Telecommunications Radar

Courseware Sample

38542-F0
Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="DANGER" /></td>
<td><strong>DANGER</strong> indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.</td>
</tr>
<tr>
<td><img src="image" alt="WARNING" /></td>
<td><strong>WARNING</strong> indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.</td>
</tr>
<tr>
<td><img src="image" alt="CAUTION" /></td>
<td><strong>CAUTION</strong> indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.</td>
</tr>
<tr>
<td><img src="image" alt="CAUTION" /></td>
<td><strong>CAUTION</strong> used without the <em>Caution, risk of danger</em> sign, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.</td>
</tr>
<tr>
<td><img src="image" alt="Caution, risk of electric shock" /></td>
<td>Caution, risk of electric shock</td>
</tr>
<tr>
<td><img src="image" alt="Caution, hot surface" /></td>
<td>Caution, hot surface</td>
</tr>
<tr>
<td><img src="image" alt="Caution, risk of danger" /></td>
<td>Caution, risk of danger</td>
</tr>
<tr>
<td><img src="image" alt="Caution, lifting hazard" /></td>
<td>Caution, lifting hazard</td>
</tr>
<tr>
<td><img src="image" alt="Caution, hand entanglement hazard" /></td>
<td>Caution, hand entanglement hazard</td>
</tr>
<tr>
<td><img src="image" alt="Notice, non-ionizing radiation" /></td>
<td>Notice, non-ionizing radiation</td>
</tr>
<tr>
<td><img src="image" alt="Direct current" /></td>
<td>Direct current</td>
</tr>
<tr>
<td><img src="image" alt="Alternating current" /></td>
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<td><img src="image" alt="Both direct and alternating current" /></td>
<td>Both direct and alternating current</td>
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<td>Earth (ground) terminal</td>
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<td>Symbol</td>
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<tr>
<td>--------</td>
<td>-------------</td>
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<tr>
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<td><img src="image2" alt="Symbol" /></td>
<td>Frame or chassis terminal</td>
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<td><img src="image3" alt="Symbol" /></td>
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Preface

If one had to identify the instrument which, by its great versatility, most extends the immense capacities of the human senses, radar would certainly be a serious candidate, if not the most serious. With a radar, one can see in the dark, measure the speed of a moving object precisely, measure the distance of a rain storm or the density of clouds, prevent collisions, obtain advance warning of an impending danger, land in dense fog, determine the relief of mountains, and much more. In a way, radars allow men to do with electromagnetic waves what they would like to be able to do using their senses. It is not surprising, therefore, that radars are used almost everywhere, even though they were invented only during the Second World War. Radars are an extension of our capacity to perceive complex situations, and they are such powerful tools that once one has understood their capabilities, radars can no longer be ignored.

The speed of propagation of electromagnetic waves (the speed of light) allows very little time to perceive a radar echo if the reflecting object is very close. Since this speed is approximately 300 m per microsecond, the radar system must be either quite far from the target or extremely rapid to perceive the effect of a return signal. If the target is far away, however, a great deal of power must be transmitted in order to obtain an echo strong enough to be detected. These are the two points which have always made practical teaching of radar in a laboratory very difficult, and at the same time, very dangerous.

It is in this context that we undertook to develop a table-top radar specifically designed for teaching radar principles in a safe way within a laboratory classroom; a project which was said at first to be technically impossible. We have taken into consideration not only all the technical details but also the needs of the student in this field, of his or her capacities, of safety standards, and finally, of the versatility required of the apparatus. We put all the energy necessary into this project, and today, the Radar Training System is available and ready to provide the student with a unique learning experience.

We hope that you will have as much pleasure using this system and discovering its potential as we have had conceiving and producing it.

Acknowledgements

We thank the following people from Laval University for their participation in the development of the Radar Instructional Program: John Ahern, M.Sc.A; Gilles Y. Delisle, Ph.D; Michel Lecours, Ph.D.; Marcel Pelletier, Ph.D.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.
About This Manual

*Radar* is the courseware series which accompanies the Radar Training System. Volume 1 of this series, *Principles of Radar systems*, provides instruction in the basic principles of radar, and allows the student to make quantitative measurements of the various phenomena without using expensive measuring instruments.

This manual is divided into four units:

Unit 1, *Fundamentals of Pulsed Radar*, provides a solid understanding of the fundamentals of pulsed radar, and lays the groundwork for understanding the other forms of radar. The A-scope display, the range-delay relationship, radar antennas, and the radar equation are explained. A section in the first exercise deals with safety.

Unit 2, *A Pulsed Radar System*, covers the elements generally found in a pulsed radar system, such as the radar transmitter and receiver, the antenna driving system, and the PPI display. Detailed explanations about the design and operation of most of these elements are provided.

Unit 3, *CW Radars*, presents continuous-wave and frequency-modulated continuous-wave radars. The equations governing these types of radar and the operation of practical systems are explained.

Unit 4, *Troubleshooting Radar Systems*, presents basic techniques used to troubleshoot various types of radar systems.

The exercises in this manual provide a systematic and realistic means of learning the subject matter. Each exercise contains:

- a clearly defined *Exercise Objective*.
- a *Discussion* of the theory involved.
- a *Procedure Summary* which provides a bridge between the theoretical *Discussion* and the laboratory *Procedure*.
- a detailed, step-by-step laboratory *Procedure* in which the student observes and measures important phenomena. Illustrations facilitate connecting the modules and guide the student's observations. Throughout the *Procedure*, questions direct the student's thinking process and help in understanding the principles involved.
- a *Conclusion* to summarize the material presented in the exercise.
- a set of *Review Questions* to verify that the material has been well assimilated.
Safety with RF fields

When studying radar systems, it is very important to develop good safety habits. Although microwaves are invisible, they can be dangerous at high levels or for long exposure times. The most important safety rule when working with microwave equipment is to avoid exposure to dangerous radiation levels.

In normal operation, the radiation levels in the Radar Training System are too low to be dangerous. The power radiated by the Radar Transmitter in CW mode is typically 2 mW from 8 GHz to 10 GHz. The maximum power density produced by the Radar Training System is thus equal to 0.08 mW/cm² from 8 GHz to 10 GHz.

In order to develop good safety habits, you should, whenever possible, set the RF Power switch to the STANDBY position before placing yourself in front of the transmitting antenna. Your instructor may have additional safety directives for this system.

For your safety, do not look directly into the source of microwave radiation while power is being supplied to the Radar Transmitter.

Systems of units

Units are expressed using the SI system of units followed by the units expressed in the US customary system of units (between parentheses).
Sample Exercise

Extracted from

Principles of Radar Systems
Exercise 2-1

Pulsed Radar Transmitter and Receiver

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the operating principles of a pulsed radar transmitter and receiver. You will also be familiar with the Radar Transmitter and Radar Receiver of the Radar Training System.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Radar Transmitters
- Radar receivers
- The Radar Transmitter
- The Radar Receiver

DISCUSSION

Radar Transmitters

The purpose of the transmitter in a pulsed radar system is to produce a pulsed RF signal which can be transmitted by the antenna. The RF signal is generated either by a high-power RF oscillator, or a low-power RF oscillator followed by an RF amplifier.

The high-power oscillator converts pulses of dc power directly to pulsed RF at microwave frequencies, as shown in Figure 2-2a. The most commonly used high-power RF oscillator in radar is the magnetron. This is a type of vacuum tube oscillator developed near the beginning of World War II. It is widely used because of its simplicity, ruggedness and efficiency. Its name comes from the fact that it uses a magnetic field to modify the trajectory of electrons in motion.

Figure 2-2b shows a low-power RF master oscillator followed by a power amplifier. The amplifier accepts the low-power RF signal and amplifies it to produce a high-power signal. One common type of high-power amplifier used in radar transmitters is the grided traveling wave tube amplifier. A control grid inside this tube acts as a modulator and allows a low-power pulse signal to key the amplifier on and off.

A simplified block diagram of the Radar Transmitter is shown in Figure 2-2c. A solid-state RF oscillator produces a low-power RF signal. This signal is not amplified, but is simply modulated by a modulator to produce low-power radar pulses.
Ex. 2-1 – Pulsed Radar Transmitter and Receiver • Discussion

Figure 2-3 shows the waveforms present in a pulsed radar transmitter, where a pulse train is used to modulate a continuous, sinusoidal RF carrier. Typical carrier frequencies for conventional radars range from 220 mHz to 35 GHz. The modulating pulses are rectangular, although somewhat rounded due to bandwidth limitations. The resulting waveform is a pulsed sine wave.
The pulse repetition frequency (PRF, or $f_p$) is the number of pulses transmitted per unit time. Typical PRF’s range from several hundred hertz to several hundred kilohertz. The interpulse period $T$ is equal to $1/f_p$.

The pulse width $\tau$ is the pulse duration. It is usually defined as the time interval between the points where the instantaneous value equals 50% of the peak amplitude. Typical pulse widths range from 0.02 µs to 60 µs, with 1 µs being a common value.

The peak power of a pulsed radar signal is equal to the power of the individual pulses (i.e. power when the transmitter is transmitting). The average power is:

$$P_{avg} = P_{peak} \frac{\tau}{T}$$

where $P_{avg}$ is the average power. $P_{peak}$ is the peak power. $\tau$ is the pulse width. $T$ is the interpulse period.

The average power can be thought of as the energy per pulse $P_{peak} \times \tau$ divided by the interpulse period $T$, or as the peak power multiplied by the duty factor of the transmitter $\tau/T$.

The maximum detection range of a radar is partly determined by the total amount of energy transmitted per unit time, i.e. the average power. To increase detection range, average power can be increased by increasing either the peak power or the pulse width, thus increasing the energy per pulse. As was seen in
Exercise 1-2, however, increasing the pulse width deteriorates the range resolution of the radar. Increasing the PRF, without changing the pulse width, also increases the average power, but for reasons which will be explained in a later volume, decreases the maximum range at which the target range can be accurately determined.

Radar receivers

Most radar receivers operate by detecting the envelope of the received signal in order to recover the original modulating waveform. Envelope detection is illustrated in Figure 2-4. The high frequency carrier is removed from the signal, and only the positive portion of the envelope is retained. The detected pulses are then amplified for further processing and display.

![Received Radar Pulses](image)

![Detected Pulses](image)

**Figure 2-4. Envelope detection.**

Envelope-detecting receivers can be divided into two main types: tuned radio frequency (TRF) and superheterodyne. In a TRF receiver, the envelope detection is carried out directly at the RF frequency, as shown in Figure 2-5. This type of receiver is seldom used, since it is generally more costly than a superheterodyne receiver with equal performance.

![Tuned radio frequency (TRF) receiver](image)

**Figure 2-5. Tuned radio frequency (TRF) receiver.**

The most commonly used type of radar receiver is the superheterodyne receiver, shown in Figure 2-6. In this type of receiver, the received signal is mixed with a local oscillator signal. The mixer produces a signal at a frequency equal to the difference between the RF signal frequency and the local oscillator frequency. This intermediate frequency (IF) is much lower than the original RF signal frequency. The IF signal is amplified and filtered by an IF amplifier before the envelope detection takes place.
Because the envelope detection takes place at a relatively low intermediate frequency, the superheterodyne receiver is less costly and more flexible than a TRF receiver. Many variations of the basic superheterodyne design are used in radar systems. Often, the RF signal is applied directly to the mixer without amplification, in order to reduce the cost of the receiver. This, however, reduces the sensitivity of the receiver.

In certain radar applications, envelope detection alone does not satisfy the system requirements. In this case, a quadrature detector is often used. This type of detector is capable of detecting the phase of the received signal as well as the amplitude.

Figure 2-7 shows a typical quadrature detector. The input signal is either the RF signal directly from the antenna, or an IF signal. The input signal is divided between two channels, each having a mixer. In both channels, the input signal is mixed with a reference signal from the local oscillator. However, a phase shift is introduced so that the two reference signals are in quadrature (90° out of phase).

As the range of a target varies, the amplitude of the detected pulse varies between a positive and negative maximum. This was observed in Unit 1 using the A-scope display. With a quadrature detector, the two output signals are in quadrature. When a pulse in the I (in-phase) channel is at a maximum amplitude, the same pulse in the Q (quadrature) channel is at a null (zero amplitude). If the target range changes slightly so that the pulse in the I channel is at a null, the pulse in the Q channel will be at a maximum, either positive or negative depending on the design of the receiver and the direction of target motion.
The I and Q pulses from a quadrature detector are never at a null at the same time. In many receivers, the I and Q signals are eventually combined to produce a unipolar pulse signal whose amplitude is independent of the phase of the echo signal.

Together, the I and the Q output signals fully represent the phase and amplitude information contained in the received signal. Radar systems using digital signal processing techniques often require both amplitude and phase information. For this reason, quadrature detection is becoming more and more common in modern radar systems. A receiver which detects both the amplitude and phase of the received signal is said to be a coherent receiver.

A superheterodyne receiver translates the received signal to an intermediate frequency. In some receivers, however, the received signal is translated directly to the baseband (dc) without passing through an intermediate frequency. This is accomplished by applying the received RF signal to the mixer(s), and using a local oscillator signal at the same frequency as the RF signal. The mixer produces a signal at a frequency equal to the difference frequency, which is zero (dc), thus recovering the modulating waveform in one step. This type of receiver is known as a homodyne, or DC-IF receiver.

