SAULT COLLEGE OF APPLIED ARTS & TECHNOLOGY

SAULT STE. MARIE, ONTARIO

COURSE OUTLINE

Course Title: MICROWAVE AND RADAR

Code No.: ELN 203-6

Program: ELECTRONIC TECHNOLOGY

Semester: FIFTH

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Author: NORM BARKER

New: ______ Revision: X

APPROVED: [signature] 1983-05-27
Chairperson Date

Microwave and Radar	ELN 203-6
Course Name	Course Number

PHILOSOPHY/GOALS:

Through a physical rather than mathematical approach, this course will develop in the graduates a thorough understanding of microwave generation and transmission, together with skills in microwave systems measurements. In addition the graduate will receive a general background in radar principles.

METHOD OF ASSESSMENT (GRADING METHOD):

Student performance will be evaluated by means of written tests, quizzes, and at least one seminar presentation with a supporting paper. Microwave measurement skills will be evaluated through on-going subjective judgement of individual participation in laboratory exercises together with written reports. Grading will be as follows:

A	76 - 100%
B	66 - 75%
C	55 - 65%
X	Less than 55%

TEXTBOOK(S):

INTRODUCTION TO MICROWAVE THEORY AND MEASUREMENTS (A.L. Lance)

MICROWAVE & RADAR

ELN 203-6

TEXTS: Introduction to Microwave Theory and Measurements (A. L. LANCE)

Technical Manual - Radar Type D202 (Decca Radar Ltd.)

Microwave Theory & Measurements (H.P.)

Hewlett Packard Application Notes

REFERENCE TEXTS:

Microwave Theory and Application (Stephen F. Adam)

Principles of Radar (M.I.T. Radar School Staffs)

Microwave Semiconductor Devices and Circuit Applications (H. A. Watson)

Introduction to Radar Systems (Skolnik)

Hewlett-Packard Application Notes

Introduction to Microwaves (Wheeler)

Generation and Transmission of Microwave Energy (U.S. Army, TM 11-673)

COURSE OUTLINE

	TOPIC	Periods Lec	Lab	Topic Description	Assignment
Block 1	1	6		Review Transmission Line Theory	1
	2	6		Waveguides Propagation within rectangular waveguides Formation of λg wave patterns Modes of operation Group & phase velocities Methods of coupling Waveguide Hardware Cylindrical Waveguides	2
		4	3	Waveguide Components Impedance Matching Devices Terminations Waveguide Junctions Directional Couplers Radiating Elements Ferrite Devices	3
	3	1	2	Microwave Dectors	
	4	2	1	Cavity Resonators Field Patterns Tuning Methods Applications	
Block 2	5	6	6	Microwave Sources (vacuum tube) Klystron Magnetron Travelling wave tube Backward - wave oscillator	4
	6	1	3	Microwave Semiconductor Devices Gunn Diode Yig Tuning Pin Diode Modulator & source levelling Step Recovery Diode & Harmonic Generation Impatt Diode	5
Block 3	7	3	20	Microwave Measurement Frequency Power Attenuation S.W.R. Impedance Smith Chart Applications Microwave Measuring Instruments - theory of operation Microwave Detectors	6 7

COURSE OUTLINE

	TOPIC	Periods Lec	Lab	Topic Description	Assignment
Block 4	8			Radar Principles	
		10		Classification of Radars - pulse, FM, doppler	8
				Minimum & maximum range considerations	
				Range Discrimination	
				Position Determination - polar & rectangular	
				Classification - search, track, etc.	
				Display systems	
				Duplexers	
				Antenna Systems & scanning techniques	
	9			The Canadian Radar System	
		6		MOT and Defense systems	
				Binary integration of radar video	
				Statistical analysis of digitized signals	
				Detection of Radar Signals in Noise	
Block 5	10			Decca Marine Radar	
		15	6	Detailed Circuitry study	
				Testing & adjusting	

TEACHING OBJECTIVES

and

LAB EXPERIMENTS

M I C R O W A V E   A N D   R A D A R

ELN 203-5

Specific Objectives

1. Recall that a non-resonant transmission line is an infinite length of transmission line or a line terminated by a resistance equal to the characteristic impedance (Zo) of the line.

