicated as a percentage below the horizontal indicator bar of the meter) is maximum.

a. If the maximum signal level obtained on the SWR Meter is between 70 and 90% of full scale and the horizontal indicator bar stays green, the equipment is properly adjusted. Go immediately to step 8.

> **Note:** *To obtain the maximum dynamic range of measurement on the SWR Meter (once its amplifier has been tuned), a maximum level between 70 and 90% on the SWR Meter with Input-3 Gain set to 0 dB is ideal.*

b. If the maximum signal level obtained on the SWR Meter is between 10% and 70% of full scale, loosen the thumbscrew of the Slotted Line and very slightly readjust the depth of its probe so that the maximum signal level indicated by the SWR Meter is between 70 and 90% of full scale (and the green bar stays green) once the thumbscrew of the

Slotted Line has been re-tightened (the tightening of the thumbscrew will cause the signal level to vary slightly).

Do not insert the probe too deep inside the Slotted Line, otherwise the measurements may be erroneous. Instead slightly readjust the attenuation provided by the Variable Attenuator if the maximum reachable Signal Level stays below 70% of full scale, until this signal is within 70 and 90% of full scale.

> **Note:** *The adjustment process may be tedious at first, since a small change in probe depth results in a significant change in the SWR Meter's signal level, however it will become easier with practice.*

c. If you are unable to tune the SWR Meter's amplifier because the maximum signal level exceeds the measurement scale (the horizontal indicator bar of the meter turns to red), loosen the thumbscrew of the Slotted Line. Readjust the depth of the Slotted Line's probe in order to obtain a significant reading on the SWR Meter (a signal level of, for example, about 25% of full scale, once the thumbscrew of the Slotted Line has been re-tightened since its tightening will cause the signal level to change slightly). Then, tune the frequency of the SWR Meter to obtain the maximum signal level on this meter. If this level is not between 70 and 90% of full scale, very slightly readjust the depth of the Slotted Line's probe so that the maximum signal level indicated by the SWR Meter is between 70 and 90% of full scale (and the green bar never turns from green to red) once the thumbscrew of the Slotted Line has been re-tightened.

> **Note:** *The voltage produced by the Slotted Line decreases as the probe is withdrawn from the waveguide; conversely, the voltage increases as the depth of penetration of the probe is increased. The probe needs to be partially withdrawn from the Slotted Line's waveguide to obtain valid measurements on the SWR Meter and a good dynamic range. The probe must not be fully inserted into the Slotted Line's waveguide, otherwise its crystal detector may not operate in the square-law region, causing the SWR Meter readings to be erroneous.*

☐ 8. Very slightly move the probe of the Slotted Line around the 54-mm position on the graduated waveguide, while observing the Signal Level on the SWR Meter; then locate the probe over the maximum (if not already there) to obtain the maximum Signal Level on the SWR Meter.

> **Note:** *If this causes the Signal Level to become lower than 70% or higher than 90% of full scale, very slightly readjust the depth of the Slotted Line's probe to bring the Signal Level back to 70-90% of full scale, with a green bar that turns to red, when the probe is at the maximum.*

☐ 9. Click on the REFERENCE button of the SWR Meter to set the reference level to 0.0 dB.

☐ 10. Measure the distance between the two minima nearest the shorted load.

a. Slowly move the probe of the Slotted Line along the waveguide until you find the minimum which is closest to the load ($NULL_1$). Increase Gain Input 3 to 20 dB, and then 40 dB if necessary. Record the location of $NULL_1$ in the row "9.6 GHz" of Table 1-2.

b. Slowly move the probe toward the source until you encounter the second minimum ($NULL_2$), changing Gain Input 3 as necessary. Record the location of $NULL_2$ in the row "9.6 GHz" of Table 1-2.

RF OSCILLATOR'S OUTPUT SIGNAL FREQUENCY	$NULL_1$ (mm)	$NULL_2$ (mm)	GUIDED WAVELENGTH, λ_g (mm)	CALCULATED FREQUENCY (GHz)
9.6 GHz				
10.1 GHz				
10.6 GHz				

Table 1-2. Frequency measurements with the slotted line.