**The Radar Transmitter**

The front panel of the Radar Transmitter is shown in Figure 2-8. The carrier frequency is determined by the FREQUENCY controls in the RF OSCILLATOR section. When set to VAR., the frequency can be adjusted manually from 8 GHz to 10 GHz. In the CAL. position, the carrier frequency is set to a calibrated 9.4 GHz. In the MOD. position, the carrier frequency is modulated according to the FREQUENCY MODULATION controls. Frequency modulation, however, is not used during pulsed operation. At all times, the voltage at the CONTROL VOLTAGE MONITOR OUTPUT is a linear function of the carrier frequency.

The ISOLATOR passes RF power in one direction only. It is used to protect the RF OSCILLATOR from RF power that could be reflected in a backwards direction.

The RF POWER switch allows the RF power to be switched on or off. When in the STANDBY position, no RF power reaches the DIRECTIONAL COUPLER, and the STANDBY LED is lit. When in the ON position, the RF power is passed and the ON LED flashes on and off.
The DIRECTIONAL COUPLER divides the RF power and sends part of it to the RF OSCILLATOR OUTPUT. This output provides the local oscillator signal for the Radar Receiver. The rest of the RF power is available at the CW / FM-CW RF OUTPUT. The RF power at this output is continuous.

If pulsed operation is desired, the continuous RF power is coupled to the CW RF INPUT of the MODULATOR. The MODULATOR uses pulses received from the PULSE GENERATOR to modulate the RF waveform. The resulting pulsed RF signal is available at the PULSED RF OUTPUT.

The PULSE GENERATOR generates very short pulses which are synchronized with the pulses at the TRIGGER INPUT. The PULSE WIDTH can be set to 1, 2, or 5 ns, or to VARIABLE. The TRIGGER INPUT signal is a synchronization signal supplied by the Radar Synchronizer.

**The Radar Receiver**

The front panel of the Radar Receiver is shown in Figure 2-9. This receiver contains a quadrature detector. Since the quadrature detector of the Radar Receiver produces I and Q signals which represent both the amplitude and phase of the received signal, this receiver can be considered to be coherent.

The POWER DIVIDER at the RF INPUT divides the received RF signal, which is then sent to two mixers. The HYBRID JUNCTION divides the LOCAL OSCILLATOR signal into two reference signals which are in quadrature. These reference signals are sent to their respective mixers.

The LOCAL OSCILLATOR signal comes from the RF OSCILLATOR OUTPUT of the Radar Transmitter (see Figure 2-8). This signal is derived directly from the RF signal produced by the RF OSCILLATOR. Since the LOCAL OSCILLATOR signal is at the same frequency as the transmitted and received RF signals, the mixers translate the received RF signal directly to the baseband. Therefore, this receiver is of the homodyne type.
The two POWER DIVIDERS following the mixers divide the mixer output signals to provide the signals required for the various outputs. The PULSED OUTPUT signals are amplified by the two WIDEBAND AMPLIFIERS. The 1-kHz FILTERS, and the CW DOPPLER and FM-CW OUTPUTs are not used in pulsed operation.

**PROCEDURE OUTLINE**

The Procedure is divided into the following sections:

- The Radar Transmitter
- Setting up the basic pulsed radar
- The Radar Receiver

**PROCEDURE**

**The Radar Transmitter**

In this section, you will determine the relationship between the control voltage and frequency of the Radar Transmitter RF OSCILLATOR by measuring the control voltage for various frequencies, and then plotting the relation on a graph. You will also observe the shape of the Radar Transmitter PULSE GENERATOR output signal for various pulse widths, using the Dual-Channel Sampler, and calculate the duty factor of this signal according to the settings made on the Radar Training System. The block diagram of the system used to sample the PULSE GENERATOR output signal is shown in Figure 2-12.

In this exercise, you are often asked to set the target range so that the amplitude of the target blip observed on the A-scope display is positive and maximum. However, with time, the amplitude of the target blip may vary. This is due to the RF OSCILLATOR of the Radar Transmitter which may experience a slight frequency drift with temperature. To reduce drift to a minimum, it is preferable to let the Radar Training System warm up for at least half an hour before beginning this exercise. If the amplitude of the target blip still varies significantly, slightly readjust the target range as required.
1. The main elements of the Radar Training System, that is the antenna and its pedestal, the target table and the training modules, must be set up properly before beginning this exercise. Refer to Appendix B of this manual for setting up the Radar Training System, if this is not done yet.

Set up the modules on the Power Supply / Antenna Motor Driver as shown in Figure 2-10.

![Module Arrangement Diagram]

**Figure 2-10. Module Arrangement.**

On the Radar Transmitter, make sure that the RF POWER switch is in the STANDBY position.

On the Antenna Controller, make sure that the MANual ANTENNA ROTATION MODE is selected and that the SPEED control is in the 0 position.

Set the POWER switch of the Power Supply to the I (on) position, and then those of the other modules.

2. Connect the CONTROL VOLTAGE MONITOR OUTPUT of the Radar Transmitter to channel 1 of the oscilloscope. This output provides a signal which is identical with that controlling the RF OSCILLATOR frequency.

On the Radar Transmitter, depress the VARiable FREQUENCY push button, then set the RF OSCILLATOR frequency to minimum.

Make the appropriate settings on the oscilloscope to observe the CONTROL VOLTAGE MONITOR OUTPUT signal.

3. On the Radar Transmitter, set the RF OSCILLATOR frequency to 8.2 GHz.

Measure the dc voltage at the CONTROL VOLTAGE MONITOR OUTPUT of the Radar Transmitter, then note the result in the first row of the CONTROL VOLTAGE column of Table 2-1.
Carry out the same manipulations for the other frequencies listed in Table 2-1.

### Table 2-1. Control voltage versus frequency for the RF OSCILLATOR of the Radar Transmitter.

<table>
<thead>
<tr>
<th>CONTROL VOLTAGE</th>
<th>FREQUENCY</th>
</tr>
</thead>
<tbody>
<tr>
<td>V dc</td>
<td>GHz</td>
</tr>
<tr>
<td></td>
<td>8.2</td>
</tr>
<tr>
<td></td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>9.0</td>
</tr>
<tr>
<td></td>
<td>9.4</td>
</tr>
<tr>
<td></td>
<td>9.8</td>
</tr>
</tbody>
</table>

4. In Figure 2-11, plot the relation between the frequency and control voltage of the RF OSCILLATOR, using the results noted in Table 2-1.

Describe the relationship between the control voltage and frequency of the RF OSCILLATOR. Determine the slope of this relationship.
5. Remove the cable connecting the CONTROL VOLTAGE MONITOR OUTPUT of the Radar Transmitter to the oscilloscope.

Figure 2-12 shows how to connect the Dual-Channel Sampler in order to sample the output signal of the Radar Transmitter PULSE GENERATOR. Connect the modules as shown in this figure.

*Use a medium-length (approximately 75 cm) SMA cable to connect the PULSE GENERATOR OUTPUT of the Radar Transmitter to the I-CHANNEL PULSE INPUT of the Dual-Channel Sampler.*
6. Make the following adjustments:

On the Radar Transmitter

RF OSCILLATOR FREQUENCY ................... CAL.
PULSE GENERATOR PULSE WIDTH .......... 1 ns

On the Radar Synchronizer

PRF MODE ................................................... SINGLE
PRF......................................................... 216 Hz

On the oscilloscope

Time Base ...................................................... X-Y
Channel X ...................................................... 0.2 V/DIV (DC coupled)
Channel Y ...................................................... 0.2 V/DIV (Set to GND)

Set the X- and Y-position controls of the oscilloscope so that the trace is centred on the screen.

Set the Y-channel input coupling switch of the oscilloscope to the DC position. If an offset voltage is present at the I-CHANNEL SAMPLED OUTPUT of the Dual-Channel Sampler, the trace on the oscilloscope screen will shift up or down. If this happens, adjust the I-CHANNEL DC OFFSET control of the Dual-Channel Sampler so that the trace is centred on the oscilloscope screen.

7. On the Dual-Channel Sampler, select the 1.8-m RANGE SPAN, make sure that the GAIN controls are in the CALibrated position, then set the ORIGIN control so that the output signal of the PULSE GENERATOR is centred on the fourth division of the oscilloscope screen.
On the Radar Transmitter, vary the PULSE WIDTH setting of the PULSE GENERATOR while observing its output signal on the oscilloscope screen, then set the PULSE WIDTH to 1 ns. Figure 2-13 shows an example of what you might observe on the oscilloscope screen for various PULSE WIDTH settings.

![Figure 2-13](image)

- **a**) PULSE WIDTH : 1 ns.
- **b**) PULSE WIDTH : 2 ns.
- **c**) PULSE WIDTH : 5 ns.

*Figure 2-13. Output signal of the PULSE GENERATOR for various PULSE WIDTH settings, sampled with the Dual-Channel Sampler.*
Using the PULSE WIDTH and the actual PRF, calculate the actual duty factor of the pulse signal provided by the PULSE GENERATOR. Recall that the actual PRF is 1024 times the PRF selected on the Radar Synchronizer, as explained in Appendix E.

Setting up the basic pulsed radar

In this section, you will set up a basic pulsed radar and calibrate the A-scope display. The block diagram of this system is shown in Figure 2-14.

8. Remove the SMA cable and the 50 Ω load from the PULSE INPUTS of the Dual-Channel Sampler.

Figure 2-14 shows the block diagram of the basic pulsed radar that can be obtained using the Radar Training System. Connect the modules according to this block diagram.
Figure 2-14. Block diagram of the basic pulsed radar.
9. Refer to Appendix C of this manual to calibrate the A-scope display so that its origin is located approximately 1.0 m from the antenna horn and its range span is equal to 1.8 m. Once you have finished the calibration, the display on the oscilloscope should resemble Figure 2-15.

![Calibrated A-scope display of a fixed target located at the origin.](image)

Range Span: 1.8 m

Figure 2-15. Calibrated A-scope display of a fixed target located at the origin.

The Radar Receiver

In this section, you will observe a target blip on the A-scope display while varying the pulse width on the Radar Transmitter, in order to compare the shape of the target blip with that of the PULSE GENERATOR output signal. You will also observe the I- and Q-CHANNEL PULSED OUTPUT signals of the Radar Receiver simultaneously to determine the phase relationship between these two signals. You will finally observe the role of the reference (local oscillator) signal in the frequency translation of the received RF signal to baseband, by disconnecting the LOCAL OSCILLATOR INPUT signal.

10. On the Target Controller, use the Y-axis POSITION control to place the target at the far end of the target table, then vary the target range by a few millimeters so that the peak voltage of the target blip on the A-scope display is positive and maximum.
On the Radar Transmitter, vary the PULSE WIDTH setting of the PULSE GENERATOR while observing the target blip on the A-scope display, then set the PULSE WIDTH to 1 ns. Figure 2-16 shows an example of what you might observe on the oscilloscope screen for various PULSE WIDTH settings.

Figure 2-16. Fixed target blip for various PULSE WIDTH settings on the Radar Transmitter.
Procedure

Compare the shape of the target blip with that of the PULSE GENERATOR output signal. Are they alike? Why?

11. On the oscilloscope, disconnect the end of the cable connected to channel X, then connect it to the external triggering input.

Connect the I- and Q-CHANNEL SAMPLED OUTPUTS of the Dual-Channel Sampler to channels 1 and 2 of the oscilloscope, respectively.

Make the appropriate settings on the oscilloscope to obtain a stable display of the I- and Q-CHANNEL PULSED OUTPUT signals of the Radar Receiver. These signals are presently sampled by the Dual-Channel Sampler.

Figure 2-17 shows an example of what you might observe on the oscilloscope screen.

![Figure 2-17. I- and Q-CHANNEL PULSED OUTPUT signals of the Radar Receiver.](image)

On the Target Controller, use the Y-axis POSITION control to slowly decrease the target range so that the amplitude of the I-CHANNEL PULSED OUTPUT signal passes from a positive maximum to a negative maximum and then to another positive maximum. While doing this, observe both signals on the oscilloscope screen.
Describe what you observe on the oscilloscope screen.


Describe the relationship between the I- and Q-CHANNEL PULSED OUTPUT signals.


What is the cause of the phase relationship between the I- and Q-CHANNEL PULSED OUTPUT signals?


12. On the Radar Transmitter, place the RF POWER switch in the STANDBY position.

On the Radar Receiver, disconnect the end of the SMA cable connected to the LOCAL OSCILLATOR INPUT.

On the Radar Transmitter, place the RF POWER switch in the ON position.

Observe the oscilloscope screen. Are there any signals at the I- and Q-CHANNEL PULSED OUTPUT? Why?


13. On the Radar Transmitter, make sure that the RF POWER switch is in the STANDBY position. The RF POWER STANDBY LED should be lit. Place all POWER switches in the O (off) position and disconnect all cables.

CONCLUSION

In this exercise, you plotted the relationship between the control voltage and frequency of the RF OSCILLATOR. You found that the frequency of the RF OSCILLATOR varies linearly at a rate of 0.25 GHz per volt as the control voltage varies.
You observed that the shape of the target blip resembles that of the PULSE GENERATOR output signal, since the Radar Receiver detects the envelope of the received signal.

You also observed the I- and Q-CHANNEL PULSED OUTPUT signals of the Radar Receiver simultaneously and found that these signals are in quadrature. Finally, you verified that a reference (local oscillator) signal is required to carry out the frequency translation of the received RF signal to baseband.

