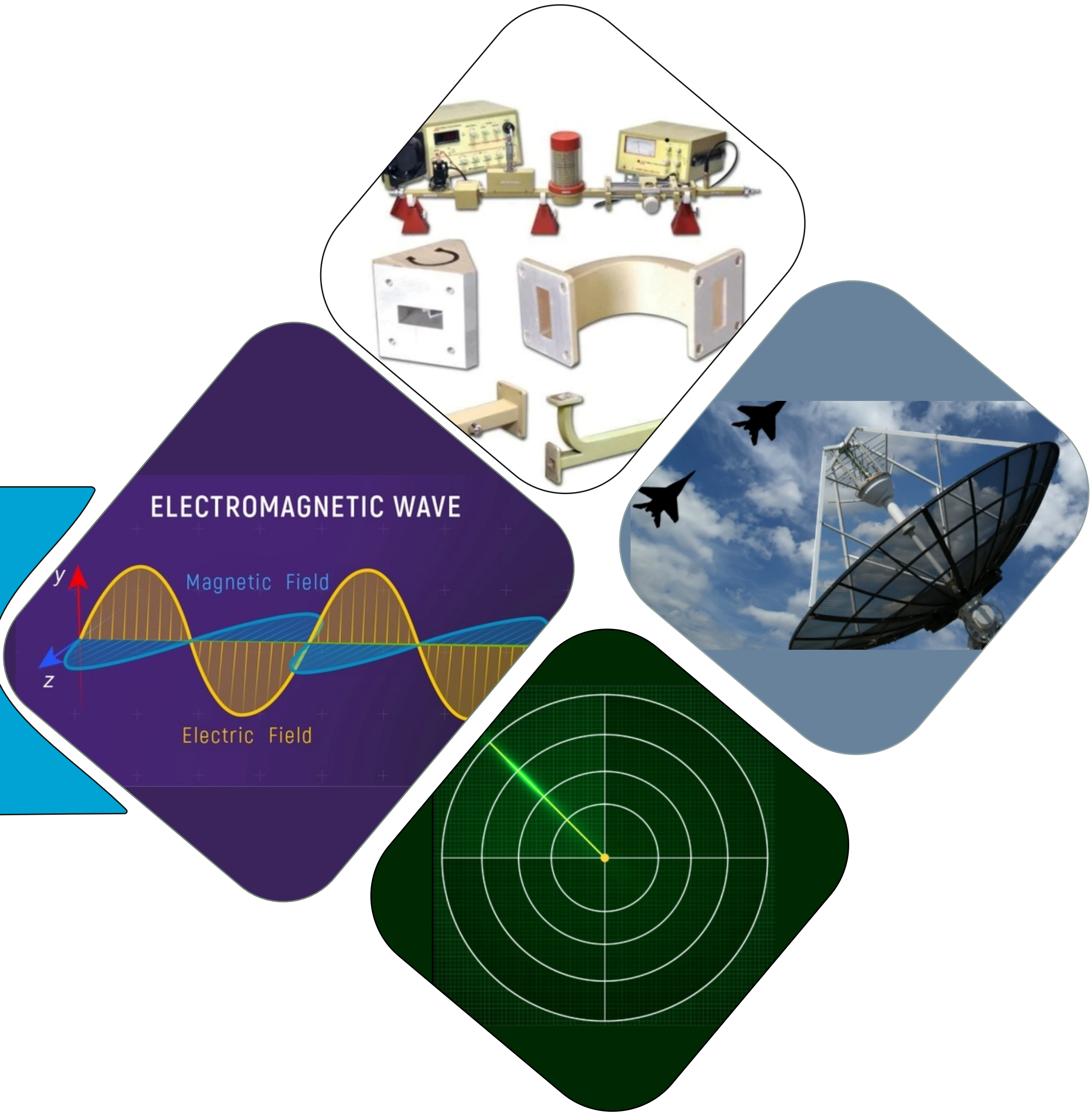
SCHEME :K

Name :_______________________________
Roll No.:__________ Year : 20 ____ 20 ___
Exam Seat No. :_______________________

LABORATORY MANUAL FOR

MICROWAVE ENGINEERING & RADAR SYSTEM (315342)



ELECTRONICS ENGINEERING GROUP

MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION, MUMBAI
(Autonomous)(ISO21001:2018)(ISO/IEC27001:2013)

VISION

To ensure that the Diploma Level Technical Education constantly matches the latest requirements of technology and industry and includes the all-round personal development of students including social concerns and to become globally competitive, technology led organization.

MISSION

To provide high quality technical and managerial manpower, information and consultancy services to the industry and community to enable the industry and community to face the changing technological and environmental challenges.

QUALITY POLICY

We, at MSBTE, are committed to offer the best-in-class academic services to the students and institutes to enhance the delight of industry and society. This will be achieved through continual improvement in management practices adopted in the process of curriculum design, development, implementation evaluation and monitoring system along with adequate faculty development Programs.

CORE VALUES

MSBTE believes in the followings:

- Skill development in line with industry requirements.
- Industry readiness and improved employability of Diploma holders.
- Synergistic relationship with industry.
- Collective and cooperative development of all stake holders.
- Technological interventions in societal development.
- Access to uniform quality technical education.

A Laboratory manual
for

Microwave Engineering and RADAR System

(315342)

Semester – V

(DE/EJ/ET/EX/IE/TE)

Maharashtra State
Board of Technical Education, Mumbai

(Autonomous) (ISO 21001:2018) (ISO/IEC 27001:2013)

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Board of Technical Education, Mumbai
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4th Floor, Government Polytechnic Building, 49, Kherwadi,
Bandra (East), Mumbai – 400051.

MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION

Certificate

This is to certify that Mr./Ms. ……………………………………………. Roll No. ………. Of fifth Semester of Diploma in ……………… of Institute …………………………………………………………….. (Code: ………) has attained pre-defined practical outcomes (PROs) satisfactorily in course **Microwave Engineering and RADAR System (315342)** for the academic year 20…… to 20…… as prescribed In the curriculum.

Place: …………… Enrollment No.: ……………

Date: …………… Exam Seat No.: ……………

Course Teacher **Head of Department** **Principal**

Seal Of Institute

Preface

The primary focus of any engineering laboratory/field work in the technical education system is to develop the much-needed industry relevant competencies and skills. With this in view, MSBTE embarked on this innovative 'K' Scheme curricula for engineering diploma programs with outcome-based education as the focus and accordingly, a relatively large amount of time is allotted for the practical work. This displays the great importance of laboratory work, making each teacher, instructor and student realize that every minute of the laboratory time needs to be effectively utilized to develop these outcomes, rather than doing other mundane activities. Therefore, for the successful implementation of this outcome-based curriculum, every practical has been designed to serve as a ***'vehicle'*** to develop this industry identified competency in every student. The practical skills are difficult to develop through 'chalk and duster' activity in the classroom situation. Accordingly, the 'K' scheme laboratory manual development team designed the practicals to ***focus*** on the ***outcomes***, rather than the traditional age-old practice of conducting practical's to 'verify the theory' (which may become a byproduct along the way).

This laboratory manual is designed to help all stakeholders, especially the students, teachers and instructors to develop in the student the predetermined outcomes. It is expected from each student that at least a day in advance, they have to thoroughly read through the concerned practical procedure that they will do the next day and understand the minimum theoretical background associated with the practical. Every practical in this manual begins by identifying the competency, industry relevant skills, course outcomes and practical outcomes which serve as a key focal point for doing the practical. The students will then become aware about the skills they will achieve through the procedure shown there and necessary precautions to be taken, which will help them to apply in solving real-world problems in their professional life.

This manual also provides guidelines to teachers and instructors to effectively facilitate student- centered lab activities through each practical exercise by arranging and managing necessary resources in order that the students follow the procedures and precautions systematically ensuring the achievement of outcomes in the students.

Microwave engineering plays a crucial role in the design and development of communication system, antennas, waveguides, and microwave devices. Simultaneously, radar system are integral to defense, weather forecasting, navigation, and traffic management. Understanding the principles behind the operation of microwave components and radar system is essential for aspiring engineers in the field of electronics, communication, and applied system.

Although best possible care has been taken to check for errors (if any) in this laboratory manual, perfection may elude us as this is the first edition of this manual. Any errors and suggestions for improvement are solicited and highly welcome.

Program Outcomes (POs)

Following program outcomes are expected to be achieved through the practical of the course.

PO1: Basic and Discipline specific knowledge: Apply knowledge of basic mathematics, science and engineering fundamentals and engineering specialization to solve the broad-based Electronics Engineering group program problems.

PO2: Problem analysis: Identify and analyze well-defined Electronics Engineering group program problems using codified standard methods.

PO3: Design/ development of solutions: Design solutions for well-defined technical problems and assist with the design of Electronics Engineering group program systems components or processes to meet specified needs.

PO4: Engineering Tools, Experimentation and Testing: Apply modern Electronic Engineering group program tools and appropriate technique to conduct standard tests and measurements.

PO5: Engineering practices for society, sustainability and environment: Apply appropriate Electronics Engineering group program technology in context of society, sustainability, environment and ethical practices.

PO6: Project Management: Use Electronics Engineering group program management principles individually, as a team member or a leader to manage projects and effectively communicate about well- defined engineering activities.

PO7: Life-long learning: Ability to analyze individual needs and engage in updating in the context of Electronics Engineering group program technological changes.

List of Industry Relevant Skills

The following industry relevant skills of the competency "Maintain telecommunication systems which contains microwave components." are expected to be developed in the student by undertaking the practical of this laboratory manual

1. Use relevant electronic component, measuring instruments, equipment to carryout.
2. Inspect given component/electronic circuit.
3. DO circuit connections as per the given circuit diagram, carryout measurements, plot graph and do necessary calculations.
4. Maintain electronic circuit.
5. Construct simple electronic circuit.

Practical - Course Outcome matrix

Course Level Learning Outcomes (COs)

CO1 - Select waveguide for given microwave communication system.

CO2 - Test performance of microwave components.

CO3 - Construct RF circuits using RF devices.

CO4 - Interpret working of RADAR based systems for range detection.

CO5- Maintain SONAR and various types of RADAR systems as microwave application.

Sr. No.	Title of the Practical	CO 1	CO 2	CO 3	CO 4	CO 5
1.	Measurement of VSWR and reflection coefficient for the given length of transmission line	✓	-	-	-	-
2.	Determination of the frequency and wavelength of rectangular waveguide for TE10 mode.	✓	-	-	-	-
3.	Measurement of power division in microwave tees E-plane, H- plane and E-H plane using microwave test bench setup	-	✓	-	-	-
4.	Determination of coupling factor and insertion loss of the given circulator and isolator	-	✓	-	-	-
5.	Measurement of phase shift of microwave phase shifter	-	✓	-	-	-
6.	Determination of tuning range of Reflex Klystron Microwave Tube	-	-	✓	-	-
7.	Determination of output power and frequency of Gunn diode and plot its V-I characteristics.	-	-	✓	-	-
8.	Determination of the maximum range of Doppler RADAR	-	-	-	✓	-
9.	Determination of the rotations per minute (RPM) of a moving object using RADAR.	-	-	-	✓	-
10.	Simulation of RADAR based practical’s using any freeware/open-source simulation software	-	-	-	✓	-

Guidelines to Teachers

1. Teacher should provide the guideline with demonstration of practical to the students with all features.
2. Teacher shall explain prior concepts to the students before starting of each practical.
3. Involve students in the performance of each experiment.
4. Teacher should ensure that the respective skills and competencies are developed in the students after the completion of the practical exercise.
5. Teachers should give opportunities to students for hands-on experience after the demonstration.
6. Teacher is expected to share the skills and competencies to be developed in the students.
7. Teacher may provide additional knowledge and skills to the students even though not covered in the manual but are expected of the students by the industry.
8. Finally give practical assignments and assess the performance of students based on tasks assigned to check whether it is as per the instructions.
9. Teacher is expected to refer complete curriculum document and follow guidelines for implementation
10. At the beginning of the practical which is based on the simulation, teacher should make the students acquainted with any simulation software environment.

Instructions for Students

1. Listen carefully to the lecture given by the teacher about course, curriculum, learning structure, skills to be developed.
2. Organize the work in the group and make a record of all observations.
3. Do the calculations and plot the graph wherever it is required in the practical
4. Students shall develop maintenance skills as expected by industries.
5. Student shall attempt to develop related hand-on skills and gain confidence.
6. Student shall develop the habits of evolving more ideas, innovations, skills etc. those included in scope of manual
7. Student should develop the habit to submit the practical on date and time.
8. Student should prepare well while submitting a write-up of exercise.

Content Page

List of Practical's and Progressive Assessment Sheet

Note: Out of above suggestive LLOs -

- '*' Marked Practical's (LLOs) Are mandatory.
- Minimum 80% of above list of lab experiment are to be performed.
- Judicial mix of LLOs are to be performed to achieve desired outcomes.

Practical No. 1: Measurement of VSWR and reflection coefficient for the given length of transmission line

I Practical Significance:

High VSWR or reflection coefficient indicates a significant amount of power is reflected back to the source, potentially causing issues like reduced signal strength, distortion, and instability in the system.
In antenna systems, VSWR directly impacts the efficiency and radiation pattern of the antenna. High VSWR can lead to reduced radiation efficiency, loss of gain, and unintended side lobes. Understanding VSWR and reflection coefficient helps in designing transmission lines that are well-matched to the load, minimizing signal reflections and ensuring efficient power transfer. Impedance matching is crucial for efficient power transfer between a signal source and a load VSWR and reflection coefficient measurements help in identifying mismatches and implementing impedance matching techniques.
High VSWR or reflection coefficient values can point to problems such as incorrect load impedance, damaged transmission line, or faulty components, aiding in troubleshooting and maintenance.

II Industry / Employer Expected outcome(s)

Accurately measuring VSWR and the reflection coefficient is critical for maintaining the integrity of signal transmission, maximizing power delivery, and ensuring that systems meet industry standards, ultimately leading to improved system performance and reduced maintenance costs.

III Course Level Learning outcome(s)

- CO1 - Select waveguide for given microwave communication system.

IV Laboratory Learning outcome(s)

- LLO 1.1 Calculate VSWR and reflection coefficient for given length of transmission line.

V Relevant Affective Domain related outcome(s)

- The measurement process can not only provide technical knowledge but also foster essential skills and attitudes for success in future engineering endeavors.

VI Relevant Theoretical Background.

The electromagnetic field at any point of transmission line may be considered as sum of two traveling waves the incident wave and reflected wave. The reflected wave is set up by reflection of incident wave from the load impedance the presence of two traveling waves. Give rise to standing wave along the line. The maximum field strength is found where two waves are in phase & minimum where two waves add in opposite phase the distance between two successive minimum (or maximum) is half the guide wavelength on the line The ratio of electrical field is called reflection Co-efficient. The voltage standing wave ratio

(VSWR) is defined as ratio between maximum & minimum field strength along the line

Hence VSWR, S =Emax/Emin

Reflection Co-efficient, ρ =Er/Ei

The above equation gives following Eq

$$|\rho|=|S-1/S+1|$$

VII Circuit diagram.

a. Sample Circuit/Experimental Setup:

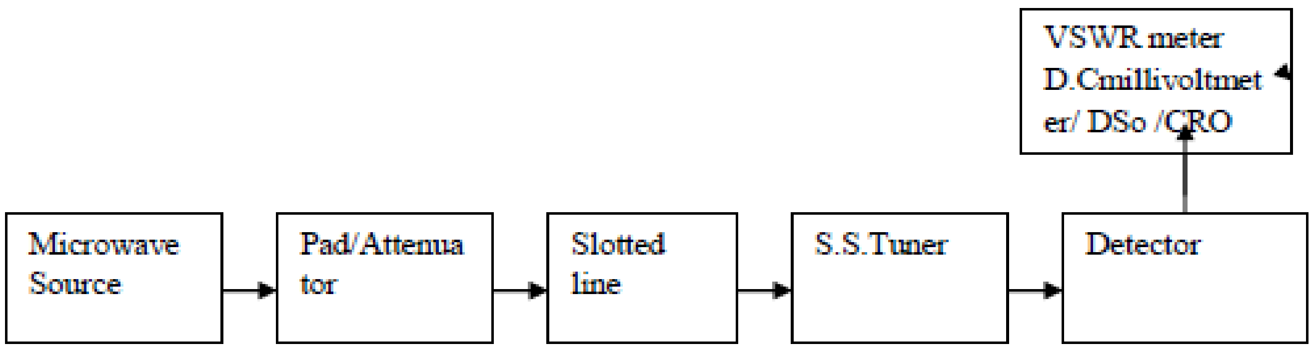

Figure 1.1: Set up for VSWR measurement

b. Actual Circuit/Experimental Setup used in laboratory with related equipment rating:

VIII Required Resources/ apparatus/equipment with specifications:

Sr. No.	Name of Resource	Specification	Quantity
1	Digital Multimeter	Digital Multimeter: 3 and ½ digit display with R, V, I measurements, Diode and BJT testing.	1
2	Digital IC Tester	Tests a wide range of Digital IC's such as 74 Series, 40/45 Series of CMOS IC's.	1
3	DC Regulated power supply	Floating DC Supply Voltages 0 -30V; 0-2 A. Automatic Overload (Current Protection). Constant Voltage and Constant Current Operation. Digital Display for Voltage and Current Adjustable Current Limiter. Excellent Line and Load Regulation.	1
4	Breadboard	5.5cm X 17 cm.	1
5	IC	7404, 7408, 7432 or any IC of equivalent function.	1 each
6	LED	Red/Yellow color 5 mm.	1
7	Connecting wires	Single strand 0.6 mm Teflon coating.	As required
8	Resistor	330 Ω or 1KΩ of 0.5W or 0.25W power rating.	1

IX Precaution to be followed (Safety instructions / Rules / Standards):

1 Ensure proper grounding of the test setup to minimize stray reflections and ensure accurate measurements
2 Control the temperature to maintain stable readings, as temperature can affect impedance and VSWR.
3 Keep the length of the transmission line short to minimize reflections at the end of the line.
4 Ensure all connections are clean and secure to avoid poor contact.

X Procedure:

1. Set up the equipment as shown in circuit diagram.
2. Keep variable attenuator at maximum position.
3. Keep control knobs of klystron power supply as below: -
4. "ON" the klystron power supply, VSWR meter & cooling fan.
5. Turn the meter switch of klystron power supply to beam voltage at 300V.
6. Rotate reflector knob to get reading in D C mill voltmeter.
7. Move the probe along with slotted line to change the reading in DC -Mill voltmeter to get Maximum reading i.e., Emax.
8. Keep all control knob as it is, move the probe to next minimum position note the voltage i.e., Emin
9. Repeat the above steps for change of SS tuner probe depth & record corresponding SWR.
10. Set the SS tuner on 9mm and get the deflection on VSWR meter. Set the VSWR. meter to 1 by course and fine and gain knob adjustment.

11. Move on the slotted line to get Emin note the VSWR from the meter.
12. Change SS tuner probe depth and measure VSWR.

XI Required Resources

Sr. No.	Name of Resource	Specifications	Quantity
1			
2			
3			
4			

XII Actual Procedure:

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XIII Observation Table:

Table 1: VSWR and reflection coefficient measurement for transmission line

S S tuner position	Emax	Emin	VSWR S= Emax/Emin	VSWR from meter	Reflection coefficient
2mm					
4mm					
6mm					
8mm					
10mm					
12mm					
14mm					
16mm					

XIV Result(s):

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XV Interpretation of Result(s):

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XVI Conclusion and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions. Teachers must design such questions to ensure achievement of identified CO.

1 Explain Relationship between VSWR and Reflection coefficient.
2 State the specification of VSWR.
3 Calculate the magnitude of reflection coefficient, when VSWR is 3.

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/links/ Virtual Lab Link.

1. https://youtu.be/ImNRca5ecF0?si=ENGwgy-t7yEDjBh7
2. https://youtu.be/Y1HUnyXanlE?si=CJzuHjd3tP4m9Izs

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	Working in teams	10%
Product Related (10 Marks)		**40%**
05	Correctness of output	10%
06	Interpretation of Result	05%
07	Conclusions	05%
08	Practical related questions	15%
09	Submitting the journal in time	05%
Total (25 Marks)		**100%**

Marks Obtained			**Dated signature of Teacher**
Process Related (15)	**Product Related (10)**	**Total (25)**	

Practical No. 2: Determination of the frequency and wavelength of rectangular waveguide for TE_{10} mode

I Practical Significance:

The experiment aims to determine the frequency and wavelength of a rectangular waveguide operating in the TE_{10} mode. An input signal is generated and passed through the waveguide. The frequency is measured using a frequency meter by observing dips in power. The guide wavelength is calculated by measuring the distance between maxima or minima of the signal along the slotted section of the waveguide. Cutoff wavelength is calculated using the inner dimension of the waveguide. Free space wavelength and frequency are then determined using the measured values and relationships between guide wavelength, cutoff wavelength, and free space wavelength. The experiment is repeated for different frequencies and the results are analyzed.

II Industry / Employer Expected outcome(s)

This practical is expected to develop the following skills for the industry-identified competency:

'Maintain telecommunication system which contain microwave components'

III Course Level Learning outcome(s)

- CO1 – Select waveguide for given microwave communication system.

IV Laboratory Learning outcome(s)

- LLO 2.1- Use the frequency meter with microwave test bench setup to determine the frequency and wavelength of waveguide for TE_{10}.

V Relevant Affective Domain Related outcome(s)

1 Follow safe practices.
2 Handle instruments carefully
3 Follow ethical practices

VI Relevant Theoretical Background.

Mode represents in wave guides as either TE m, n/ TM m, n
Where TE– Transverse electric,
TM– Transverse magnetic
m– Number of half wave length variation in broader direction.
n–Number of half wave length variation in shorter direction.

$$\frac{\lambda_g}{2} = (d_1 - d_2)$$

Where d1 and d2 are the distance between two successive minima/maxima.

It is having highest cut off frequency hence dominant mode.

For dominant TE_{10} mode in rectangular wave-guide λo, λg and λc are related as below

$$\frac{1}{\lambda_0} = \sqrt{\frac{1}{\lambda g^2} + \frac{1}{\lambda c^2}}$$

Where λo is free space wavelength
λg is guide wavelength
λc is cutoff wavelength

For TE_{10} mode, $\lambda c = \frac{2a}{m}$

Where m = 1 in TE_{10} mode and 'a' is broad dimension of waveguide
The following relationship can be proved

$$C = f\lambda$$

Where $c = 3 \times 10^8$ m/sis velocity of light and f is frequency

VII Circuit diagram.

a) Simple Circuit/Experimental Setup:

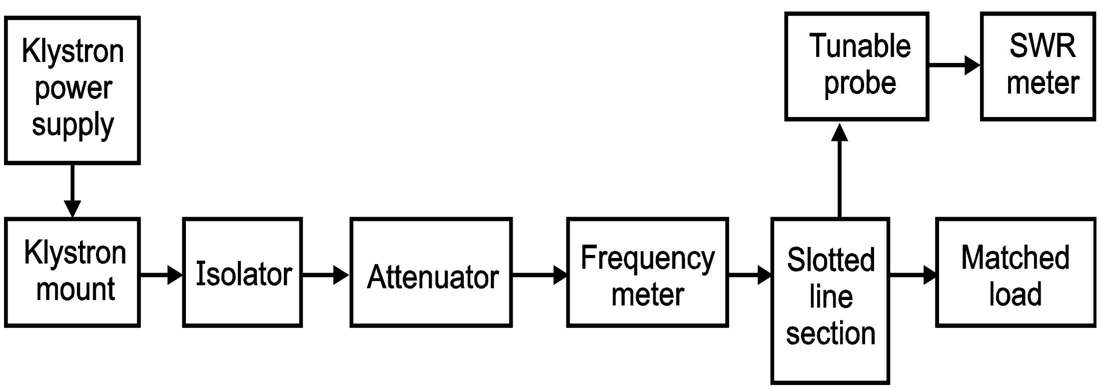

Figure 2.1: Set up for frequency and wavelength measurement.

b) Actual Circuit/Experimental Setup used in laboratory with related equipment rating:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Instrument/Components	Specification	Quantity
1.	Klystron tube	Typical Range: UHF to X-band (0.3 GHz – 12 GHz), CW (Continuous Wave) Power: 1kW to 100 kW (typical), Beam Voltage range Typically 20 kV to 150 kV, Beam current 10-100 mA Gain: 40–60 dB	**1**
2.	Klystron Power supply	Output voltage range 20 kV to 150 kV (DC), Output current:50 mA to 50A, Output power range: Low-power units: ~1 kW	**1**
3.	Klystron mount	-	**1**
4.	Isolator	Frequency range: (2.0–4.0 GHz, 8.0–12.0 GHz), Insertion loss: 0.2 to 1.0 dB Isolation: 20 dB to 30 dB or more VSWR: < 1.2:1	**1**
5.	Frequency meter	Frequency Range: RF/microwave meters: Up to 3 GHz, 6 GHz, 20 GHz, or higher	**1**
6.	Variable attenuator	Attenuation Range: 0 to 10 dB, 0 to 30 dB, 0 to 60 dB, or higher, Impedance: 50 Ω, VSWR: < 1.2:1	**1**
7.	Slotted section	Frequency Range: Depends on the waveguide size or coaxial line, Slot Length: Typically, 25 cm to 50 cm,	**1**
8.	Tunable probe	Frequency Range: Depends on the waveguide band, High sensitivity to the electric field (E-field) in the waveguide, Mechanical Resolution: Typically, 0.01 mm to 0.1 mm	**1**
9.	VSWR meter	Frequency Range: Depends on the model and intended application, VSWR Measurement range: 1.0 to 10.0, Directivity: ≥ 25 dB, Impedance: 50 Ω	**1**
10.	Waveguide stand	-	**1**
11.	Movable short/matched termination	-	**1**

IX Precautions to be followed

1. Ensure proper grounding of the test setup to minimize stray reflections and ensure accurate measurements.
2. Control the temperature to maintain stable readings, as temperature can affect impedance and VSWR.
3. Keep the length of the transmission line short to minimize reflections at the end of the line.
4. Ensure all connections are clean and secure to avoid poor contact.
5. Be mindful of the high frequencies and power levels involved in microwave experiments.