2. Summarize the conditions that exist on a non-resonant line.

3. Recall that a resonant line is one that is not terminated by R = Zo.

4. Draw diagrams to show standing waves of E and I on an open circuited line and shorted line.

5. Recall the following expressions and use them in solving transmission line problems.

$$SWR\ (\sigma) = \frac{E_{MAX}}{E_{MIN}}$$

$$Zo = \sqrt{\frac{L}{C}}$$

$$\text{Reflected voltage} = \text{incident voltage} \times \frac{R_L - Zo}{R_L + Zo}$$

where R_L = terminating resistor

$$\text{Coefficient of relection } (r) = \frac{\sigma - 1}{\sigma + 1}$$

$$\text{Zo of matching transformer} = \sqrt{Z_S \times Z_R}$$

where Z_S = sending-end impedance

Z_R = receiving-end impedance

Specific Objectives

BLOCK 1 - Waveguides Topic 2

1. Summarize the advantages and disadvantages of waveguides over coax lines.

2. Recall that energy propogates along a waveguide in the form of electrostatic and magnetic fields.

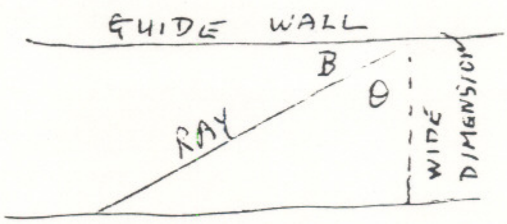
3. Recall the following conditions necessary for the propogation of energy in a waveguide:

   a) Wavefronts are reflected at the interior wall of the waveguide and that the reflected angle is equal to the incident angle.

   b) The angle of incidence (made by the ray A the guide wall) is related to (in air) and the wide dimension of the waveguide such that

$$\sin \angle B = \frac{n \lambda_c}{2b} \quad \text{OR} \quad \cos \theta = \frac{\lambda}{2b}$$

   when B is the angle of incidence and n is an integer and is unity for the fundamental mode, and b is the wide dimension of the waveguide. Refer to FIG. 1.



   c) The wavefront is inverted on reflection.

4. Describe the boundary conditions that must be satisfied for propogation within a waveguide.

   a) the field must be continuous through the region in which the dielectric is constant; the frequency must therefore be the same throughout that region.

Specific Objectives

BLOCK 1 - Waveguides Topic 2 continued

4. b) the electrostatic field is always perpendicular to the surface on which it acts: at the waveguide wall there is no component of the electrostatic field parallel to the wall.

   c) the electrostatic and magnetic fields are perpendicular to each other.

5. Recall that the cut-off frequency λ_c is that frequency for which Sin B is unity, that is when

$$\lambda_a = 2b$$

6. Recall that the guide wavelength $\lambda_g = \frac{\lambda_c}{\cos B}$ and λ_g is therefore greater than λ_a.

7. Calculate λ_g and λ_c when guide dimensions and frequency are known.

8. Recall the system of mode identification for rectangular and circular waveguides.

9. Reproduce from memory drawings to illustrate the dominant mode in:

   a) rectangular
   b) circular waveguides

10. Describe in qualitative terms, group and phase velocities, and calculate their values when given the information to determine $\angle B$ in #3 above. OR $\angle \theta$

11. Describe in qualitative terms, methods of coupling energy into and out of waveguides [probe, loop, aperture].

12. Reproduce from memory drawings to illustrate methods of achieving impedance matching in waveguides:

Stubs	transformer
Partitions	tuning slugs
Flared sections	

13. Recall the constraints on twists and bends.

Specific Objectives

BLOCK 1 - Waveguides Topic 2 continued

14. Reproduce from memory a drawing of each of the following items and explain the operation in qualitative terms:

    a) magic tee
    b) directional coupler
    c) choke joint

15. Identify radiating and non-radiating slots in a waveguide wall.

16. Discuss the advantages and disadvantages of waveguides.

17. Discuss in qualitative terms the following characteristics of ferrite devices:

    a) composition
    b) properties pertinent to microwave technology
    c) gyromagnetic resonant frequency

18. With the aid of diagrams describe the action of the following ferrite devices:

    a) isolator
    b) coupler
    c) faraday rotator

19. Illustrate and explain the application of ferrite circulators in a system employing two transmitter receivers (main and standby) and a single antenna.