☐ 11. Increase the frequency of the Voltage-Controlled RF Oscillator's output signal to 10.1 GHz:

– In the RF Oscillator (VCO) section of the LVDAM-MW Settings panel, adjust the value of the Control Voltage parameter until the Frequency Meter indicates 10.1 GHz.

– Perform step 10 again to measure the distance between the two minima nearest the shorted load. Record your results in Table 1-2, in the row "10.1 GHz".

☐ 12. Increase the frequency of the Voltage-Controlled RF Oscillator's output signal to 10.6 GHz:

– In the RF Oscillator (VCO) section of the LVDAM-MW Settings panel, adjust the value of the Control Voltage parameter until the Frequency Meter indicates 10.6 GHz.

– Perform step 10 again to measure the distance between the two minima nearest the shorted load. Record your results in Table 1-2, in the row "10.6 GHz".

☐ 13. From the data recorded in Table 1-2, calculate the guided wavelength, λ_g, for each setting of the RF OSCILLATOR FREQUENCY. Record your results in Table 1-2.

Guided wavelength, $\lambda_g = 2\,(NULL_2 - NULL_1)$

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☐ 14. Based on the guided wavelengths recorded in Table 1-2, calculate the frequency of the Voltage-Controlled RF oscillator's output signal for each setting of the RF OSCILLATOR FREQUENCY. Record your results in the row "CALCULATED FREQUENCY".

> **Note:** *Use Equation 1-1 in the DISCUSSION section of this exercise to calculate the frequency. The width of the waveguide, a, is 0.0229 m.*

☐ 15. Calculate the variation in the ($NULL_2$ - $NULL_1$) difference that occurred over the 9.6-10.6 GHz frequency variation range of the RF oscillator's output signal.

$[NULL_2 - NULL_{1\ (9.6\ GHz)}] - [NULL_2 - NULL_{1\ (10.6\ GHz)}] =$ ______ mm

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Observe that the variation in the ($NULL_2$ - $NULL_1$) difference is quite small compared with that of the RF oscillator's output signal frequency (9.6-10.6 GHz). This indicates that frequency measurements with the Slotted Line provide an acceptable, though limited accuracy.

Frequency Measurements with the Resonant Cavity Frequency Meter

☐ 16. Disconnect the supply cable (DB-9 connector) of the Voltage-Controlled RF Oscillator from the RF OSCILLATOR SUPPLY AND CONTROL OUTPUT of the Data Acquisition Interface.

☐ 17. **Taking care not to modify the adjustment of the Slotted Line's probe depth**, modify your microwave circuit in order to obtain the circuit shown in Figure 1-9.