**REVIEW QUESTIONS**

1. Why is the magnetron the most commonly used high-power RF oscillator in radar?

2. Describe the usual waveform of the transmitted radar signal.

3. How do most radar receivers operate?

4. What is the main advantage of a superheterodyne receiver over a tuned radio frequency (TRF) receiver?

5. What is the main advantage of the quadrature detector?
Sample Exercise
Extracted from
Analog MTI Processing
Vector-Processing MTI

**EXERCISE OBJECTIVE**

When you have completed this exercise, you will be familiar with phenomenon of blind phases and their elimination using vector-processing MTI.

**DISCUSSION OUTLINE**

The Discussion of this exercise covers the following points:

- Blind Phases
- Quadrature phase detector
- Vector-processing MTI

**DISCUSSION**

**Blind Phases**

A phase-processing MTI system consists of a coherent radar with one delay-line canceller, as shown in Figure 2-27. In this system, the received RF echo signal is heterodyned in the phase detector with the coherent reference signal. The amplitude of each pulse in the coherent video signal (the phase detector output signal) is a function of the phase and amplitude of the echo signal. If the target is moving, the changing phase of the echo signal causes the amplitude of the coherent video signal to vary from pulse to pulse.

The coherent video is processed using a delay-line canceller which suppresses the pulses corresponding to fixed targets. The cancelled video, which contains only moving-target information, is full-wave rectified before display on a PPI.

![Figure 2-27. Phase-processing MTI radar with homodyne receiver.](image-url)
Ex. 2-2 – Vector-Processing MTI  ●  Discussion

With a moving target, the coherent video at the output of the phase detector consists of pulses with a sine-wave envelope, as shown in Figure 2-28a. If the phases of the echoes are such that two successive pulses in the video signal have the same amplitude, these pulses are cancelled by the delay-line canceller, even though the target is moving. This results in a pulse of zero amplitude in the cancelled video, as shown in Figure 2-28b. This phenomenon is known as **blind phases**.

![Diagram showing coherent, cancelled, and unipolar videos](image)

**Figure 2-28. The blind-phases phenomenon.**

Blind phases can cause nulls in the unipolar video signal, as seen in Figure 2-28c. This results in reduced sensitivity of the radar. Even if the phases are such that no pulses are completely cancelled, the fact that the amplitude of the unipolar video signal drops periodically causes a loss of sensitivity. The problem of reduced sensitivity caused by blind phases can be eliminated by using a quadrature phase detector.
Quadrature phase detector

The envelope of the received signal in a pulsed radar is

\[
v_{rec} = A \sin[2\pi(f_t \pm f_d)t + \phi_0] = A \sin(2\pi f_t t + \phi)
\]

(2-10)

where \(v_{rec}\) is the received signal waveform, 
\(A\) is the amplitude of the received signal, 
\(f_t\) is the transmitted frequency, 
\(f_d\) is the Doppler frequency, 
\(\phi_0\) is the phase shift due to the target range, 
\(\phi\) is the phase of the received signal relative to the reference signal.

As shown in Figure 2-29, the received signal \(A \sin(2\pi f_t t + \phi)\) can be represented as a vector of length \(A\) and angle \(\phi\). This vector can be broken down into two components in phase quadrature: the in-phase component \(I = A \cos \phi\) and the quadrature component \(Q = A \sin \phi\).

![Figure 2-29. Phasor diagram of the received signal.](image)

The quadrature phase detector, or I and Q detector, detects both the in-phase and the quadrature components of the received signal separately. As seen in Figure 2-30, this type of detector has two channels: the I (in-phase) channel and the Q (quadrature) channel.
The I channel is identical to the single-channel phase detector in Figure 2-27. In channel Q, however, the coherent reference signal undergoes a phase shift of 90° before being applied to the phase detector. The coherent reference signals are therefore in phase quadrature:

\[
\text{I - channel coherent reference} = k \sin(2\pi f_t t) \\
\text{Q - channel coherent reference} = k \cos(2\pi f_t t)
\]

(2-11) (2-12)

where \( k \) is the amplitude of the reference signals,

\( f_t \) is the frequency of the reference signal (in a homodyne receiver; in a superheterodyne receiver, the reference signal would be at the intermediate frequency).

The I-channel output of the quadrature detector is the in-phase component of the signal \( A \cos \varphi \). In the Q channel, heterodyning the received signal \( A \sin(2\pi f_t t + \varphi) \) and the phase-shifted reference signal \( k \cos 2\pi f_t t \) yields the quadrature component \( A \sin \varphi \). Together, the in-phase and quadrature components define the vector which represents the received signal. Each component of this vector is processed in a separate delay-line canceller for MTI. This is called \textbf{vector-processing MTI}.

\textbf{Vector-processing MTI}

Figure 2-31 shows the receiver section of a homodyne vector-processing MTI radar. There is a delay-line canceller for each of the I and Q channels. The outputs of the I- and Q-channel cancellers are combined in the magnitude detector to produce a unipolar video signal.
Figure 2-31. Vector-processing MTI receiver.
The operation of the vector-processing MTI receiver can be explained as follows. If a target at range \( R_0 \) is moving, the phase \( \varphi \) of the signal at the input of the quadrature detector input is a function of time and of the Doppler frequency:

\[
\varphi \text{ (moving target)} = \pm 2\pi f_d t + \varphi_0
\]  
(2-13)

where \( f_d \) is the Doppler frequency, \( \varphi_0 \) is the phase shift due to the range \( R_0 \).

Assuming the Doppler frequency is positive, the envelopes of the pulse trains at the I and Q outputs of the quadrature detector are therefore

\[
I = A \cos \varphi
\]

\[
I = A \cos(2\pi f_d t + \varphi_0)
\]  
(2-14)

\[
Q = A \sin \varphi
\]

\[
Q = A \sin(2\pi f_d t + \varphi_0)
\]  
(2-15)

where \( I \) and \( Q \) are the envelopes of the I- and Q-channel output signals of the quadrature detector,

\( A \) is the amplitude of the received echo signal,

\( f_d \) is the Doppler frequency of the received echo signal,

\( \varphi_0 \) is the phase shift due to the range \( R_0 \).

These two waveforms are illustrated in Figure 2-32a and Figure 2-32b respectively. They are identical except for a 90° phase shift. The Doppler period \( 1/f_d \) and the pulse-repetition interval \( T = 1/f_p \) are shown in the figure.
Figure 2-32. Signals in a vector-processing MTI receiver.
In the delay-line cancellers, each pulse is stored for one pulse repetition interval and then subtracted from the following pulse. Consider two successive pulses at the input of the I-channel canceller. If the first pulse occurs at time \( t \), its amplitude is:

\[
a_1 = A \cos(2\pi f_d t + \varphi_0)
\] (2-16)

The second pulse occurs at time \( t + T \), where \( T = 1/f_p \) is the pulse repetition interval. The amplitude of this pulse is:

\[
a_2 = A \cos[2\pi f_d(t + T) + \varphi_0]
\] (2-17)

The result of the subtraction is:

\[
I_o = a_2 - a_1
\]

\[
I_o = -2A \sin(\pi f_d T) \sin\left[2\pi f_d\left(t + \frac{T}{2}\right) + \varphi_0\right]
\]

where \( I_o \) is the I-channel canceller output signal, \( a_1 \) and \( a_2 \) are the amplitudes of two successive pulses in the canceller input signal, \( A \) is the amplitude of the received echo signal, \( f_d \) is the Doppler frequency of the received echo signal, \( T \) is the pulse-repetition interval, \( f_p \) is the pulse-repetition frequency (PRF), \( \varphi_0 \) is the phase shift due to the range \( R_0 \).

This is the I-channel canceller output signal shown in Figure 2-32c. Similarly, the Q-channel canceller output signal is:

\[
Q_o = 2A \sin\left(\pi \frac{f_d}{f_p}\right) \cos\left(2\pi f_d t + \pi \frac{f_d}{f_p} + \varphi_0\right)
\] (2-19)

The I-and Q-channel canceller outputs are applied to the magnitude detector. If \( \theta = 2\pi f_d t + \pi(f_d/f_p) + \varphi_0 \) the result is:

\[
\text{Magnitude} = \sqrt{I_o^2 + Q_o^2}
\]

\[
\text{Magnitude} = \left[4A^2 \sin^2\left(\pi \frac{f_d}{f_p}\right)\left(\sin^2 \theta + \cos^2 \theta\right)\right]^{1/2}
\]

\[
\text{Magnitude} = \left|2A \sin\left(\pi \frac{f_d}{f_p}\right)\right|
\] (2-20)
Equation (2-20) shows that the output of the magnitude detector is a constant value between 0 and 2 A. This is the amplitude of the pulse train at the magnitude detector output, shown in Figure 2-32a. Changing the sign of the Doppler frequency has no effect on the magnitude.

Since the output of the magnitude detector is independent of the phase of the received signal, a vector-processing MTI radar does not suffer from blind phases. Both the in-phase and quadrature components of the signal are utilized. As a result, the receiver sensitivity is approximately 3 dB better than with phase-processing MTI.

In a practical radar receiver, the magnitude detector circuit often only approximates the $\sqrt{I^2 + Q^2}$ operation. Although this causes some fluctuation of the pulse amplitudes at the magnitude detector output, it does not significantly affect operation of the receiver.

Most modern MTI radars use a vector-processing configuration. Since MTI removes fixed clutter from the PPI display, the desired moving targets are much easier to observe. One limitation of MTI, however, is that the target's radial velocity must be non-zero for the target to be displayed. A moving target whose direction is perpendicular to the line of sight will have a Doppler frequency of

$$f_d = \frac{2f_c}{c} v \cos 90° = 0 \text{ Hz}$$

Since the Doppler frequency is zero, the video pulses corresponding to this target will be cancelled by the delay-line cancellers. For this reason, most MTI radars have provision for turning off the MTI function. This allows the operator to switch between MTI and normal operation, to see if any desired targets are being eliminated by the MTI.

Note that, when the MTI function of the receiver is off (the MTI cancellers in Figure 2-31 are bypassed), it is still advantageous to have two channels in quadrature and a magnitude detector. In this case, the input signals to the magnitude detector are $A \cos \varphi = I$ and $A \sin \varphi = Q$. The output of the magnitude detector is a constant value $\sqrt{I^2 + Q^2}$.

Other types of signal processing are often used either in conjunction with MTI or when the MTI is turned off. These will be studied in Unit 3 of this manual.

**PROCEDURE OUTLINE**

The Procedure is divided into the following sections:

- Set up and calibration
- Adjustments
- The blind phases phenomenon
- Elimination of blind phases

**PROCEDURE**

**Set up and calibration**

1. Before beginning this exercise, the main elements of the Radar Training System (the antenna, the target table and the training modules) must be set up as shown in Appendix B.
Turn on all modules and make sure the POWER ON LEDs are lit.

2. Turn on the computer, start the LVRTS software, select Analog Pulse Radar and click OK. This begins a new session with all settings set to their default values and with all faults deactivated. If the software is already running, click Exit in the File menu and then restart the LVRTS software to begin a new session.

3. Connect the modules as shown on the Analog Pulse Radar tab of the LVRTS software. For details of connections to the Reconfigurable Training Module, refer to the RTM Connections tab of the software.

   Make the connections to the 9632 (D/A Output Interface) plug-in module only if you wish to connect a conventional radar PPI display to the system.

   The SYNC. TRIGGER INPUT of the Dual-Channel Sampler and the PULSE GENERATOR TRIGGER INPUT of the Radar Transmitter must be connected directly to OUTPUT B of the Radar Synchronizer without passing through BNC T-connectors.

4. Make sure the Radar Training System has been calibrated according to the instructions in Appendix C. Then set the RF POWER switch on the Radar Transmitter to the STANDBY position.

Adjustments

5. Make the following adjustments:

   On the Radar Transmitter

   RF OSCILLATOR FREQUENCY .................... CAL.
   PULSE GENERATOR PULSE WIDTH ........ 1 ns

   On the Radar Synchronizer / Antenna Controller

   PRF ............................................. 288 Hz
   PRF MODE .................................. SINGLE
   DISPLAY MODE .............................. POSITION

   On the Dual-Channel Sampler

   RANGE SPAN ................................... 3.6 m

   In the LVRTS software

   System Settings
   MTI ............................................. On
   Log./Lin. Mode .................................. Lin.
   Radar Display Settings
   Range ........................................... 3.6 m
6. Place the target table so that its grid is located approximately 1.5 m from the Rotating-Antenna Pedestal, as shown in Figure 2-33. Make sure that the metal rail of the target table is correctly aligned with the shaft of the Rotating-Antenna Pedestal.

![Figure 2-33. Position of the target table and Rotating-Antenna Pedestal.](image)

Place a small metal plate target on the mast of the target table. Orient the target so that it squarely faces the Radar Antenna, and then tighten the screw to secure the target to the mast.

Stop the antenna movement and align the antenna with the target.

7. Connect probe E to TP3 of the Display Processor. Connect probes1 and 2 to TP5 and TP9, respectively, of the MTI Processor. These signals come from the I-channel MTI circuit input and the magnitude detector output, respectively.

**The blind phases phenomenon**

8. Show the oscilloscope and adjust it as follows:

   - Channel 1: 0.2 V/div (DC coupled)
   - Channel 2: 0.1 V/div (DC coupled)
   - Time Base: 5 ms/div
   - Trigger Source: E
   - Trigger Level: 2 V
   - Trigger Slope: +

   Set the oscilloscope to Continuous Refresh.
On the Radar Transmitter, depress the RF POWER push button. The RF POWER ON LED should start to flash on and off. This indicates that RF power is being radiated by the Radar Antenna.

