Lab 8: Microwave Propagation in Rectangular Waveguides

Goal

Study electromagnetic wave propagation in waveguides

Objectives

1. Generation of Microwaves using Klystron tube
2. Observe Transverse Electric (TE) modes in rectangular wave guide
3. Measurement of the rectangular wave guide wavelength

Expectations

1. You are expected to take detailed notes during each step outlined in the procedure that can be used during the lab report write-up.
2. You are expected to provide a neat table of the data that you measured where you clearly label what each data set is and include units for all measured quantities.
3. You are expected to clearly record the measured values of any components that you use.
4. You are expected to clearly record the detail related to images captured by the oscilloscope.
5. You are expected to make your final plots in a program such as Excel. Make sure that your data points appear clearly on the plots, that all axes are clearly labeled and have units.
6. If it is possible to compare your measurements with an expectation or a prediction, you are expected to do so in your lab report
7. You are expected to answer the questions encountered in this manual as well as discuss exercises given during the lectures in your lab write up.

Introduction to Concepts

Waveguides are used to transfer electromagnetic power efficiently from one point in space to another. A rectangular hollow waveguide with conducting walls is shown in Figure 1 where a and b are the inner side lengths ($a > b$) The wave is assumed to propagate in the positive z direction.

There are two modes of electromagnetic waves supported by a rectangular waveguide. The mode depends on the longitudinal (along the direction of wave propagation) component of the electric (E) or magnetic (B) fields. If $E_z = 0$ and $B_z \neq 0$ then a transfer electric wave

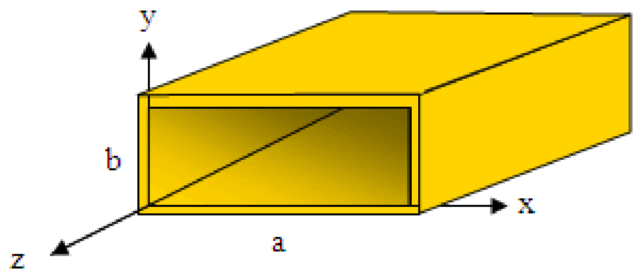

Figure 1: Rectangular waveguide geometry and ideal waveguide is invariant in z direction

(TE) wave and conversely $B_z = 0$ and $E_z \neq 0$ produce a transfer magnetic (TM) wave. The electromagnetic wave within the waveguide can be derived using Maxwell's equations with appropriate boundary conditions applies (refer to electromagnetism text book like Griffith). The allowed wavenumber (k) inside the waveguide and the frequency ($\omega = 2\pi f$) of the input electromagnetic wave are related by,

$$k = \frac{1}{c}\sqrt{\omega^2 - \omega_{mn}^2} \tag{1}$$

and,

$$\omega_{mn} = c\pi\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2} \tag{2}$$

Where a and b are dimensions of the rectangular waveguide, and ω is the input frequency. The ω_{mn} is called the "cut-off" frequency. Input frequencies less than the ω_{mn} will not propagate inside the rectangular waveguide. The lowest "cut-off" frequency for a rectangular waveguide occurs for the mode TE_{10} where,

$$\omega_{10} = c\pi/a \tag{3}$$

The electric and magnetic field patterns of the mode TE_{10} are shown in the Figure 2.

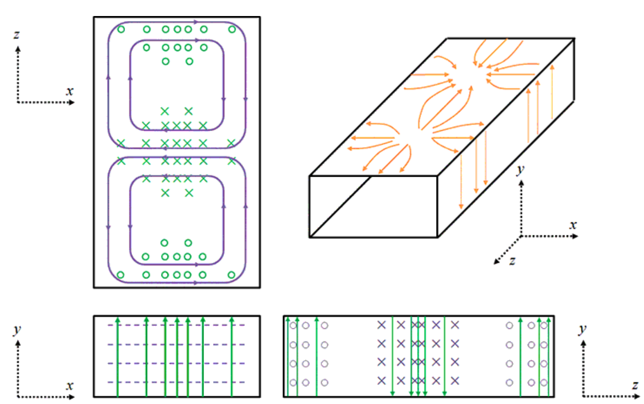

Figure 2: Fields pattern of the fundamental mode, TE_{10}. The green lines represent the E-field, the purple lines the B-field and orange lines the J-field (current density).