X Procedure:

1. Set up the components and equipment's as shown in figure2.1.
2. Set the variable attenuator at maximum (for no attenuation) position
3. First connect the matched termination after slotted section
4. Keep the control knobs of SWR Meter as below:
   - Gunn Bias Knob: Fully anticlockwise
   - Mode Switch: Normal Position
   - Gain (Course & Fine): Mid Position
   - SWR/dB switch: dB position
5. Keep the control knob of Gunn Power Supply as below:
   - Crystal:200 ohm
   - Pin bias Knob: Fully anticlockwise
   - Pin Mod frequency: Mid position
   - Mode switch: Internal mod. Position

6. Set the micrometer of Gunn Oscillator for required frequency of operation.
7. Switch On the Gunn power supply, SWR Meter and cooling fan
8. Measure the Gunn diode current corresponding to the various voltages controlled by Gunn bias knob through the LCD, do not exceed the bias voltage above 10 volts.
9. Figure 2.1 Tune the probe for maximum reading in dB on SWR meter.
10. Tune the frequency meter to get a 'dip'(minimum reading) on SWR LCD display and note down the frequency directly from frequency meter. Now you can detune the DRF Meter.
11. Move the tunable probe along with the slotted line to get the reading in SWR meter. Move the tunable probe to a minimum Gain position. To get accurate reading, it is necessary to increase the SWR meter range dB switch to higher position, record the probe position i.e. d1.
12. Move the probe to next minimum position and record the probe position again i.e. d2.
13. Calculate the guide wavelength as twice the distance between two successive minimum positions obtained as above.

$$\lambda_g = 2(d1-d2)$$

14. Measure the wave-guide inner broad dimension 'a' which will be around 22.86 mm for Xband.

$$\lambda_c = 2a$$

15. Calculate the frequency by following equation:

$$f = \frac{c}{\lambda_0} = c\sqrt{\frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}}$$

Where c =3 x 10^8 meter/sec. i.e., velocity of light.

16. Verify it with frequency obtained by frequency meter.
17. Above experiment can be verified at different frequencies.

XI Resources Used:

Sr. No.	Instrument /Components	Specifications	Quantity
1			
2			

XII Actual procedure followed

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XIII Observation

Sr. No.	Beam Voltage	Repeller Voltage	Frequency	1^{st} d_1	2^{nd} d_2	Difference	λ_g

Calculations:

XIV Result(s)

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XV Interpretation of Results:

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XVI Conclusions and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions. Teachers must design such questions to ensure achievement of identified CO.

1. List the significance of accurately determining the guide wavelength
2. How do the physical dimensions of the waveguide affect its cutoff frequency?
3. If the operating frequency is below the cutoff frequency, explain what will happen.
4. Justify TE_{10} mode dominant in rectangular waveguides
5. State the relation between guide wavelength, free-space wavelength, and cutoff wavelength

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/links/Virtual lab Link

1. https://youtu.be/QpoL7tpAFGU
2. https://youtu.be/Y3szgmhuXeg
3. https://youtu.be/qnoEJAozspw

XIX Assessment Scheme:

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of component	20%
03	Measuring value using suitable instrument	20%
04	Working in team	10%
Product Related (10 Marks)		**40%**
05	Interpretation of result	15%
06	Conclusions	05%
07	Practical related questions	15%
08	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process Related (15)	**Product Related (10)**	**Total (25)**	

Practical No. 3: Measurement of power division in microwave tees E- plane, H- plane and E-H plane using microwave test bench setup

I Practical Significance

Understanding power division and phase relationships is critical for designing microwave systems where signals need to be split for distribution, combined for amplification, or manipulated in specific ways.

The power division characteristics of these tees are important for impedance matching, ensuring efficient power transfer and minimizing reflections.

By measuring and characterizing these tees, engineers can ensure that they meet the specific requirements of their application, such as isolation, insertion loss, and return loss.

A microwave test bench setup typically includes a microwave source, a power meter (or diode detector), and appropriate connectors/adapters to measure the power at the ports of the tee.

Voltage Standing Wave Ratio (VSWR) measurements are often performed to assess the quality of the match between the tee and the rest of the system.

II Industry / Employer Expected outcome(s):

Measuring power division in microwave tees is a fundamental process in microwave engineering. It allows engineers to verify the performance of these key components and design microwave systems that effectively split, combine, and manipulate signals.

III Course Level Learning outcome(s)

- CO2 - Test performance of microwave components.

IV Laboratory Learning outcome(s)

- LLO 3.1 Test the output of microwave test bench setup to ensure power division in microwave Tees E- plane, H- plane and E-H plane.
- LLO 3.2 Interpret the result from reading.

V Relevant Affective Domain related outcome(s)

- The experiment fosters a positive attitude toward learning about microwave components and their applications

VI Relevant Theoretical Background.

Microwave tees (E-plane, H-plane, and E-H plane) are three-port waveguide junctions used for power division and combining. Measuring power division involves feeding a signal into one port and measuring the power output at the other two ports. E-plane tees divide power into two outputs 180 degrees out of phase, while H-plane tees combine power in phase. Magic tees combine both functions, offering more complex power division and isolation options. A microwave test bench setup with power meters and a signal source is used for these measurements.

a) E- plane Tee:

This tee divides power into two output ports that are 180 degrees out of phase with each other. If power is fed into one port, it's split equally between the other two ports

Figure 3.1: E-plane Tee

b) H- plane Tee:

This tee combines power from two input ports into a single output port with the outputs in phase with each other. It acts as a power combiner when power is fed into two ports, with the output at the third port being the sum of the inputs.

Figure 3.2: H-plane Tee

c) **Magic Tee:**

This four-port device combines E-plane and H-plane functionalities, allowing for both power division and combining. It's used for various applications like mixing, duplexing, and impedance measurements.

Figure 3.3: Magic Tee

VII Circuit diagram.

a. **Simple Circuit/Experimental setup:**

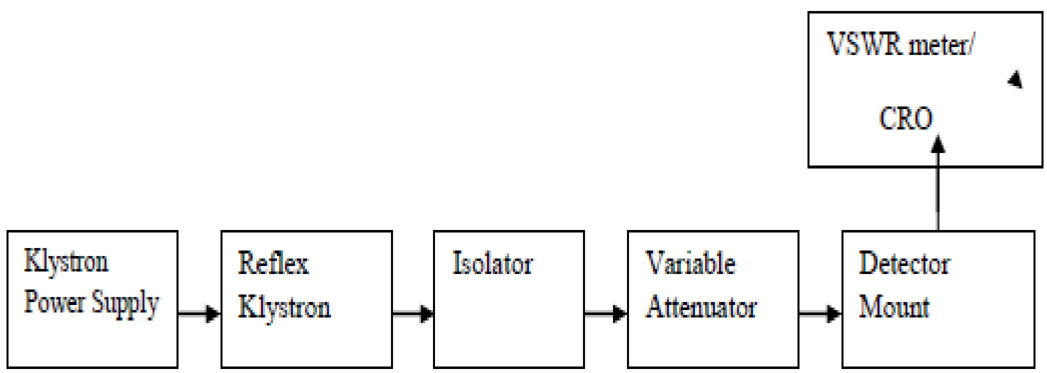

Figure 3.4: Input Power Measurement

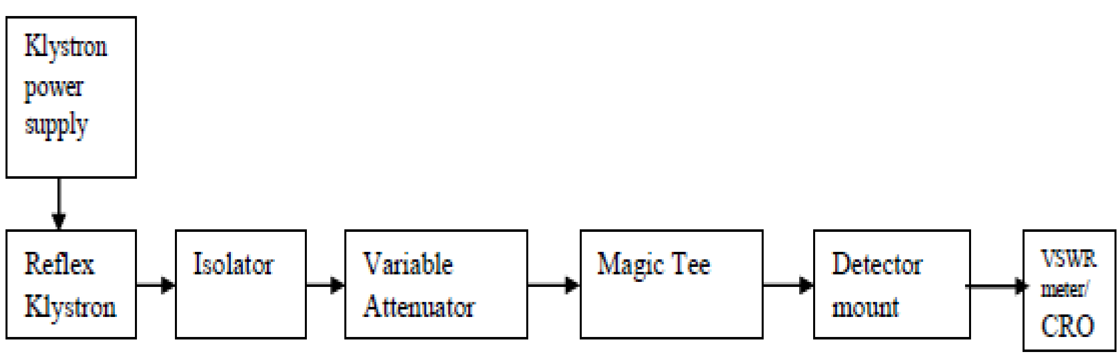

Figure 3.5: Coupled/Isolator Power Measurement

b. Actual Circuit/Experimental Setup used in laboratory with related equipment rating:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
01	Klystron power supply	Typically, 230V AC (±10%, 50 Hz)	01
02	Frequency meter	Frequency ranges, 20 GHz, 27 GHz, or 40 GHz.	01
03	VSWR meter	220 VAC, ± 10%, 50 Hz.	01
04	CRO	25MHz DSO	01

IX Precautions to be followed

1. Ensure all ports of the tee (except the input) are properly terminated with matched loads.
2. Calibrate the detectors before use to ensure accuracy.
3. Handle the tee and other components with care to prevent damage.
4. Be mindful of the high frequencies and power levels involved in microwave experiments.

X Procedure

- **Part A: General setup:**

1. Setup the equipment's as indicated in fig.
2. Keep the control knob of klystron power supply as mentioned below
   - i. Mode switch: AM
   - ii. Beam voltage knob: Fully anticlockwise
   - iii. Repeller voltage knob: Fully clockwise
   - iv. Meter switch: Cathode voltage position
3. Measurements or isolation between E and H arms.
   - i. Set the attenuator around 20dB. Let these settings be A1 dB.
   - ii. Obtain reference readings on VSWR meter.

Preferable in the 40 dB range of VSWR meter

iii. Disconnected and setup all the instruments as shown in fig.

iv. Reduce the attenuation till the VSWR meter reads the value obtained in step ii). Note attenuation setting A2 dB. The difference in the attenuator (A1 – A2) dB given the isolation in dB.

- **Part B: Experimental setup for demonstrating the 3 dB power division in collinear arms:**

1. Apply the power input to either at E or H arm.
2. Set the attenuator to get reference readings on VSWR meter without the components under test. Note the attenuator settings A1 dB.
3. Connect Magic tee.
4. Reduced attenuation to get the reference reading obtained in step ii) (step 3.ii) from part 1).
5. Note down the attenuator setting A2 dB.

The difference in the attenuator setting given the ratio of power coupled to collinear arm to that main arm, in dB. This value should be around 3 dB>

XI Required Resources:

Sr. No.	Name of Resource	Specifications	Quantity
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XII Actual procedure:

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XIII Observation table:

Table 1: Isolator Measurement

Attenuator setting when measuring input to E-arm A1(dB)	**Attenuator setting when measuring input to H-arm A2(dB)**

Table 2: Isolator Measurement

Attenuator setting when measuring input to E/H-arm A1(dB)	**Attenuator setting when measuring power collinear arm A2(dB)**

Calculation:

- Isolation between E and H arms dB= (A1-A2) dB

- Coupling between Collinear arms and E/H arms dB= (A1-A2) dB

XIV Result(s):

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XV Interpretation of Results:

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XVI Conclusions and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions for reference. Teachers must design such questions to ensure achievement of identified CO.

1. State the different modes of operation in an E-H plane tee?
2. How does the phase shift affect the power division in the E-H plane tee?
3. Make out the differences between E-Tee, H-Tee & E-H Tee.

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/links/Virtual lab Link

1. https://youtu.be/Js1AhrkxN4E?si=VuQvhnCTa5RG1GLe
2. https://www.youtube.com/watch?v=ZPKEy6yfBAQ

XIX Assessment Scheme:

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	working in teams	10%
Product Related (10 Marks)		**40%**
05	Correctness of output	10%
06	Interpretation of Result	05%
07	Conclusions	05%
08	Practical related questions	15%
09	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process Related (15)	**Product Related (10)**	**Total (25)**	

Practical No. 4: Determination of coupling factor and insertion loss of the given circulator and isolator

I Practical Significance:

Low insertion loss is essential for efficient signal transmission and minimizing power dissipation in a system. A high insertion loss can reduce the overall system gain and impact its performance.

II Industry / Employer Expected outcome(s)

Accurate knowledge of coupling factor and insertion loss allows engineers to optimize system design, ensuring that the desired isolation between ports is achieved and that minimal signal loss occurs.
These parameters are key factors in choosing the right circulator or isolator for specific applications, ensuring compatibility with other system components

III Course Level Learning outcome(s)

- CO2 - Test performance of microwave.

IV Laboratory Learning outcome(s)

- LLO 4.1 Evaluate coupling factor and insertion loss of given circulator.
- LLO 4.2 Evaluate coupling factor and insertion loss of given Isolator.

V Relevant Affective Domain related outcome(s)

Developing a positive attitude towards experimentation, a willingness to learn from mistakes, and an appreciation for the importance of precision and accuracy in measurements.

VI Relevant Theoretical Background.

1. **Circulator:**

   The circulator is a multi-port junction that permits transmission in certain ways. A circulator is a passive non-reciprocal three- or four-port device, in which a microwave or radio frequency signal entering any port is transmitted to the next port in rotation (only). A wave incident in port A is coupled to port B only; a wave incident at port B is coupled to port C only and so on

2. **Isolator:**

   The isolator is a two-port, non-reciprocal device that transmits power in one direction while absorbing power in the opposite direction. It's essentially a "one-way valve" for microwave energy. Isolators are often used to prevent reflected power from a load from interfering with the source or other sensitive components in a microwave.

3. **Insertion Loss (Forward Loss):**

   It is defined as the ratio of power supplied by a source to the input port to the power detected by a detector in the coupling arm, i.e., output arm with other port terminated in a matched load.

VII Circuit diagram.

a. Sample circuit/Experimental setup:

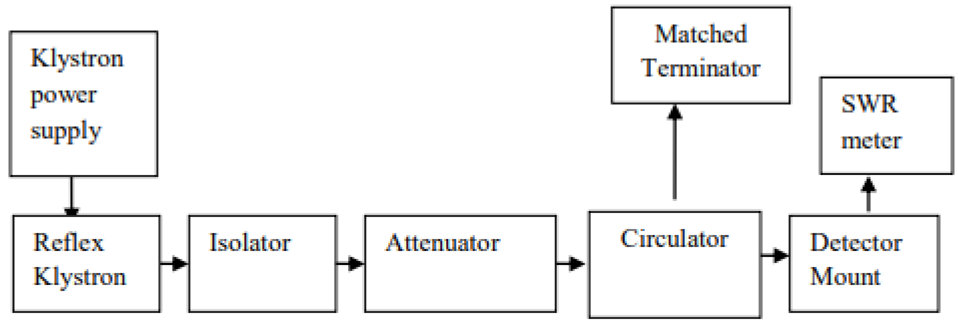

Figure 4.1: Set up Measurement of Power

b. Actual Circuit/Experimental Setup used in laboratory with related equipment rating:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Name of Resources	Specifications	Quantity
01	Klystron power supply	Typically, 230V AC (±10%, 50 Hz)	01
02	Frequency meter	frequency ranges, 20 GHz, 27 GHz, or 40 GHz.	01
03	VSWR meter	220 VAC, ± 10%, 50 Hz.	01
04	CRO	25MHz DSO	01

IX Precautions to be followed

1. Avoid damaging the components through rough handling or improper assembly.
2. Do not exceed the maximum power rating of the components during measurements.

X Procedure:

1. Setup the microwave test bench as shown in diagram (initially without circulator) i.e., directly connect detector with VSWR in order to measure input A1.
2. Set the variable attenuator at maximum position.
3. Keep the control knob of Klystron power supply as mentioned below:
   i. Mode Switch: AM
   ii. Beam voltage knob: Fully anti-clockwise
   iii. Repeller voltage knob: Fully clockwise
   iv. Meter switch: Cathode voltage function
4. Keep the control knob of VSWR meter as below:
   i. Range dB: 50 dB position
   ii. Input switch: Crystal low impedance.
   iii. Meter switch: Normal position.
   iv. Gain (course fine): Mid position.
5. Switch „ON" the klystron power supply.
6. Switch „ON" the VSWR Meter.
7. Switch „ON" the cooling fan.
8. Set some reference reading in VSWR meter by adjusting the variable attenuator. Note this attenuator setting as A1 dB.
9. Carefully remove the detector setup and insert circulator as in the setup diagram with power fed to port 1.
10. Measure output at port 2 with terminated in matched load.
11. Reduce the attenuation to get the reference reading in VSWR/CRO as per setup 6.

    Note down attenuator setting as (A2) dB
12. Interchange the position of detector setup and matched load between ports 2 and ports 3

    Adjust attenuator setting to get reference reading. Note this attenuator setting as A21 dB.

XI Required Resources:

Sr. No.	Name of Resource	Specifications	Quantity
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XII Actual procedure followed

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XIII Observation Table

Table 1: Measure Power

A1(dB)	A2(dB)	A3(dB)

Calculations:

Isolation loss dB= (A1-A2) db

Insertion dB= (A1-A3) db

XIV Result(s)

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XV Interpretation of Results

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XVI Conclusions and Recommendation

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XVII Practical Related Questions

Note: Below given are few sample questions for reference. Teachers must design such questions to ensure achievement of identified CO.

1 Compare rectangular waveguide and circular.
2 State two advantages and two applications of circular waveguide.
3 State the main function of isolator.

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/ links/Virtual lab Link

1. https://youtu.be/GMnjeHK88uo
2. https://youtu.be/EeEoanWLANM

XIX Assessment Scheme:

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	working in teams	10%
Product Related (10 Marks)		**40%**
05	Correctness of output	10%
06	Interpretation of Result	05%
07	Conclusions	05%
08	Practical related questions	15%
09	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process Related (15)	**Product Related (10)**	**Total (25)**	

Practical No. 5: Measurement of phase shift of microwave phase shifter.

I Practical Significance:

Precise phase control in phased array antennas allows for electronic beam steering, enabling efficient and dynamic antenna radiation patterns.
Phase shifters are used to null out unwanted signals by generating a counter-phase signal, improving signal quality and reducing interference.
Phase shifters are used in communication systems to modulate and demodulate signals, ensuring reliable transmission and reception of information.
Phase shifters are used to create and manipulate signals for various applications, such as frequency multiplication and signal processing techniques.

II Industry / Employer Expected outcome(s)

Measuring the phase shift of a phase shifter is crucial for applications like phased array antennas and radar systems. Expected outcomes in the industry include accurate phase shift control, low insertion loss, and a wide operating bandwidth.

III Course Level Learning outcome(s)

- CO2 - Test performance of microwave components.

IV Laboratory Learning outcome(s)

- LLO 5.1 Calculate various parameters to test performance of microwave phase shifter.

V Relevant Affective Domain related outcome(s)

Measuring the phase shift of a microwave phase shifter understands the importance of precision and accuracy in scientific experiments, and the potential impact of errors on the overall results. This includes developing a sense of responsibility for accurate measurements and understanding the limitations of measurement techniques, as well as demonstrating a positive attitude towards learning and continuous improvement in experimental skills.

VI Relevant Theoretical Background.

Phase shifters are devices that change the phase angle of a signal passing through them without significantly changing its amplitude. In microwave communication systems, phase shifters are crucial for beam steering in phased array antennas and other applications. The phase shift can be measured by observing the shift in the position of the voltage minima (or maxima) along a slotted.

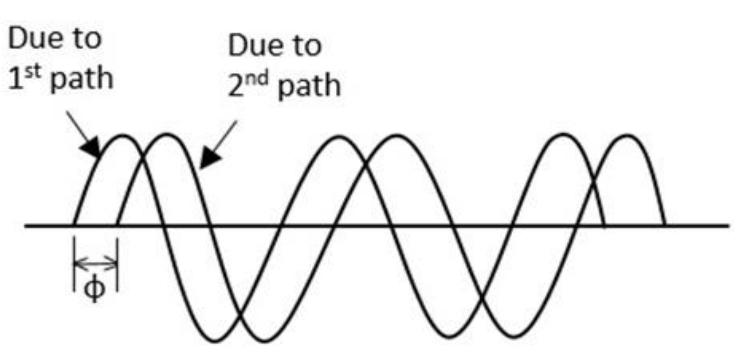

Figure 5.1: Phase Shift

$$\text{Phase Shift (Degree)} \quad \phi = 360 \times freq \times \Delta t$$

$$\text{Phase Shift (radian)} \quad \phi = 360 \times freq \times \Delta t \times Pi/180$$

$$\text{Time Shift} (\Delta t) = \frac{\phi}{360 \times freq}$$

$$\text{Frequency (f)} = \frac{\phi}{360 \times \Delta t}$$

$$\text{Wavelength} = c/f$$

VII Circuit diagram.

a. Sample Circuit/Experimental setup:

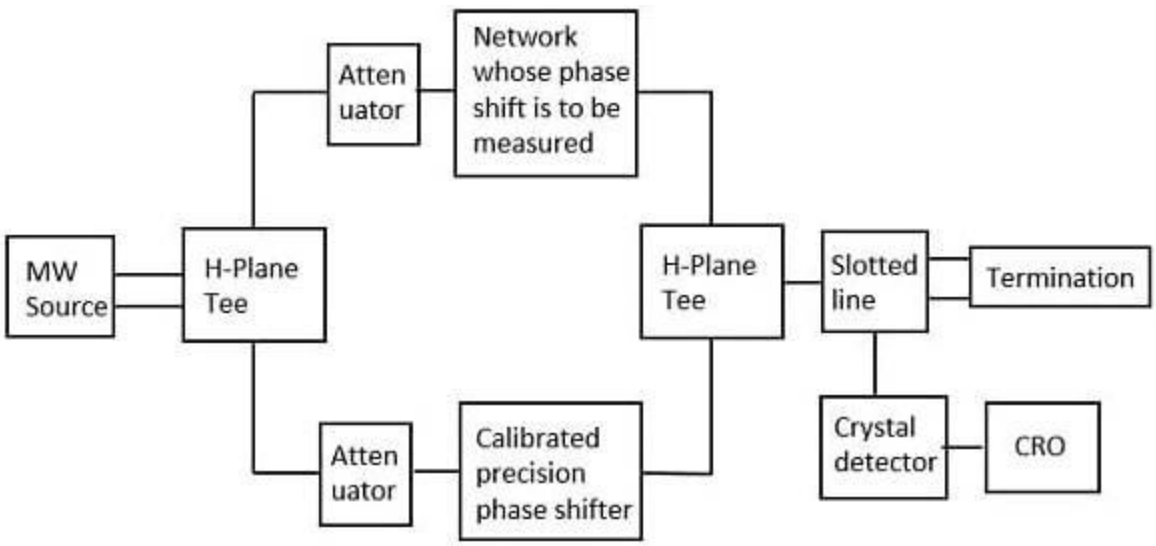

Figure 5.2: Measurement of Phase Shift

b. Actual Circuit/Experimental Setup used in laboratory with related equipment rating:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Name of Resource	Suggested Broad Specification	Quantity
01	Klystron power supply	Typically, 230V AC (±10%, 50 Hz)	01
02	Frequency meter	frequency ranges, 20 GHz, 27 GHz, or 40 GHz.	01
03	VSWR meter	220 VAC, ± 10%, 50 Hz.	01
04	CRO	25MHz DSO	01
05	D.C voltmeter	0 to 20 V	01

IX Precautions to be followed

1. Ensure proper alignment of the components.
2. Avoid reflections by using matched terminations.
3. Handle microwave equipment carefully to avoid damage.
4. Take multiple readings for accuracy.

X Procedure:

1. Set up the microwave test bench with the waveguide, source, and detector.
2. Adjust the frequency of the microwave source on the slotted line without the phase line.
3. Note the initial position of a voltage minimum on the slotted line without the phase shifter.
4. Insert the phase shifter and adjust it to introduce a known phase change.
5. Note the new position of the voltage minimum.
6. Calculate the phase shift using the formula above.
7. Repeat the procedure for different phase shifter settings.

XI Resources used

Sr. No.	Name of Resources	Specifications	Quantity
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XII Actual procedure followed

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XIII Observation Table:

Table 1: Measurement of phase shift

No Phase Shifter Setting Initial Position (cm)	Final Minima Position (cm)	Δt (cm)	Λ (cm)	Phase Shift

XIV Result(s):

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XV Interpretation of Results:

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XVI Conclusions and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions for reference. Teachers must design such questions to ensure achievement of identified CO.

1. State the types of phase shifter and give its application?
2. State the principle of phase shifter
3. Mention the roll of a slotted line in Micro wave phase shifter?

