ECE 451

Automated Microwave Measurements Laboratory

# Experiment 02 - Coaxial Transmission Line Measurement using Slotted Line

## 1 Introduction

This experiment introduces, in details, the slotted line, an instrument that makes use of the reflection phenomenon that is seen at microwave frequencies. The slotted line is used to measure the voltage standing wave ratio (VSWR) created by reflections from the device under test (DUT). This is useful because directly measuring current and voltage at microwave frequencies is difficult. These VSWR measurements can then be used to calculate the unknown impedance of the DUT at the microwave frequency of interest. In the last experiment, you have studied the RF detector and learnt how to determine its square-law region in which your measurement should take place. This experiement will be an illustration of why that is important.

**Useful links**

1. Slotted Line Lab video on Youtube
2. VSWR 101 video on Youtube
3. Slotted Line Reference Document

## 2 Background

The Type 874-LBA Slotted Line shown in Figure 1 is designed to measure the voltage standing wave pattern produced by any load connected to it. Its characteristic impedance is 50 ohms. The outer conductor is slotted for a length of approximately 50 centimeters, and a small shielded probe extends into the region between the two conductors. The probe is mounted on a carriage, which slides along the outside of the outer conductor. The penetration of the probe into the line and, hence, the capacitive coupling between the probe and the line, can be adjusted over a wide range by means of a screw adjustment. Cross-sectional views of the probe arrangment are shown in Figure 2. Since the probe is capacitively coupled to the line, the voltage induced in the probe circuit is proportional to the voltage existing between the inner and outer conductors of the line at the probe position. The RF voltage induced in the probe circuit is detected by the detector integrated in the probe carriage.

