Objective:

Students will learn how to measure a standing wave pattern and to use the result to calculate the reflection coefficients for various loads.

Introduction:

The performance of a transmission line can be explained in terms of the electromagnetic waves traveling on that line. The wave traveling away from the generator (incident wave) and the wave traveling toward the generator (reflected wave) combine to produce a stationary interference pattern. The ratio of the reflected wave to the incident wave at any point on the line is defined as the reflection coefficient Γ. If the line is lossless, the magnitude of the reflection coefficient is the same at all points on the line. If the line is lossy (has attenuation), both the incident and reflected waves are attenuated by $e^{-\alpha l}$. Here again, α is the attenuation constant in Nepers/unit length and l is the distance from the load to the point on the line being considered. The magnitude of the reflection coefficient at the point l from the load is then the product of the reflection coefficient at the load and the attenuation factor $e^{-2\alpha l}$.

When a sine wave is sent down a transmission line and there is a reflected wave generated at the load, a stationary interference pattern is generated on the line. This interference pattern is referred to as a standing wave. The maximum amplitude (maxima) of the standing wave occurs when the incident and reflected waves are in phase or when they are an integral multiple of 360° out of phase. The minimum amplitude (minima) occurs when the two waves are 180° out of phase or an odd integral multiple of 180°. The distance between adjacent maximum points is one half-wavelength, as is the distance between adjacent minimum points. The amplitude at other points along the line is the vector sum of incident and reflected waves.

In this lab exercise, you will use a section of slotted transmission line to investigate this wave phenomenon. The slotted line is a rigid section of transmission line that has a longitudinal slot (gap) machined in the outer conducting surface. This slot allows for the insertion of a voltage probe to measure the RMS magnitude of the standing wave within the line without any appreciable radiation loss occurring from the line. In addition, most slotted lines are constructed using air as the dielectric material in order to limit the attenuation characteristics. This means that the magnitude of the reflection coefficient will be relatively constant at all points on the line.

In the slotted coaxial section, the TEM excitation mode is assumed (the dominant mode in coaxial lines). This means that no potential differences occur between the two sides of the slot at equal longitudinal distances along the line. If this assumption is true, or very close to true, no radiation will occur.

To sample the electric field within the line, a small probe is inserted into the slot and aligned parallel to the electric field lines within the transmission line. This allows a small amount of power to be coupled from the line and applied to a detection circuit. The sampled level is then displayed on a voltmeter or a spectrum analyzer, giving a relative indication of the voltage at any point along the slot. Voltmeters designed for this purpose are called standing wave ratio (SWR) meters. It is critical that the probe have minimal effect on the internal wave behavior for accurate measurements. Permitting the probe to extend only a short distance within the line minimizes probe interference.

INSTRUMENTATION:

Slotted line (GR-874 -LBA/-LBB with 50Ω characteristic impedance)
Signal generator
Spectrum Analyzer
874-L10L 10 cm line extension
874-WO3 open circuit termination
874-WN3 short circuit termination
50 Ω termination.
100 Ω termination.
3dB attenuator
6dB attenuator

PROCEDURE:

IMPORTANT: Be very careful when connecting the GR 874 connectors. Align them first and push them partially together with minimum force to be sure alignment is correct. Once the alignment is confirmed, push them completely together.

1. INITIAL SETUP

Slotted-Line

a. Connect the RF-out port of the Signal Generator to the input port of the slotted-line.

b. Connect the left-hand probe port on the slotted-line to the RF-in port of the Spectrum Analyzer.

c. Leave the "termination" end of the slotted line open (unterminated).

Signal Generator

d. Turn on the RF Signal Generator and allow the device to fully boot-up.

e. Unless instructed differently, set the Signal Generator to output an RF waveform having a **frequency** of **800 MHz.** Additionally, set the output power level to an **amplitude** of **+10dBm**. Be sure the **modulation** function is turned **OFF**.

f. Turn **ON** the **RF Output**.