[Space for Answers]

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XVIII References/Suggestions for further reading:

1. https://youtu.be/SHA2M0g5AwM
2. https://youtu.be/VTSl5nhuxKg

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	working in teams	10%
Product Related (10 Marks)		**40%**
05	Correctness of output	10%
06	Interpretation of Result	05%
07	Conclusions	05%
08	Practical related questions	15%
09	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process Related (15)	**Product Related (10)**	**Total (25)**	

Practical No. 6: Determination of tuning range of Reflex Klystron Microwave Tube

I Practical Significance:

The tuning range of a reflex klystron, a type of microwave tube, is determined by both the mechanical and electronic tuning methods. The mechanical tuning involves changing the dimensions of the resonant cavity, while electronic tuning involves adjusting the repeller voltage.

II Industry / Employer Expected outcome(s)

This practical is expected to develop the following skills for the industry-identified competency:
'Maintain telecommunication system which contain microwave components'

III Course Level Learning outcome(s)

- CO3 – Construct RF circuits using RF devices.

IV Laboratory Learning outcome(s)

- LLO 6.1- Test the performance of Reflex Klystron Microwave Tube.
- LLO 6.2- Calculate tuning range.

V Relevant Affective Domain related outcome(s)

- Follow safe practices.
- Handle instruments carefully.
- Follow ethical practices.

VI Relevant Theoretical Background:

The schematic diagram of reflex klystron tube is shown below which uses only a single re-entrant microwave cavity as resonator. The electron beam emitted from the cathode K is accelerated by the grid G and passes through the cavity anode A to the repeller space between the cavity anode and repeller electrode.

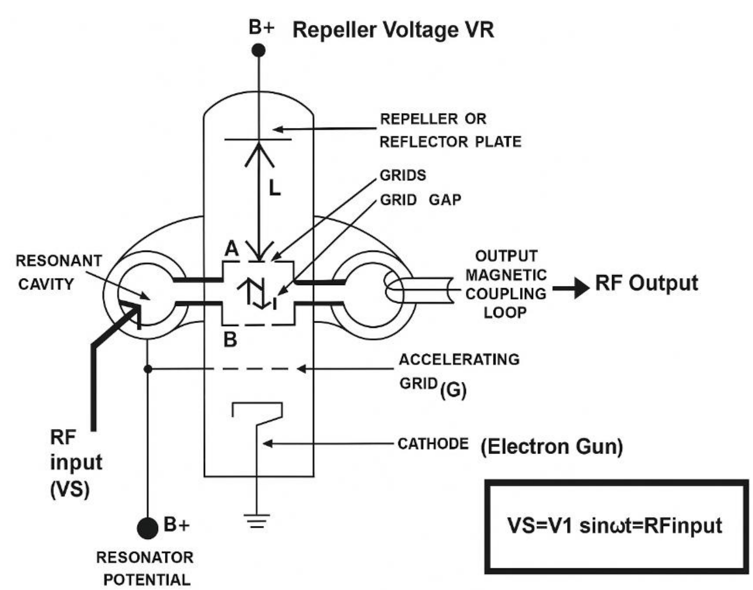

Figure 6.1: Reflex Klystron

Due to D.C. voltage in the cavity circuit, RF noise is generated in the cavity. This electromagnetic noise field in the cavity becomes pronounced at cavity resonant frequency. The electrons passing through the cavity gap 'd' experience this RF field and are velocity modulated in the following manner. The electrons as shown in Fig. 6.1, which encounter positive half cycle of the RF field in the gap 'd' will be accelerated, those (reference electrons), b which encounter zero RF field will pass with unchanged original velocity, and the electrons C, which encountered the negative half cycle will be retarded on entering the repeller space.

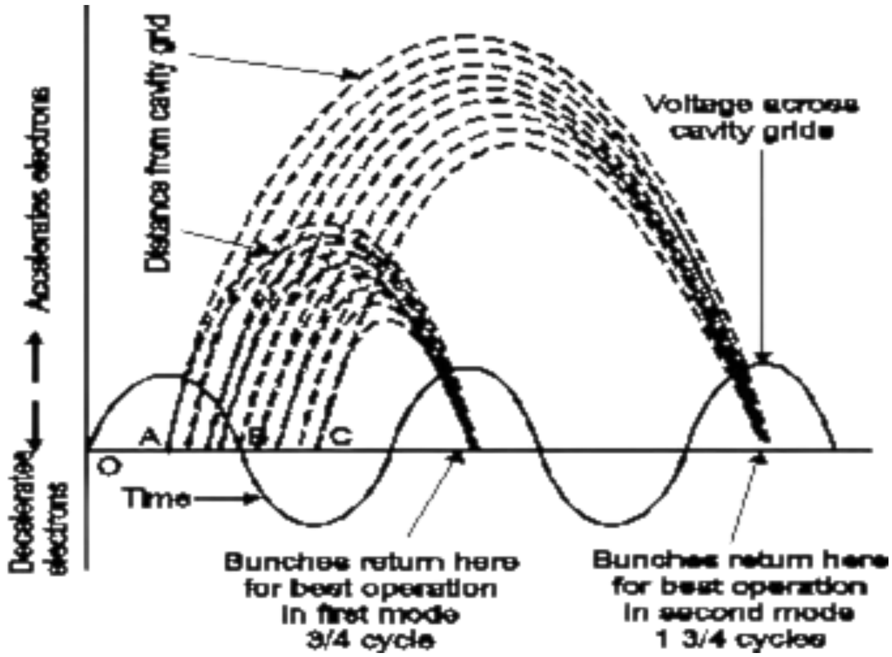

Figure 6.2: Apple gate Diagram

All these velocities modulated electrons will be repelled back to the cavity by the repeller due to its negative potential the repeller distance L and the voltages can be adjusted to receive all the velocity modulated electrons at a same time on the positive peak of the cavity RF voltage cycle. Thus, the velocity modulated electrons are bunched together and lose their kinetic energy when they encounter positive decaying cycle of the RF field. This loss of energy is thus transferred to the cavity to conserve the total power. If the power delivered by the bunched electrons to the cavity is greater than the power loss in the cavity, the electromagnetic field amplitude at the resonant frequency of the cavity will increase to produce microwave oscillations. The RF power is coupled to the output load by means of small loop which forms the center conductor of the coaxial line. When the power delivered by the electrons becomes equal to the total power loss in the cavity system, a steady microwave oscillation is generated at the resonant frequency of the cavity.

The bunched electrons in a reflex klystron can deliver maximum power to the cavity at any instant which corresponds to the positive peak of the RF cycle of cavity oscillation. If T is the time period at the resonant frequency, t0 is the time taken by the reference electron to travel in the repeller space between entering the repeller space at b and returning to the cavity at positive peak voltage on forming electron bunch then,

$$t_0 = \left(n + \frac{3}{4}\right) T = NT \text{ where, } N = n + \frac{3}{4} \text{ with } n = 0, 1, 2, 3, \ldots$$

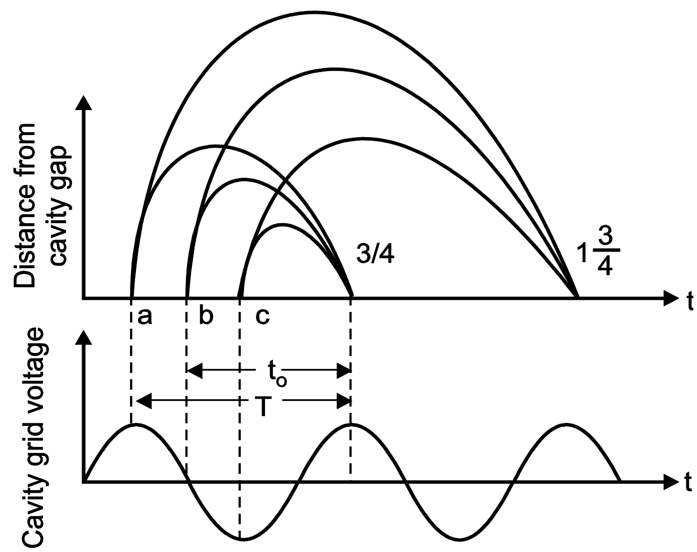

Figure 6.3: Apple gate Diagram

Thus, by adjusting repeller voltage, for given dimensions of the reflex klystron, the bunching can be made to occur at N = $\frac{1}{4}$, 1, $\frac{3}{4}$, 2, $\frac{3}{4}$ and so on for modes n = 0, 1, 2, 3 etc. It is obvious that the lowest order mode $\frac{3}{4}$ occurs for maximum value of the repeller voltage when the transit time t_0 of the electrons in the repeller space is minimum. Higher order modes occur at lower repeller voltages. As the highest repeller voltage causes maximum return acceleration of bunched electrons, the power output of lowest mode is maximum and that of highest mode is minimum.

VII Circuit diagram.

a) Sample circuit/Experimental setup:

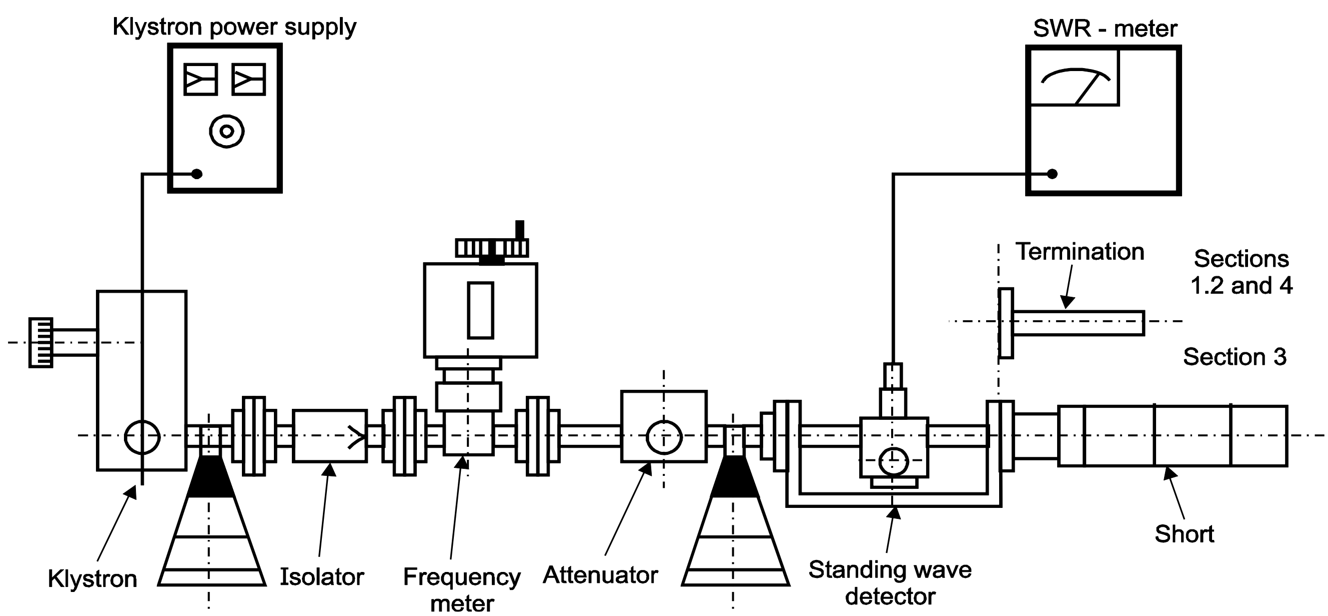

Figure 6.4: Set up of Reflex Klystron Test bench for Square Wave Modulation Operation

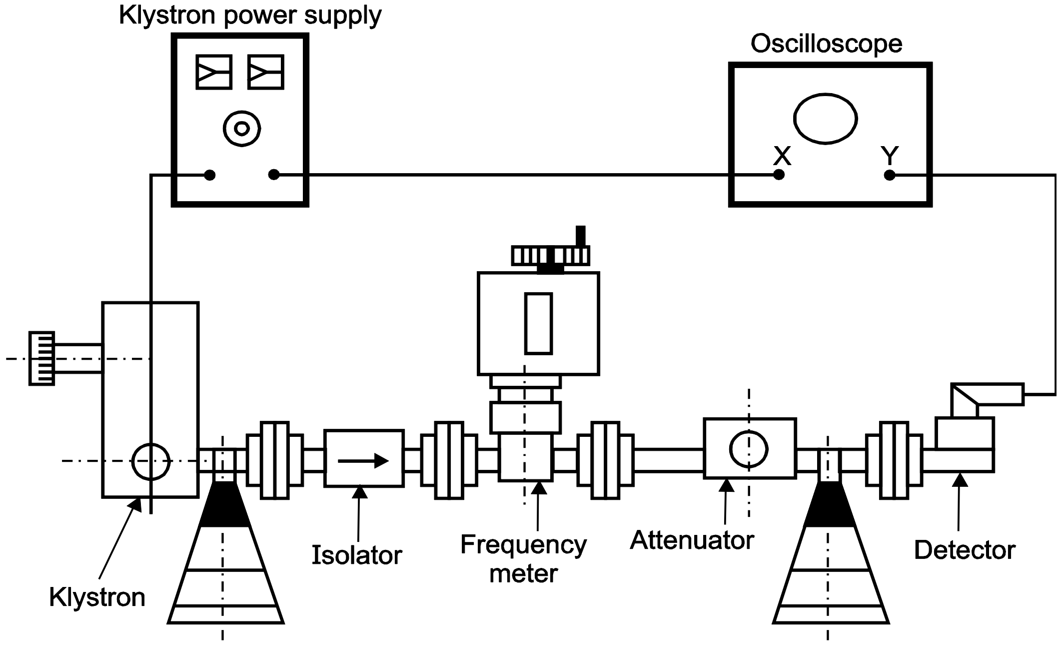

Figure 6.5: Mode study set up of Reflex Klystron Tube

b) Actual Circuit/Experimental Setup used in laboratory with related equipment rating:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Instrument/Components	Specification	Quantity
1.	Klystron tube	Typical Range: UHF to X-band (0.3 GHz – 12 GHz), CW (Continuous Wave) Power: 1kW to 100 kW (typical), Beam Voltage range Typically 20 kV to 150 kV, Beam current 10-100 mA Gain: 40–60 dB	1
2.	Klystron Power supply	Output voltage range 20 kV to 150 kV (DC), Output current:50 mA to 50A, Output power range: Low-power units: ~1 kW	1
3.	Klystron mount	-	1
4.	Isolator	Frequency range: (2.0–4.0 GHz, 8.0–12.0 GHz), Insertion loss: 0.2 to 1.0 dB Isolation: 20 dB to 30 dB or more VSWR: < 1.2:1	1
5.	Frequency meter	Frequency Range: RF/microwave meters: Up to 3 GHz, 6 GHz, 20 GHz, or higher	1
6.	Variable attenuator	Attenuation Range: 0 to 10 dB, 0 to 30 dB, 0 to 60 dB, or higher, Impedance: 50 Ω, VSWR: < 1.2:1	1
7.	Detector Mount	IN23	1
8.	VSWR meter	Frequency Range: Depends on the model and intended application, VSWR Measurement range: 1.0 to 10.0, Directivity: ≥ 25 dB, Impedance: 50 Ω	1
9.	Slotted Waveguide stand	-	1
10.	Multimeter	50mV RMS,500mV RMS	1
11.	BNC Cable	-	2

IX Precautions to be followed

1. Ensure proper grounding of the test setup to minimize stray reflections and ensure accurate measurements.
2. Control the temperature to maintain stable readings, as temperature can affect impedance and VSWR.
3. Keep the length of the transmission line short to minimize reflections at the end of the line.
4. Ensure all connections are clean and secure to avoid poor contact.

5. Be mindful of the high frequencies and power levels involved in microwave experiments.

X Procedure:

A. Square wave modulation operation:

1. Connect the test bench as shown below in Fig. 6.3 for square wave modulation operation.
2. Set the variable attenuator to minimum, klystron power supply to minimum and repeller voltage to maximum.
3. Set modulation to AM which applies internal 1 kHz square wave along with dc repeller voltage of 150 volts. Adjust modulation amplitude, repeller voltage in order to obtain good square wave on the oscilloscope.
4. If the obtained output of square wave is small, tune the detector plunger and adjust again the repeller voltage.
5. After obtaining maximum amplitude of square wave on the oscilloscope, replace the oscilloscope from detector and connect SWR meter in power display mode.
6. Rotate the frequency meter to observe dip in the output with oscilloscope and note down the resonating frequency directly.
7. Decrease repeller voltage in some suitable steps and note down corresponding resonating frequency using oscilloscope and power by using SWR meter.
8. Plot absolute repeller voltage on x-axis and frequencies on y-axis and measure the power output and modulation frequency.

B. Mode Study of Reflex Klystron:

1. Set the klystron to FM modulation and keep amplitude of FM maximum, frequency range of FM to medium range
2. Set beam voltage around 300 V and vary repeller voltage to obtain mode pattern on the oscilloscope (mode pattern looks like half wave rectified waveforms)
3. Vary the repeller voltage to obtain one mode at a time on the oscilloscope. Scan through all modes one by one. Normally 3 to 4 modes are observable with the available repeller voltage range.
4. Adjust the repeller voltage to obtain the first mode to be displayed on the oscilloscope, now rotate the frequency meter till a dip is observed in the mode pattern. The corresponding direct frequency readout is the center frequency of that mode. The Y-axis can be treated as measure of power.
5. Note down all the repeller voltages and their corresponding frequencies. If V01 and V02 are the repeller voltages for two successive modes then, calculate mode number 'n' from the following equation,

$$\frac{V01}{V02} = \frac{N2}{N1} = \frac{(n+1)+\frac{3}{4}}{n+\frac{3}{4}} \quad \text{Noting that } n = \frac{3}{4} = N$$

6. From the mode number 'n' calculate transit time T by knowing corresponding frequency as,

$$\text{transit time of mode} = \frac{n + \frac{3}{4}}{f} = \frac{N}{f} \text{ and hence } t1 = \frac{N1}{f1}\text{ , } t2 = \frac{N2}{f2} \text{ and so on}$$

7. The electronic tuning range of reflex klystron is calculated between the two successive modes is given by,

$$\text{Electronic Tuning Range} = \frac{f2 - f1}{V02 - V01} \text{ Hertz per volts}$$

8. Plot resonant frequencies on Y-axis and corresponding repeller voltages on X-axis and show mode diagrams.

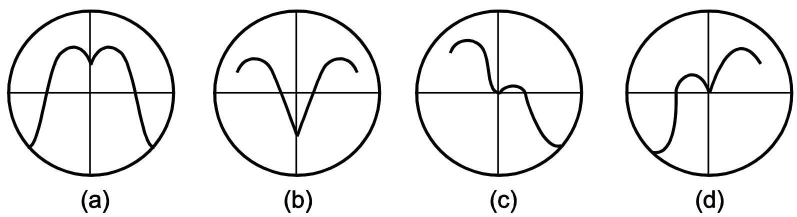

Figure. 6.6: Sample mode patterns of reflex Klystron Tube

XI Required Resources

Sr. No.	Instrument /Components	Specifications	Quantity
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XII Actual procedure followed

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XIII Observation Table:

A. Square wave modulation operation:

Repeller Voltage (volts)	Observed Frequency (GHz)

B. Mode study:

<table>
<tr><th>Repeller Voltage (Volts)</th><th>Mode frequency (GHz)</th><th>Mode number = n</th><th>$N = n + \frac{3}{4}$</th><th>Transit Time
T = N/F (seconds)</th><th>Electronic tuning range (Hz/V)
ETR = $\left|\frac{(f_2 - f_1)}{(V_{02} - V_{01})}\right|$</th></tr>
<tr><td>V_{01} =</td><td>f_1 =</td><td rowspan="2"></td><td>$N_1 = n + \frac{3}{4} =$</td><td>$T1 = N_1/f_1$
=</td><td rowspan="2"></td></tr>
<tr><td>V_{02} =</td><td>f_2 =</td><td>$N_2 = (n + 1) + \frac{3}{4} =$</td><td>$T_2 = N_2/f_2$
=</td></tr>
</table>

Calculations:

XIV Result(s):

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XV Interpretation of Results:

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XVI Conclusions and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions for references. Teachers must design such questions to ensure achievement of identified CO.

1. If the measured frequencies are 8.95 GHz and 9.20 GHz, calculate the tuning range?
2. Calculate the percentage tuning range if the center frequency is 9.0 GHz.
3. State the significance of electronic tuning in reflex klystrons.
4. List practical applications of reflex klystrons in microwave engineering.

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/links/Virtual lab Link

1. https://youtu.be/GsgGKnpk4xE
2. https://me-iitr.vlabs.ac.in/exp/reflex-klystron/theory.html

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	Working in teams	10%
Product Related (10 Marks)		**40%**
05	Interpretation of result	15%
06	Conclusions	05%
07	Practical related questions	15%
08	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			**Dated signature of Teacher**
Process Related (15)	**Product Related (10)**	**Total (25)**	

Practical No. 7: Determination of output power and frequency of Gunn diode and plot its V-I characteristics

I Practical Significance:

Output power and frequency of a Gunn diode, along with plotting its V-I characteristics is crucial for understanding its performance and applications. The V-I characteristics reveal the Gunn diode's unique negative resistance region, essential for oscillation. The output power and frequency, measured using specialized equipment, demonstrate the diode's microwave generation capabilities.

II Industry / Employer Expected outcome(s)

- This practical is expected to develop the following skills for the industry-identified competency:
  'Maintain telecommunication system which contain microwave components'

III Course Level Learning outcome(s)

- CO3 – Construct RF circuits using RF devices.

IV Laboratory Learning outcome(s)

- LLO 7.1- Test the performance of Gunn diode.
- LLO 7.2- Calculate output power and frequency.

V Relevant Affective Domain related outcome(s)

1. Follow safe practices.
2. Handle instruments carefully.
3. Follow ethical practices.

VI Relevant Theoretical Background.

Gunn diodes are negative resistance devices which are normally used as low power oscillator at microwave frequencies in transmitter and also as local oscillator in receiver front ends. J. B. Gunn in 1963 discovered microwave oscillation in Gallium Arsenide (GaAs), Indium Phosphide (InP), and cadmium telluride (CdTe). These semiconductors possess closely spaced energy valley in the conduction band (multiple conduction band). When a d.c. voltage is applied across these semiconductor materials, an established electric field will transfer the electrons from lower valley to upper valley. At higher electric field, most of the electrons will be transferred into the higher energy satellite valley where the effective electron mass becomes larger and thus electron mobility is slower than lower energy valley. As the conductivity is directly proportional to the mobility of electrons, the conductivity and thus the current decreases with an increase in the applied electric field. This phenomenon is described as transferred electron effect and the device is called Transferred Electron Device (TED) or Gunn diode. There for the material behaves as negative resistance device over the range of the applied voltage and can be used in microwave oscillators.