On the Dual-Channel Sampler, disconnect the Q-CHANNEL PULSE INPUT. This leaves only the I channel connected. In this case, the system operates as a phase-processing MTI radar.

Observe that there is no target echo at the output of the magnitude detector, which is in fact the output of the phase-processing MTI radar, because the MTI circuit is enabled and the target is fixed.

9. On the Target Controller, make sure that the X- and Y-axis SPEED controls are in the MINimum position and then make the following settings:

- MODE ........................................................................................................... SPEED
- DISPLAY MODE .......................................................................................... SPEED

Set the Y-axis SPEED control so that the target speed is equal to approximately 30 cm/s.

Figure 2-34 shows an example of what you might observe on the oscilloscope screen. You can use the Refresh button to refresh and freeze the display.

![Oscilloscope display](image)

Channel 1 .................................................................................................... 0.2 V/div
Channel 2 .................................................................................................... 0.1 V/div
Time base .................................................................................................... 5 ms/div

Figure 2-34. Echo signal of a moving target at the I-channel MTI circuit input and magnitude detector output (phase-processing MTI).

Observe that there are periodic nulls in the moving target echo signal at the magnitude detector output. What is this phenomenon called?
Describe the problem related to this phenomenon.

10. Connect probe 2 to TP7. The signal at TP7 presently comes from the I-channel MTI circuit output. Figure 2-35 shows an example of what you might observe on the oscilloscope screen.

![Oscilloscope screenshot](image)

Channel 1: 0.2 V/div
Channel 2: 0.1 V/div
Time base: 5 ms/div

Figure 2-35. Echo signal of a moving target at the input and output of the I-channel MTI circuit.

Carefully observe the echo signals on the oscilloscope screen, then explain how blind phases occur.

Elimination of blind phases


Reconnect the Q-CHANNEL PULSED OUTPUT of the Radar Receiver to the Q-CHANNEL PULSE INPUT of the Dual-Channel Sampler, while observing the echo signal at the magnitude detector output on the oscilloscope screen. When both the I and Q channels are connected, the system operates as a vector-processing MTI radar. Figure 2-36 shows an example of what you might observe on the oscilloscope screen.
The quadrature of the I and Q channels of the Radar Receiver may not be perfect. This causes a slight fluctuation in the signal at TP9. However, this does not significantly affect the operation of the vector-processing MTI radar.

Figure 2-36. Echo signal of a moving target at the I-channel MTI circuit input and magnitude detector output (vector-processing MTI).

What is the effect of using vector-processing MTI on the moving target echo signal at the output of the magnitude detector?

What is the effect of using vector-processing MTI instead of phase-processing MTI on the sensitivity of the receiver. Explain.

12. Connect probes 1 and 2 to TP7 and TP8 of the MTI Processor. These signals presently come from the I- and Q-channel MTI circuit outputs.

Figure 2-37 shows an example of what you might observe on the oscilloscope screen.
Figure 2-37. Echo signal of a moving target at the I-and Q-channel MTI circuit outputs.

Carefully observe the echo signals on the oscilloscope screen, then explain why blind phases are eliminated with vector-processing MTI.

MTI circuit effect on fixed and moving target blips on the PPI display

13. In the System Settings, set MTI to Off.

Close the oscilloscope and show the Radar Display.

Replace the small metal plate target on the mast of the target table with the half-cylinder target. Orient the target so that it squarely faces the Radar Antenna, and then tighten the screw to secure the target to the mast.

14. Start the antenna rotation (set the ANTENNA ROTATION MODE on the Antenna Controller to PRF LOCK, or screw in the connector at the POWER OUTPUT of the Antenna Motor Driver).

Figure 2-38 shows an example of what you might observe on the PPI display once the Radar Antenna has carried out a complete turn.
Observe the PPI display for a few turns of the Radar Antenna to locate the moving target blip.

In the System Settings, set MTI to ON, while observing the PPI display.

Figure 2-39 shows an example of what you might observe on the PPI display once the Radar Antenna has carried out a complete turn, after the MTI circuit was enabled. If necessary, increase the Gain or reduce the Display Threshold.
Describe the effect the MTI circuit has on fixed and moving target blips on the PPI display. Explain why.

15. Disconnect the cable at the Q-CHANNEL PULSE INPUT of the Dual-Channel Sampler. The system operates as a phase-processing MTI radar once more, because only one channel is used to detect moving targets.

Carefully observe the moving target blip on the PPI display for many revolutions of the Radar Antenna.
Compare the moving target blip obtained with phase-processing MTI to that obtained in the previous step with vector-processing MTI. Explain.


16. Reconnect the Q-CHANNEL PULSED OUTPUT of the Radar Receiver to the Q-CHANNEL PULSE INPUT of the Dual-Channel Sampler. The system again operates as a vector-processing MTI radar.

On the Target Controller, set the Y-axis SPEED control to the MINimum position to stop the target, then set the X-axis speed control so that the target moves in the other direction at a speed of approximately 30 cm/s.

Observe the PPI display for a few revolutions of the Radar Antenna.

Describe what you observe on the PPI display. Explain.


17. On the Target Controller, set the Y-axis SPEED control to MAXimum. Explain what you observe on the Radar Display.


18. On the Radar Transmitter, make sure that the RF POWER switch is in the STANDBY position. The RF POWER STANDBY LED should be lit. If no one else will be using the system, turn off all equipment.
CONCLUSION

In this exercise, you saw that blind phases are periodic nulls in the echo signal of a moving target obtained with a phase-processing MTI radar. You found that blind phases are undesirable because they reduce receiver sensitivity. You learned how a vector-processing MTI radar eliminates blind phases, thus increasing the receiver sensitivity. You observed that the MTI circuit removes only fixed target blips on the PPI display, because it rejects the echoes from fixed targets but not those from moving targets. You saw that the size of moving target blips, on the PPI display, obtained with a phase-processing MTI radar varies considerably from one antenna scan to another, whereas it varies very little with a vector-processing MTI radar. Finally, you observed that the vector-processing MTI radar is unable to detect a moving target whose radial velocity is null.

REVIEW QUESTIONS

1. Explain the phenomenon of blind phases.

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

2. What effect do blind phases have on the operation of the radar?

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________

3. Explain the operation of a quadrature phase detector.

__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
__________________________________________________________________________
4. Explain vector-processing MTI.

5. How does vector-processing improve the performance of an MTI radar?
Sample Exercise

Extracted from

Digital MTD Processing
Fast Fourier Transform (FFT) Processing

**Exercise Objective**

When you have completed this exercise, you will be familiar with the processing required to sense Doppler frequencies. You will also be familiar with Doppler ambiguity and with blind (dim) speeds.

**Discussion Outline**

The Discussion of this exercise covers the following points:

- How a digital filter works
- Doppler ambiguities
- Blind (dim) speeds

**Discussion**

One of the main advantages of MTD processing over MTI processing is that the MTD processor senses the Doppler frequencies of the targets. There are two reasons for sensing these frequencies: to determine range rates, and to resolve returns from two targets in the same range-azimuth cell.

Doppler frequencies are sensed using a bank of digital Doppler filters, each tuned to a progressively higher frequency band. These filters are simulated, or formed, by a computer that performs a series of numerical calculations.

**How a digital filter works**

*Acquiring the data*: the I- and Q-channel baseband signals are sampled and A/D converted at the input of the digital processor. The interleaved I and Q data pairs are written into memory in range order, as shown by the arrow in Figure 2-8a.
The I and Q data in each memory location represents the amplitude and phase of the return from a specific range cell. Once data for an entire CPIP has been stored in memory bank A, the system begins writing data from the next CPIP into memory bank B.
Ex. 2-2 – Fast Fourier Transform (FFT) Processing  •  Discussion

While data is being written into memory bank B in range order, data is read out from memory bank A in **batch order**: all cells from one range are read out sequentially, then all those from the next higher range (Figure 2-8b). The cells read in this order are called **batch cells**, and all the batch cells for a given range increment together are called a **batch range cell.**

*Forming the filters:* Figure 2-9a shows I and Q data from 4 batch cells. Since these I and Q values are constant, this represents a fixed target.

![Diagram of batch cells and phasor representations](image)

**Figure 2-9.** I and Q data for fixed target (4 batch cells).

The data pair in each batch cell forms a complex number that represents the amplitude and phase of the return from a specific range cell at a specific instant, and can be represented as a phasor, as shown in Figure 2-9b.

Figure 2-10 shows data produced by a moving target. Because of the Doppler shift, the I and Q data for this batch range cell change from one sample to the next, and the phasor representation of the data rotates from one sample to the next. The rate at which the phasor rotates is equal to the apparent Doppler frequency.
A digital filter adds up (integrates) data from a number of samples in such a way that the result is appreciable only if the Doppler frequency lies within a given narrow band. The process used is called the discrete Fourier transform (DFT).

The discrete Fourier transform: the digital filter effectively projects the I and Q components of the phasor representing each sample onto a rotating coordinate system ($X$ and $Y$ in Figure 2-11). It then adds the projections vectorially to determine the filter output.
Ex. 2-2 – Fast Fourier Transform (FFT) Processing ♦ Discussion

Figure 2-11. Projecting the data \((I_n, Q_n)\) onto a rotating coordinate system \((X, Y)\).

The projections for one of the filters are computed using the following formulae:

\[
X_n = I_n \cos \theta_n + Q_n \sin \theta_n \\
Y_n = I_n \cos \theta_n - Q_n \sin \theta_n
\]

where \(n\) is the sample number, \(X_n\) and \(Y_n\) are the projections of \(I_n\) and \(Q_n\) on the rotating coordinates, \(\theta_n\) is the angle between the two coordinate systems.

The \(n\) values \(\cos \theta_n\) and \(\sin \theta_n\) are called the filter coefficients. These are stored permanently in memory and used as needed in the calculations.

The values \(X_n\) and \(Y_n\), for a specific number of samples, are computed and separately summed. This produces two sums \(X\) and \(Y\). Then the two sums are added vectorially using the equation:

\[
Z = \sqrt{X^2 + Y^2}
\]

where \(Z\) is the magnitude of the vector sum of the individual phasors.

If the Doppler frequency \(f_d\) of the target is equal to the frequency \(f_f\) of the filter, the phasor representing the samples rotates at the same speed as the rotating coordinate system, and the filter output level will be at a maximum. If the two frequencies are different, however, the filter output level will be considerably less. Figure 2-12 shows the frequency response of one of the formed filters.
The main lobe of the frequency response covers a small range of frequencies referred to as the filter passband. Unfortunately, sidelobes are always present in the frequency response of this type of digitally formed filter. Because of the sidelobes, targets may be detected in outputs of several adjacent filters. The filter coordinates can be weighted to reduce the sidelobe levels.

The fast Fourier transform: forming a bank of digital filters using the DFT requires a tremendous number of computations. A special form of the DFT, called the fast Fourier transform (FFT), can be used to reduce the computation load significantly.

With the FFT, the number of filters formed is equal to the number of samples integrated (equal to the number of pulses processed during the CPI), and the total passband of the filter bank is equal to the PRF ($f_r$). Therefore, an 8-point FFT requires that 8 pulses (8 values of I and 8 of Q) be processed for each CPI, and simulates 8 Doppler filters.

Figure 2-13 shows the main lobes of the frequency response curves of the 8 Doppler filters.
The output level of each Doppler filter corresponds to the level of the Doppler frequencies present in one narrow frequency band of radar return signal. These frequency bands are referred to as spectral components or FFT components. Since the passband of Doppler filter 0 encompasses the 0-Hz region, it is a zero-velocity filter (ZVF). Therefore the level of FFT component 0 corresponds to the level of ground clutter and slowly-moving targets. Spectral components 1-7 correspond to progressively higher Doppler frequencies.

**Doppler ambiguities**

*Spectrum of a coherent pulsed radar signal*: the spectrum of a coherent pulsed radar signal consists of lines whose separation in frequency is equal to the PRF (Figure 2-14). The central line corresponds to the carrier frequency $f_c$. The other lines are upper and lower sidebands caused by the pulse modulation of the carrier.

![Diagram of Doppler ambiguities](image)
The quadrature phase detector in the radar receiver translates the spectrum to the baseband (Figure 2-15). The spectrum is now centred on 0 Hz. When a pulse spectrum is Doppler shifted, all spectral lines are shifted by the Doppler frequency \( f_d \). The shift can be up or down, depending on target direction.

![Diagram of spectrum](image)

Figure 2-15. Spectrum of a coherent baseband signal.

*How ambiguities come about:* since the spectral lines are separated by the PRF, and the passband of the Doppler filter bank is equal to the PRF, only one spectral line falls within the passband of the Doppler filter bank (Figure 2-16). However, there is no way of telling which line it is.

As a result, when the Doppler frequency is greater than the PRF, the central line of the spectrum is outside the passband of the filter bank, but one of the lower sidebands falls within it (Figure 2-16c). The apparent Doppler frequency of the target is the frequency of that sideband.