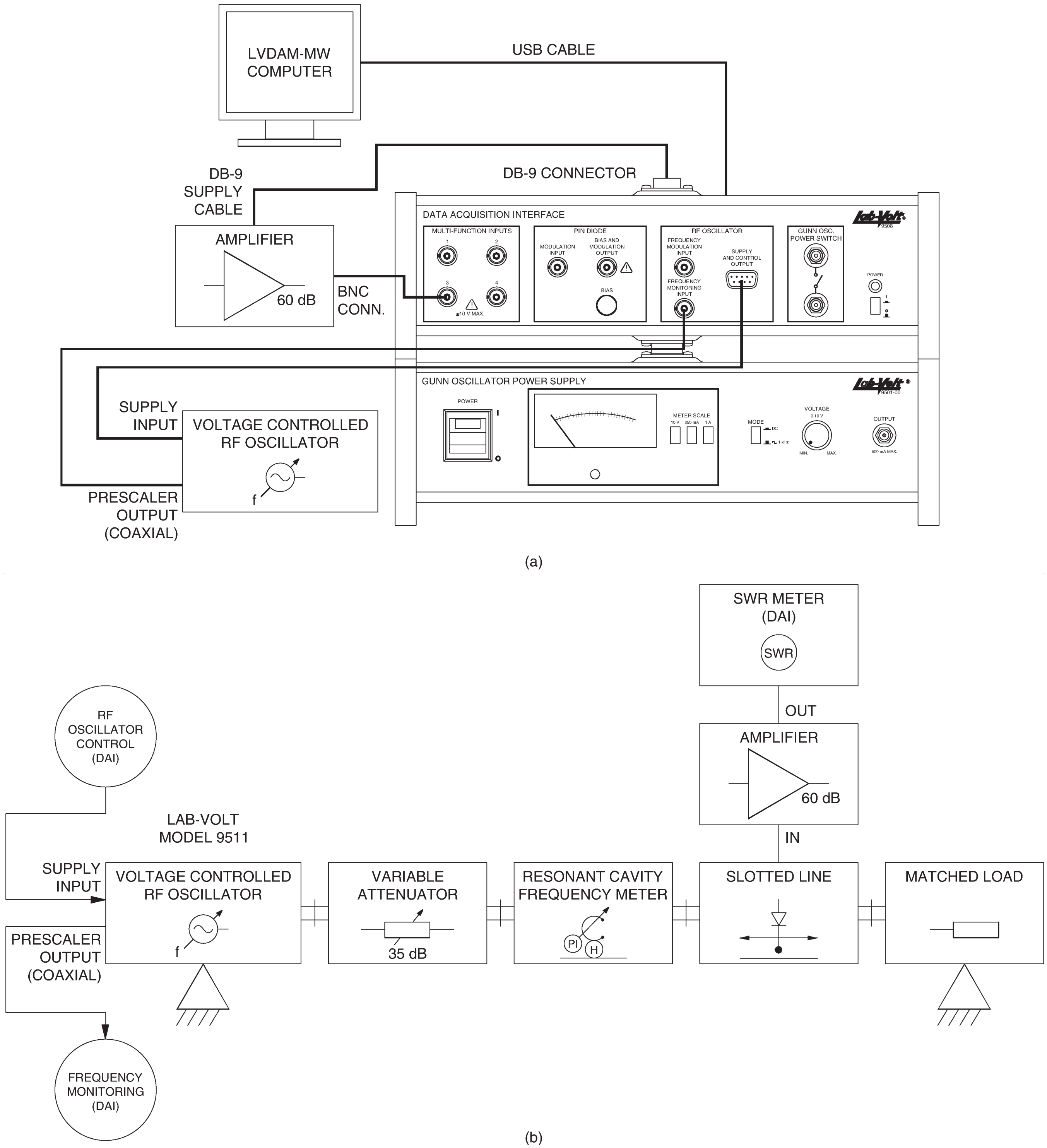

Figure 1-9. Frequency measurements with the Resonant Cavity Frequency Meter.

Leave the rest of the equipment connected and set as before.

Reconnect the supply cable (DB-9 connector) of the Voltage-Controlled RF Oscillator to the RF OSCILLATOR SUPPLY AND CONTROL OUTPUT of the Data Acquisition Interface.

Wait for about 5 minutes to allow the Voltage-Controlled RF Oscillator to warm up.

☐ 18. Move the Slotted Line around the 40.0-mm position. With the current setup, the load is matched so the position of the Slotted Line is not critical.

☐ 19. Set the attenuation provided by the Variable Attenuator to the maximum. To do this, set the blade position of the Variable Attenuator to 10 mm approximately (turn the attenuator adjustment screw fully clockwise).

☐ 20. Set the tuning screw (plunger position) of the Resonant Cavity Frequency Meter to 0 mm. [The 0-mm mark on the linear (vertical) scale of the sleeve intersects the "0" mark on annular scale of the tuning screw.]

☐ 21. In the Settings panel of LVDAM-MW, ensure that the following settings are made:

Function Input 3 . . . . SWR Meter
Gain Input 3 . . . . 20 dB
60 dB Ampli on Input 3 . . . . ON

☐ 22. In LVDAM-MW, select the Data Table function, which will bring up the Data Table. In this Table, manually enter the column titles and figures recorded in Table 1-3 below. Use the Properties command of the Data Table's Edit Menu to enter the headers of the columns and the corresponding units. Save your Data Table.