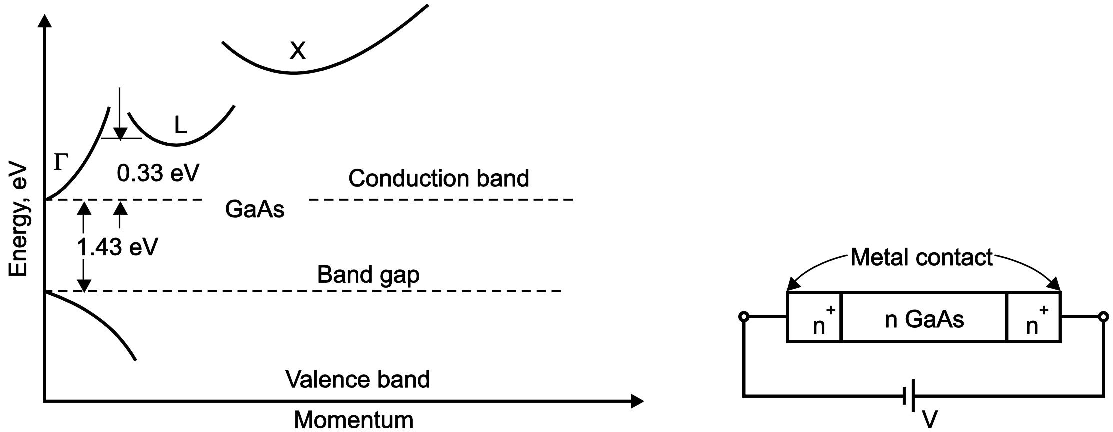

Figure 7.1: Gunn diode

In a Gunn oscillator, the Gunn diode is placed in a resonant cavity. In this case the oscillation frequency is determined by cavity dimension than by the diode itself. Although Gunn oscillator can be amplitude modulated with bias voltage, separate PIN modulator using PIN diode for square wave modulation can be used

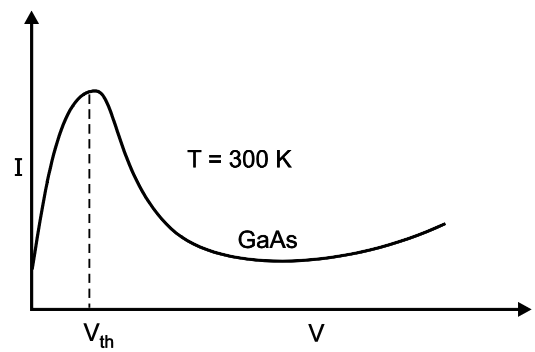

Figure 7.2: VI characteristics of Gunn diode

VII Circuit Diagram.

a) Sample circuit/ Experimental setup:

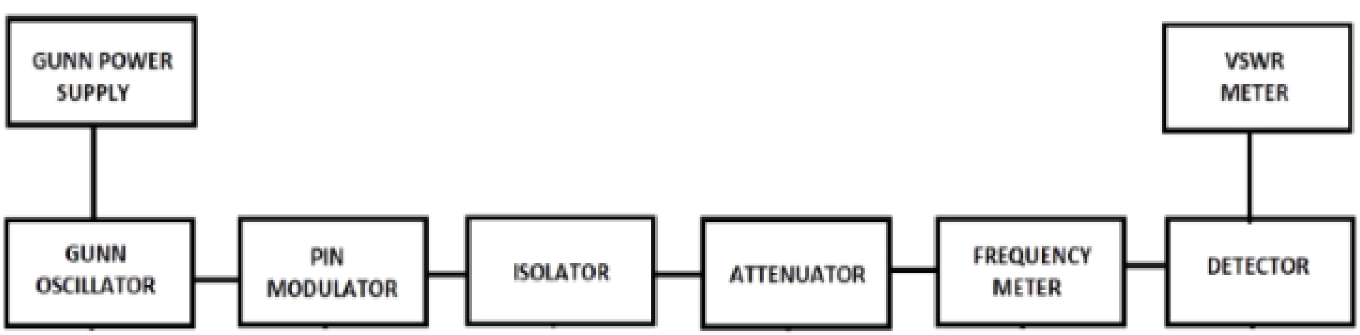

Figure 7.3: Bench setup for V-I Characteristics of Gunn Diode

b) Actual Circuit/Experiment Setup use in laboratory with related equipment rating:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Instrument/Components	Specification	Quantity
1.	Gunn Power Supply	Min Output power:10mW	**1**
2.	Gunn Oscillator	8.6 to 11.6 GHz	**1**
3.	PIN diode modulator	Max RF power:1W	**1**
4.	Isolator	Frequency range: (2.0–4.0 GHz, 8.0–12.0 GHz), Insertion loss: 0.2 to 1.0 dB Isolation: 20 dB to 30 dB or more VSWR: < 1.2:1	**1**
5.	Frequency meter	Frequency Range: RF/microwave meters: Up to 3 GHz, 6 GHz, 20 GHz, or higher	**1**
6.	Variable attenuator	Attenuation Range: 0 to 10 dB, 0 to 30 dB, 0 to 60 dB, or higher, Impedance: 50 Ω, VSWR: < 1.2:1 Average Power:2W Max Insertion loss:0.2dB	**1**
7.	Detector Mount	IN23	**1**
8.	VSWR meter	Frequency Range: Depends on the model and intended application, VSWR Measurement range: 1.0 to 10.0, Directivity: ≥ 25 dB, Impedance: 50 Ω	**1**

9.	Slotted Waveguide stand	-	**1**
10.	Multimeter	50mV RMS,500mV RMS	**1**
11.	BNC Cable	-	**2**

IX Precautions to be followed

1. Ensure proper grounding of the test setup to minimize stray reflections and ensure accurate measurements.
2. Never connect or disconnect live wiring.
3. Ensure all connections are clean and secure to avoid poor contact.
4. Be mindful of the high frequencies and power levels involved in microwave experiments.

X Procedure:

1. Arrange the equipment test bench set up in the following order:
2. Gunn power supply with PIN modulator → Isolator → PIN diode modulator → Variable attenuator → Frequency meter → Slotted waveguide section → Detector mount with detector → Matched.
3. The output of detector can be either connected to oscilloscope or SWR meter**.**
4. General set up is as follows:
   a) Variable attenuator at its minimum position.
   b) Gunn bias voltage fully anticlockwise.
   c) PIN bias voltage fully anticlockwise.
   d) VSWR meter to its normal operating mode, input low impedance, range dB switch 40 to 60 dB.
   e) Gain control knob of VSWR meter to fully clockwise.
5. Set the micrometer of Gunn oscillator for required frequency of operation (Approximately 10 mm main scale).
6. Switch on the Gunn power supply, SWR meter and cooling fan.

I. Current-Voltage Characteristics of Gunn diode:

1. Set Gunn power supply in continuous operating mode
2. Slowly increase the Gunn bias voltage in suitable steps and note down corresponding Gunn current.
3. Do not exceed the Gunn bias voltage beyond 10 volts.
4. Plot the current and voltage readings as shown in the characteristics above and note down threshold voltage at which the current is maximum.
5. Take ratio of applied bias voltage to the current and note down resistance in negative operating region.

XI Resources Used

Sr. No.	Instruments/Components	Specifications	Quantity
1			
2			

XII Actual procedure followed

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XIII Observation Table:

Current-Voltage Characteristics of Gunn diode:

Gunn Bias voltage (V)	Gunn Current (A)	Resistance (Negative region) in Ohms = $R = \frac{V}{A}$
1		
2		
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Calculations:

XIV Result(s):

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XV Interpretation of Results:

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XVI Conclusions and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions for reference. Teachers must design such questions to ensure achievement of identified CO.

1. Justify Gunn diodes used in microwave oscillators rather than amplifiers.
2. List some practical applications of Gunn diodes in communication systems.
3. Compare the Gunn diode with other microwave oscillators like the klystron or magnetron.
4. If the Gunn diode produces 15 mW of power at a bias voltage of 8 V, calculate its efficiency.
5. State the typical shape of the Gunn diode V-I characteristics curve?

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/links/Virtual lab Link

1. https://meiitr.vlabs.ac.in/exp/gunndiode/theoyhtml
2. https://youtu.be/rJc0uXco9zI

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	Working in teams	10%
Product Related (10 Marks)		**40%**
05	Interpretation of result	15%
06	Conclusions	05%
07	Practical related questions	15%
08	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process Related (15)	**Product Related (10)**	**Total (25)**	

Practical No. 8: Determination of the maximum range of Doppler RADAR

I Practical Significance:

Doppler RADAR works by measuring the frequency shift (Doppler shift) of a returned radar signal from a moving target. It is widely used in military, aviation, weather forecasting, and traffic speed detection. The radar range equation is used to estimate the maximum detection range of a radar system. Practical significance of maximum range is target detection, Weather forecasting, speed measurement and Surveillance and Navigation.

II Industry / Employer Expected outcome(s)

- This practical is expected to develop the following skills for the industry-identified competency:

  'Maintain telecommunication system which contain microwave components'

III Course Level Learning outcome(s)

- CO4 – Interpret working of RADAR based systems for range detection.

IV Laboratory Learning outcome(s)

- LLO 8.1- Use Doppler RADAR to detect maximum range.

V Relevant Affective Domain related outcome(s)

1. Select proper programming environment.
2. Follow ethical practices.

VI Relevant Theoretical Background.

The radar equation relates the range of radar to the characteristics of the transmitter, receiver antenna, target, and environment. If the power of the radar transmitter is denoted by P, and if an isotropic antenna is used (one which radiates uniformly in all directions), the power density (watts per unit area) at a distance R from the radar is equal to the transmitter power divided by the surface area $4\pi R^2$ of an imaginary sphere of radius R, or

$$\text{Power density from isotropic antenna} = \frac{P_t}{4\pi R^2}$$

Radars employ directive antennas to channel, or direct, the radiated power P_t into some particular direction. The gain G of an antenna is a measure of the increased power radiated in the direction of the target as compared with the power that would have been radiated from an isotropic antenna. It may be defined as the ratio of the maximum radiation intensity from the subject antenna to the radiation intensity from a lossless, isotropic antenna with the same power input. (The radiation intensity is the power radiated per unit solid angle in a given direction.) The power density at the target from an antenna with a transmitting gain G is

$$\text{Power density from directive antenna} = \frac{P_t G}{4\pi R^2}$$

The target intercepts a portion of the incident power and reradiates it in various directions The measure of the amount of incident power intercepted by the target and reradiated back in the direction of the radar is denoted as the radar cross section a, and is defined by the relation

$$\text{Power density of echo signal at radar} = \frac{P_tG}{4\pi R^2}\,\frac{\sigma}{4\pi R^2}$$

The radar cross section a has units of area. It is a characteristic of the particular target and is a measure of its size as seen by the radar. The radar antenna captures a portion of the echo power. If the effective area of the receiving antenna is denoted A., the power P, received by the radar is

$$= \frac{P_tG}{4\pi R^2}\,\frac{\sigma Ae}{4\pi R^2} = \frac{P_tGAe\sigma}{(4\pi)^2\,R^4}$$

The maximum radar range R_{max} is the distance beyond which the target cannot be detected. It occurs when the received echo signal power P, just equals the minimum detectable signal S.

$$R_{max} = \left|\frac{P_tGAe\sigma}{(4\pi)^2\,S_{min}}\right|$$

VII Simple Simulation Code

a) Sample MATLAB code to determine maximum range of Doppler RADAR:

```
% Doppler Radar Maximum Range Calculation - MATLAB Script
% ----- Given Parameters -----
Pt = 1000;                  % Transmit power in Watts (W)
G_dB = 30;                  % Antenna gain in dB
G = 10^(G_dB/10);           % Convert dB to linear scale
f = 10e9;                   % Frequency in Hz (10 GHz X-band)
c = 3e8;                    % Speed of light in m/s
lambda = c / f;             % Wavelength in meters
sigma = 1;                  % Radar Cross Section (RCS) in m^2
Smin = 1e-13;               % Minimum detectable signal (receiver sensitivity) in Watts
% ----- Radar Range Equation -----
R_max = ((Pt * G^2 * lambda^2 * sigma) / ((4*pi)^3 * Smin))^(1/4);
% ----- Display Result -----
fprintf('Maximum Detection Range: %.2f km\n', R_max / 1000);
```

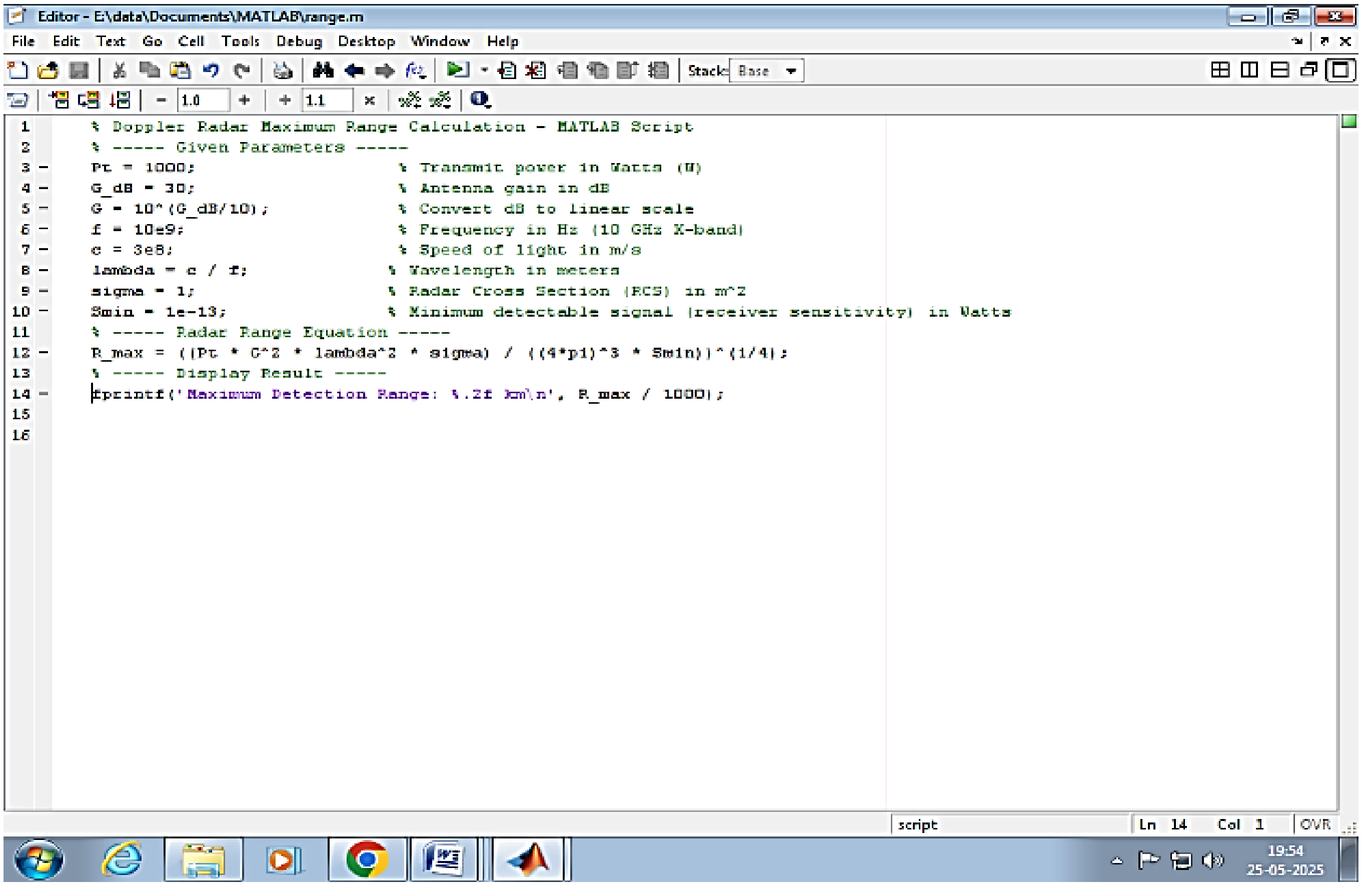


Figure 8.1: MATLAB Code

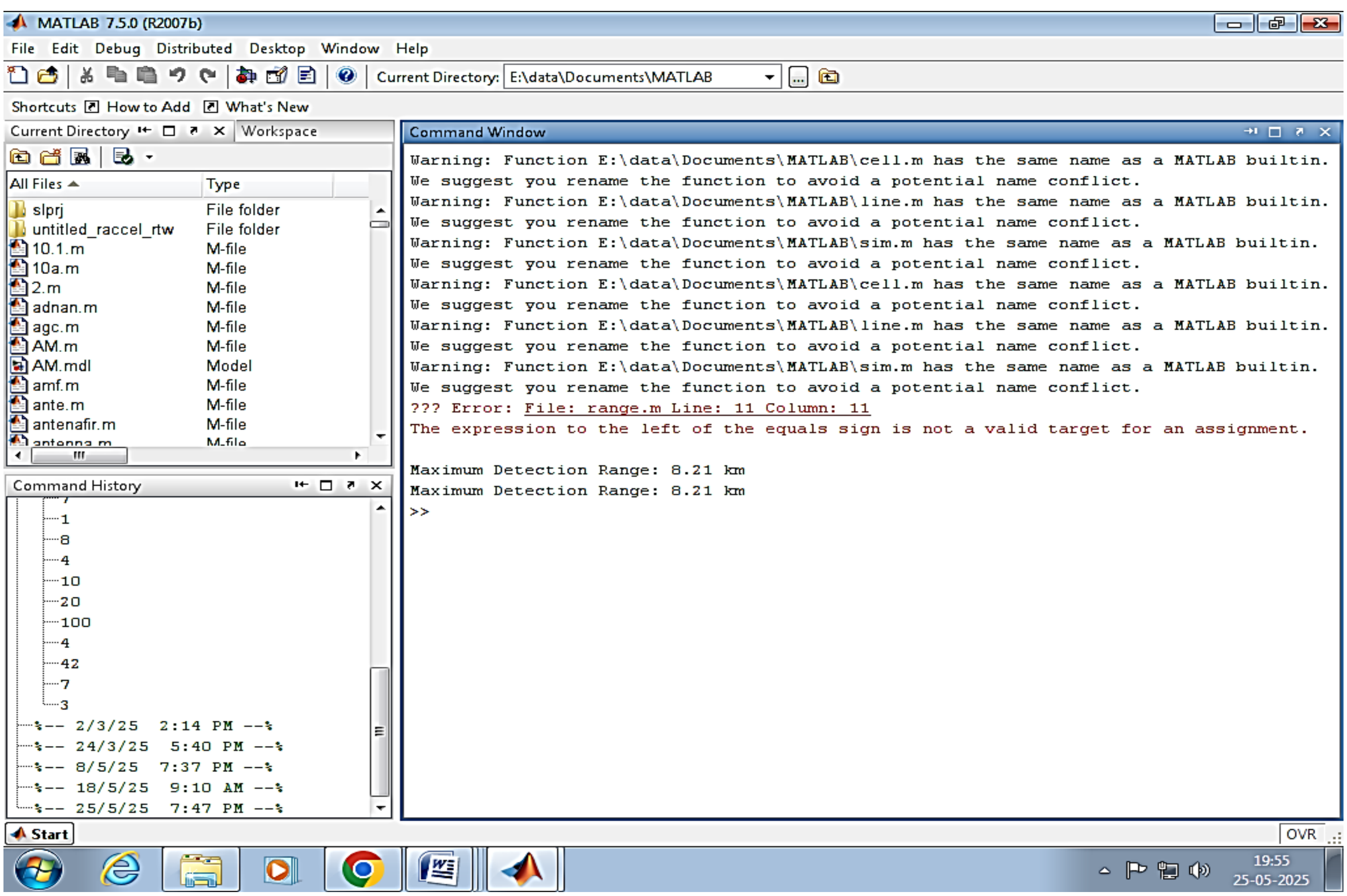


Figure 8.2: MATLAB Simulation Output

b) Actual simulation code used in laboratory:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Instrument/Components	Specification	Quantity
1.	Computer	Latest Processor	1
2.	Simulation Software	LabView/MATLAB/SCILAB/PSpice/HS Spice/Multisim/Proteus or any relevant open-source simulation software	1

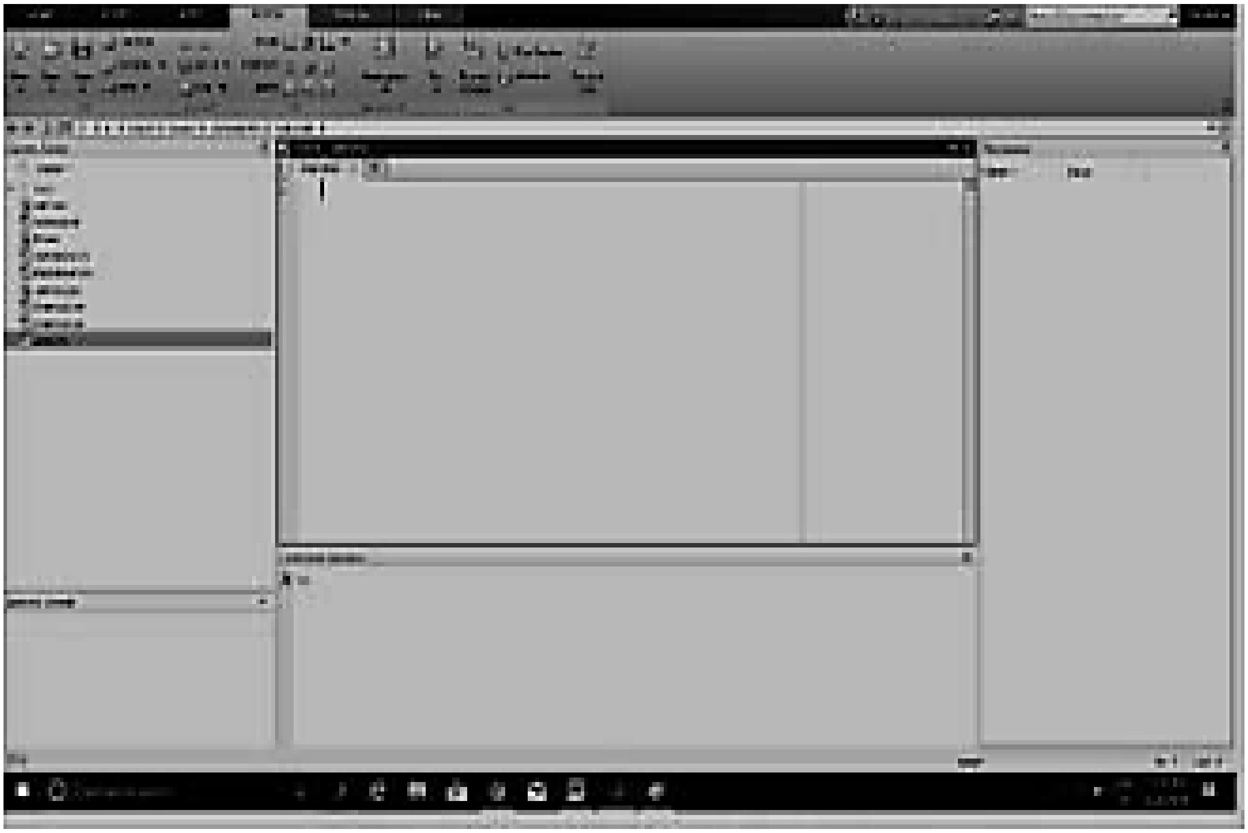
IX Precautions to be followed

1 Ensure proper earthing to the computer system.
2 Ensure compatibility of computer system with software.
3 Ensure proper installation of simulation software

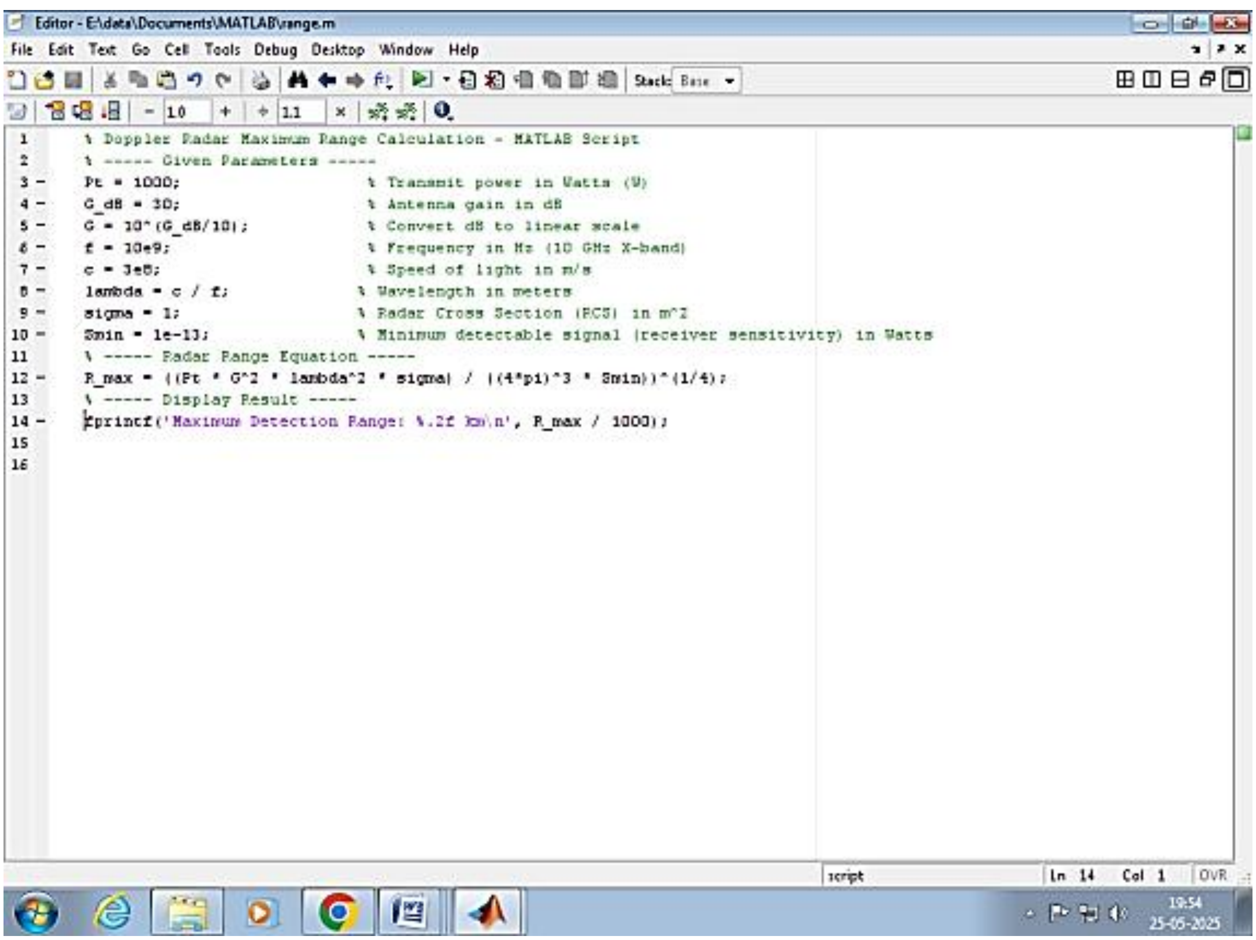
X Procedure:

To determine maximum range of Doppler RADAR

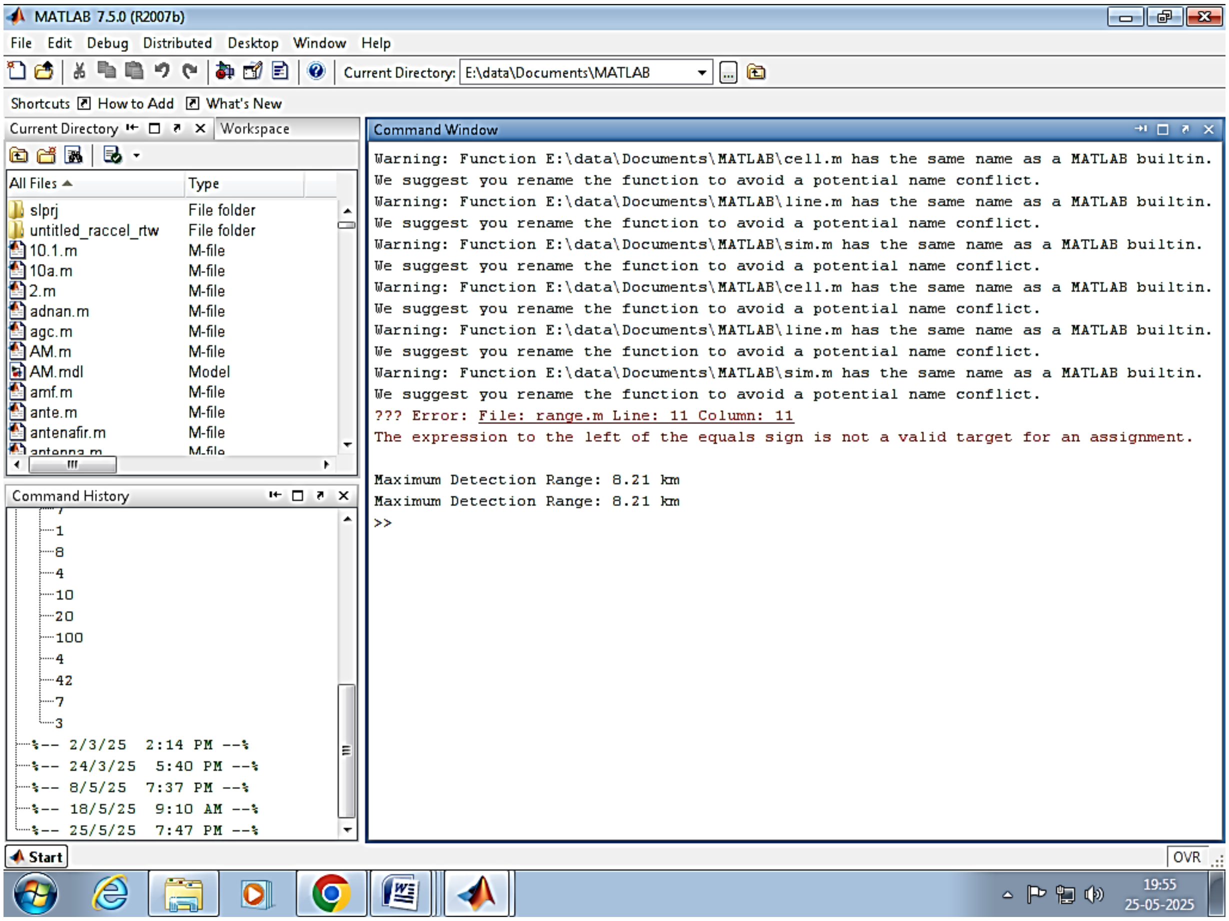
1 Open MATLAB and create a new script file.