The Lectronic Research Labs Microwave Training Kit (LRL-550B) is a practical kit to study wave propagation in waveguides with a source of microwaves with a wavelength of about 3.3 cm (or 9 GHz). A rectangular waveguide is connected to a Klystron. The kit can be used to access the mode of operation of the waveguide and the cut of frequency. The experimental apparatus is shown in Figure 3. On left, the microwave source is attached to the wave guide. Then an attenuator waveguide is connected to the source. Purpose of it is to attenuate the transmitted EM intensity. Then a waveguide with a intensity detector is attached. A custom-made waveguide with a detector to prob EM wave intensity inside the

Figure 3: The experimental apparatus. The rectangular waveguide is connected to the microwave source

waveguide as shown in Figure 4 is attached to monitor EM waves. The detector has an output proportional to the square of the input. A cross sectional view of the detector is shown in Figure 5. The detector will change the RF signal to a DC current read using the meter located in the main power supply (see Figure 6). Then another attenuator waveguide is connected to the source. Purpose of it is to attenuate the reflected EM intensity. The waveguide is terminated with a reflector. The experiment setup is configured to produce standing waves within the waveguide.

PLEASE READ CAUTIONS CAREFULLY BEFORE CONTINUING

- **Klystrons get extremely hot when in use and must not be handled while hot! Serious burns can result.**
- **Klystron mount, power supplies, and Klystron tube plate caps have high voltages present when in use: Exercise extreme CAUTION!, Shock or death can result.**

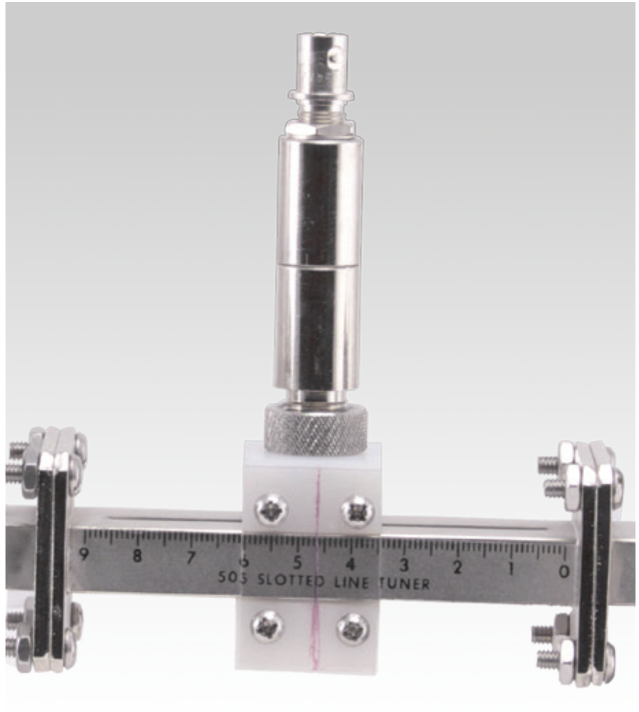

Figure 4: The slotted waveguide and the detector. The movable detector can probe along the waveguide and scan along the vertical coordinate.

- **RF power levels in this kit are not harmful, but a human eye may be damaged by low levels of radiation**
- **Do not look into any waveguide at any time when units are on.**

Preliminary Lab Questions

1. Calculate the cut-off frequency and cut-off wavelength for TE_{mn} modes $m, n = 0, 1, 2$ given $a = 2.286\ cm$ and $b = 1.016\ cm$ and tabulate the result.

2. If the input frequency to the rectangular waveguide is 9.0 GHz, using the cut-off frequencies you computed in above step, show that the only possible TE_{mn} mode for the waveguide is TE_{10} mode.

3. Using the equation 1 compute the wavenumber for the waveguide if input frequency to the rectangular waveguide is 9.0 GHz and for TE_{10} mode.

4. Given the wavenumber k = $\frac{2\pi}{\lambda}$, calculate the wavelength and frequency for the waveguide if input frequency to the rectangular waveguide is 9.0 GHz

5. The detector described in the Figure 5 reads the square of the input electric field amplitude. Find a relation for the distance between two maxima or minima and the wavelength of the electromagnetic wave?

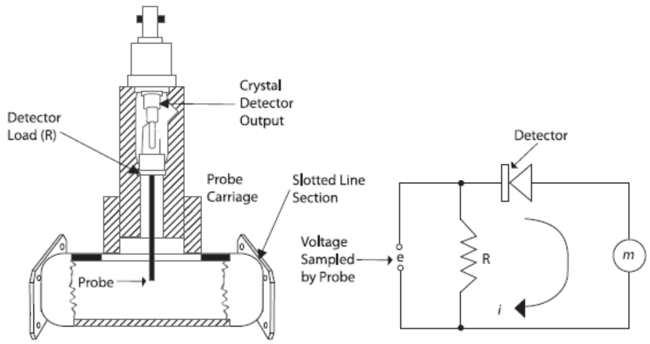

Figure 5: The slotted waveguide and the detector: (a). Cutaway Sketch of a Slotted Section with Probe, Carriage, and Detector (b). Equivalent Detector Circuit