Spectrum Analyzer

g. Press **Frequency > Center** and type in the frequency you set on the signal generator. Then press **Span** and enter **10 kHz**. This will cause the analyzer display to show the frequency component and power level detected from the probe.

h. Press **Amplitude > Ref Level > -20 dBm**. Then press **Scale/Div > 5 dB**. The amplitude range of the signal from the probe should have a maximum and minimum that will fit on the screen.

i. Move the probe carriage enough to create a strong signal component peak in the center of the display. It does not have to be a maximum. Press **Marker > Marker 1**. Then press the **Peak Search** button and the marker should position on the detected frequency component. You will read amplitude values of the marker during other steps. It is important to keep the marker centered on the signal component when reading its amplitude.

NOTE: Check all RF connections if erratic amplitude variation of the signal component occurs without touching the apparatus.

2. MEASUREMENTS: Frequency, Wavelength, and Line Length

a. With the slotted line unterminated, record the **locations** of **four consecutive points**: a voltage **maximum**, a **minimum**, a **maximum**, and the next **minimum**. These locations are read from the pointer on the centimeter (cm) scale. Estimate values to the nearest millimeter marks. Record your measurements in **Table 3.1** for this and all other steps.

Note – You do not have to record amplitudes for this step.

Note – That the maxima occur when the signal component is strongest and the minima occur when the signal component is weakest.

b. Which is easier to measure accurately, the location of a maxima or the location of a minima? Why? (Think about what the standing wave pattern looks like on the transmission line.)

c. Place an 874-W03 "OPEN" terminator on the "termination" end of the slotted-line and perform the same measurements as in step 2(a).

d. Place an 874-L10L between the 874-W03 and the end of the line, and perform the same measurements as in step 2(a).

e. Remove the 874-W03 from the end of the 874-L10L and replace it with an 874-WN3 "SHORT" terminator. Perform the same measurements as in step 2(a).

f. Remove the 874-L10L, place the 874-WN3 short back on the end of the slotted line, and perform the same measurements as in step 2(a).

3. MEASUREMENTS: VSWR

For this set of measurements, you will record both maxima and minima locations and amplitudes. It is recommended that you measure amplitudes in dBm. You are interested in finding the dB difference between the signal level at a maximum and the signal level at a minimum. This signal level difference is the VSWR on the line expressed in dB.

a. Replace the 874-WN3 with the loads listed below and measure: the signal level at a "maxima", the location of the "maxima", the signal level at a "minima", and location of the "minima".

- 100 Ω termination.
- 50 Ω termination.
- 3dB attenuator, other end terminated with WO3 (open).
- 3dB attenuator, other end terminated with WN3 (short).
- 6dB attenuator, other end terminated with WO3 (open).
- 6dB attenuator, other end terminated with WN3 (short).

Lab Report Submission Requirements:

You must **generate and submit** (via email as specified in the "Course Introduction" handout) an electronically-generated, "memo-style" report that contains (in the order specified):

a) A **cover sheet** that clearly shows your name, the lab # and title, and the submission date, (Note – you may show this information as the header of the first page if you prefer)

b) A fully-labeled **data table** that shows all of your in-lab measured values, and (Note – create the table yourself; do **not** simply scan and attach the handwritten lab sheet)

c) An **analysis section** in which you perform all of the tasks and answer all of the questions specified in the following "Analysis" section:

Analysis:

1. Using the consecutive voltage maxima and minima locations from measurement step **2a**, **determine** the operating **wavelength** and **frequency** of the waveform within the slotted-line and **compare** these values to the theoretical frequency and wavelength based upon the signal generator settings and the fact that it's an air-filled slotted line.
2. Using the measurements from step **2a**, **determine** the **location** the electrical "open circuit" at the end of the slotted line with reference to the centimeter scale attached to the line.
   (i.e. – assume the scale does not stop at 55 cm)
3. **Answer** the question specified in step **2b** of the measurement procedure.
4. Using the consecutive voltage maxima and minima measurements from steps **2c-2f**, **locate** the (electrical) **positions** of the actual "**open-circuit**" in the **874-W03** terminator, the "**short-circuit**" in the **874-WN3** terminator, and the actual **100 Ω load**, with respect to the centimeter scale on the slotted line as a reference (i.e. – assume the scale does not stop at 55 cm).
5. Using the measurements from steps **2c-2f**, **calculate** the **electrical lengths** of the **874-W03**, the **874-L10L**, and the **874-WN3** terminators. (Note – this is **NOT** the same as wavelength)