20. a) Sketch a rotary vane phase shifter and discuss its construction.

    b) Recall that the input 90°- differential phase section receives energy in the TE_{11} mode and produces two E fields, one parallel to the dielectric and the other perpendicular to it. The former of the two fields has the greater propagation constant and is delayed by 90°. The resultant field consists of two orthogonally polarized TE_{11} Fields of equal amplitude and 90 electical degrees apart, which constitutes a circularly polarized field rotating in a CW direction.

    c) The half-wave (centre) section resolves each of its two input fields into two components, one parallel to and one perpendicular to its dielectric plate. Its output can be represented by two E vectors 180 electrical degrees apart and rotating at twice the angular velocity of the $\lambda/4$ wave signal.

    d) The output $\lambda/4$ section recombines the fields of the centre section and produces a linearly polarized field having the same direction of the incident field but with a phase change of 2 θ where θ is the angle through which the half-wave (centre) section was rotated with respect to the $\lambda/4$ plates.

Specific Objectives

BLOCK 1 - Microwave Detectors   Topic 3

1. Recall and discuss the characteristics of crystal detectors and bolometers (barretters and thermistors) under the following headings:

   a) Physical Construction
   b) Power Handling
   c) Sampling Method
   d) Load Impedance
   e) Temperature Coefficient
   f) Sensitivity and Response Curve
   g) Time constant
   h) Application
   i) Testing
   j) Care in Using and Handling
   k) Interpretation of Manufacturers' Data

MICROWAVE SOURCES (vacuum tube)

Specific Objectives

BLOCK 1 - Cavity Resonators Topic 4

1. Recall that cavity resonators have a very high Q and are used at microwave frequencies in place of L-C circuits; that they consist of a hollow chamber with conducting walls, usually plated on the inside with a good conducting metal.

2. Recall that a cavity resonator may be of any shape but always can be considered as a distorted version of simple resonator consisting of a length of waveguide, either circular or rectangular, terminated at both ends by conducting walls.

3. Recall that its resonant frequency is determined by the physical dimensions of the cavity.

4. Recall that energy exists in the cavity in the form of electrostatic and magnetic fields, and the boundary conditions for waveguides apply to cavity resonators.

5. Recall that the modes of operation are identified in a manner similar to those in waveguides but with the addition of a third subscript indicating the number of patterns along the length of the cavity.

6. Recall that cavity resonators may be tuned by changing the physical dimensions of the cavity, adjusting the penetration of a tuning plug or adjusting the orientation of a tuning paddle.

7. Recall that energy may be coupled into or extracted from a cavity resonator by means of coupling loops, dipoles or apertures.

8. Reproduce from memory the equivalent circuit of a wavemeter tuneable cavity and describe its operation in qualitative terms.

9. Reproduce from memory and describe in qualitative terms how an absorption type wavemeter may be used to determine the frequency of a signal within a waveguide.

10. Drawing the equivalent circuit of an echo box and describe how it may be used to monitor the operation of a transmitter - receiver system.

Specific Objectives

BLOCK 2 - Multi-Cavity Klystron Topic 5

1. Physical Construction

   Reproduce from memory a diagram to show the principle components and DC potentials with respect to the cathode.

   Electron gun. Two re-entrant resonant cavities concentric with electron beam. Collector

2. Explain in qualitative terms the manner in which the electron beam is velocity modulated by the RF electrostatic field developed by the buncher grids: that bunching action results in no net interchange of energy between beam and cavity.

3. Explain in qualitative terms that the second cavity [in a two cavity system] must be critically located with respect to the electron beam. That the signal developed in the second [catcher] cavity will be an amplified version of the signal in the first (buncher) cavity.

4. The buncher cavity may be excited by a signal coupled in from a coax line, and RF power may be coupled from the second cavity to a transmission system.

5. With correct cavity spacing, critically - adjusted operating voltages, and feedback from the second to the first cavity, the device will operate as a microwave oscillator.

6. When more than two cavityies are used it is possible, with critical adjustment, for all cavities except the first to absorb energy from the electron beam and improve velocity modulation for the next cavity.

Specific Objectives

BLOCK 2 - Reflex Klystron Topic 5

1. Reproduce from memory, a diagram showing the principle components (electron gun, cavity-grid assembly and repeller). Include in this diagram the relative DC voltages and explain why the tube must not be operated without - ve potential on the repeller.