2 Write a program to calculate maximum range of Doppler RADAR.



3 Save and run file.



XI Resources used

Sr. No.	Name of Resource	Specifications	Quantity
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XII Actual procedure followed

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XIII Observation:

Actual Simulation Output:

XIV Result(s):

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XV Interpretation of Results:

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XVI Conclusions and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions for reference. Teachers must design such questions to ensure achievement of identified CO.

1. In a Doppler RADAR speed gun, why is range limited to a few hundred meters?
2. How does Doppler RADAR distinguish between stationary and moving targets?

3. A Doppler radar operates at a frequency of 10 GHz and transmits 500 W of power. The antenna gain is 30 dB, the radar cross-section (RCS) of the target is **1 m²**, and the receiver sensitivity is 1×10^{-12} W. Calculate the maximum range of the radar.
4. If the RCS of the target in Q1 drops from 1 m² to 0.01 m² (e.g., stealth aircraft), what will be the new maximum range?

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/links/Virtual lab Link

1 https://youtu.be/UKbQcEZIKgc
2 https://youtu.be/jIHmCivJ8vM
3 https://youtu.be/ix_cx_M-uwg

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	Working in teams	10%
Product Related (10 Marks)		**40%**
05	Correctness of output	10%
06	Interpretation of Result	05%
07	Conclusions	05%
08	Practical related questions	15%
09	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process Related (15)	Product Related (10)	Total (25)	

Practical No. 9: Determination of the rotations per minute (RPM) of a moving object using RADAR.

I Practical Significance:

RADAR systems can directly determine the rotational speed (RPM) of a moving object, particularly those with rotating parts like propellers or blades, by analyzing the Doppler effect of the reflected signals. This principle known as micro-Doppler radar, leverages the changes in frequency caused by the object's rotation, allowing for the calculation of RPM. This practical will help the students to understand real life applications such as Drones and UAVs, Wind Turbines, Industrial Applications.

II Industry / Employer Expected outcome(s)

- This practical is expected to develop the following skills for the industry-identified competency:
  'Maintain telecommunication system which contain microwave components'

III Course Level Learning outcome(s)

- CO4 – Interpret working of RADAR based systems for range detection.

IV Laboratory Learning outcome(s)

- LLO 9.1- Calculate the rotations per minute of a moving object (e.g., fan, Pendulum etc.) based on RADAR.

V Relevant Affective Domain related outcome(s)

1. Follow safe practices.
2. Handle instruments carefully.
3. Follow ethical practices.

VI Relevant Theoretical Background.

Nvis 2001 RADAR Trainer is a complete training system for teaching and learning in the laboratory It consists of trainer board, which contains the circuitry for Doppler signal processing and transmitter and receiver box with horn antenna and a tripod. A tripod is useful in changing the height of RADAR as an angle of RADAR. Nvis 2001 trainer unit contains.

1) CW Transmitting Oscillator
2) Transmitting and receiving horn antenna
3) Mixer
4) Audio amplifier and filter
5) Alarming circuit
6) Object counting circuitry
7) LED indication
8) A comparator for making a pulse over a predefined threshold

CW transmitter oscillator generates the oscillation of frequency 10 GHz. A horn antenna is feeded with this signal output of oscillator also it is given to the mixer block where it is working as local oscillator input of mixer. Another input for mixer is RF signal, which is reradiated signal from target or object with the shift in frequency of oscillations and this shift in frequency is called Doppler frequency. This is the IF output of mixer, which is in audio range

VII Circuit diagram.

a) Simple circuit/ Experimental setup:

Figure 9.1: Sample Experimental Setup

b) Actual Circuit/Experimental Setup used in laboratory with related equipment rating:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Instrument/Components	Specification	Quantity
1.	RADAR Trainer kit setup	Transmitting Frequency: 10 GHz, Output Power: 10 to 15mW, Operating Voltage: 8.6 V or adjustable, Antenna: Horn and parabolic dish with LNA and mounting, IF Output: Audio range, Power Supply: 230V +/- 10%, 50Hz	1
2.	CRO	25 MHz, dual scope	1
	DSO	Bandwidth 30 MHz – 200 MHz Analog channels 2-4	
3.	Simulation Software	Relevant open source simulation software	1

XIX Precautions to be followed

1. Do not switch ON the power supply unless you have checked the circuit connections as per the circuit diagram.
2. While doing the experiment, adjust the proper volt/div and times/div selection on CRO/DSO.
3. Connect kit and CRO/DSO as shown in fig 9.1.
4. Ensure compatibility of computer system with software.
5. Ensure proper installation of simulation software.

X Procedure:

Figure 9.2: Set up for Procedure

1. Take a tripod stand from the suitcase.
2. Fit the trans-receiver unit on the tripod stand and adjust the suitable height for experiment.
3. Connect the SMPS supply to the trainer Nvis 2001.
4. Connect the din connector cable from trainer board (left side of trainer) to Trans-receiver unit

5. Firstly Switch 'On' the SMPS supply and then "Power" switch on the trainer board. (After switch on "Power" switch near LED will be glow.) Note: 'Power' switch is provided only for ON or OFF at the time of experiment and SMPS switch is a main switch.
6. Switch 'On' the buzzer on trainer board and set "Level" Potentiometer in fully clockwise direction.
7. Connect a CRO probe on test point of "Doppler Frequency Signal" (f_d) and wave your hand or reflected in front of antenna.
8. For maximum gain detection adjust the "Detection Adjust" potentiometer in such a way that moving object in front of antenna can be detected with beep sound and also observe the signals on the Oscilloscope/DSO.
9. If any noise is observed on CRO then adjust the "Level" Potentiometer to reduce the noise.

   Note: Since all the reflected signals (f_d) are of very low frequencies and always we have to capture the events, so it is better to use PC with the software Nvis 2001 provided to observe the waveforms instead of using analog scopes. (Digital storage oscilloscopes may be used).
10. Connect the audio cable from EP socket (left side of trainer) to line In/MIC in input (sound card input) of PC.
11. Open the software window. (If software is not installed then first install it).
12. Select "Start Acquisition" on the software window.
13. If any noise is occurred on software window, then again adjust the "Level" potentiometer to reduce the noise.
14. Connect a fan at full speed in front of RADAR at a suitable distance from antenna to get the proper deflection in the form of Doppler frequency.
15. Now measure the Doppler frequency at test point 'f_d' CRO or software window.

Procedure for using Software:

a) Install the software and open it
b) Connect the audio cable from EP socket (left side of trainer) to line In/MIC in input (sound card input) of PC.
c) Select "Start Acquisition" on the software window.
d) If any noise is occurred on software window, then again adjust the "Level" potentiometer to reduce the noise.
e) Now we can observe the waveform on PC. For measurements we have to select "Stop Acquisition" and then we can measure the frequency and time by selecting "Doppler frequency calculation".
f) We can also observe the waveform in frequency and time domain.

XI Resources used

Sr. No.	Name of Resource	Specifications	Quantity
1			
2			
3			
4			

XII Actual procedure followed

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XIII Observation:

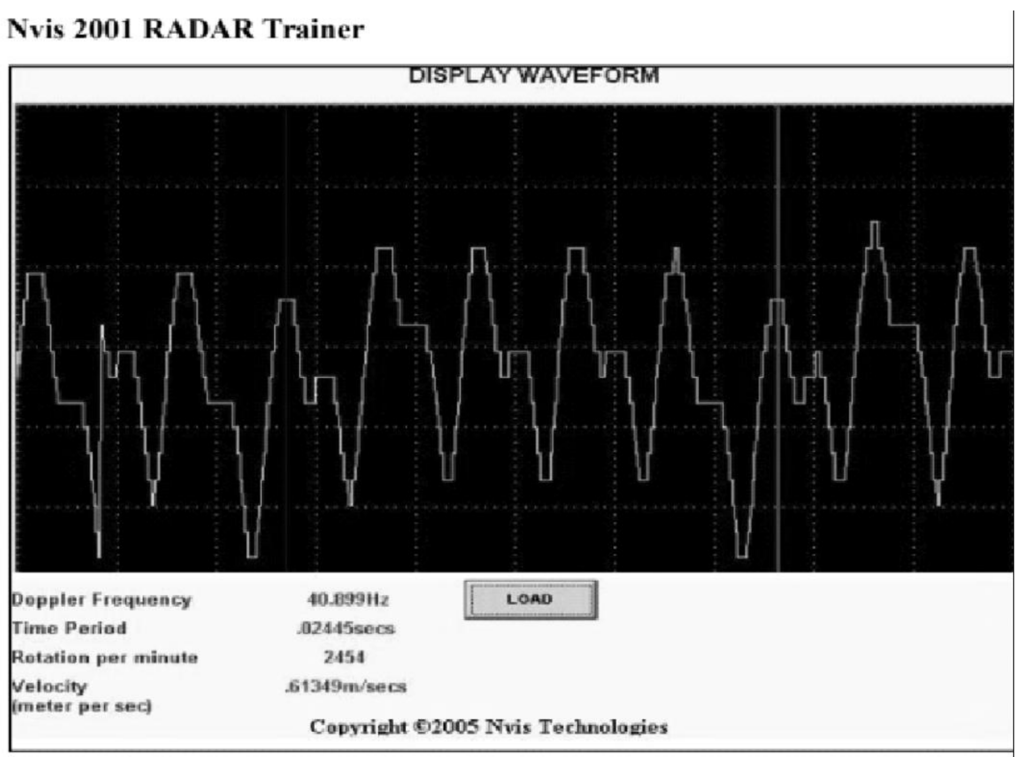

Figure 9.3: Actual Simulation Output

XIV Result(s):

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XV Interpretation of Results:

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XVI Conclusions and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions for reference. Teachers must design such questions to ensure achievement of identified CO.

1. State type of RADAR (e.g., CW, FMCW, pulse-Doppler) is best suited for measuring RPM?
2. State the minimum and maximum RPM range that the RADAR can reliably detect?
3. Justify the Doppler frequency shift related to the RPM of the rotating object?
4. How can RADAR-based RPM measurement be integrated into an existing SCADA or PLC-based control system?
5. How does weather (rain, fog, dust) impact RPM measurement using RADAR?

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/links/Virtual lab Link

1. https://youtu.be/C2fpUkYozd8
2. https://youtu.be/N3ezIesMjVI
3. https://youtu.be/Y2DaxQuTOYM

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	Working in teams	10%
Product Related (10 Marks)		**40%**
05	Interpretation of result	150%
06	Conclusions	05%
07	Practical related questions	15%
08	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process Related (15)	**Product Related (10)**	**Total (25)**	

Practical No. 10: Simulation of RADAR based practical's using any freeware/ open-source simulation software.

I Practical Significance:

The pulse repetition frequency (PRF) significantly affects the RADAR range equation by influencing the maximum unambiguous range and potentially introducing range ambiguities. A higher PRF leads to a shorter maximum unambiguous range and can cause multiple targets at different distances to be misinterpreted as a single target closer to the RADAR, while a lower PRF increases the maximum unambiguous range. The radial velocity of a target causes a Doppler shift in the frequency of reflected electromagnetic waves, resulting in a waveform that exhibits a shift from the original frequency. This shift is directly proportional to the targets velocity and is observed differently for various frequency bands. The practical significance lies in the ability to use this Doppler shift for various applications including RADAR, astronomy and medical imaging. Blind speed in MTI RADAR refers to target radial velocities that are undetectable due to the RADAR's pulse repetition frequency (PRF). Moving targets with blind speed velocities appear stationary to the MTI RADAR much like ground clutter leading to missed detections. This practical will help the students in RADAR system design, as the choice of PRF impacts range accuracy, clutter and the ability to detect multiple.

II Industry / Employer Expected outcome(s)

This practical is expected to develop the following skills for the industry-identified competency
'Maintain telecommunication system which contain microwave components'

III Course Level Learning outcome(s)

- CO4 – Interpret working of RADAR based systems for range detection.
- CO5 – Maintain SONAR and various types of RADAR systems as microwave application.

IV Laboratory Learning outcome(s)

- LLO 10.1- Investigate the effect of pulse repetition frequency (PRF) on Radar range equation using MATLAB coding
- LLO 10.2- Observe the waveform of effect of radial velocity of the target on Doppler frequency generation for various frequency bands
- LLO 10.3- Test the effect of blind speed on the performance of MTI RADAR
- LLO 10.4- Investigate the effect of pulse repetition frequency on clutter attenuation.

V Relevant Affective Domain related outcome(s)

1. Select proper programming environment.
2. Follow ethical practices.

VI Relevant Theoretical Background.

The unambiguous Radar range is dependent on pulse repetition frequency related with equation:

$$\text{Run} = \text{unambiguous radar range} = \frac{c}{(2 \times f_p)}$$

where $c = 3 \times 10^8$ m/s and f_p = pulse repetition frequency of the operating Radar system

The increased pulse repetition frequency fp will result in minimum achievable unambiguous range of the Radar. It happens so because at higher pulse frequency repetition there are high chances of receiving echo signal for the first transmitted pulse after transmitting second pulse and hence leading to false or ambiguous range

On the other hand, keeping too low pulse repetition frequency will increase achievable unambiguous radar range but, vulnerable to pick up large amount of clutter in the received echo signal. Therefore, moderate amount of pulse repetition frequencies is always advisable. In the programming code, written in MATLAB we implement the calculation of unambiguous Radar range Run for various values of pulse repetition frequencies ranging from 10 Hz to 1 KHz.

The changes in the frequency of an electromagnetic signal that propagates from radar to moving target and back to the radar introduces frequency shift in the signal. As shown in figure 10.1 if 'R' is the target distance from radar then total number of wavelengths in two-way path from radar to target and back is $2R/\lambda$. Where each wavelength corresponds to phase change of 2π radians. If ϕ denotes total phase change in the two-way propagation then $\phi = 2\pi \times 2R/\lambda = 4\pi R/\lambda$. If the target is in motion, then the distance 'R' changes, which tends to change the phase ϕ, therefore differentiating the phase with respect to time

$$\frac{d\phi}{dt} = \frac{d}{dt} 4\pi R/\lambda = \frac{4\pi}{\lambda}\frac{dR}{dt} = \frac{4\pi}{\lambda} V_r = \omega_d = \text{angular velocity} = 2\pi f_d$$

$V_r = \frac{dR}{dt}$ = radial velocity in m/s and f_d is the Doppler frequency

Doppler Frequency = $f_d = 2Vr/\lambda = 2ftV_r/c$ where f_t is the radar operating frequency = c/λ.

If Doppler frequency is in Hz, radial velocity in knots (kt) and radar wavelength in meters then,

Doppler frequency $f_d(\text{Hz}) = 1.03\ V_r(\text{kt})/\lambda\ (\text{m}) \approx V_r(\text{kt})/\lambda\ (\text{m})$ 1 knot = 1 kt = 0.51444 m/s and 1 m/s = 1.943 knot

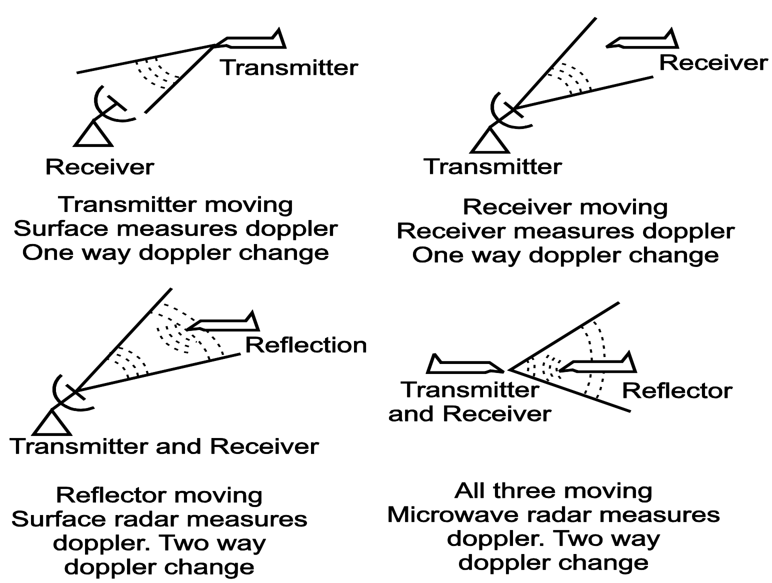


Figure 10.1: Doppler creation in different ways

Pulsed transmit signal produce spectra which is discrete in nature composed of a number of individual frequencies rather than containing all frequencies. If the pulses are periodic, the individual spectral lines, representing individual sinusoids are uniformly spaced and separated by PRFs. Doppler ambiguities happen when, it is unknown that which transmit pulse caused a particular receive spectral line. Doppler ambiguity occurs when Doppler shift is greater than half of frequency difference between transmit spectral lines, violating Nyquist sampling criteria. As shown in Fig.10.3 the taller solid line represents illumination spectrum and are separated by PRF. The wider part is associated with transmit line represents spectrum of stationary clutter, and the wider part is associated with transmit line represents spectrum of stationary clutter, and shorter dashed lines are target echo spectrum. In Fig. 10.3 (a) Doppler shift is less than half of spacing between illumination spectral lines, therefore this target is unambiguous in Doppler shift In Fig. 10.3 (b) the Doppler shift is greater than half of PRF. The analysis returns apparent Doppler shift f_a from the nearest illumination line, therefore this target is ambiguous in Doppler shift

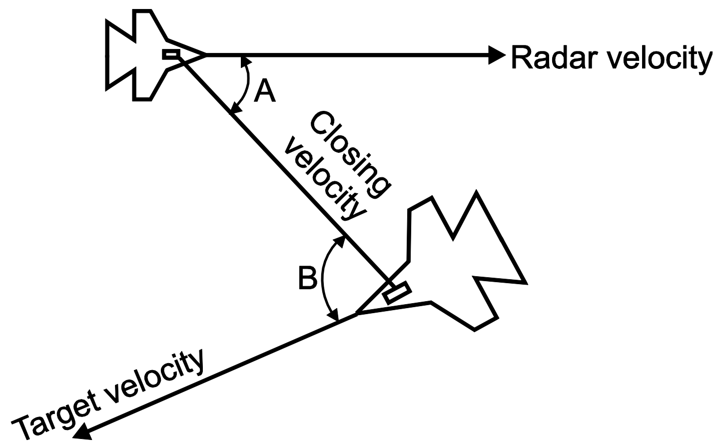


Figure 10.2: Dependence of Doppler on Closing Velocity

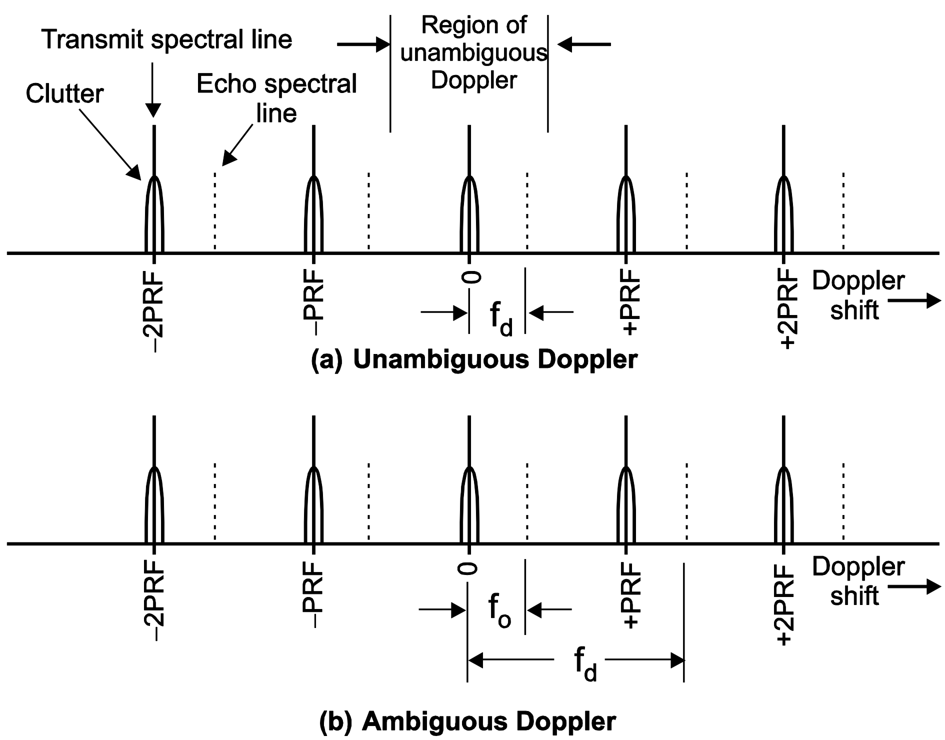


Figure 10.3: Doppler Ambiguity

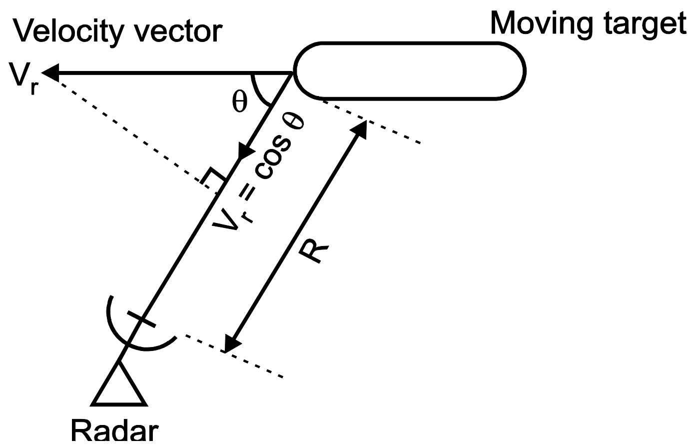


Figure 10.4: Doppler Frequency Phenomenon

Pulsed radars which make use of Doppler frequency shift are categorized as Moving Target Indication radars (MTI) and Pulse Doppler radars. MTI radars have low PRF and therefore their performance will not be affected by ambiguities in range but they may have ambiguity in Doppler frequency shift. Pulsed Doppler radars on the other hand have large PRF and therefore their performance will be affected by numerous range ambiguities, but avoids ambiguities in Doppler frequency shifts. The local oscillator of superheterodyne receiver of MTI radar must be more stable than for radar which does not employ Doppler principle. If the phase of local oscillator changes significantly between pulses, then an un-cancelled clutter echo residue may result at the output of delay line canceller. This may be treated as presence of moving target even if there is presence of only clutter echo. Therefore, it is needed to make the local oscillator of a receiver of MTI radar more stable in operation. A stable local oscillator is used for same purpose is being called as stalo. The IF stage is designed as a matched filter as usual in radars. The phase detector follows the IF stage which combines the received signal at IF and reference signal from coho to produce difference frequency signal.