When the Doppler frequency is negative (opening target) the central line is always below the passband. However, one of the upper sidebands will be within the passband (Figure 2-16d). For this reason, a target moving slowly away from the radar may have an apparent Doppler frequency close to the PRF, and produce high-order FFT components.
Figure 2-16. Doppler ambiguity.
Blind (dim) speeds

Because of Doppler ambiguity, the apparent Doppler frequency of a non-tangential moving target can be zero (Figure 2-16e). In fact, the apparent Doppler frequency of any target whose real Doppler frequency is a multiple of the PRF is 0 Hz.

With MTI processing, these moving targets would be cancelled. Radial velocities that produce no output from the MTI canceller are called blind speeds. With MTD processing, these targets produce an output from the zero-velocity filter (ZVF).

In the absence of clutter, this presents no problem with MTD. Since the target changes position from scan to scan, it is not averaged into the clutter map, and can be easily detected. In areas of high clutter, however, the thresholds for ZVFs are already high, and therefore sensitivity to zero-Doppler targets is reduced. For this reason, non-zero radial velocities that produce an apparent Doppler frequency of 0 Hz are called dim speeds.

Staggered PRF: to alleviate the loss of sensitivity due to dim speeds, two CPIs (A and B) are used with different PRFs. A separate bank of Doppler filters is formed for each CPI. If a target spectral line lies within the ZVF of one PRF, it may not lie within the ZVF of the other PRF. This helps detect targets moving at dim speeds, and also helps detect targets in weather clutter.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set up and calibration
- Adjustments
- Observing FFT components

PROCEDURE

Set up and calibration

1. Before beginning this exercise, the main elements of the Radar Training System (the antenna, the target table and the training modules) must be set up as shown in Appendix B.

   Turn on all modules and make sure the POWER ON LEDs are lit.

2. Turn on the computer, start the LVRTS software, select Digital Pulse Radar and click OK. This begins a new session with all settings set to their default values and with all faults deactivated. If the software is already running, click Exit in the File menu and then restart the LVRTS software to begin a new session.
3. Connect the modules as shown on the Digital Pulse Radar tab of the LVRTS software. For details of connections to the Reconfigurable Training Module, refer to the RTM Connections tab of the software.

- Make the connections to the 9632 (D/A Output Interface) plug-in module only if you wish to connect a conventional radar PPI display to the system.

- The SYNC. TRIGGER INPUT of the Dual-Channel Sampler and the PULSE GENERATOR TRIGGER INPUT of the Radar Transmitter must be connected directly to OUTPUT B of the Radar Synchronizer without passing through BNC T-connectors.

4. Make sure the Radar Training System has been calibrated according to the instructions in Appendix C. Then set the RF POWER switch on the Radar Transmitter to the STANDBY position.

Adjustments

5. Make the following adjustments:

On the Radar Transmitter

- RF OSCILLATOR FREQUENCY.................. CAL
- PULSE GENERATOR PULSE WIDTH........... 1 ns

On the Radar Synchronizer / Antenna Controller

- PRF ................................................. 288 Hz
- PRF MODE...................................... SINGLE
- ANTENNA ROTATION MODE ................. PRF LOCK
- DISPLAY MODE.............................. POSITION

On the Dual-Channel Sampler

- RANGE SPAN...................................... desired observation range

In the LVRTS software

- System Settings
- Baseline Adjustment......................... Off
- Radar Display Settings
- Operation Mode ............................. MTD
- Range............................................ desired observation range
- FFT 0 Detection Mode ...................... Fixed Threshold
- FFT 0 Fixed Threshold ...................... 1.5 V
- FFT 1-7 Detection Mode ..................... Fixed Threshold
- FFT 1-7 Fixed Threshold ..................... 1.5 V

6. Stop the antenna and point the antenna towards the target table.

Place a half-cylinder target on the mast of the target table. Adjust the Target Controller so that the target moves radially (along the Radar Antenna beam axis) at a speed of approximately 10 cm/s.
Depress the RF POWER push button. The RF POWER ON LED should start to flash on and off. This indicates that RF power is being radiated by the Radar Antenna.

**Observing FFT components**

7. Show the Data Monitor. Each of the three monitors in the Data Monitor allows you to display the output levels of one set of Doppler filters. You select the FFT Component (from 0 to 7) and the PRF (High or Low), and the monitor displays the Doppler Filter output levels for all range cells in the observation range.

Observe each of the FFT Components 0 to 7 as the target moves towards and away from the antenna. (The PRF setting should be the same in each monitor.) Figure 2-17 shows an example of what you might observe for FFT Components 0 and 1.

![Figure 2-17. FFT Components 0 and 1 (target speed = 10 cm/s).](image)
With a target speed of 10 cm/s and the PRF set to 288 Hz, which of the 8 FFT components is the strongest? Explain.

8. Stop the target and examine each of the FFT components. Explain what you observe.

9. Vary the target speed between 0 and maximum speed, with the target moving radially. What effect has the speed on the level of FFT Component 0?

10. Set the target speed to maximum, and observe FFT Components 1 and 7 in Monitors 1 and 2 as the target moves. Explain what you observe.

11. A Doppler frequency of 0 Hz will produce a maximum output in FFT filter 0. What is the lowest non-zero positive Doppler frequency that will also produce a maximum output in FFT filter 0, when the PRF = 18 Hz?
12. Figure 2-18 shows a graph of the frequency response of the 8 Doppler filters formed by the FFT. Calculate the Doppler frequency that corresponds to each peak in the graph, when the PRF = 18 Hz, and write it in the appropriate box. Then calculate the range rates that produce these Doppler frequencies (remember that a positive range rate produces a negative Doppler frequency).

![Diagram of FFT spectral components and Doppler frequency range rates.](image)

Figure 2-18. Frequency response of Doppler filter bank (PRF = 18 Hz).

13. On the Radar Synchronizer, set the PRF to 18 Hz.

For each different range rate in Figure 2-18, do the following:

a) Adjust the Target Controller so the target moves radially at a speed approximately equal to the absolute value of the range rate. As the target closes (approaches the antenna), the range rate is negative; as it opens, the range rate is positive (note that the DISPLAY of the Target Controller rounds off the SPEED to the nearest whole number).

b) Observe all of the FFT Components. Use all three monitors if you wish. You may find it convenient to observe:

- FFT Components 1 and 7,
- FFT Components 2 and 6,
- FFT Components 3 and 5,
- FFT Component 4,
- FFT Component 0.

Note that when the target stops to change direction, the level of FFT Component 0 increases briefly.
At each range rate, observe which FFT component has the highest output level when the target is closing and when it is opening. Do your observations correspond to the graph in Figure 2-18? Explain.

14. Calculate the frequencies that correspond to FFT filters 0 to 7 when the PRF = 144 Hz.

Calculate the lowest range rate that will produce a maximum output in FFT filter 1 when the target is closing.

15. Adjust the Target Controller so the target moves radially at approximately 3 cm/s. On the Radar Display, set FFT 0 Fixed Threshold to 0.05 V.

On the Radar Synchronizer, set the PRF to 144 Hz, SINGLE PRF MODE.

Start the antenna rotation (set the ANTENNA ROTATION MODE on the Antenna Controller to PRF LOCK, or screw in the connector at the POWER OUTPUT of the Antenna Motor Driver). Then set the Baseline Adjustment to On.

After several antenna scans, you should see an X corresponding to the slowly moving target. Because the threshold is now fixed at a very low level, other Xs caused by noise are likely to appear as well.

On the Data Monitor, select FFT Components 0, 1 and 7 for observation in Monitors 1, 2, and 3. Enable the Sector Selector and use the Sector setting to select the sector in which the moving target is located, as shown in Figure 2-19. If necessary, move the target slightly. The target does not have to be in the center of a CPI; it can be on the edge as shown in the figure. Note whether the target is in the high-PRF CPI (the first one going clockwise) or the low-PRF CPI. Then set the PRF of all three monitors in the Data Monitor to High or Low accordingly.
16. Adjust the Target Controller so the target moves radially at 29 cm/s. When the antenna scans the moving target, you should now see a significant level in FFT Component 1 or 7, depending on whether the target is opening or closing. If the target is changing direction when it is scanned, FFT Component 0 will have a significant level.
17. On the Radar Display, set FFT 0 Detection Mode and FFT 1-7 Detection Mode to CFAR. After the antenna has completed several rotations, the moving target will appear on the Radar Display (the CFAR detection mode will be studied in the next exercise).

Set Map Display to On and display the FFT Component 1 map. After a certain delay, all cells for which FFT Component 1 has a significantly high level will be shown on the display. Increase the Map Intensity to 90%.

Position the Radar Display and the Data Monitor so you can see them both, and observe them for several minutes. If the target is closing when it is scanned by the antenna, FFT component 1 should be strong on both the Radar Display and in the Data Monitor.

If the target was opening when it was scanned by the antenna, however, FFT component 1 will be weak on the Radar Display and in the Data Monitor, and FFT Component 7 will be strong on the Data Monitor.

On the Radar Display, set the Map Threshold to 0.05 V and repeat your observations.

Display the FFT Component 7 map and make the same observations. Explain the use of the FFT maps in the LVRTS software. What is the effect of increasing the Map Threshold?

18. On the Radar Display, set the Map Threshold to 0. Display Components 2 and 6 on the Data Monitor. Display the FFT maps for these components on the Radar Display. Repeat for FFT components 3 and 5, and then 4. What do you observe?

19. Display the FFT 0 Map on the Radar Display. What do you observe?
**20.** Adjust the Target Controller so that the target moves tangentially at maximum speed. On the Radar Display, observe the map for FFT Components 0 to 7. In which of these FFT maps is the target visible? Explain.

**21.** On the Radar Transmitter, make sure that the RF POWER switch is in the STANDBY position. The RF POWER STANDBY LED should be lit. If no one else will be using the system, turn off all equipment.

**CONCLUSION**

In this exercise, you observed the results of FFT processing in the Digital MTD/PPI Processor, using the Data Monitor. You observed that fixed targets, tangentially moving targets, and targets moving at dim speeds produce an output for FFT component 0, and that moving targets produce outputs for other components, depending on target speed and direction.
Sample Exercise

Extracted from

Tracking Radar
Exercise 4

Angle Tracking Techniques

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the principles of the following angle tracking techniques: lobe switching, conical scan, and monopulse. You will be able to demonstrate how lobe switching is implemented in the Lab-Volt Tracking Radar.

DISCUSSION

Angle Tracking

Angle tracking is the continuous estimation of the angular position (azimuth, elevation, or both azimuth and elevation) of a particular target. Automatic angle tracking is usually achieved by estimating the angular error between the target angular position and some reference direction, usually the direction of the antenna axis, and generating an error signal to modify the antenna direction so as to correct the angular error as perfectly as possible. As a result, the antenna axis direction corresponds to the target angular position.

There are several techniques used in tracking radars for achieving angle tracking. This exercise describes the principles of the following three angle tracking techniques: lobe switching, conical scan, and monopulse (simultaneous lobbing). Emphasis is put on the lobe switching technique by showing how it is implemented in the Lab-Volt Tracking Radar and explaining the crossover loss which results from antenna beam crossover. The next exercise will focus on how signals related to the angular error, obtained using lobe switching, are processed to perform automatic angle tracking.

Lobe Switching

Lobe switching, which is also referred to as sequential lobbing, alternately switches the antenna beam between two angular positions of the same plan that are slightly separated from each other. Figure 4-1 (a) is a polar representation of the antenna beam (main lobe without the side lobes) in the two positions. Notice that the beam positions are symmetrical with respect to the antenna axis. The antenna beam in position 1 is often referred to as the left lobe. Similarly, the antenna beam in position 2 is often referred to as the right lobe.
Figure 4-1 (b) shows the amplitude of the echo signal versus time for a target at the location shown in Figure 4-1 (a). The target echo amplitude obtained when the beam is in position 2 is higher than that obtained when the beam is in position 1 because the target is to the right of the antenna axis. If, on the other hand, the target were to the left of the antenna axis, the amplitude obtained in position 1 would be higher than that obtained in position 2. The magnitude of the difference in amplitude between the target echoes obtained in positions 1 and 2 is a measure of the angular error between the antenna axis direction and the target direction. Furthermore, the polarity of the difference indicates the direction in which the antenna must be moved in order to correct the angular error, i.e., to align the antenna axis with the target direction.

Note that the lobe switching technique described above allows angle tracking in one plane only. If both the azimuth and elevation of the tracked target are desired, switching of the antenna beam in two orthogonal planes is required.

When performing angle tracking, the angular error is maintained as low as possible in order to align the antenna axis with the target direction as perfectly as possible. Figure 4-2 illustrates this situation. The amplitude, or level, of the target echo is the same for both beam positions. This level, which is referred to as the two-way beam crossover level, is less than that which would be obtained if the target were aligned with the antenna beam axis (two-way beam maximum level). This results in a signal loss, and thus, reduces the signal-to-noise (S/N) ratio at the receiver input. This reduction in S/N ratio is called crossover loss.

Note: The term "two-way" is used in the above paragraph because it is considered that the same antenna is used for both emission and reception.
Conical Scan

The conical scan angle tracking technique is similar to the lobe switching technique discussed above. With conical scan, the antenna beam is made to rotate continuously, usually about the antenna reflector axis, instead of being switched between discrete positions. Figure 4-3 illustrates the conical scan technique.
the magnitude and direction of the angular error, respectively. Azimuth and elevation error signals are generated by first extracting the amplitude modulation from the received signal and then processing the extracted modulation. These error signals are then used to correct the antenna direction so that the beam rotation axis is aligned with the target. Note that there is no amplitude modulation on the target echo signal when the beam rotation axis is perfectly aligned with the target.