   Hint: You already used your minima/maxima locations to locate the end of the slotted line and the position of the electrical end of the W03 terminator. The length of the W03 terminator is the difference between position of the electrical end of the W03 terminator and the end of the unterminated slotted line.
6. **Accurately draw** the standing wave **patterns** on the slotted line for steps **2c** (open) and **2f** (short) of the test procedures (without the 10cm extensions). Be sure to label the centimeter positions of the measured minima and maxima, as well as the location (position) of the actual "open" or "short" at the end of the line. (Refer to Figures 3-17 and 3-28 of your textbook.)
7. **Calculate** the theoretical **VSWR** for each of the loads used in measurement step **3** assuming that each load is accurately marked and calibrated.

   Create a **table** to **compare** the measured VSWRs with the calculated theoretical VSWRs.

Note – the entire submission must be electronically (computer) generated. Scans or pictures of handwritten material or hand-drawn diagrams will NOT be accepted for this experiment.

Kennesaw State University | **ECET 3410** Laboratory Exercise **No. 3**
Electrical Engineering Technology | **Slotted-Line Data Sheet**

Name: ______________________________________ **Section (Day/Time):** __________________
(Print Name – Last Name First)

Load	1st Min		1st Max		2nd Min		2nd Max	
	Loc. (cm)	Amp	Loc. (cm)	Amp	Loc. (cm)	Amp	Loc. (cm)	Amp
Unterminated								
Open W03								
Open W03+L10L								
Short WN3+L10L								
Short WN3								
100Ω								
50Ω								
3dB Atten. + WO3								
3dB Atten. + WN3								
6dB Atten. + WO3								
6dB Atten. + WN3								

TABLE 3.1 – SLOTTED LINE MEASUREMENTS

Appendix:

This is a discussion illustrating the effect of attenuators on observed VSWR of transmission lines. If an attenuator is placed between the load and the VSWR measurement point it will improve the VSWR compared to that observed for just the load. Equation 1 shows the reflection coefficient of a line when it has attenuation.

$$|\Gamma| = |\Gamma_{Load}| e^{-2\alpha l} \tag{1}$$

The term $e^{-2\alpha l}$ is the two-way attenuation of the voltage amplitude on the line. For lumped attenuators, the attenuation is localized to the attenuator, but the ratio of voltage amplitude attenuation has the same effect on VSWR as the 2-way attenuation on a lossy line.

A 3dB attenuator will have 6dB of 2-way attenuation, or -6dB of 2-way gain. It will attenuate both the incident and reflected wave by 3dB. So for a 3dB attenuator and an open circuit or short circuit termination ($|\Gamma| = 1$), merely convert the two-way attenuator *gain* to voltage ratio and multiply this by the reflection coefficient of the load. Equation 2 is the reflection coefficient due to an attenuator with 1-way attenuation A in dB.

$$|\Gamma| = |\Gamma_{Load}|\, 10^{-\left(\frac{2A}{20}\right)} \tag{2}$$

If A = 3dB the result is:

$$|\Gamma| = |1|\, 10^{-\left(\frac{2(3)}{20}\right)} = 0.5 \tag{3}$$

The VSWR is:

$$\text{VSWR} = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+0.5}{1-0.5} = 3 \tag{4}$$

This is considerably better than VSWR = ∞ for an open circuit. The VSWR in dB is (since Γ is a voltage ratio):

$$\text{VSWR} = 20\log_{10}(3) = 9.5\,\text{dB} \tag{5}$$

Placing small-value attenuators (≤6dB) between components in RF and microwave circuits can reduce adverse effects due to component VSWR. The disadvantage is the reduced forward gain due to the attenuator.