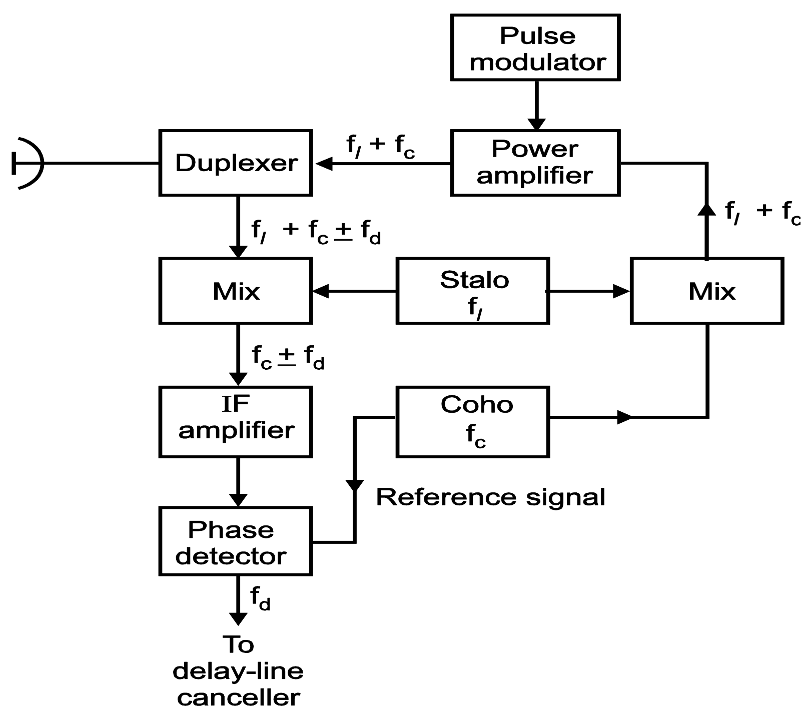


Figure 10.5: Block diagram of MTI Radar

This difference frequency is the Doppler frequency. The coho stands for coherent oscillator and it signifies that phase of reference signal is same as that of phase of transmitted signal. The coherency with the transmitted signal is obtained by using sum of the coho and stalo signals as input to power amplifier. The combination of coho and stalo is sometimes being called as receiver- exciter portion of MTI radar. The output of phase detector is input to delay line canceller. This delay line acts as high pass filter to separate Doppler shifted echo signal of moving target from stationary clutter. The frequency response of single delay line canceller is given by: $H(f) = 2 \sin (\pi f_d T_p)$ where f_d is the Doppler shift and T_p is the pulse repetition period The magnitude of this response is sketched in figure; the frequency response will be zero when$\pi f_d T_P = 0, \pm \pi, \pm 2\pi, \pm 3\pi$ …... Therefore $f_d = 2 V_r/\lambda = n f_p = n/T_p$ for n = 0, 1, 2, …… Therefore if the moving target has its Doppler frequency at pulse repetition frequency and its harmonics then target will not be detected at all even if it is actually present. The typical speed of a moving target at pulse repetition frequency and its harmonics, when the target becomes undetected is called as Blind speed of the target. It indicates that, the delay line canceller will produce zero response when Doppler frequency ($f_d = 2V_r/c$) becomes equal and multiple of PRF. The radial velocities of a moving target at which the blind speed occurs is given by, $f_d = 2 f_t V_r/c = n f_p = n / T_p = 2 f_t V_r / c$ therefore $n f_p = 2 f_t V_r /c$ hence $V_r = n \lambda f_p /2$ for n = 1, 2, 3 The "Clutter" is defined as, unwanted echoes from natural environment which include echoes from land, sea, weather (particularly rain), birds, insects etc. Point or discrete clutter echoes include TV and water towers, buildings and other similar structures that produce large back scatter. Large clutter echoes can mask the echoes from desired targets and thus limit the capacity of the radar. The echoes from land and sea are examples of surface clutters, while the echoes from rain, chaff are the examples of volume clutter. The measurement of clutter echo is clutter cross section per unit area denoted by σ_0. Therefore, clutter cross section per unit area $\sigma_0 = \sigma_c/A_c$ where σ_c = radar cross section of clutter occupying area A_c and sometimes σ_0 is also called as scattering coefficient or normalized RCS. The limitation of single delay line canceller is insufficient attenuation of clutter that results from finite width of clutter spectrum. The clutter spectrum has finite width due to internal motions of clutter, instabilities of stalo and coho oscillators, imperfections of radar and signal processors and finite duration of signal. The clutter attenuation is given by:

$$CA = \frac{f_p^2}{4\pi^2 \sigma_c^2} = \frac{f_p^2 \lambda^2}{16\pi^2 \sigma_r^2} \quad \text{where, } \sigma_c = 2\sigma_v/\lambda$$

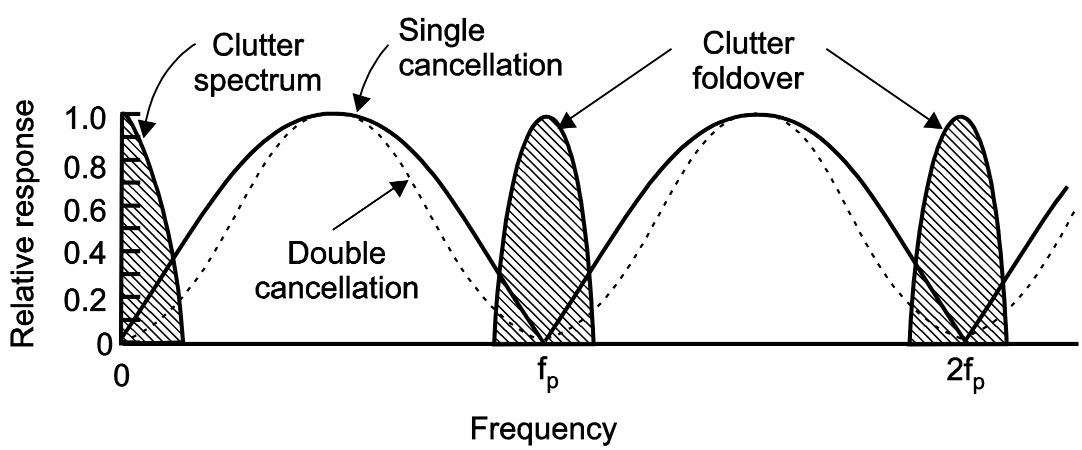


Figure 10.6: Clutter attenuation comparison between single and double DLC's

VII Simple Simulation Code

a) Sample MATLAB code to investigate the effect of pulse repetition frequency (PRF) on Radar range equation:

```
% Program to plot graph of pulse repetition frequency vs unambiguous radar range

C = 3.0e+8;                              % Speed of light (m/s)
Fp = 10:10:1000;                         % Pulse Repetition Frequency (Hz)
Run = C ./ (2 .* Fp);                    % Unambiguous range in meters
Run_nmi = 1.9438 .* Run / 1000;          % Convert to nautical miles (1 nmi = 1852 m)
plot(Fp, Run_nmi, 'r-', 'LineWidth', 2); % Plot with red line
title('Plot of Unambiguous Range vs Pulse Repetition Frequency');
 xlabel('Pulse Repetition Frequency (Hz)');
 ylabel('Unambiguous Range (nmi)');
   grid on;
```

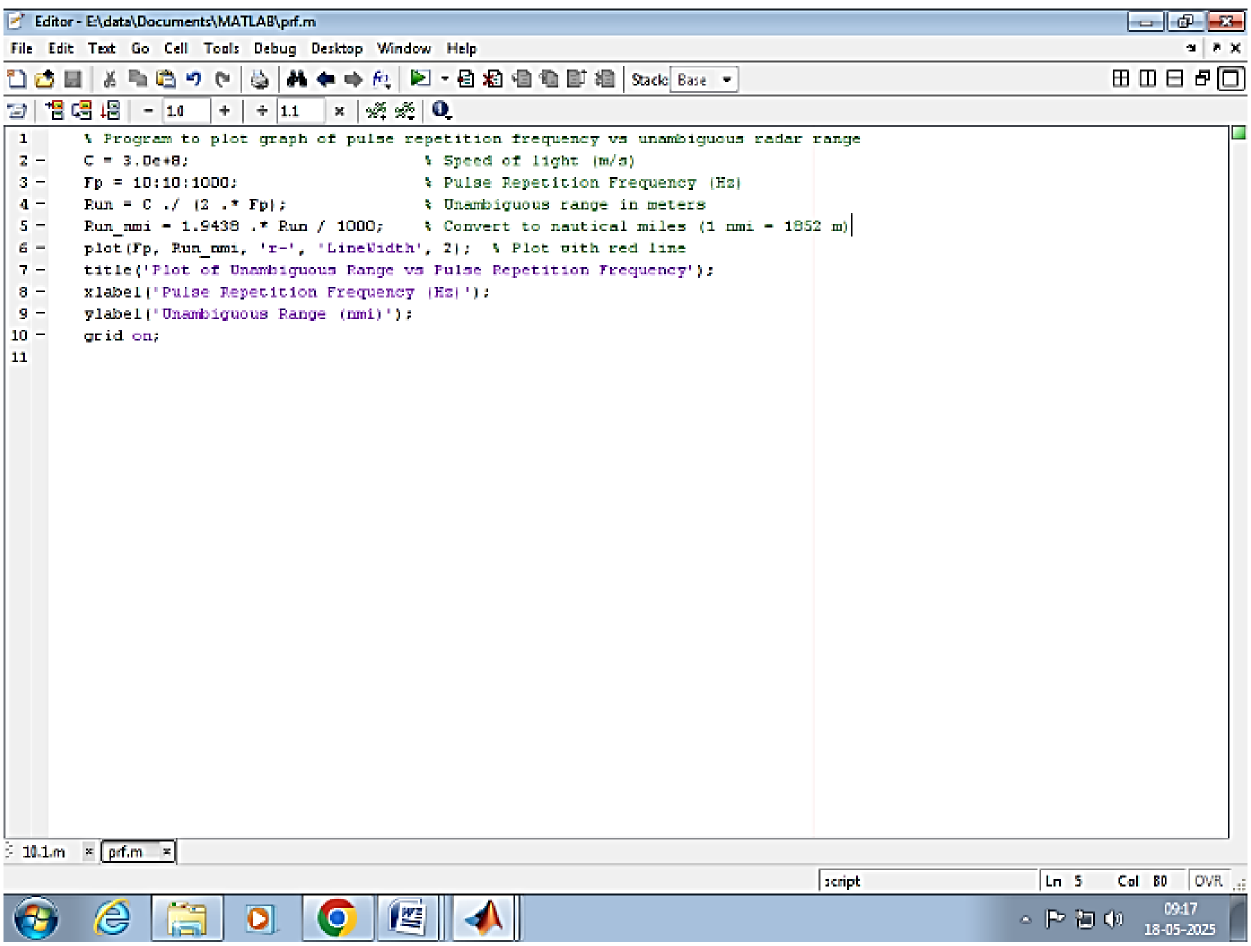


Figure 10.7: MATLAB Code

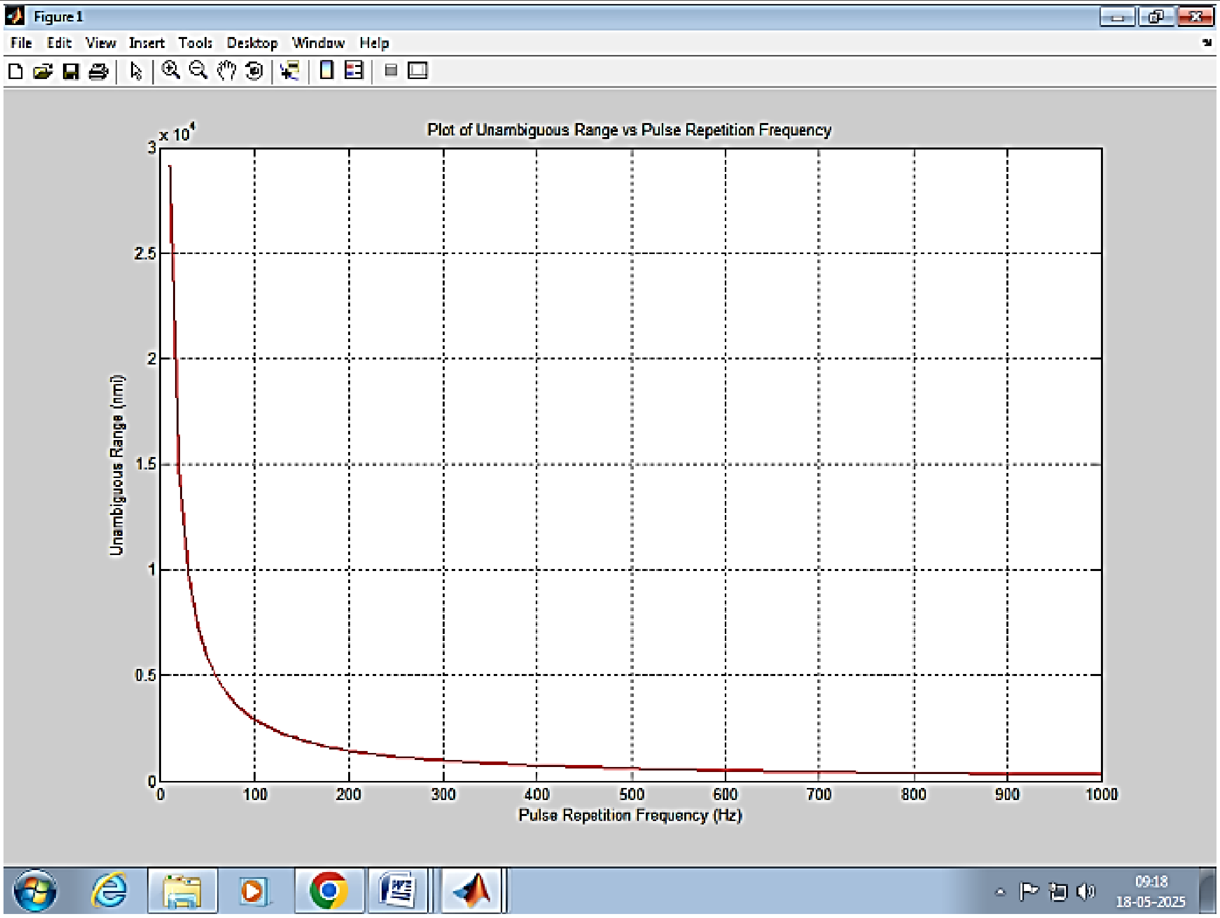


Figure 10.8: MATLAB Simulation Output

b) Sample MATLAB code to observe the waveform of effect of radial velocity of the target on Doppler frequency generation for various frequency bands:

```
% Program to plot graph between Doppler frequency and radial velocity for
% different RF frequency bands
c = 3.0e+8; % speed of light
ft1 = 15.0e+6; % HF band
ft2 = 220.0e+6; % VHF band
ft3 = 435.0e+6; % UHF band
ft4 = 1.3e+9; % L band
ft5 = 3.2e+9; % S band
ft6 = 5.6e+9; % C band
ft7 = 9.4e+9; % X band
ft8 = 13.7e+9; % Ku band
ft9 = 35.0e+9; % Ka band
ft10 = 94.0e+9; % W band
Vr = 1:10:10000; % radial velocity ranging from 1 to 10000 knots
```

```
Fd_HF = (ft1.*Vr)/c; % Doppler for HF band
Fd_VHF = (ft2.*Vr)/c; % Doppler for VHF band
Fd_UHF = (ft3.*Vr)/c; % Doppler for UHF band
Fd_L = (ft4.*Vr)/c; % Doppler for L band
Fd_S = (ft5.*Vr)/c; % Doppler for S band
Fd_C = (ft6.*Vr)/c; % Doppler for C band
Fd_X = (ft7.*Vr)/c; % Doppler for HF band
Fd_Ku = (ft8.*Vr)/c; % Doppler for Ku band
Fd_Ka = (ft9.*Vr)/c; % Doppler for Ka band
Fd_W = (ft10.*Vr)/c; % Doppler for W band
loglog (Vr,Fd_HF,'k-',Vr,Fd_VHF,'k--',Vr,Fd_UHF,'b-',Vr,Fd_L,'b--',...
Vr,Fd_S,'g-',Vr,Fd_C,'g--',Vr,Fd_X,'r-',Vr,Fd_Ku,'r--',...
Vr,Fd_Ka,'c-',Vr,Fd_W,'c--');
title ('Plot of Radial velocity Vs Doppler Frequency');
xlabel ('Radial velocity Vr in knots');
ylabel ('Doppler frequency Fd in Hz');
legend ('HF','VHF','UHF','L','S','C','X','Ku','Ka','W')
grid on;
```

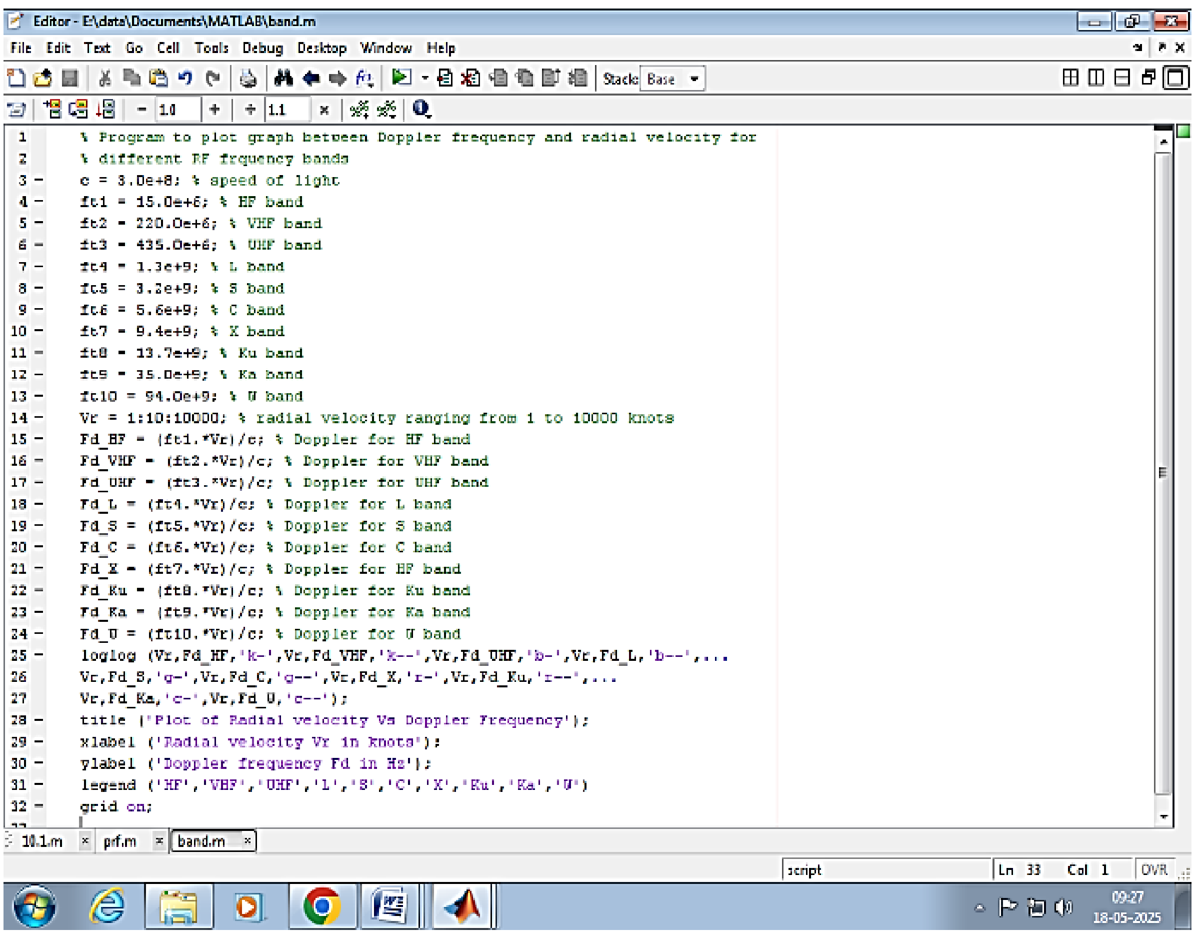


Figure 10.9: MATLAB Code

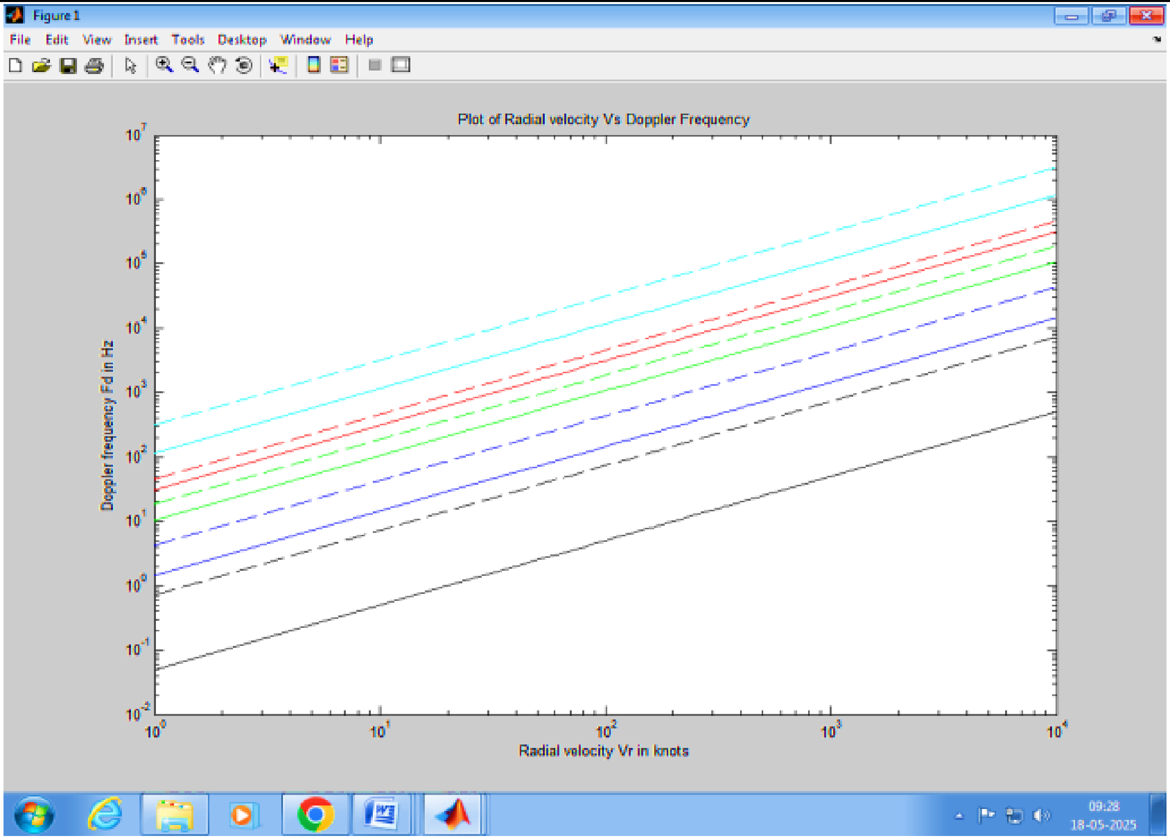


Figure 10.10: MATLAB Simulation Output

c) Sample MATLAB code to test the effect of blind speed on the performance of MTI RADAR:

```
% Frequency response of single delay line canceler
% Demonstration of blind speed effects
clear;                          % Clear previous variables
fp = 1e9;                        % PRF = 1 GHz
tp = 1 / fp;                    % PRI = 1 / PRF
fd = 0:fp/200:5*fp;             % Doppler frequency (up to 5x PRF)
HF = abs(2 * sin(pi * fd * tp));  % Frequency response of single DLC
plot(fd, HF, 'm', 'LineWidth', 2);
title('Frequency Response of Single Delay Line Canceler');
xlabel('Doppler Frequency (Hz)');
ylabel('Magnitude Response |H(f)|');
grid on;
```