> **Note:** *During the experiment, you will fill the Data Table by manually entering the Plunger Position values in the table, since this parameter is not acquired by the Data Acquisition Interface. (Only the parameters measured with the Power Meter, SWR Meter, and Oscilloscope can be recorded automatically using the Record Data function of the Data Table.)*

RF OSCILLATOR'S OUTPUT SIGNAL FREQUENCY (GHz)	PLUNGER POSITION (mm)
9.6	
9.7	
9.8	
9.9	
10.0	
10.1	
10.2	
10.3	
10.4	
10.5	
10.6	

Table 1-3. Calibrating the tuning screw of the Resonant Cavity Frequency Meter.

☐ 23. In the RF Oscillator (VCO) section of the LVDAM-MW Settings panel, set the frequency of the Voltage-Controlled RF Oscillator's output signal to 9.6 GHz:

– Set the Frequency Control parameter to Automatic. This enables the Frequency (GHz) parameter, enabling you to enter the desired RF oscillator frequency directly, without having to adjust the control voltage.

– Enter "9.6" next to the Frequency (GHz) parameter. This sets the frequency of the Voltage-Controlled RF Oscillator's output signal to 9.6 GHz. This frequency is indicated by the Frequency Meter.

Ensure that the Amplitude Modulation parameter in the RF Oscillator (VCO) section is set to ON.

☐ 24. Using the steps below, tune the Resonant Cavity Frequency Meter to resonance. Note and record the position of the cavity plunger and the frequency of the RF oscillator's output signal.

a. With Gain Input 3 set to 20 dB, adjust the screw of the Variable Attenuator until the signal level obtained on the SWR Meter is between 70 and 90% of full scale.

b. Scan through the frequency tuning range of the SWR Meter with the cursor to find the frequency at which the Signal Level (indicated as a percentage below the horizontal indicator bar of the meter) is maximum. Set the cursor to this frequency.

> **Note:** *If the signal level indicated on the SWR Meter decreases below 70% of full scale while trying to tune the SWR Meter, slightly decrease the attenuation of the microwave signal with the Variable Attenuator until the signal level obtained on the SWR Meter is between 70 and 90% when the SWR Meter's amplifier is properly tuned. Do not change Gain Input 3; leave this gain set to 20 dB.*

c. Once the SWR Meter has been tuned to obtain the maximum signal level, click on the REFERENCE [⤒] button of the SWR Meter.

d. Very slowly turn the tuning screw of the Resonant Cavity Frequency Meter in the counterclockwise direction, through 1/12-turn steps, until you observe a slight decrease (dip) of about 0.25 dB (typical) in the SWR Meter reading. The dip might be hard to detect if you turn the screw too fast, due to the high quality factor Q (selectivity).

The Resonant Cavity Frequency Meter is now tuned to the frequency of the RF oscillator's output signal. Fine tune the tuning screw to maximize the dip of the SWR Meter. Note the position of the plunger and enter it in row "9.6" of your Data Table.

☐ 25. Fill in the remainder of your Data Table by setting the frequency of the Voltage-Controlled RF Oscillator's output signal to each of the other values listed in this table. For each frequency setting, repeat step 24 and enter your result in the Data Table. Save your table.

☐ 26. In LVDAM-MW, select the Graph function of the Data Table. In the Axis section of the Graph, select the proper variables for the X and 1-Y Axes in order to plot the RF Oscillator's output signal frequency as a function of the position of the Resonant Cavity Frequency Meter's plunger.

The curve obtained should resemble that shown in Figure 1-10. Describe the relationship between the depth of the cavity's plunger and the resonant frequency of the cavity.