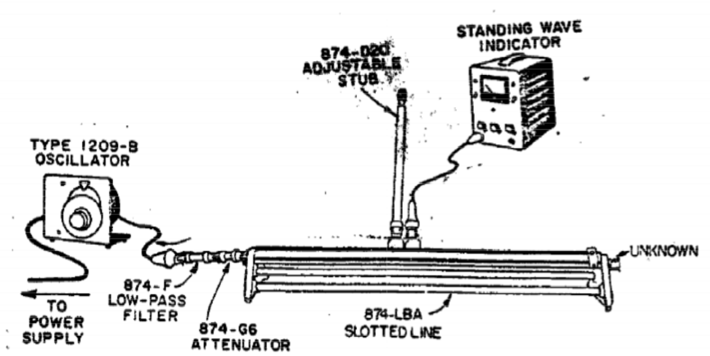


Figure 1: Slotted line setup

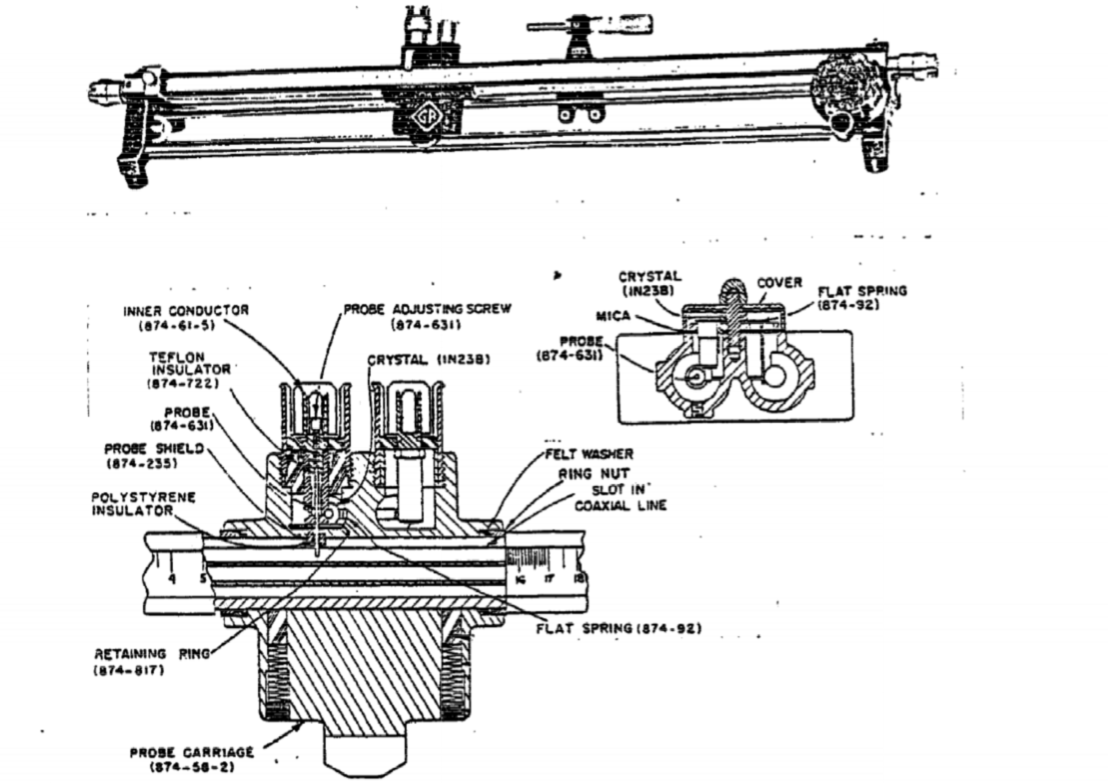


Figure 2: Slotted line and its cross-sectional view

### Tuning the Crystal Detector (For your reference only, please do not adjust)

The crystal rectifier built into the carriage is tuned by means of the adjustable stub, which is effectively connected in parallel with it in order to increase the sensitivity and to provide selectivity. The stub is adjusted until maximum output is indicated by the detector.

Be sure the stub is not tuned to a harmonic of the desired signal rather than to the fundamental. Confusion may result in some cases if the tuning is done with a high VSWR on the line, as the minima of the harmonics may not be coincident with the minima of the fundamental and, consequently, the harmonic content of the signal picked up by the probe may be greater than that present in the local oscillator output. To minimize the possibility of mistuning, the probe should be tuned with a low VSWR on the line, for instance, with the line terminated in a 50-ohm termination. As a check, the distance between two adjacent voltage mimina when the line is terminated in a short circuit can be measured. If the stub is tuned correctly, the spacing should be a half wavelength.

### Probe Penetration Adjustment (For your reference only, please do not adjust)

The probe penetration should be adjusted for adequate senstivity as well as insignificant effect on the measured VSWR. The presence of the probe affects the VSWR because it is a small admittance in shunt with the line. It has the greatest effect at a voltage maximum, where the line impedance is high.

To adjust the probe penetration, remove the tuning stub connected to the left-hand connector and turn the small screw found inside the inner connector (Figure 2). Clockwise rotation of the screw increases the coupling. In most cases in which moderate VSWR's are measured, a penetration of about 30% of the distance between the two conductors gives satisfactory results. For this experiment, your probe penetration has been initially adjusted to give approximately 30% coupling as indicated below.

To adjust the coupling to 30%, increase the coupling until the probe strikes the center conductor of the slotted line; then back it off six full turns of the screw. The point of contact between the probe and the center conductor is most easily measured by connecting an ohmmeter between the inner and outer conductors of the line with the standing wave indicator connected as shown in Figure 1. Using the 2000 ohm range on the ohmmeter, note the point at which the resistance suddenly drops from a very high value to a reasonably low value. The crystal is in series with this circuit, so the resistance will not drop to zero. No indication will be obtained if the crystal has been removed. Do not screw the probe down tight against the center conductor, as it will damage the probe.

The amount of the probe penetration can be visually checked by looking at the probe though the slot from one end of the line.

The effect of the probe coupling on the VSWR can be determined by measurement of the VSWR at two different degrees of coupling. If the measured VSWR is the same in both cases, the probe coupling used has no significant effect on the measurement. If the measured VSWR's are different, additional measurements should be made with decreasing amounts of probe penetration until no difference occurs. However, as pointed out in the previous paragraph, a 30% coupling usually gives satisfactory results except when the VSWR is high, which usually requires a large coupling.

# 3 Pre-lab

1. The concepts of VSWR and reflection coefficient are closely related and sometimes interchangable. Given one, it should be trivial to derive the other. Convert the following given values into the other (assuming 50Ω system)

    - A load whose VSWR is 5.0
    - A load impedance whose reflection coefficient is 0.2

2. Show that an unknown load $Z_L$ terminating an ideal transmission line (TL) with characteristic impedance $Z_0$ can be calculated from the measured VSWR by the following equation,

$$Z_L = Z_0 \frac{1 - j\text{VSWR}\tan(\beta d_{min})}{\text{VSWR} - j\tan(\beta d_{min})}$$

    where $d_{min}$ is the distance from the load to the first minimum voltage location on the line toward the generator.