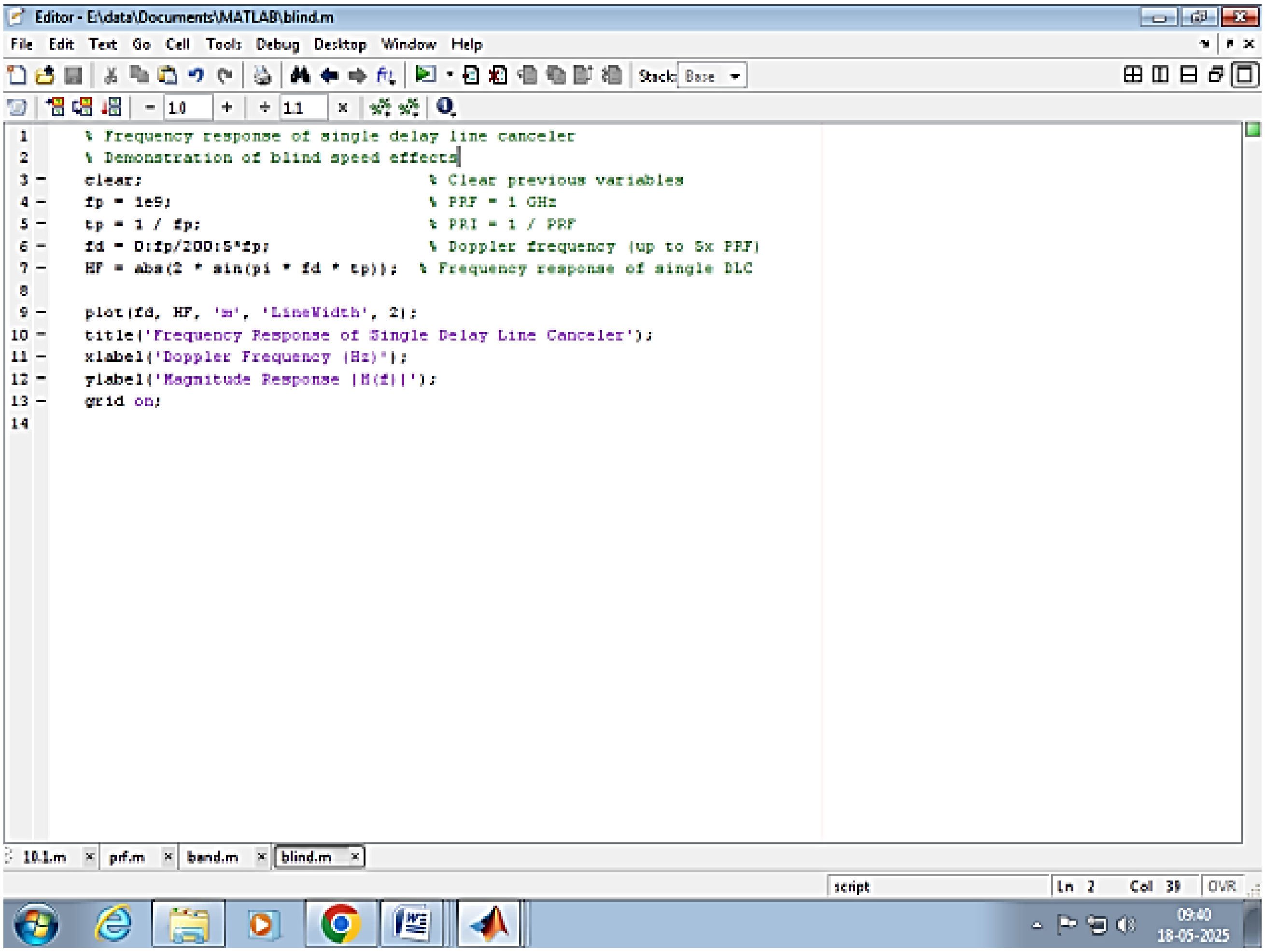


Figure 10.11: MATLAB Code

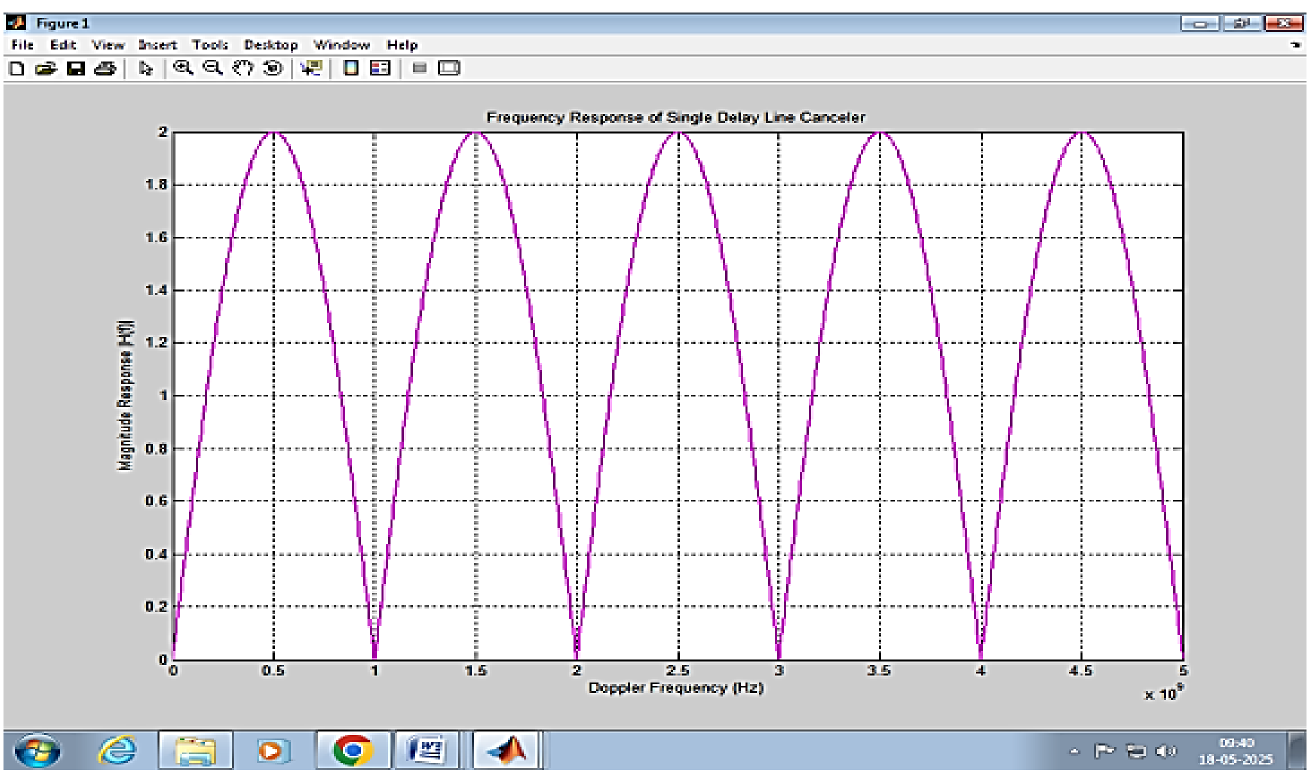


Figure 10.12: MATLAB Simulation Output

d) Sample MATLAB code to Investigate the effect of pulse repetition frequency on clutter attenuation

```
% Program to plot clutter attenuation Vs PRF for single line DLC
Vol_RCS = 1.0; % Volume RCS = 1 sqm
wavelength = 0.3; % frequency of radar operation ft = 1 GHz
sample = 100; % PRF = 100 Hz
fp = 0:sample:1.0e+6; % PRF array
CA = (wavelength^2.* fp.*fp)/(16*pi*pi*Vol_RCS*Vol_RCS);


% clutter attenuation of single DLC
plot (fp,CA,'r--');
title ('Plot of clutter attenuation VS PRF');
xlabel ('Pulse repitition frequency (Hz)');
ylabel ('Clutter attenuation');
grid on;
```

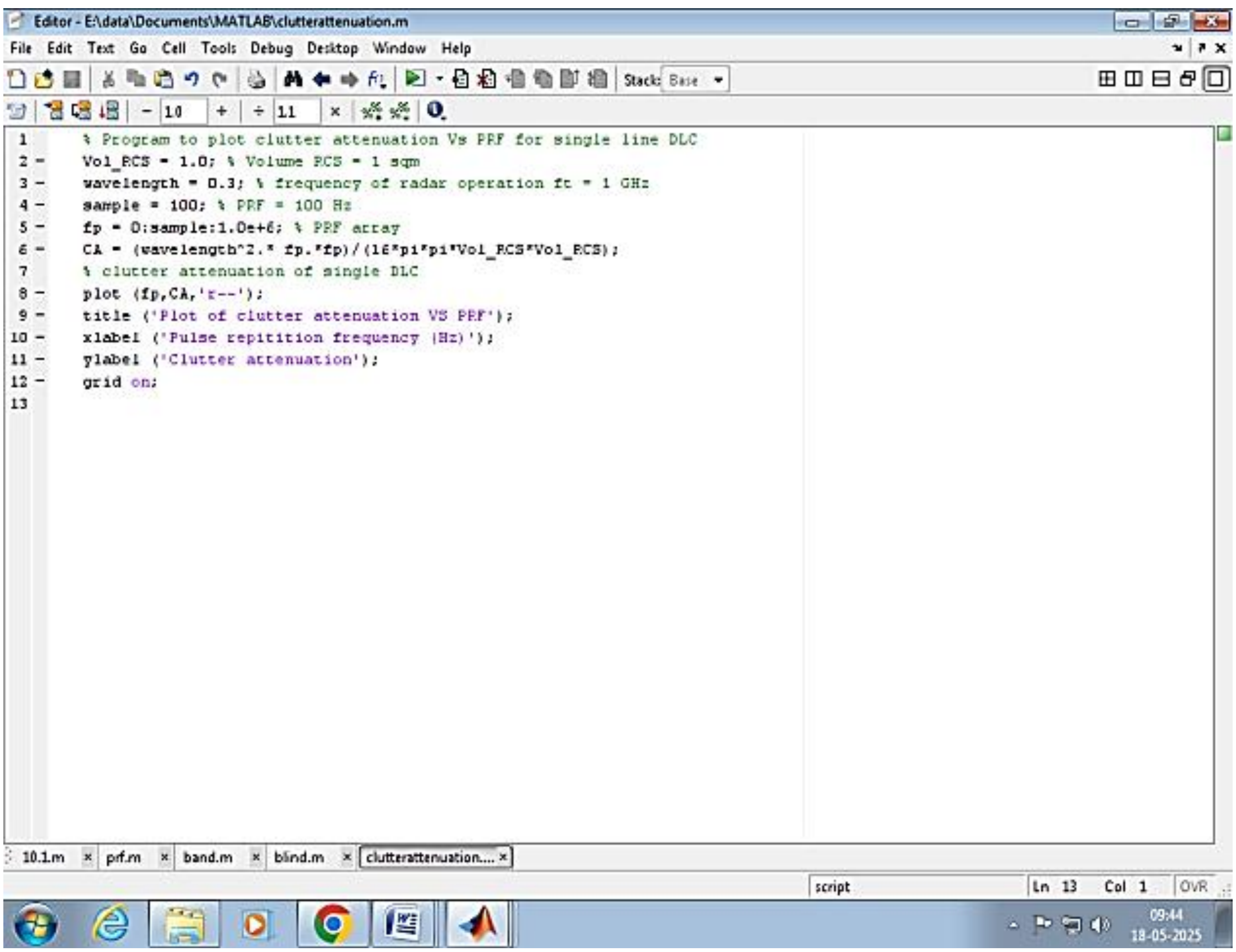


Figure 10.13: MATLAB Code

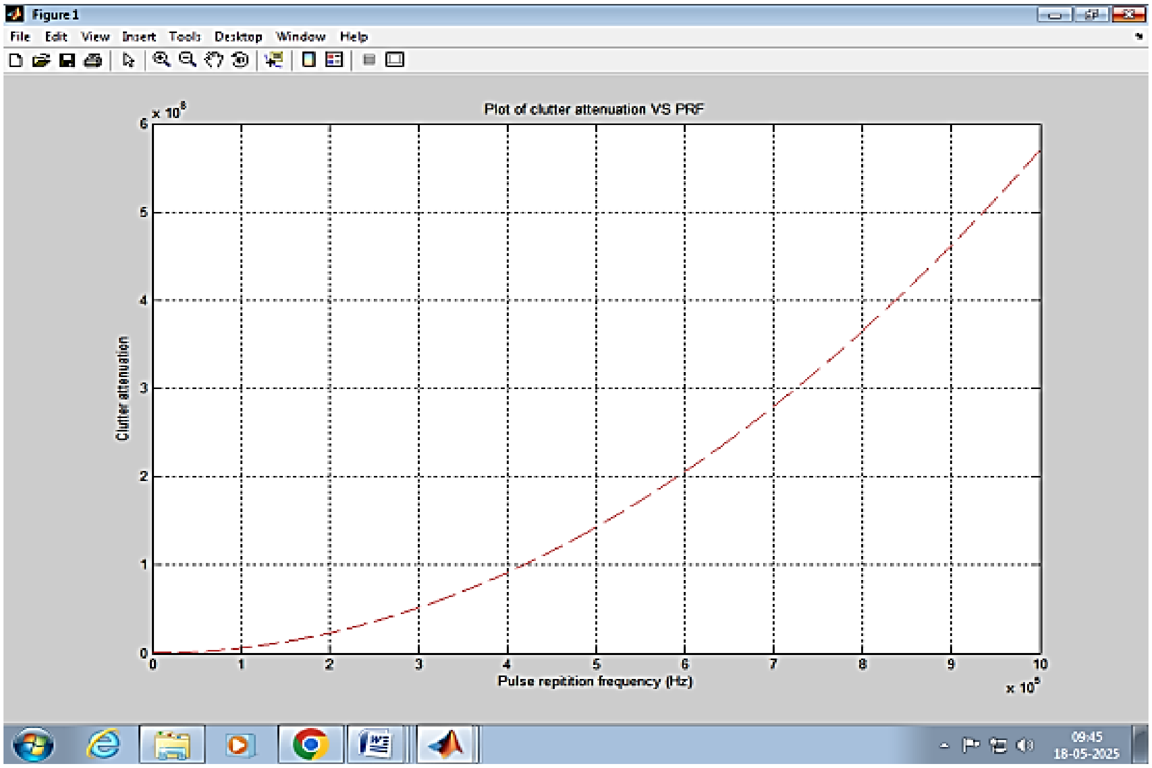


Figure 10.14: MATLAB Simulation Output

e) Actual simulation code used in laboratory:

VIII Required Resources/apparatus/equipment with specifications:

Sr. No.	Instrument/Components	Specification	Quantity
1.	Computer	Latest Processor	1
2.	Simulation Software	LabView/MATLAB/SCILAB/PSpice/HS Spice/Multisim/Proteus or any relevant open-source simulation software	1

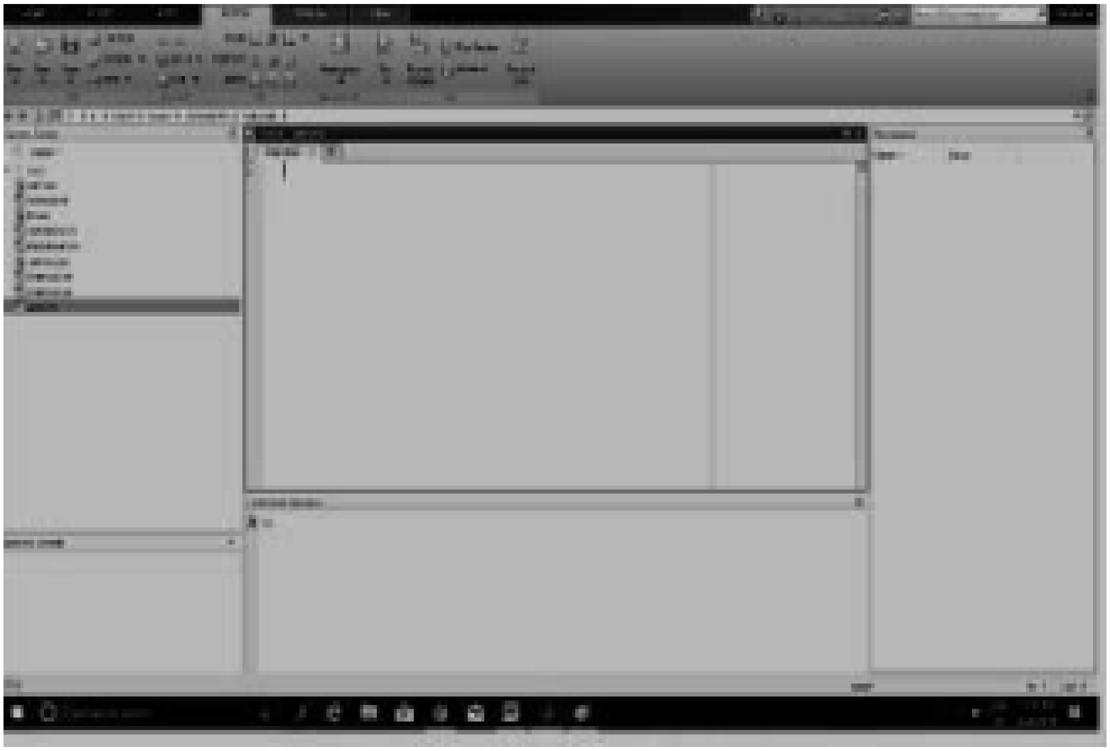
IX Precautions to be followed (Safety instructions / Rules / Standards)

1. Ensure proper earthing to the computer system.
2. Ensure compatibility of computer system with software.
3. Ensure proper installation of simulation software.

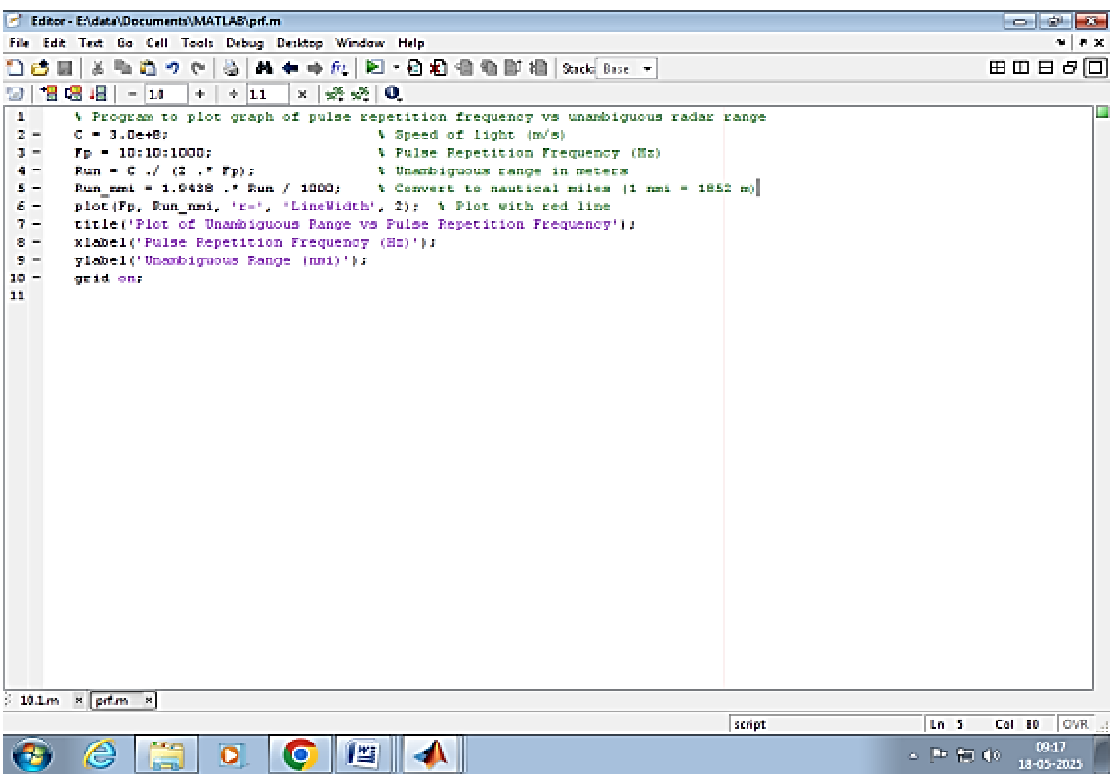
X Procedure:

- **Part I: To investigate the effect of pulse repetition frequency (PRF) on Radar range equation**

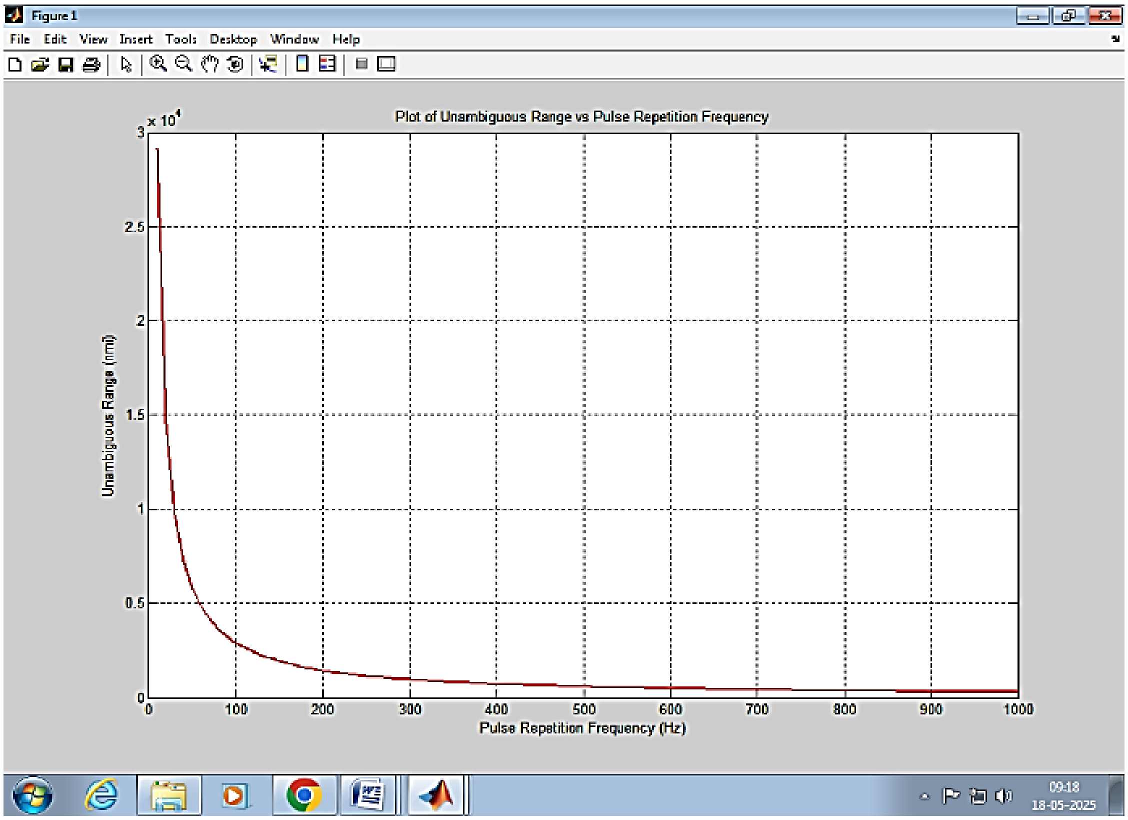
1. Open MATLAB and create a new script file.



2. Write a program to calculate values for unambiguous range Run for different values of plus repletion frequencies ranging from 10 Hz to 1 KHz in steps of 10 Hz each.

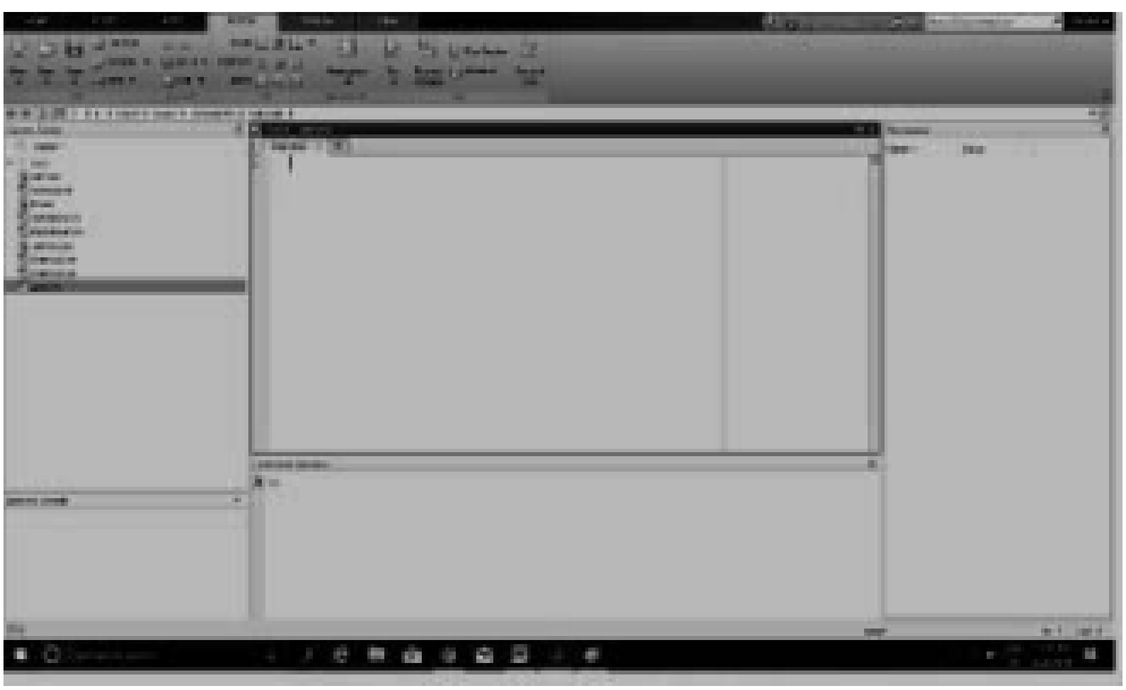


3. Save and run file.
4. Plot the unambiguous radar range on Y axis with pulse repletion frequencies on X axis with neat labels.