Figure 6: The Klystron power supply, the signal amplifier and the DC current meter included in the unit 510A

Equipment and Parts

All equipments and parts are supplied with the Lectronic Research Labs Microwave Training Kit (LRL-550B)

1. Microwave source (510A) - 1
2. Klystron tube (503A) - 1
3. Waveguide attenuators (506) - 2
4. Slotted line with probe and detector (505) - 1
5. Short circuit terminator (532) - 1
6. Waveguide stands (523) - 2

Procedure

Initial Set-Up

The following steps will help you to successfully complete the experimental procedure to obtain data. Set switches and controls on 510A as follows:

1. AC Power Switch : OFF
2. Speaker Switch : ON
3. RF Switch : ON
4. Attenuator Switch : 0dB
5. Meter Switch : POWER
6. VSWR Output Control : MAX. COUNTER CLOCKWISE
7. Power Balance Control : 12 O'CLOCK
8. Klystron Repeller Control : 12 O'CLOCK

Main Set-Up

The goal is to arrange the equipment as shown in Figure 3

1. Connect 503A Klystron Tube mount to left side of 506 Variable Flap Attenuator.
2. Connect the right side of 506 Variable Flap Attenuator to left side of 505 Slotted Line
3. Connect the second 506 Variable Flap Attenuator to the right side of the 505 Slotted Line.
4. Attached the 532 Shorting Plate to the Flap attenuator.
5. Place a 523 Waveguide Stand under each side of Test Assembly, and adjust each stand until the assembly is elevated in a stable position
6. Using a BNC Cable, connect the detector on the slotted line to POWER input connector located at the center of 510A Power Supply.
7. Insert 8-Prong Plug from 503A Klystron Mount into socket located on left side of 510A Power Supply.
8. Turn ON the power supply switch in 510A
9. Allow 3-5 minutes warm-up time before taking any measurements.
10. Turn 'KLYSTRON REPELLER' knob in the 510A clockwise to about 2 o'clock.
11. Turn the **left-side** 506 Variable Flap Attenuator to 0 dB.

12. Move probe on slotted line (505) to get a maximum deflection on the DC ammeter.

13. Adjust 'POWER BALANCE' knob in the 510A to obtain a maximum DC ammeter reading. Note : Turning knob clockwise increases meter reading; counter-clockwise deceases reading.

14. Move the probe on slotted line (505) for a minimum reading.

15. Adjust the **right-side** 506 Variable Flap Attenuator for a reading of about 1/4 scale. (Note : You can also leave the 506 Variable Flap Attenuator at the maximum attenuation, 24 dB)

16. Slowly move the probe along the slotted line and measure locations of minima and maxima (node and anti-node). Use the entire available slotted line range. **Sometime the microwave signal strength drifts or change due to Klystron power fluctuations. Therefore you may need to restart your measurements if such changes occur.**

17. Repeat your measurements to collect two runs (trials) ★

18. Tabulate node and anti-node locations and intensity readings. ★

19. Using consecutive measurements of node locations calculate the wavelength of the electromagnetic wave travelling inside the waveguide (Use your knowledge of standing waves to relate distance between nodes to its wavelength) ★

20. Using consecutive measurements of anti-node locations calculate the wavelength of the electromagnetic wave travelling inside the waveguide (Use your knowledge of standing waves to relate distance between nodes to its wavelength) ★

21. Assuming the standing wave travels at speed of light, calculate the frequency of the standing wave travelled in the waveguide ★

22. Perform this calculation for all your trials ★

23. Find the average and standard deviation for wavelength and frequency of the standing wave travelled in the waveguide★

24. Using the necessary equation derived at the "Preliminary Lab Questions" calculate the expected waveguide wavelength for mode numbers $n = 0, 1, 2$ and $m = 0, 1, 2$ given the input microwaves are 9 GHz ★

25. Does any of wavelength measurements closely match to the expected waveguide wavelength for mode numbers $n = 0, 1, 2$ and $m = 0, 1, 2$ ★

26. Does your results agree with calculations? Use standard deviation and percent error to determine this ★

27. Using the equation 1 and the wavelength you measured, calculate the input wavelength to the waveguide ★

28. Using the input wavelength to the waveguide you just calculated in the above step, calculate the input frequency of the waveguide ★

29. Does your results agree with the actual input microwave wavelength and frequency? Use standard deviation and percent error to determine this ★