3. It is well known that input impedances along the TL at locations multiple integrers of half-wavelength apart are exactly same. This property is very useful when it comes to measurements where the absolute distance along the TL is partly unavailable to us. One of the most important steps in such measurement scenarios is to locate points that are multiple integrers of a half-wavelength away from the load (i.e. to locate A and B in Figure 3). Assuming that we have full knowledge of the TL termination and access to all mesurement equipment that is used in this experiment (see the list below), how would we find these points?

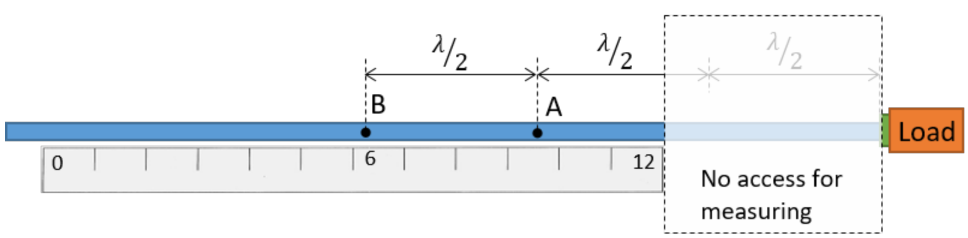


Figure 3: Limited access measurement environment

4. As introduced in the *Background* section, in order to capture the voltage at any location along the line, an RF detector is integrated inside the probe. Before we perform any measurement with the slotted line, it is important to know the operational range of this detector. Many failures in measurements are simply due to lack of proper understanding of the working range of the equipment. In the lab, you will first repeat the measurement you have done in Experiment 01 to idenitfy the "square-law" region of this detector. To set up for this measurement, input is fed into one end of the line, and the other end is terminated by some load. Which load would you use to terminate the line, and where along the line would you put the probe to observe the output voltage? Explain your choice.

# 4 Equipment

- Agilent MXG Analog Signal Generator (N5183A).
- Keysight Digital Voltmeter (DVM) (34461A)
- General Radio (GR) Slotted line.
- N-type, BNC cables.
- N-type terminations.
- Calibrated 2.5 VSWR load.
- Calibrated 5.0 VSWR load.

# 5 Procedure

1. Based on your discussion in question 4 of the *Pre-lab* section, measure the "square-law" region of the detector integrated in the probe of the line (i.e. its slope and intercept). The source frequency should be 650MHz, as later we will excite the slotted line with this frequency. Is it different from the 8474B detector? Use a plot with measurement data from both the slotted-line detector as well as the 8474B detector to illustrate your answer.

   **Note:** Before you perform any measurements with the slotted line, ensure the stub on the probe is correctly adjusted to maximize the output on the voltmeter (just for better sensitivity). This can be done by setting the input power to -10dBm (this value will stay the same throughout this experiment), terminating the line with a matched load, then pulling the stub in or out until a maximum voltage at a fixed location is observed on the DVM.

2. Before you proceed, check that -10dBm input power is reasonable to excite the slotted line. If not, show your data and discuss with with your TA to determine an appropriate input power level for this experiment.

3. Terminate the line with a short and measure with an excitation at 650MHz. Find more than one minimum and one maximum (if possible); record both the locations on the line and the voltages at those locations. Calculate the distance between the minimum and its adjacent maximum, then calculate the frequency and compare it with the frequency set on the signal generator.

4. Now, terminate the line with an open and repeat step 3. How do the locations of these minima and maxima compare to those of the short? Comment and justify using transmission line theory.

5. Measure the VSWR of the calibrated 2.5 and 5.0 VSWR terminations at 650MHz. Also, repeat the frequency validation as above. Verify VSWR values.

6. Now, you will infer the **impedance** of the calibrated 2.5 and 5.0 VSWR terminations at 650MHz. Think carefully and obtain enough data to calculate the impedance of the calibrated terminations. Hint: use answers to question 2 and 3 in the *pre-lab* section. Use the algebraic equation (given in *Pre-lab*) and Smith Chart to find the impedances. Compare the results from both methods.

NOTE: The length markings on the slotted line do not have any absolute meaning. Think of them as simply a ruler placed along the length of the slotted line for your convenience.

# 6 Conclusion

1. Why is the slotted line useful? Which parameters does it allow you to measure or calculate?

2. What are measurements required to calculate the impedance of the unknown when it is placed directly on the slotted line?

3. Use plots and data to explain why -10dBm (or any other power level you used) is a reasonable level for input power in this experiment.