The lobe switching and conical scan techniques each requires several successive echo pulses to determine the angular error. These pulses should be free of any other sources of amplitude modulation for the angular error to be determined as accurately as possible. Any additional source of amplitude modulation, such as target radar cross-section fluctuation for example, is likely to degrade the angle tracking accuracy.

Monopulse Technique

The monopulse technique, which is also referred to as the amplitude-comparison monopulse technique, uses an antenna that provides two independent beams which slightly overlap as shown in Figure 4-5(a). The two beams are used simultaneously.

The echo signal received with beam 1 is subtracted from that received with beam 2. This generates the difference pattern shown in Figure 4-5(b). The signs in the difference pattern indicate the polarity of the echo signal that results from this pattern (difference signal). For example, when a target is to the left of the antenna axis, the amplitude of the echo signal obtained with beam 1 is higher than that obtained with beam 2 and the difference signal is positive. Conversely, when a target is to the right of the antenna axis, the amplitude of the echo signal obtained with beam 2 is higher than that obtained with beam 1 and the difference signal is negative. The echo signals received with the two beams are also added together. This generates the sum pattern shown in Figure 4-5(c). The echo signal which results from this pattern (sum signal) is always positive.
Angle Tracking Techniques

The magnitude of the difference signal is a measure of the angular error. However, it gives no information about the angular error direction. The error direction is obtained by comparing the polarity (or phase) of the difference signal with that of the sum signal. When a target is to the left of the antenna axis, the difference signal is positive, and thus, the sum and difference signals are of the same polarity (in phase). Conversely, when a target is to the right of the antenna axis, the difference signal is negative. As a result, the sum and difference signals are of opposite polarities (180° out of phase).

Note that the monopulse technique allows the angular error to be determined from a single target echo pulse. This is a great advantage over the lobe switching and conical scan techniques because this prevents pulse-to-pulse amplitude modulation from affecting the angle tracking accuracy. Furthermore, there is no reduction in the S/N ratio at the receiver input (crossover loss) because the radar receiver processes the sum signal.

Lobe Switching Implementation in the Lab-Volt Tracking Radar

The lobe switching technique is used in the Lab-Volt Tracking Radar to perform angle tracking. Lobe switching is obtained using a dual-feed parabolic-reflector antenna. The tracking radar transmits and receives RF power through either one of the two antenna feeds (horns). When the left horn is used, the antenna beam is to the right of the antenna axis (reflector axis) as shown in Figure 4-6(a). Conversely, when the right horn is in operation, the antenna beam is to the left of the antenna axis as shown in Figure 4-6(b).
Angle Tracking Techniques

Figure 4-6. Beam patterns obtained with a dual-feed parabolic-reflector antenna.

a) Beam pattern obtained with left horn in operation

b) Beam pattern obtained with right horn in operation
A microwave switch like that shown in Figure 4-7 is mounted on the antenna. This switch allows horn selection. A dc bias voltage must be added to the RF signal at the common port of the switch in order to bias diodes D₁ and D₂. The polarity of this bias voltage determines whether the RF signal flows through port 1 (left horn) or port 2 (right horn) of the switch. When the bias voltage is positive, diode D₁ is reverse biased, diode D₂ is forward biased, and the RF signal flows through port 2 (right antenna horn). Conversely, when the bias voltage is negative, diode D₁ is forward biased, diode D₂ is reverse biased, and the RF signal flows through port 1 (left antenna horn).

Figure 4-7. Simplified diagram of the microwave switch mounted on the Tracking Radar antenna.

Figure 4-8 shows the RF interconnection of the radar antenna, Rotating-Antenna Pedestal, Radar Transmitter, Radar Receiver, and Radar Target Tracking Interface (plug-in module, Model 9633). A bias voltage coming from the lobe switching control circuit of the Radar Target Tracker is added to the Radar Transmitter output signal through the RF bias tee in the Radar Target Tracking Interface. The inductor prevents the RF signal from entering the lobe switching control circuit and the capacitor prevents the bias voltage from reaching the Radar Transmitter output. A blocking capacitor prevents any residual bias voltage from entering the sensitive input stage of the Radar Receiver.
Procedure Summary

In the first part of the exercise, Equipment Setup, you will set up the Tracking Radar, position the target table with respect to the Tracking Radar, and calibrate the Tracking Radar.

In the second part of the exercise, Lobe Switching, a dc voltage will be added to the Radar Transmitter output signal to perform manual lobe switching. You will choose the antenna beam position by changing the polarity of the dc voltage.

In the third part of the exercise, Antenna Beam Patterns, you will select one of the two beam positions and then scan a target by rotating the Dual Feed Parabolic Antenna by 1°-steps. For each step, you will record the target echo amplitude and the antenna azimuth. You will repeat this manipulation for the other beam position. You will then plot on a single graph the antenna beam pattern for each of the two positions. You will use this graph to determine the beam maximum level, beam crossover level, and the crossover loss.
Angle Tracking Techniques

In the fourth part of the exercise, *Lobe Switching Control*, the signal from the LOBE SWITCH CONTROL OUTPUT of the Radar Target Tracker will be used to switch the antenna beam between the two positions. You will observe this signal as well as the radar video signal when a target is located to either the right or left of the antenna axis. You will also observe how the lobe control rate affects these signals.

**PROCEDURE**

**Equipment Setup**

☐ 1. Before beginning this exercise, the main elements of the Tracking Radar Training System (i.e., the antenna and its pedestal, the target table, the RTM and its power supply, the training modules, and the host computer) must be set up as shown in Appendix A.

   On the Radar Transmitter, make sure that the RF POWER switch is set to the STANDBY position.

   On the Antenna Controller, make sure that the MANual ANTENNA ROTATION MODE is selected and the SPEED control is set to the 0 position.

   Turn on all modules and make sure the POWER ON LED's are lit.

☐ 2. Turn on the host computer, start the LVRTS software, select *Tracking Radar*, and click OK. This begins a new session with all settings set to their default values and with all faults deactivated. If the software is already running, click *Exit* in the *File* menu and then restart the LVRTS software to begin a new session.

☐ 3. Connect the modules as shown on the *Tracking Radar* tab of the LVRTS software. For details of connections to the Reconfigurable Training Module, refer to the *RTM Connections* tab of the software.

   **Note:** Make the connections to the Analog/Digital Output Interface (plug-in module 9632) only if you wish to connect a conventional radar PPI display to the system or obtain an O-scope display on a conventional oscilloscope.

   **Note:** The SYNC. TRIGGER INPUT of the Dual-Channel Sampler and the PULSE GENERATOR TRIGGER INPUT of the Radar Transmitter must be connected directly to OUTPUT B of the Radar Synchronizer without passing through BNC T-connectors.

   Connect the hand control to a USB port of the host computer.
4. Make the following settings:

On the Radar Transmitter

RF OSCILLATOR FREQUENCY ........ CAL.
PULSE GENERATOR PULSE WIDTH ....... 1 ns

On the Radar Synchronizer / Antenna Controller

PRF ........................................ 288 Hz
PRF MODE ......................... SINGLE
ANTENNA ROTATION MODE ........ PRF LOCK.
DISPLAY MODE ....................... POSITION

On the Dual-Channel Sampler

RANGE SPAN ..................... 3.6 m

In the LVRTS software

System Settings:
Log./Lin. Mode ..................... Lin.
Gain .................................. as required
AGC .................................. Off

Radar Display Settings:
Range ............................... 3.6 m

5. Connect the cable of the target table to the connector located on the rear panel of the Target Controller. Make sure that the surface of the target table is free of any objects and then set its POWER switch to the I (on) position.

Place the target table so that its grid is located approximately 1.2 m from the Rotating-Antenna Pedestal, as shown in Figure 4-9. Make sure that the metal rail of the target table is correctly aligned with the shaft of the Rotating-Antenna Pedestal.
6. Calibrate the Tracking Radar Training System according to the instructions in sections I to V of Appendix B.

Lobe Switching

7. On the Radar Target Tracking Interface (plug-in module, Model 9633), remove the cable which interconnects the LOBE SWITCH CONTROL OUTPUT and LOBE SWITCH CONTROL INPUT of the Radar Target Tracker.

Connect the LOBE SWITCH CONTROL INPUT of the Radar Target Tracker to the +15-V dc output of the Power Supply using the BNC connector/banana plug cable provided with the Tracking Radar. This applies a +15-V dc bias voltage to the microwave switch of the Dual Feed Parabolic Antenna (radar antenna).

8. On the Radar Transmitter, make sure that the RF POWER push button is depressed. The RF POWER ON LED should flash on and off to indicate that RF power is being radiated by the radar antenna.

Using the hand control, slightly vary the direction of the radar antenna so that the amplitude of the target echo pulse on the O-Scope Display is maximum.
Angle Tracking Techniques

Is the target located to the right or left of the radar antenna axis (when looking at the target from the radar antenna)?

Which horn of the radar antenna is used?

☐ 9. Using a small metal plate target, gradually block the aperture of the radar antenna horn which you think is not used. While doing this, observe the target echo pulse on the O-Scope Display.

Describe what happens. Briefly explain.

Does this confirm the answer you gave in the previous step about the radar antenna horn that is used?

☐ Yes ☐ No

☐ 10. On the Radar Transmitter, set the RF POWER switch to the STANDBY position. The RF POWER STANDBY LED should be lit.

Disconnect the LOBE SWITCH CONTROL INPUT of the Radar Target Tracker from the +15-V dc output of the Power Supply then connect it to the -15-V dc output of the same module. This applies a -15-V dc bias voltage to the microwave switch of the radar antenna.

☐ 11. On the Radar Transmitter, depress the RF POWER push button. The RF POWER ON LED should start to flash on and off.

Using the hand control, slightly vary the direction of the radar antenna so that the echo pulse of the target appears on the O-Scope Display. Slightly readjust the direction of the radar antenna so that the amplitude of the target echo pulse is maximum.

Is the target located to the right or left of the radar antenna axis (when looking at the target from the radar antenna)?

Which horn of the radar antenna is used?
Angle Tracking Techniques

☐ 12. Using a small metal plate target, gradually block the aperture of the radar antenna horn which you think is not used. While doing this, observe the target echo pulse on the O-Scope Display.

Describe what happens. Briefly explain.

Does this confirm the answer you gave in the previous step about the radar antenna horn that is used?

☐ Yes  ☐ No

Antenna Beam Patterns

☐ 13. On the Radar Transmitter, set the RF POWER switch to the STANDBY position. The RF POWER STANDBY LED should be lit.

Remove the small metal plate target from the mast of the target table.

Place a large metal plate target on the mast of the target table. Make sure that the target squarely faces the radar antenna, and then tighten the screw to secure the target to the mast.

On the Target Controller, use the Y-axis position control to place the target at the far end of the target table. The target range is now approximately 2.0 m since the grid of the target table is approximately 1.1 m from the horns of the radar antenna.

☐ 14. In LVRTS, disconnect the Oscilloscope probes 1 and 2 from TP1 and TP2 of the MTI Processor. Disconnect the Oscilloscope probe E from TP8 of the Radar Target Tracker. Connect the Oscilloscope probe 1 to TP9 (radar video signal) of the Radar Target Tracker. Connect the Oscilloscope probe E to TP3 (PRF TRIGGER INPUT) of the Display Processor.

Make the following settings on the Oscilloscope:

- Channel 1 ......................... 0.5 V/div
- Channel 2 .............................. Off
- Time Base ........................ 0.5 ms/div

Set the Oscilloscope to Continuous Refresh.

On the Radar Transmitter, depress the RF POWER push button. The RF POWER ON LED should start to flash on and off.

Slightly rotate the radar antenna so as to maximize the amplitude of target echo pulse at TP9.
Angle Tracking Techniques

In LVRTS, set the Gain of the MTI Processor so that the amplitude of the target echo pulse at TP9 is approximately 0.7 V.

15. Manually rotate the radar antenna counterclockwise until the amplitude of the target echo pulse at TP9 decreases to approximately 0.07 V. Record in the first row of Table 4-1 the azimuth of the radar antenna (indicated on the O-Scope Display) and the amplitude of the target echo pulse at TP9.

Manually rotate the radar antenna clockwise by steps of 1° so that the radar antenna beam (right lobe) scans the target. For each step, record in Table 4-1 the azimuth of the radar antenna and the amplitude of the target echo pulse at TP9.

<table>
<thead>
<tr>
<th>ANTENNA AZIMUTH</th>
<th>TARGET ECHO AMPLITUDE (RIGHT LOBE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>degrees</td>
<td>V</td>
</tr>
</tbody>
</table>

Table 4-1. Target echo amplitude (at TP9) versus radar antenna azimuth (right lobe).

16. On the Radar Transmitter, set the RF POWER switch to the STANDBY position. The RF POWER STANDBY LED should be lit.

Disconnect the LOBE SWITCH CONTROL INPUT of the Radar Target Tracker from the −15-V dc output of the Power Supply then connect it to the +15-V dc output of the same module.
Angle Tracking Techniques

On the Radar Transmitter, depress the RF POWER push button. The RF POWER ON LED should start to flash on and off and the target echo pulse should appear at TP9.

☐ 17. Manually rotate the radar antenna clockwise until the amplitude of the target echo pulse at TP9 decreases to approximately 0.07 V. Record in the first row of Table 4-2 the azimuth of the radar antenna and the amplitude of the target echo pulse at TP9.

