Lab 2: Slotted Line and SWR Meter

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Introduction:

In this lab you will learn how to characterize and use a 50-ohm slotted line, crystal detector, and standing wave ratio (SWR) meter to measure an unknown impedance.

The apparatus used is shown below. The slotted line is a (rigid) continuation of the coaxial transmission lines. Its characteristic impedance is 50 ohms. It has a thin slot in its outer conductor, cut along z. A probe rides within (but not touching) the slot to sample the transmission line voltage. The probe can be moved along z to sample the standing wave ratio at different locations. It can also be moved into and out of the slot by means of a micrometer in order to adjust the signal strength. The probe is connected to a crystal (diode) detector that converts the time-varying microwave voltage to a DC value with the help of a low speed modulation envelope (1 kHz) on the microwave signal. The DC voltage is measured using the SWR meter (HP 415D).
Using Slotted Line to Measure an Unknown Impedance:

The magnitude of the line voltage as a function of position is:

\[ |V(z)| = |V_0^+| \left| 1 - \Gamma e^{-2\beta l} \right| = |V_0^-| \left| 1 + \Gamma e^{j(\theta-2\beta l)} \right| \quad \text{with} \quad \Gamma = |\Gamma| e^{j\theta} \quad \text{and} \quad l \text{ the distance from the load towards the generator.} \]

Notice that the voltage magnitude has maxima and minima at different locations.

\[ V_{\text{max}} = |V_0^+|(|1 + \Gamma|) \quad \text{when} \quad \theta - 2\beta l = \pi \]

\[ V_{\text{min}} = |V_0^-|(|1 - \Gamma|) \quad \text{when} \quad \theta - 2\beta l = 0 \]

The SWR is defined as: \( \text{SWR} = \frac{V_{\text{max}}}{V_{\text{min}}} = \frac{1 + |\Gamma|}{1 - |\Gamma|} \). So if one knows the SWR, one knows the magnitude of the reflection coefficient. Also notice that \( 1 \leq \text{SWR} \leq \infty \). And \( \text{SWR} = 1 \) indicates a matched load, while \( \text{SWR} = \infty \) is for a short or an open load.

If two successive voltage minima are measured at \( l_1 \) and \( l_2 \), then we have

\[ \theta - 2\beta l_1 = \pi \quad \text{and} \quad \theta - 2\beta l_2 = 3\pi \quad \text{so that} \quad 2\beta (l_1 - l_2) = 2\pi \quad \text{. Therefore, the signal wavelength on the line can be obtained from} \quad l_1 - l_2 = \frac{\lambda}{2} \quad \text{since} \quad \beta = \frac{2\pi}{\lambda} \quad \text{.} \]

The principles of using the slotted line to measure an unknown impedance is as follows.

A short load is connected to the end of the slotted line. A standing wave pattern is obtained on the line. Measure one voltage minimum and record its location \( l_0 \), which will be used as a reference point. Change the load to the unknown impedance and move the probe to the closest voltage minimum \( l_1 \).
Measure the SWR at this point, which will give $|\Gamma|$, as well as the shift of the minimum point $l_{\text{min}} = l_1 - l_0$. Since $\theta - 2\beta l_{\text{min}} = \pi$, the phase of the reflection coefficient can be obtained as $\theta = \pi + 2\beta l_{\text{min}}$. Based on $\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0}$, the unknown impedance can be calculated. (Note: Using Smith chart would be an easier way to obtain the result.)

**Tuning the Crystal Detector:**

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. To avoid mistuning, the probe should be tuned with a low SWR on the line, for instance, with the line is terminated with a matched load (50 ohms).

1. Connect a 50-ohm load to the line. (What is the ideal SWR on the line now?)
2. The indicator of the SWR meter should be at its most left. Change the range dial knob to higher dB value until the indicator moves to the center of the screen.
3. Slightly adjust the stub on the probe to reach maximum output (the indicator of the SWR meter deflects maximally to the right).

**Operation of HP 415D SWR Meter:**

The SWR meter is a low-noise tuned amplifier-voltmeter calibrated in dB and SWR. The amplifier has a 3-dB bandwidth of approximately 25 Hz, and is centered at about 1 kHz. It takes the voltage maximum on the line as a reference and the meter reading gives $V_{\text{max}} / V_z$, where $V_z$ is the voltage amplitude at location $z$ on the line. Since this measurement is relative, the reading should be normalized to SWR=1 or 0 dB by adjusting the GAIN knob when a voltage maximum is obtained (where the indicator deflects
most to the right). Therefore, when the probe reaches the minimum, the reading, $V_{\text{max}} / V_{\text{min}}$, is the SWR on the line.

The operation and the normalization of the SWR meter should follow the procedures listed below.

1. SWR meter settings: AC power, 200 kΩ Xtal, Coarse and fine gain controls at half way, range switch at 0 dB, expand switch at NORM.
2. Move the detector along $z$ to find the maximum voltage, where the indicator deflects most to the right on the screen.
3. Vary the coarse and vernier GAIN knobs until the meter reads exactly SWR=1 or 0 dB at the position of the maximum voltage.
4. Move the detector slowly away from the voltage maximum. The indicator deflects to the left. Increase the range dial with a step of 10 dB until the indicator is in the middle of the screen (not deflected to the most left or right). Once the voltage minimum is reached, the SWR meter reading gives the actual measured SWR in both linear and dB scale. If the range dial is nonzero, the number in dB on the knob should be added to the screen reading in dB to obtain the correct SWR.

**Procedure:**

Please adjust the crystal detector and normalize the SWR meter before you start the measurement.

Set the RF signal generator to a frequency $f = 750$ MHz, 100% modulation at 1 kHz, and 8 dBm output power.

1. Connect the 50-ohm load to the line. Can you measure any voltage maximum or minimum? Why?

2. Connect the open load to the termination point. Move the probe to find a voltage minimum. Change the Range-dB dial to get a proper reading on the SWR meter. Record the location and the SWR(dB).

\[ I_{\text{min1}} = \quad \text{SWR(dB)} = \quad \]

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3. Continue moving the probe until a voltage maximum is reached. Record the location, and what do you expect the SWR meter reading to be in dB scale at this point?

\[ l_{\text{max}} = \] _________________

Can you obtain the wavelength of the signal from \( l_{\text{min1}} \) and \( l_{\text{max}} \)?

\[ \lambda = \] _________________

What is the theoretical signal wavelength calculated from the frequency that you set up on the signal generator (750 MHz)?

\[ \lambda_0 = \] _________________

Is your measured wavelength accurate?

4. Continue moving the probe until a second voltage minimum \( l_{\text{min2}} \) is reached. Record the location and calculated the signal wavelength from \( l_{\text{min1}} \) and \( l_{\text{min2}} \).

\[ \lambda = \] _________________

Which measurement is more accurate, from step 2 (max. & min.) or step 3 (min. & min.)? Why?

5. Connect a short load to the termination point (you may need to renormalize the SWR meter). Move the probe until you find a voltage minimum point. Record the location. \( l_{\text{min1}} = \) _________________

6. Switch the load to an unknown impedance (you may need to renormalize the SWR meter) and move the probe until you reach the closest minimum. Record the location and the SWR(dB).

\[ l_{\text{min2}} = \] _________________ \quad \text{SWR(dB)} = \) _________________
Calculate the unknown impedance from the above measurement using the Smith chart. $Z_L =$