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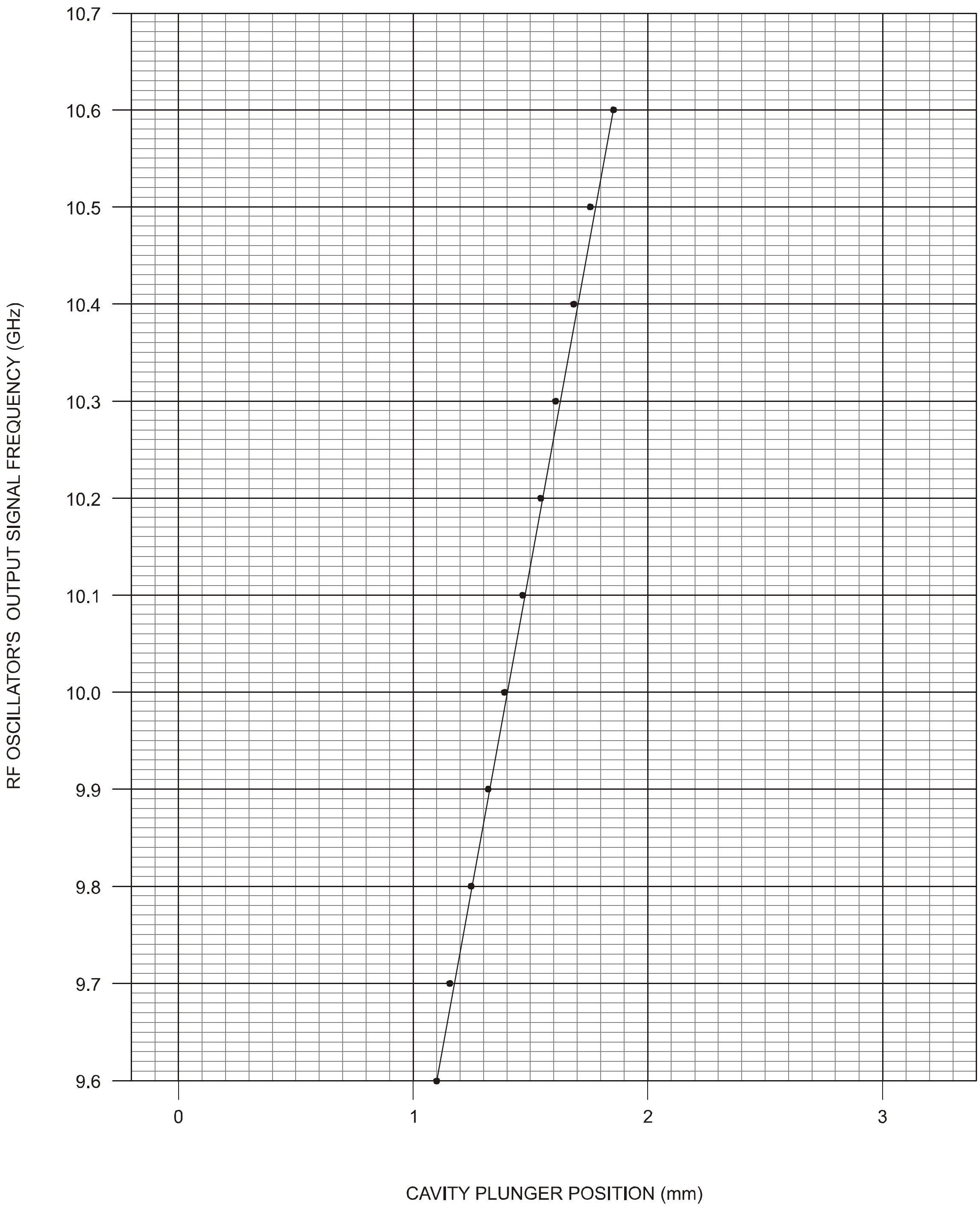

Figure 1-10. Calibration curve of the Resonant Cavity Frequency Meter.

☐ 27. Turn off the Gunn Oscillator Power Supply and the Data Acquisition Interface by setting the POWER switch to the O (OFF) position. Disassemble the setup and return all components to their storage location.

☐ 28. Close the LVDAM-MW software.

CONCLUSION

In this exercise, you were introduced to three methods of measuring the frequency of a microwave signal: slotted line, prescaler, and resonant cavity frequency measurement. You also plotted the calibration curve of a resonant cavity.

REVIEW QUESTIONS

1. When a waveguide is terminated by a short-circuited load, where do minima invariably occur in the standing wave resulting from this mismatch? Where do maxima invariably occur?

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2. Briefly explain how the frequency of a microwave signal propagating in a waveguide can be measured by using a slotted line and a SWR meter.