<table>
<thead>
<tr>
<th>ANTENNA AZIMUTH</th>
<th>TARGET ECHO AMPLITUDE (LEFT LOBE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>degrees</td>
<td>V</td>
</tr>
</tbody>
</table>

Table 4-2. Target echo amplitude (at TP9) versus radar antenna azimuth (left lobe).

Manually rotate the radar antenna counterclockwise by steps of 1° so that the antenna beam (left lobe) scans the target. For each step, record in Table 4-2 the azimuth of the radar antenna and the amplitude of the target echo pulse at TP9.

☐ 18. On the Radar Transmitter, set the RF POWER switch to the STANDBY position. The RF POWER STANDBY LED should be lit.

Use the data in Tables 4-1 and 4-2 to plot in Figure 4-10 the right and left two-way beam patterns (right and left lobes) of the radar antenna.
19. Determine the angular separation between the axes of the right and left lobes using the antenna two-way beam patterns plotted in Figure 4-10. Record the result in the following blank space.

**Angular Separation:** ______ °

Determine the maximum target echo amplitude (maximum level) obtained with the left lobe and the right lobe using the antenna two-way beam patterns plotted in Figure 4-10. Record the results in the following blank spaces.

Left-Lobe Two-Way Maximum Level: ______ V

Right-Lobe Two-Way Maximum Level: ______ V
Angle Tracking Techniques

Calculate the mean value of the right- and left-lobe two-way maximum levels to determine the two-way beam maximum level. Record the result in the following blank space.

Two-Way Beam Maximum Level: ______ V

Determine the target echo amplitude at the point the antenna two-way beam patterns in Figure 4-10 intersect. This corresponds to the two-way beam crossover level. Record the result in the following blank space.

Two-Way Beam Crossover Level: ______ V

Calculate the crossover loss using the following equation:

\[
\text{Crossover Loss} = 20 \times \log \left( \frac{\text{Two-Way Beam Crossover Level}}{\text{Two-Way Beam Maximum Level}} \right)
\]

Lobe Switching Control

20. Remove the cable connecting the LOBE SWITCH CONTROL INPUT of the Radar Target Tracker to the +15-V dc output of the Power Supply.

Interconnect the LOBE SWITCH CONTROL OUTPUT and LOBE SWITCH CONTROL INPUT of the Radar Target Tracker using a short BNC cable.

In LVRTS, connect the Oscilloscope probe 2 to TP8 (LOBE SWITCH CONTROL OUTPUT signal) of the Radar Target Tracker.

Make the following settings on the Oscilloscope:

- Channel 1: 0.2 V/div
- Channel 2: Normal
- Channel 2: 5 V/div
- Time Base: 2 ms/div
- Trigger Source: 2 (Ch. 2)
- Trigger Level: 0.0 V

Use the hand control to align the radar antenna axis with the target.

21. On the Radar Transmitter, depress the RF POWER push button. The RF POWER ON LED should start to flash on and off and the target echo pulse should appear at TP9.

Manually rotate the radar antenna counterclockwise slightly so that the target is to the right of the antenna axis. Sketch the waveforms of the radar video signal and the LOBE SWITCH CONTROL OUTPUT signal in Figure 4-11.
Note: If a printer is available, you can print the signals observed on the Oscilloscope instead of sketching them in Figure 4-11.

Figure 4-11. Radar video signal and LOBE SWITCH CONTROL OUTPUT signal (target to the right of the radar antenna axis).

Why does the amplitude of the target echo pulse change from one interpulse period to the next?

____________________________________________________________________________________

____________________________________________________________________________________

Briefly explain why the amplitude of the target echo pulse obtained when the LOBE SWITCH CONTROL OUTPUT signal is negative is higher than that obtained when the LOBE SWITCH CONTROL OUTPUT signal is positive.

____________________________________________________________________________________

____________________________________________________________________________________

____________________________________________________________________________________

☐ 22. Manually rotate the radar antenna clockwise slightly so that the target is to the left of the antenna axis. Sketch the waveforms of the radar video signal and LOBE SWITCH CONTROL OUTPUT signal in Figure 4-12.

Note: If a printer is available, you can print the signals observed on the Oscilloscope instead of sketching them in Figure 4-12.
Angle Tracking Techniques

Figure 4-12. Radar video signal and LOBE SWITCH CONTROL OUTPUT signal (target to the left of the radar antenna axis).

Briefly explain why the amplitude of the target echo pulse obtained when the LOBE SWITCH CONTROL OUTPUT signal is positive is higher than that obtained when the LOBE SWITCH CONTROL OUTPUT signal is negative.

☐ 23. In LVRTS, set the Lobe Control Rate of the Radar Target Tracker to PRF/4 while observing the signals on the Oscilloscope.

Sketch the waveforms of the radar video signal and LOBE SWITCH CONTROL OUTPUT signal in Figure 4-13.

Note: If a printer is available, you can print the signals observed on the Oscilloscope instead of sketching them in Figure 4-13.
Figure 4-13. Radar video signal and LOBE SWITCH CONTROL OUTPUT signal (target to the left of the radar antenna axis and lobe control rate set to PRF/4).

Describe what happens when the lobe control rate passes from PRF/2 to PRF/4.

☐ 24. On the Radar Transmitter, set the RF POWER switch to the STANDBY position. The RF POWER STANDBY LED should be lit. Turn off all equipment.

CONCLUSION

In this exercise, you learned that lobe switching alternately switches the antenna beam between two positions located on both sides of the radar antenna axis. You observed that when a +15-V dc voltage is applied to the LOBE SWITCH CONTROL INPUT of the Radar Target Tracker, the RF signal flows through the right horn of the radar antenna and the beam axis is to the left of the antenna axis. Conversely, when a −15-V dc voltage is applied to the LOBE SWITCH CONTROL INPUT, the RF signal flows through the left horn of the radar antenna and the beam axis is to the right of the antenna axis. You saw that the antenna two-way beam patterns obtained in the two positions overlap. You observed that the signal level at the point the two patterns intersect (two-way beam crossover level) is less than the two-way beam maximum level. You saw that in the Lab-Volt Tracking Radar, a bipolar square-wave signal is used to alternately switch the radar antenna beam between the two positions.
REVIEW QUESTIONS

1. Briefly explain how angle tracking is usually achieved in tracking radars.

2. Briefly explain the lobe-switching angle tracking technique.

3. What is the beam crossover level?

4. Briefly explain what crossover loss is.

5. What advantage does the monopulse angle tracking technique have over the lobe switching and conical scan angle tracking techniques?
Sample Exercise
Extracted from
Radar in an Active
Target Environment
Antennas in EW: Sidelobe Jamming and Space Discrimination

EXERCISE OBJECTIVE

To demonstrate that noise jamming can be injected into a radar receiver via the sidelobes of the radar antenna. To outline the effects of effective sidelobe noise jamming. To present antenna space discrimination techniques.

DISCUSSION

Introduction

Radar antenna radiation patterns when observed, can differ significantly from one antenna to the next. Nonetheless all radar antennas have certain similarities, they possess a mainlobe and numerous sidelobes. Figure 1-33 is an example of the radiation pattern of an antenna. Sidelobes are undesired irregularities in the antenna radiation pattern. When considered collectively, the antenna sidelobes are responsible for a substantial portion of an antenna’s radiated signal power. This portion can be as much as 25% of the radiated signal power in some antennas.

![H-plane radiation pattern](image)

Figure 1-33. H-plane radiation pattern for the Lab-Volt Dual Feed Parabolic Antenna (Tracking Radar antenna).
Antennas in EW: Sidelobe Jamming
and Space Discrimination

Strong antenna sidelobe levels can be a source of significant ground clutter. When used in military applications, radars with strong sidelobe signal emissions increase the radar’s susceptibility of being detected by the enemy. Strong sidelobes also give the enemy an effective means of injecting noise jamming signals, or spurious radar echo signals, see deceptive jamming signals, into the radar receiver.

Sidelobe Noise Jamming

Jamming is conducted through the sidelobes of a receiving antenna, in an attempt to cover, disrupt, or falsify returned radar signal information received through the antenna mainlobe, is known as sidelobe jamming. Sidelobe noise jamming is the preferred electronic attack used against weapon fire-control radar (tracking radar) in the denial of target range and bearing data. Noise jamming through a radar antenna’s mainlobe is to be avoided because it provides the fire-control radar with a strobe in the direction of the jamming platform, as shown in Figure 1-34 (a).

Effective spot or barrage noise jamming conducted through a radar antenna’s mainlobe and sidelobes completely blinds a radar, no matter what its angular antenna position, as illustrated in Figure 1-34 (b). However, to be effective, a sidelobe noise jamming signal must have enough power to overcome the low signal response associated with the radar antenna’s sidelobes. This forces the sidelobe jamming platform to carry large amounts of jamming resources and to employ a highly directional antenna, implying that a large platform is usually required to perform sidelobe jamming.

Figure 1-34. The effect of mainlobe and sidelobe noise jamming on a search radar.
Antennas in EW: Sidelobe Jamming and Space Discrimination

Sidelobe noise jamming can be performed by any support jammer. However, because of the efficiency of sidelobe jamming against radar, the sidelobe jamming platform becomes a high-priority target for fire-control radar belonging to the victim force. Because a rather large platform is required to carry dedicated sidelobe jamming resources, it is difficult for a friendly force to give it proper protection. Thus sidelobe jamming is more often conducted in a stand-off jamming position. The low sidelobe response of the victim radar and the long range between the jamming platform and the victim radar, implies that lots of jamming power and a highly directive antenna must be used by a sidelobe jammer in a stand-off position for radar jamming to be effective.

Stand-Off Jamming

A stand-off jamming platform is a type of support jammer. It is located beyond the interception range of hostile weapon systems. A stand-off jammer is often used to provide noise jamming cover to a force of low-RCS platforms infiltrating the detection range of an enemy acquisition or fire-control radar. The stand-off jamming platform must necessarily conduct sidelobe jamming because it is often placed in a geometrically unfavorable position with respect to the radar antenna mainlobe.

Space Discrimination

The antenna is the only device that connects the radar to its working environment. Consequently, the antenna must naturally be considered the first component of a radar system to merit the incorporation of electronic protection measures. By implementing effective EP in the antenna, the degree of damage done to a radar receiver by electronic attack can be limited. The EP can be implemented using space and/or signal discrimination techniques. Antenna space discrimination is the radar’s ability to discriminate between signals input through its mainlobe and signals input through its sidelobes.

When the victim radar has strong sidelobe levels, the stand-off jammer holds a definite advantage in the jammer/radar energy battle. It is therefore necessary to reduce the antenna sidelobe levels of the radar, a method of implementing antenna space discrimination. Low, very-low, and ultra-low sidelobe antennas (see Table 1-4) can be used not only to avoid sidelobe clutter, but to prevent a radar via its sidelobe radiated signal, from being detected by the enemy. To protect the target detection ability of a radar from the effects of sidelobe jamming, the radar antenna sidelobe levels must be between 40 to 80 dB below the maximum mainlobe level.

<table>
<thead>
<tr>
<th>ANTENNA DESCRIPTION</th>
<th>AVERAGE SIDELOBE LEVEL (dB BELOW MAINLOBE MAX. LEVEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>&gt; -30</td>
</tr>
<tr>
<td>Low Sidelobe</td>
<td>-35 to -45</td>
</tr>
<tr>
<td>Very-Low Sidelobe</td>
<td>-45 to -55</td>
</tr>
<tr>
<td>Ultra-Low Sidelobe</td>
<td>&lt; -55</td>
</tr>
</tbody>
</table>

Table 1-4. Sidelobe levels with respect to the mainlobe maximum level.
Antennas in EW: Sidelobe Jamming and Space Discrimination

Achieving such low sidelobe levels in practical antenna design is difficult and fraught with complications. To alleviate the difficulties in designing these types of radar antennas, two techniques exist to reduce by approximately 20 to 30 dB the levels of jamming signals arriving through the antenna's sidelobes. The techniques are known as sidelobe cancellation and sidelobe blanking, both function with the use of one or more omnidirectional auxiliary antennas.

By adaptively controlling the phase and the amplitude of the signals received through the auxiliary antennas, before combining them to the signal received through the main radar antenna, sidelobe cancellation can produce a null in the composite antenna pattern. The term “composite antenna pattern” is used to imply the effective radiation pattern of the main radar antenna and the sidelobe cancellation auxiliary antennas. Through continuous adaptive control, the null can be made to track a jamming signal.

Sidelobe blanking is less complex than sidelobe cancellation, however, it is only effective against low duty cycle jamming signals. The gain of the omnidirectional auxiliary antenna used in sidelobe blanking is designed to be 3 to 4 dB above the maximum sidelobe level. Sidelobe blanking functions by comparing the signal received through the auxiliary antenna to the signal received through the main radar antenna. If the auxiliary antenna signal is stronger than the main radar antenna signal, then the signal must have been received through the radar antenna sidelobes and therefore is not sent to the radar receiver. In effect, a sidelobe blanker, blocks radar receiver signal reception when a signal enters the radar system through the antenna sidelobes.

Space discrimination techniques such as low antenna sidelobes, sidelobe cancellation and blanking circuits, beamwidth control, and antenna scan control, minimize the chances a radar has of receiving unwanted sidelobe clutter and jamming. Antenna electronic protections such as those discussed make stand-off noise jamming difficult to conduct effectively against a radar.