2. Explain qualitatively the manner in which the electron beam is velocity modulated.

3. Explain in qualitative terms how magnitude of repeller voltage determines electron penetration of the drift space and thus adjusts the mode of oscillation.

4. Describe in qualitative terms the different power and bandwidth characteristics of the three modes of opertion which are usually within the range of repeller control.

5. Ability to turn on and adjust the reflex klystron for opimum performance, at the same time observing precautions for the safety of the klystron and the auxillary equipment. To this extend an ability to read and understand the manufacturer's specifications is essential.

6. Except for the energy that may be coupled in to the first cavity from an external source, all the energy extracted from a klystron is supplied by the electron beam source.

1. <u>Define</u> Multicavity velocity - modulated system employing a special diode powerful magnetic field show the physical construction of a multicavity electron resonance megnetron.

3. Describe in qualitative terms how the combined electrostatic and magnetic fields can be adjusted to produce the spiraling electron paths required for oscillation.

4. Recall that RF energy can be extracted from one of the cavities for couplir to the transmission system; and that the source of this energy is the elect beam supply.

5. Recall that the desired mode is 180° phase shift between cavities and that operation in this mode is ensured by anode block strapping.

6. Recall that electron bombardment causes cathode heating and necessatates reduction (or removal) of heater current when the magnetron is operating.

7. Understand the REIKE diagram to the extent that:

   a) frequency "pulling" is maximum when the load is adjusted for maximum pow

   b) the load must be adjusted for minimum VSWR to minimize frequency pulling

8. Recall that changing the position of the end plates effects the electron pa and is used to effect the resonant frequency of tunable magnetrons. Recall other methods of tuning - plug, vane.

9. Recall that magnetrons may be operated in a CW mode or may be modulated by pulses ranging from 10 KV to 50 KV.

10. With the aid of diagrams, describe the methods used to monitor magnetic operation:

    a) cathode current metering

    b) filament current metering

    c) high voltage metering and control

    d) output power and frequency measurement

    e) spectrum analysis

11. Recall the symptoms characteristic of arcing and the malfunctions that can cause arcing.

12. Recall the precautions to be observed in installing and seasoning (hardenin a new magnetron.

Specific Objectives

BLOCK 2 - Backward Wave Oscillator (B.W.O.) Topic 5

1. Draw a simple diagram to show the construction of a B.W.O.

2. Recall that the electron beam is a "Hollow Cylinder" passing close to the helix turns and is focussed by a strong axial magnetic field which allows movement only in the direction of the axis of tube.

3. Recall that oscillation begins in the B.W.O. when a random variation in the electron beam induces a wave in the helix winding, such a wave travelling backward (towards the electron gun) causes velocity modulation of the electron beam which results in bunching.

4. a) With the aid of a simple diagram explain how the "electronic fields" between three consecutive turns of the helix produces bunching.

   b) Recall that the maximum coupling between the helix wave and the gun occurs midway between turns and is minimum directly under the helix turns.

   c) Recall that the phase relationship between the helix wave and the velocity of the electron beam is such that any specific portion of the beam will be affected by an electric field of the same phase as it passes successive gaps along the helix wave.

5. Recall that the average electron velocity of the beam is slightly greater than the effective velocity of the helix wave.

6. Recall that the density of electron bunches increases according to a sinewave relationship as the beam progresses towards the collector.

7. Recall that the helix wave moves toward the gun and gains amplitude in a sinusoidal manner.

8. Recall that as the velocity of the electron beam is varied the phase delay of each regenerative (coupling loop between mid-turn points) will be changed. Provided that the beam current is great enough these loops will oscillate at a frequency such that the phase delay of each loop is equal to one cycle.

Specific Objectives

BLOCK 2 - Gunn Diode Topic 6

1. With the aid of a simple diagram describe the structure of a Gunn Diode.

2. Recall the "Gunn effect" - When the DC bias across A gallium Arsenide sandwich is raised to A threshold value (approximately 3 KV per cm) oscillation in the microwave region is produced.

3. Draw from memory a curve to show the typical current vs electric field characteristic of a Gunn Diode.

4. Recall that the curve may be accounted for as follows:

   During the positive portion of the curve the current increases as an increasing number of valence electrons pass into the normal (lower) conductionband, in this band electrons have low energy and high velocity. At the threshold value and during the negative resistance part of the curve some electrons pass to a second conduction band where they have high energy and low velocity.