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3. What is a prescaler? What advantage do we get by using a prescaler to measure the frequency of a microwave signal?

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4. What is a resonant cavity? Briefly explain what occurs in a resonant cavity when a microwave at a particular frequency (the resonant frequency) enters the cavity.

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5. Briefly explain how the frequency of a microwave signal propagating in a waveguide can be measured by using a resonant cavity frequency meter.

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Sample

Extracted from

Instructor Guide

Microwave Variable-Frequency Measurements and Applications

EXERCISE 1 MICROWAVE FREQUENCY MEASUREMENTS

ANSWERS TO PROCEDURE STEP QUESTIONS

☐ 10.

RF OSCILLATOR'S OUTPUT SIGNAL FREQUENCY	$NULL_1$ (mm)	$NULL_2$ (mm)	GUIDED WAVELENGTH, λ_g (mm)	CALCULATED FREQUENCY (GHz)
9.6 GHz	42.8	64.4	43.2	9.55
10.1 GHz	39.0	58.7	39.4	10.04
10.6 GHz	36.0	54.0	36.0	10.60

Table 1-2. Frequency measurements with the slotted line.

☐ 15. Frequency variation range: 9.6 GHz (lower frequency) to 10.6 GHz (upper frequency)

$[NULL_2 - NULL_{1\ (9.6\ GHz)}] - [NULL_2 - NULL_{1\ (10.6\ GHz)}]$

$= [64.4\ mm - 42.8\ mm] - [54.0\ mm - 36.0\ mm] = 3.6\ mm$

☐ 22.

RF OSCILLATOR'S OUTPUT SIGNAL FREQUENCY (GHz)	PLUNGER POSITION (mm)
9.6	1.10
9.7	1.16
9.8	1.24
9.9	1.32
10.0	1.39
10.1	1.47
10.2	1.54
10.3	1.61
10.4	1.68
10.5	1.76
10.6	1.83

Table 1-3. Calibrating the tuning screw of the Resonant Cavity Frequency Meter.

☐ 26. As the depth of the cavity's plunger is increased, the capacitive component of the tank circuit reactance increases, causing the resonant frequency of the cavity to decrease. Conversely, as the depth of the plunger is decreased, the capacitive component of the tank circuit decreases, causing the resonant frequency of the cavity to increase.

ANSWERS TO REVIEW QUESTIONS

1. A minimum invariably occurs at the load end of the waveguide, and minima occur at every even multiple of $\lambda_g/4$ from the load end (λ_g being the wavelength of the propagating wave in the waveguide).

   Maxima invariably occur at every odd multiple of $\lambda_g/4$ from the load end.

2. The waveguide is coupled to the slotted line. The slotted line is connected to the SWR meter, and is terminated by a short-circuited load to produce a standing wave in the waveguide. The microwave signal is amplitude-modulated by a 1-kHz square-wave signal to permit detection by the slotted line.

   The distance between two successive minima of the standing wave is measured with the slotted line and the SWR meter. This distance is multiplied by 2 to obtain the wavelength of the signal in the waveguide. This wavelength is then used to calculate the frequency of the signal.

3. A prescaler is an electronic circuit that divides the frequency of a signal by a precise amount, for example 10 or 100.

   The advantage of using a prescaler is that this device increases the maximum frequency that conventional frequency counters can measure, thereby eliminating the need for high-cost microwave frequency counters.

4. A resonant cavity is a section of waveguide, closed at both extremities, that is usually rectangular, cylindrical, or spherical in shape.

   When a microwave at a particular frequency (the resonant frequency) enters the cavity, the cavity comes into resonance: it behaves like a tank circuit—a capacitor and an inductor in parallel.

   At resonance, the wave is reflected back and forth in the cavity, producing standing waves that gradually intensify.

5. The cavity is coupled to the waveguide through a small hole in the wall of the cavity. The cavity is tuned until it resonates at the frequency of the microwave signal. If a SWR meter connected to a slotted line is used as the indicator, resonance will reflect as a decrease (dip) in the signal level, due to the storage of energy in the cavity at resonance.

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