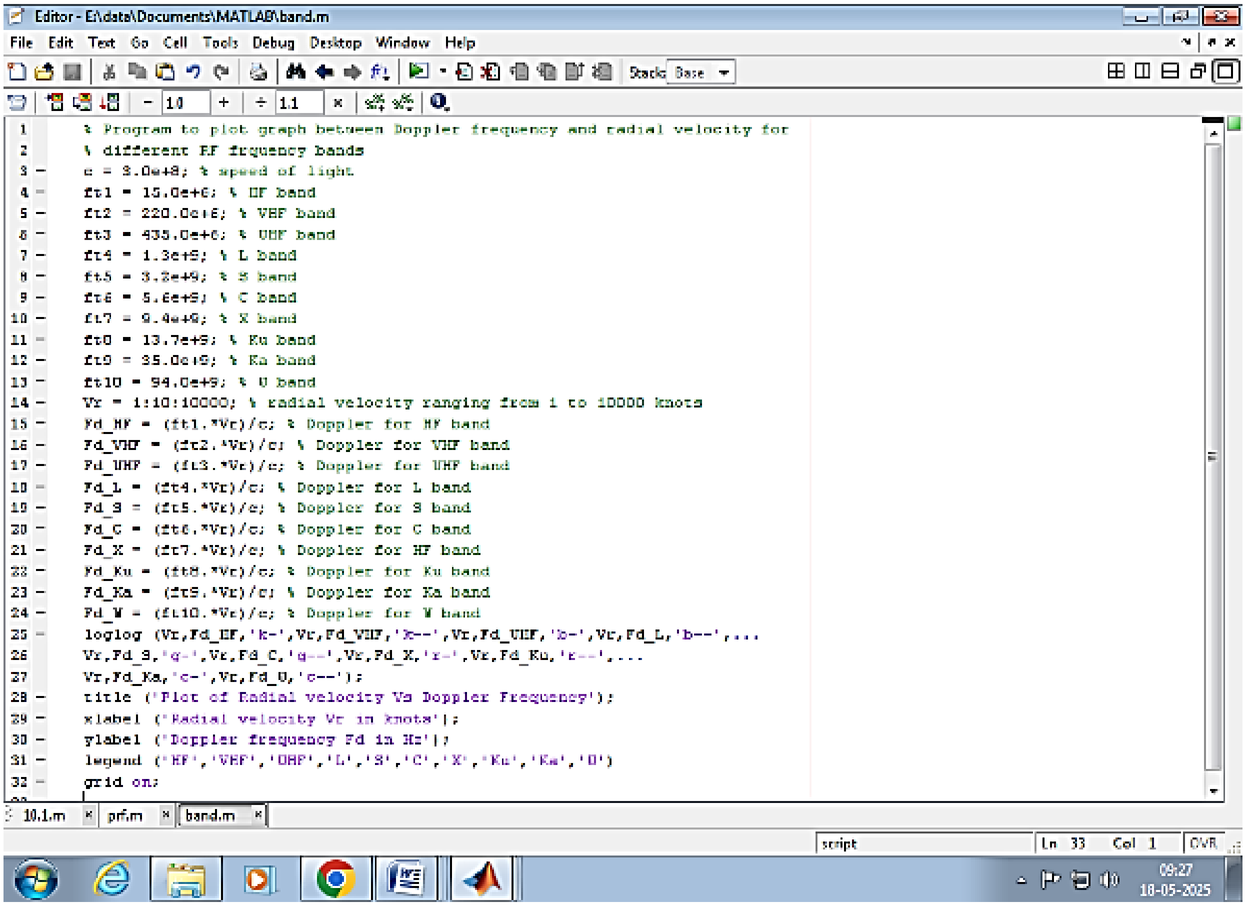


- **Part II: To observe the waveform of effect of radial velocity of the target on Doppler frequency generation for various frequency bands**

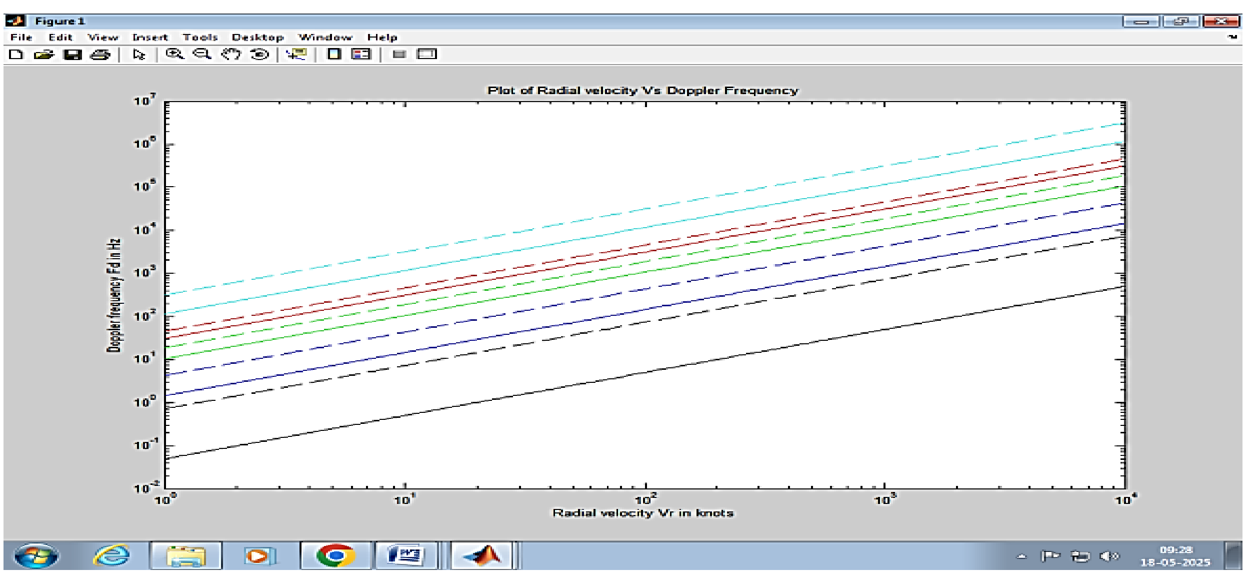
1. Open MATLAB and create a new script file.



2. Write a program.
   Implement Doppler frequency by Fd = Ft Vr / C
   Where Fd = Doppler frequency shift, Vr = radial velocity of the target, C is constant
   Vary the transmitted frequency from HF to W band frequency range

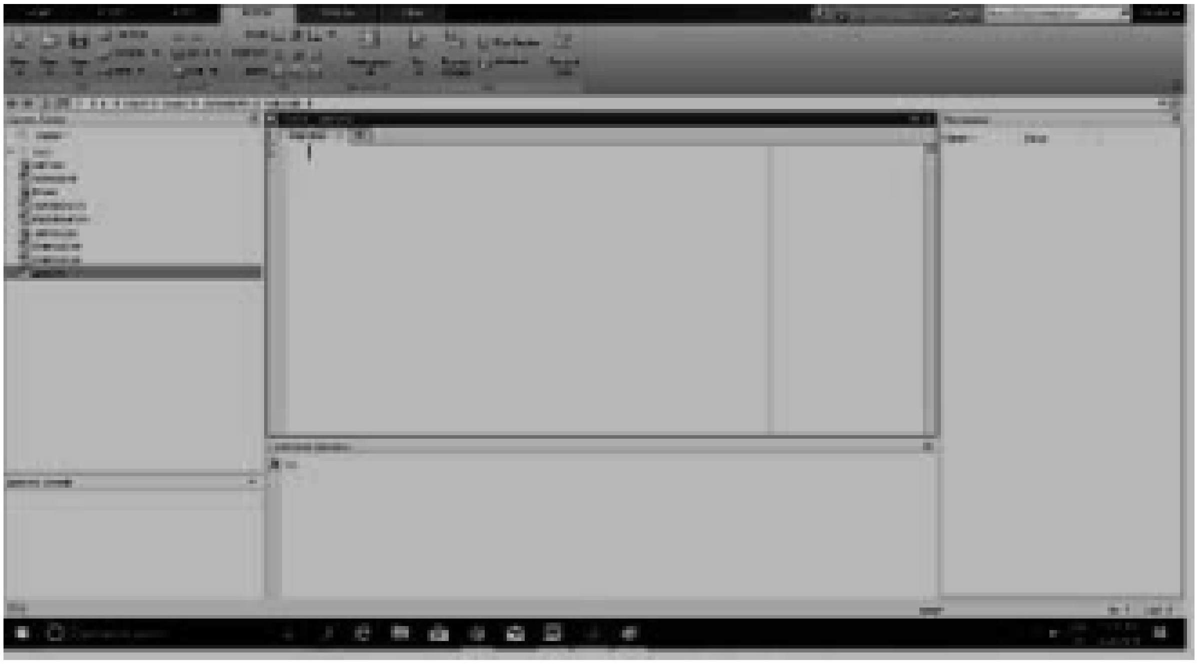


3. Save and run file.
4. Calculate Doppler frequency shift verses radial velocity of the target on log scale.

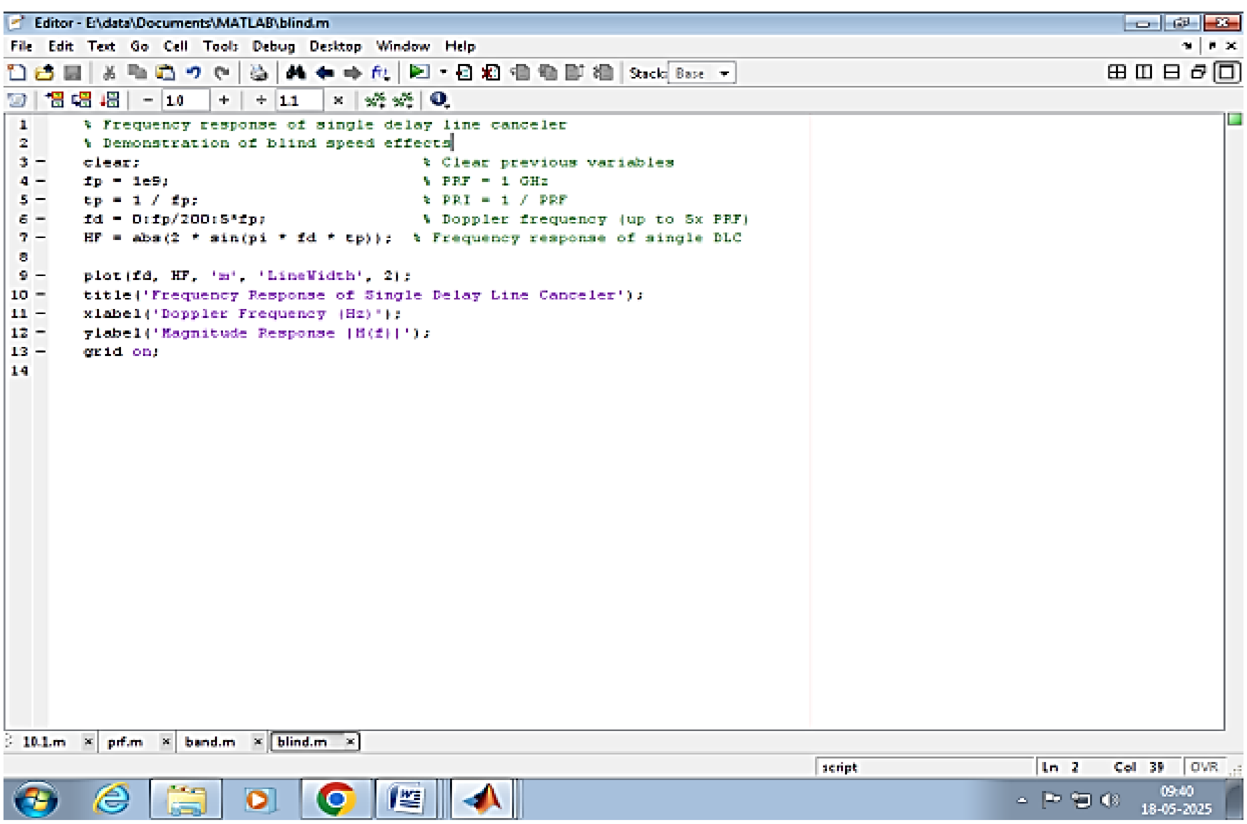


- **Part III: To test the effect of blind speed on the performance of MTI RADAR**

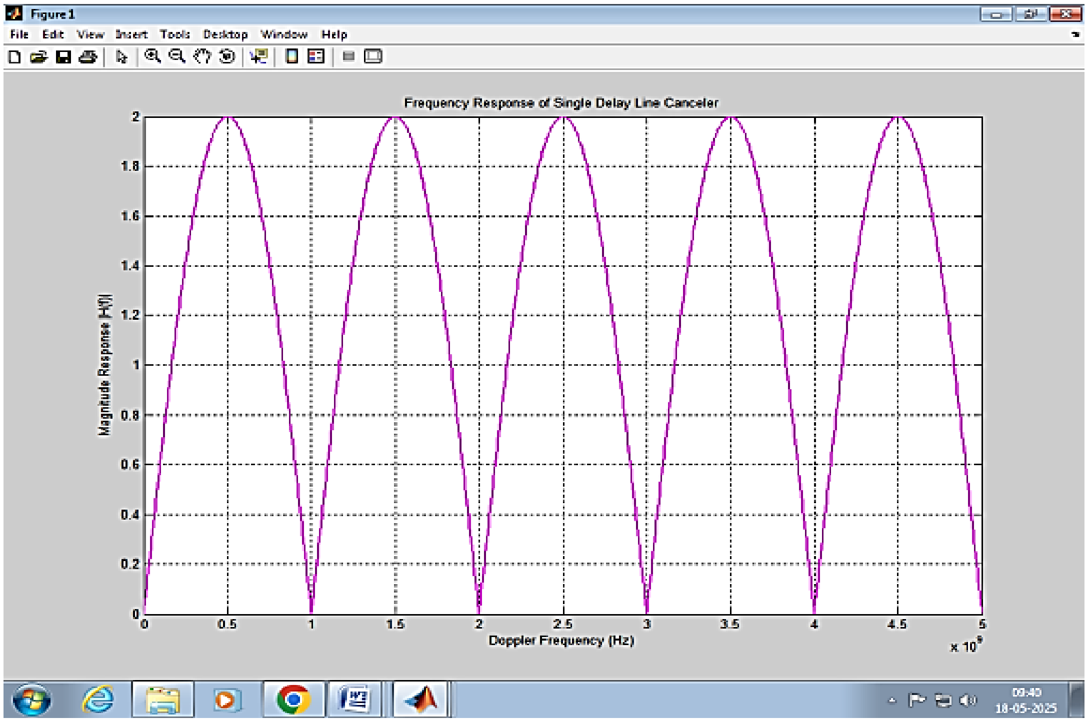
1. Open MATLAB and create a new script file.



2. Write a program
   Specify the pulse repetition frequency and generate Doppler frequency from it by using loop
   Implement frequency response function of delay line canceller

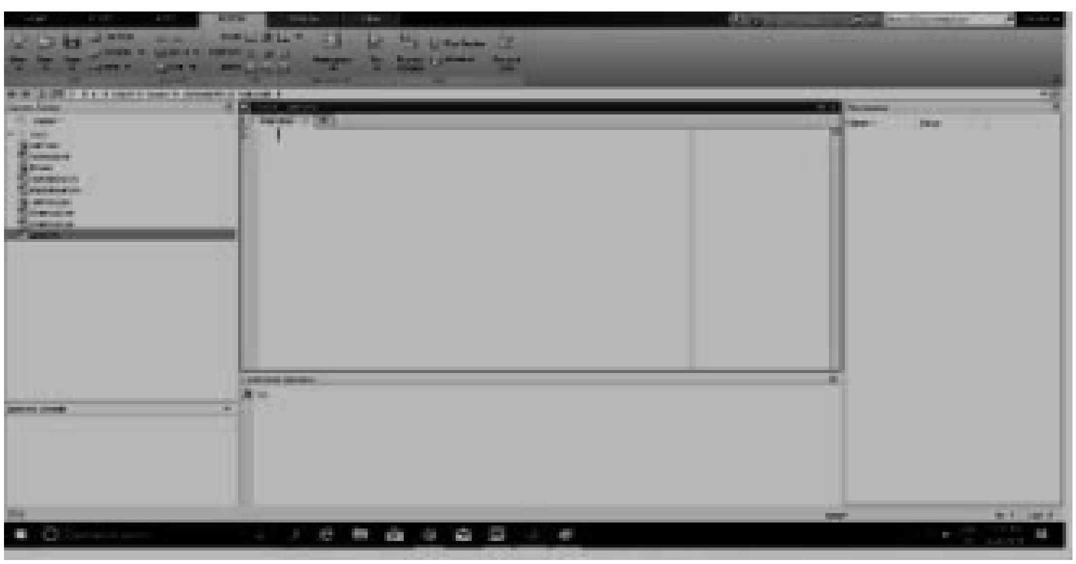


3. Save and run file.
4. Plot the graph between frequency response function of delay line canceller and pulse repetition frequency scale



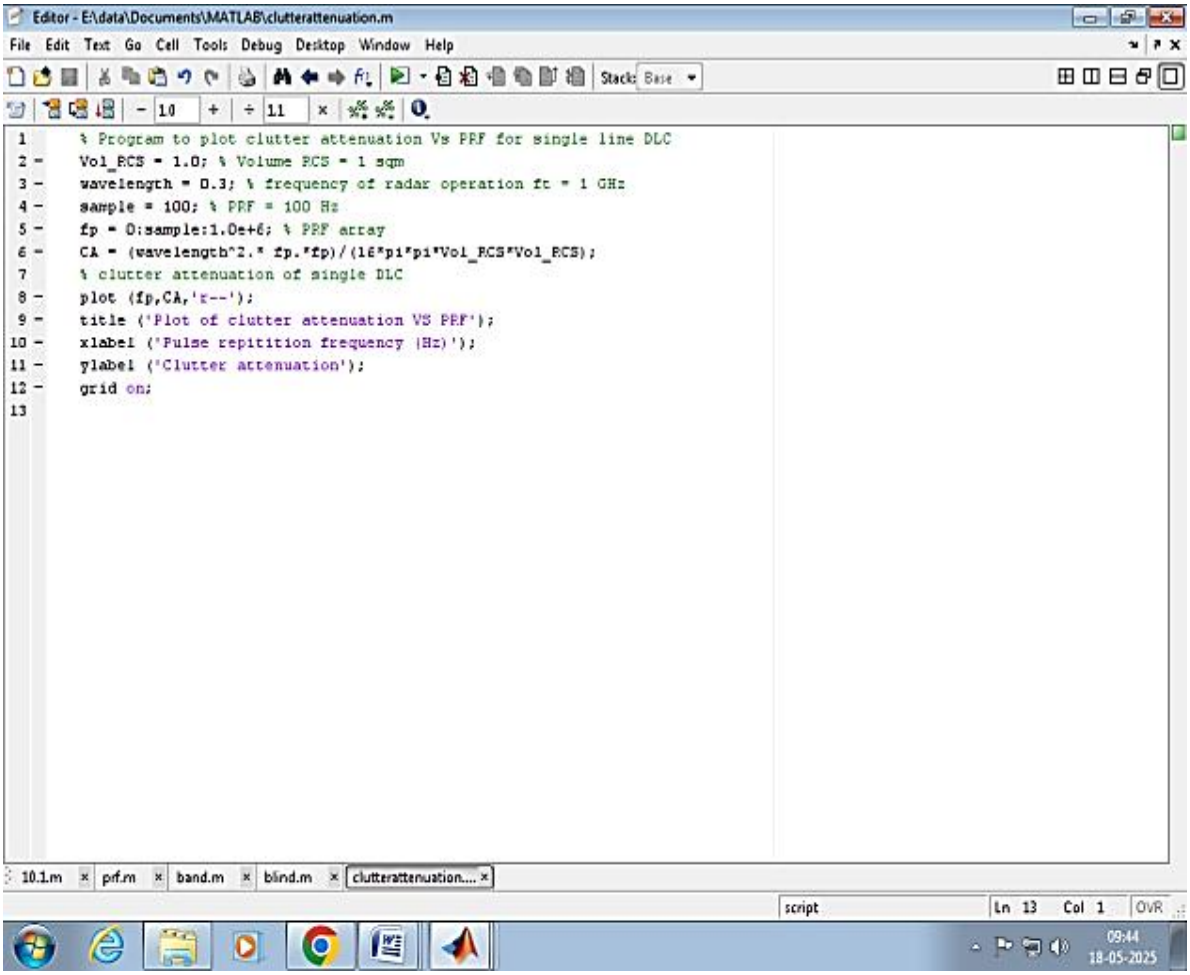
- **Part IV: To Investigate the effect of pulse repetition frequency on clutter attenuation**

1. Open MATLAB and create a new script file.

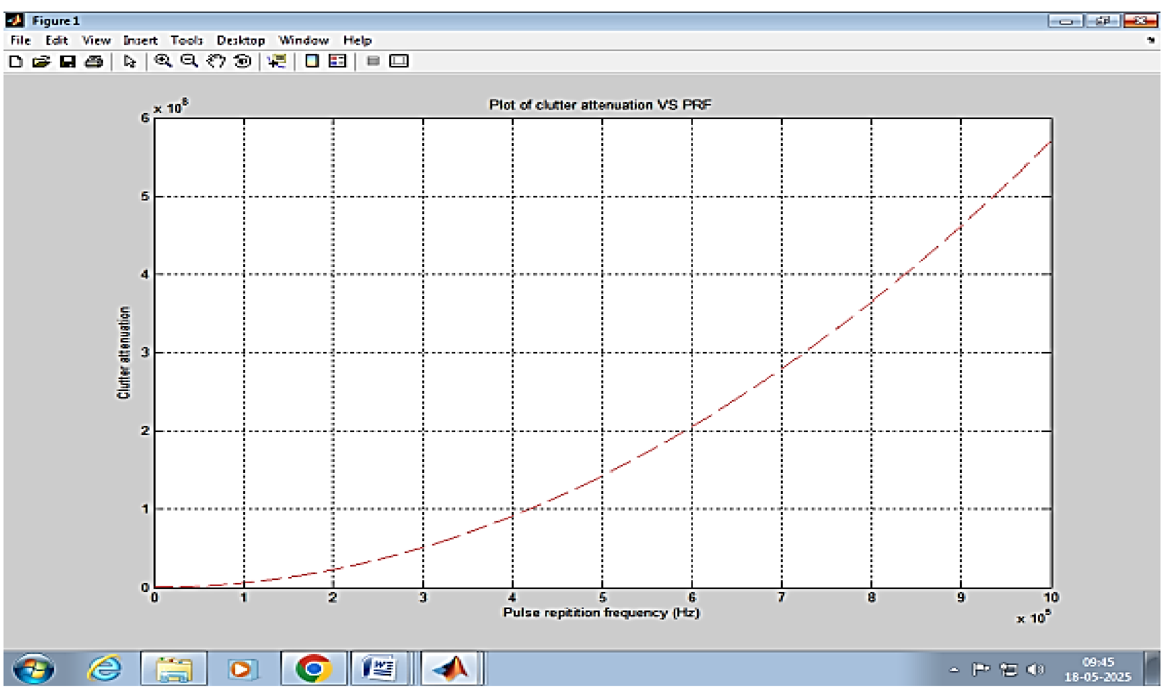


2. Write a program.

   Specify the operating frequency, pulse repetition frequency and fixed volume cross section for a stationary target.
   Vary the pulse repetition frequency in some suitable steps.
   Implement clutter attenuation equation.



3. Save and run file.
4. Plot the graph between frequency response function of delay line canceller and pulse repetition frequency scale



XI Resources Used

Sr. No.	Instrument /Components	Specifications	Quantity
1			
2			
3			
4			

XII Actual procedure

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XIII Observation table:

Table 10.1: Actual Simulation Output

XIV Result(s):

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XV Interpretation of Results:

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XVI Conclusions and Recommendations:

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XVII Practical Related Questions:

Note: Below given are few sample questions for reference. Teachers must design such questions to ensure achievement of identified CO.

1. A radar operates with PRF of 1.2 KHz, the pulse interval is 0.6μs then find pulse repetition time and pulse width?
2. The unambiguous range of the radar is 200 Km. It has a bandwidth of 1 MHz. Find the required PRF, pulse repetition interval, range resolution and pulse width?
3. A 10 GHz radar transmitting a 0.5 μs pulse with PRF of 250,000 pps illuminating a target with radial velocity of 676 m/s closing. Find the Doppler shift?
4. If an MTI radar operates at 10 GHz with PRF of 0.8 KHz then find the three lowest blind speeds.

[Space for Answers]

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XVIII References/Suggestions for further reading: include websites/links/Virtual lab Link

1. https://youtu.be/QXW0tKMBYm8
2. https://youtu.be/OnE0OqQjam8
3. https://youtu.be/Jq-k6PHu5xo

XIX Assessment Scheme

Performance Indicators		Weightage
Process Related (15 Marks)		**60%**
01	Handling of the components	10%
02	Identification of components	20%
03	Measuring value using suitable instrument	20%
04	Working in teams	10%
Product Related (10 Marks)		**40%**
05	Correctness of output	10%
06	Interpretation of Result	05%
07	Conclusions	05%
08	Practical related questions	15%
09	Submitting the journal in time	05%
Total (25 Marks)		**100 %**

Marks Obtained			Dated signature of Teacher
Process Related (15)	**Product Related (10)**	**Total (25)**	