5. Recall that because electrons travel at different speeds in the negative resistance region A bunching effect is produced. The bunching produces "E field domains" which drift from the negative to the positive domain reaches the positive terminal, and coincidently A new E domain forms at the cathode.

6. Draw from memory a simple diagram showing a Gunn Diode mounted in a tuneable cavity.

7. Recall that:

   a) The frequency of the output is principally determined by the physical thickness of the wafer.

   b) There are several techniques which can be used to tune a Gunn Device Oscillator:-

      Bias Control
      Mechanical tuning of the resonant cavity
      Variable permeability (ferrite)
      Varactor tuning
      YIG spheres

   c) Bias control tuning is usually unsatisfactory because the degree of frequenet variation and its sign will vary from one device to another.

   d) There will be a considerable variation in output power with frequency.

   e) The device most commonly used for electronic tuning is the varactor.

   f) Gunn Diodes are available for operation in the S, J and Q bands.

   g) Typical operation is from a stable D.C. source between 6 and 12 V at 100 - 200 M.A.

Specific Objectives

7. h) Typical power output lies between 2 and 20 MW at specified frequencies.

8. Recall that the extremely fast switching characteristic (ns) allows generati of extremely short pulses (3 ns) and therefore extremely accurate distance measurement.

9. Recall that doppler mode operation of the Gunn Diode permits detection of ve slight movement, even normal breathing, in an area under surveillance. Doppler measurement to within 0.15 metres an application is the high precisi docking of Super - Tankers.

MICROWAVE MEASUREMENT

Specific Objectives

BLOCK 3 Topic 7

1. Given: the HP microwave laboratory equipment

   an SWR meter

   and RF power meter

   an oscilloscope

   assemble a waveguide circuit and perform the following operations:

   A. adjust the klystron for optimum operation at a stipulated frequency.

   B. measure the VSWR of the system.

   C. adjust the system for minimum VSWR.

   D. measure the power in the waveguide.

   E. determine the attenuation of microwave components.

   F. with the aid of a Smith chart determine the impedance of a given load.

2. Draw a functional block diagram of the following test equipment and explain the purpose of each block.

   A. SWR meter

   B. Power meter

3. Draw a functional block diagram of the klystron power supply and explain the purpose and opertion of the protection circuits.

4. Using the equipments listed above investigate the characteristics of a Gunn Diode Oscillator.

Specific Objectives - Smith Chart

1. Given the quadrature components of a load and the Z_0 of a transmission line determine the normalized impedance of the load.

2. Given the normalized impedance of a load, use the Smith chart to determine:

   a) SWR on a transmission line

   b) Impedance at some specified point on the transmission line

3. Using the Hewlett-Packard micorwave laboratory equipment the SWR meter and the Smith chart "determine the impedance of a given load" device.

Specific Objectives

BLOCK 4 Topics 8 & 9

1. Recall that there are three methods used for detection by radar:

   Continuous wave (CW)
   Frequency modulation (FM)
   Pulse modulation (PM)

2. Recall that the CW method makes use of the DOPPLER effect.

3. Explain the Doppler effect in qualitative terms and recall that

$$\text{Doppler frequency (fd)} = \frac{2\ ft\ Vr}{c}$$

where ft = transmitter frequency
Vr = target radial velocity
c = speed of light

4. Recall that the CW method is most effective with targets having a high radial velocity. The difference frequency (ft - fd) is used to determine presence and speed of a moving target.

5. Recall that in the FM method the transmitter frequecny is varied continuously and at a preceise rate over a specified frequency band. The frequency of a received signal is compared with the instantaneous transmitter frequency. The difference between the two frequencies depends on the distance travelled by the reflected signal and is used as a measure of range.

6. Recall that in the FM method the Doppler effect causes range inaccuracy in the case of moving targets and this method is therefore less effective with targets whose radial velocity is high.

7. Recall that in the PM method energy is transmitted in short pulses; 0.1 - 50 micro-secs. and that range is determined on the basis of the travelling time of reflected signals.

8. Recall that the speed of radio waves is 6.18 micro-secs. per nautical mile (NM) and the return time of a received signal is therefore 12.36 micro-secs. per NM.

9. Reproduce from memory drawings to illustrate "A", "B", PPI (C) and D type presentations.

Specific Objectives

BLOCK 4 Topics 8 & 9 continued

10. Recall that accuracy of range measurement is effected by the sharpness of the leading edge of the pulse together with the ability to time the arrival of the leading edge.

11. Describe in qualitative terms how range resolution (discrimination) and minimum range are effected by the duration of the pulse.

12. Recall that radar maximum range is determined by:

    Tx power output
    Receiver sensitivity
    Pulse recurrence frequency (PFR)

13. Explain in qualitative terms how the antenna beam width effects the accuracy of determining agimuth end elevation angles and angular resolution (discrimination).

14. a) With the aid of diagrams, explain how the polar co-ordinates (Slant Range, Azimuth and Elevation) may be converted to rectangular co-ordinates.

    b) Explain how processing of rectangular co-ordinates permits prediction of future position of the "Radar Target".

15. With the aid of diagrams, describe the role and characteristics of:

    Tracking radars
    Search radars
    Height finder radars
    Beacon (IFF) radars

16. Reproduce from memory a functional block diagram of a pulsed radar and explain the function of each block.

17. Recall that the relationship between transmitter average power and peak power is given by:

$$\frac{\text{Average Power}}{\text{Peak Power}} = \frac{\text{Pulse width}}{\text{Pulse repetition time}}$$

18. Recall that the duty cycle = $\frac{\text{pulse width}}{\text{pulse repetition time}}$

Specific Objectives

BLOCK 4 Topics 8 & 9 continued

19. Given the radar equation below qualitatively, explain each of its terms.

$$R_{Max} = \frac{1}{2\sqrt{\pi}} \sqrt[4]{(P_t T) \times \left(\frac{1}{Wr_{Min}}\right) \times (G_t A_r) \times A_o}$$

20. With the aid of functional block diagrams, describe the operation of:

    A. FM type radar
    B. CW type radar

21. Recall the reasons for using a duplexer in a transmission line system.

22. With the aid of simple diagrams, describe the operation of a duplexer in a waveguide system.

23. Recall that an artificial line may be used to accomplish the following tasks:

    A. Develop a rectangular pulse
    B. Effect a time delay
    C. Store energy

24. With the aid of simple drawings describe the charging of an artificial line under the following conditions.

    A. Zo = Z source

    B. Zo Z source

    C. Zo Z source

25. With the aid of simple diagrams describe D.C. resonant charging of a pulse forming network and explain the purpose of a "hold-off" diode.

26. A. Illustrate and describe the technique of binary integration of radar receiver signals.

    B. With the aid of block diagrams and other illustrations, describe how each quantized signal (video hit) is stored in the appropriate range bin (usually ¼ mile) of memory, together with other pertinent information such as azimuth and altitude.

    C. Recall that storing hits from several previous sweeps allows processing of data covering the width and range of the antenna beam pattern.

    D. With the aid of illustrations explain how the sliding window allows monitoring of hit history during each range cell period.

Specific Objectives

BLOCK 4 Topics 8 & 9 continued

26. E. Recall that when a valid target is identified a synthetic signal is produced for display on a random access plan position indicator (rappi) at the appropriate range and azimuth. The symbol indicates which types of radar identified the target and the system may provide further information such as flight number, altitude, etc. on request.

F. With the aid of illustrations describe the statistical analysis of quantized radar video under the following headings:

A) Hits per Scan
B) Beam Splitting for Azimuth Determination
C) Probability of False Alarm
D) Adjustment of False Alarm Rate
E) Automatic Clutter Elimination (ACE)

Specific Objectives

BLOCK 5

Topic 10

DECCA MARINE RADAR D202

1. Draw a block diagram of the D202 radar; name the blocks and signals, and describe the operation at this level.

2. Given the detailed schematic diagrams explain the operation of any section of the system illustrating with waveforms as necessary.

3. Perform the tests and adjustments contained in the service manual.

4. Demonstrate the ability to troubleshoot the system and isolate failed components.

5. Conduct performance tests of TH transmitter and transmission system.

Lab Experiments 1 to 8 -- Refer to Hewlett-Packard Microwave Lab Manual

LAB EXPERIMENT #9

1. Determine the impedance of the Horn Antenna
2. Use a Slide-Screw Tuner to achieve min. swr.
3. Determine: Power Radiated
   Power Reflected
4. Develop a system to plot the radiation pattern of the Horn Antenna.

LAB EXPERIMENT #10

Investigate the characteristics of a Gunn Diode.