Procedure Summary

In the first part of the exercise, the Tracking Radar system is set up and calibrated. The Target Positioning System is also positioned correctly with respect to the Tracking Radar.

The second part of the exercise demonstrates, from a radar operator’s point-of-view, the difference between sidelobe and mainlobe noise jamming. The difference in the jamming resources required by a sidelobe jammer and a mainlobe jammer are characterized.

During the third part of the exercise, the use of track-on-jamming protection by a radar confronted with sidelobe noise jamming is demonstrated.
Antennas in EW: Sidelobe Jamming
and Space Discrimination

PROCEDURE

Setting Up the Tracking Radar

☐ 1. Before beginning this exercise, the main elements of the Tracking Radar Training System (i.e., the antenna and its pedestal, the target table, the RTM and its power supply, the training modules, and the host computer) must be set up as shown in Appendix A.

On the Radar Transmitter, make sure that the RF POWER switch is set to the STANDBY position.

On the Antenna Controller, make sure that the MANual ANTIENNA ROTATION MODE push button is depressed and the SPEED control is set to the 0 position.

Turn on all modules and make sure the POWER ON LED’s are lit.

☐ 2. Turn on the host computer, start the LVRTS software, select Tracking Radar, and click OK. This begins a new session with all settings set to their default values and with all faults deactivated. If the software is already running, click Exit in the File menu and then restart the LVRTS software to begin a new session.

☐ 3. Connect the modules as shown on the Tracking Radar tab of the LVRTS software. For details of connections to the Reconfigurable Training Module, refer to the RTM Connections tab of the software.

Note: Make the connections to the Analog/Digital Output Interface (plug-in module 9632) only if you wish to connect a conventional radar PPI display to the system or obtain an O-scope display on a conventional oscilloscope.

Note: The SYNC. TRIGGER INPUT of the Dual-Channel Sampler and the PULSE GENERATOR TRIGGER INPUT of the Radar Transmitter must be connected directly to OUTPUT B of the Radar Synchronizer without passing through BNC T-connectors.

Connect the hand control to a USB port of the host computer.

☐ 4. Make the following settings:

On the Radar Transmitter

RF OSCILLATOR FREQUENCY ........ CAL.
PULSE GENERATOR PULSE WIDTH ... 1 ns
Antennas in EW: Sidelobe Jamming and Space Discrimination

On the Radar Synchronizer / Antenna Controller

PRF ........................... 288 Hz
PRF MODE ....................... SINGLE
ANTENNA ROTATION MODE ....... PRF LOCK.
DISPLAY MODE .................. POSITION

On the Dual-Channel Sampler

RANGE SPAN ..................... 3.6 m

In the LVRTS software

System Settings:
Log./Lin. Mode ..................... Lin.
Gain ............................. as required

Radar Display Settings:
Range ............................. 3.6 m

5. Connect the cable of the target table to the connector located on the rear panel of the Target Controller. Make sure that the surface of the target table is free of any objects and then set its POWER switch to the I (on) position.

Place the target table so that its grid is located approximately 1.2 m from the Rotating-Antenna Pedestal, as shown in Figure 1-35. Make sure that the metal rail of the target table is correctly aligned with the shaft of the Rotating-Antenna Pedestal.

Figure 1-35. Position of the Rotating-Antenna Pedestal and target table.
6. Calibrate the Tracking Radar Training System according to the instructions in Appendix B.

   Set the RF POWER switch on the Radar Transmitter to the STANDBY position.

7. Make sure that the Tracking Radar is adjusted as follows:

   Operating Frequency ........................................ 10.0 GHz
   Pulse-Repetition Frequency .............................. single, 288 Hz
   Pulse Width .............................................. 1 ns
   Observation Range ....................................... 3.6 m

Sidelobe Noise Jamming Compared with Mainlobe Noise Jamming

8. Replace the semi-cylinder target installed on the target table mast with the cylinder target placed in the upright position. Position the cylinder target at the following target table coordinates: X = 65 cm, Y = 0 cm (see Figure 1-36).

   Place the Radar Jamming Pod Trainer support (part number 9595-10), provided with the Connection Leads and Accessories, onto the target table at the following coordinates: X = 45 cm, Y = 88 cm (as shown in Figure 1-36).

9. Install the Radar Jamming Pod Trainer onto its support (in the horizontal position) using the long support shaft (part number 33125-01).
Align the Radar Jamming Pod Trainer so that its horn antennas are facing the Tracking Radar antenna and aligned with the shaft of the Rotating-Antenna Pedestal. The longitudinal axis of the Radar Jamming Pod Trainer should be aligned with the shaft of the Rotating-Antenna Pedestal.

Rotate the infrared receiver on the Radar Jamming Pod Trainer toward the direction from which you will use the remote controller.

Install the Power Supply (Model 9609) of the Radar Jamming Pod Trainer on the shelf located under the surface of the target table. Connect the Power Supply line cord to a wall outlet.

Connect the power cable of the Radar Jamming Pod Trainer to the multi-pin connector located on top of the Power Supply.

10. Install the antenna positioning stand adapter (part numbers 33156 and 33160) onto the top of the positioning stand (part number 33179). Install the single-feed parabolic radar antenna (the parabolic jamming antenna) onto the positioning stand.

Adjust the height of the positioning stand so that the parabolic jamming antenna is approximately at the same level as the Tracking Radar antenna.

11. Position the parabolic jamming antenna behind and slightly beside the Radar Jamming Pod Trainer, as shown in Figure 1-36. Manually orient the parabolic jamming antenna axis toward the shaft of the Rotating-Antenna Pedestal.

Remove the 50-Ω load connected to the COMPLEMENTARY RF OUTPUT of the Radar Jamming Pod Trainer.

Using a 75-cm SMA cable, make a connection between the SMA female connector (RF INPUT) on the antenna positioning stand adapter, and the COMPLEMENTARY RF OUTPUT of the Radar Jamming Pod Trainer.

12. Turn on the Power Supply of the Radar Jamming Pod Trainer. Turn the Radar Jamming Pod Trainer on. Note that the Radar Jamming Pod Trainer status indicates that the Repeater is on.

Turn the repeater of the Radar Jamming Pod Trainer off by making the following settings on the remote controller:

- Noise ................................. Off
- AM/Blinking .............................. Off
- Repeater ................................. Off
- RGPO .................................. Off
- False Targets (FT) ................. Off

Verify that the Radar Jamming Pod Trainer status, indicated on its rear panel, shows that no jamming signal is being transmitted.
Antennas in EW: Sidelobe Jamming and Space Discrimination

13. Select the SCAN mode of the Tracking Radar to make the antenna rotate.

On the Radar Transmitter, depress the RF POWER push button. The RF POWER ON LED should start to flash on and off. This indicates that RF power is being radiated by the Dual Feed Parabolic Antenna. Target blips should appear on the Radar Display (PPI display) of the Tracking Radar.

Notice that each target displayed on the Radar Display appears as two adjacent blips and is segmented. This is normal and due to the antenna lobe switching performed by the Tracking Radar.

In LVRTS, set the Lobe Control Rate of the Tracking Radar to Off (Right) to disable antenna lobe switching. Notice that the targets are displayed normally on the Radar Display.

14. While observing the Radar Display, adjust the Gain of the MTI Processor of the Tracking Radar so that the cylinder target echo signal is clearly visible but not immersed in clutter.

Consider that the cylinder target represents a low-RCS platform infiltrating the weapon-intercept range of a fire-control radar in surveillance (search) mode. The Radar Jamming Pod Trainer when transmitting via the parabolic jamming antenna can be viewed as a support noise jamming platform in a stand-off position.

15. Using the remote controller, make the following adjustments to the Radar Jamming Pod Trainer:

- Noise: On
- Frequency: 10.0 GHz
- Frequency Bandwidth: 1.0 GHz
- Frequency Modulation: Random
- Attenuation 1: 0 dB
- Attenuation 2: 0 dB
- AM/Blinking: On
- Modulation Frequency: External
- Repeater: Off
- RGPO: Off
- False Targets (FT): Off

The Radar Jamming Pod Trainer VCO is set to an operating frequency of 10.0 GHz, the same frequency as that of the Tracking Radar. The Radar Jamming Pod Trainer is transmitting a noise jamming signal through the parabolic jamming antenna which is connected to its COMPLEMENTARY RF OUTPUT, with sufficient power to introduce noise into some of the radar antenna’s sidelobes.

Note: If noise does not cover several angular sectors on the Radar Display, make sure that the MTI Processor Gain is properly adjusted. Also make sure that the parabolic jamming antenna is at the correct height and aligned with the shaft of the Rotating-Antenna Pedestal.
Observe the Radar Display and briefly describe how sidelobe noise jamming is different from mainlobe noise jamming.

Can the cylinder target be detected?

☐ Yes  ☐ No

16. While observing the O-Scope Display, use the remote controller to turn the Radar Jamming Pod Trainer AM/BLINKING off. This redirects the RF jamming signal of the Radar Jamming Pod Trainer toward the transmit horn antenna instead of having it sent to the COMPLEMENTARY RF OUTPUT and transmitted through the parabolic jamming antenna.

What is the effect of the sidelobe jamming produced on the Radar Display?

Briefly describe how using the transmit horn antenna on the Radar Jamming Pod Trainer, instead of the parabolic jamming antenna, has had an effect on the level of noise injected into the radar receiver.

17. Using the remote controller, turn the Radar Jamming Pod Trainer AM/BLINKING on. This redirects the RF jamming signal of the Radar Jamming Pod Trainer toward the COMPLEMENTARY RF OUTPUT for transmission through the parabolic jamming antenna.

18. Note that the Radar Jamming Pod Trainer Noise Attenuation is equal to 0 dB.
Using the remote controller, slowly increase the Radar Jamming Pod Trainer Noise Attenuation 1 dB at a time until there is only a narrow jamming strobe on the Radar Display, as shown in Figure 1-37.

Figure 1-37. A narrow jamming strobe on the Radar Display.

19. The difference in the radiated noise jamming signal power ($\Delta P$) used by the Radar Jamming Pod Trainer to conduct sidelobe noise jamming and mainlobe noise jamming is proportional to the difference between the current and previous attenuation values. Record this difference in the following blank space.

$$\Delta P = \boxed{\ldots} \text{ dB}$$

What does $\Delta P$ imply about the average signal response of the radar antenna’s sidelobes?

__________________________________________________________________________________________
Antennas in EW: Sidelobe Jamming and Space Discrimination

**Sidelobe Jamming and TOJ**

- **20.** Select the MANUAL mode of the Tracking Radar to stop antenna rotation. Lock the Tracking Radar onto the echo signal of the cylinder target.

- **21.** On the Target Controller, make sure that the X- and Y-axis SPEED controls are in the MINimum position, then make the following settings:

  ```
  MODE ........................................... SPEED
  DISPLAY MODE .............................. SPEED
  ```

  Set the Y-axis SPEED control so that the target speed is equal to approximately 10 cm/s.

  You should observe that the Tracking Radar is automatically tracking the cylinder target in both range and angle.

- **22.** Using the remote controller, slowly decrease the Radar Jamming Pod Trainer Noise Attenuation 1 dB at a time, while observing the O-Scope Display.

  Note that at a certain point, sufficient noise jamming signal power is inserted through the radar antenna sidelobes to disable the Tracking Radar target lock.

  Continue lowering the Radar Jamming Pod Trainer Noise Attenuation until it is at its minimum value (0 dB).

- **23.** Enable the track-on-jamming mode of the Tracking Radar by performing the following manipulations:

  I. On the Radar Transmitter, disconnect the BNC-connector cable from the TRIGGER INPUT of the PULSE GENERATOR. This disables radar pulse transmission, however reception is maintained.

  II. In LVRTS, set the Range Lock Disable to On. This disables automatic range tracking.

  III. Orient the axis of the radar antenna toward the cylinder target. Remember that the cylinder target has the role of the infiltrating platform. Lock the Tracking Radar onto noise jamming.

  Is the Tracking Radar’s antenna pointing toward the cylinder target (infiltrating platform)?

    - Yes
    - No

  Move the stand-off jamming antenna sideways while keeping it pointed toward the shaft of the Rotating-Antenna Pedestal.
Antennas in EW: Sidelobe Jamming and Space Discrimination

Is track-on-jamming an effective countermeasure to sidelobe noise jamming? Briefly explain.

□ 24. Turn off the Tracking Radar and the Radar Jamming Pod Trainer. Disconnect all cables and remove all accessories.

CONCLUSION

Antennas in electronic warfare must be the first component of a radar system to be considered for incorporation of electronic protection measures. An antenna must incorporate space discrimination techniques to provide the radar with the capability of discriminating between signals input through its radar antenna sidelobes and its antenna mainlobe.

You demonstrated that when effective sidelobe noise jamming is conducted against an acquisition (search) radar, it reduces the radar’s ability of detecting low-RCS targets, no matter what their bearing. You showed that sidelobe noise jamming can disable a tracking radar’s target lock. You also demonstrated that the track-on-jamming capability of certain tracking radars is ineffective against sidelobe noise jamming.

You showed that a stand-off jamming platform requires a high-gain antenna and a strong noise jamming signal to penetrate effectively a radar antenna’s sidelobes.

REVIEW QUESTIONS

1. From the point-of-view of a radar operator, how does sidelobe noise jamming differ from mainlobe noise jamming?

2. Briefly explain antenna space discrimination.
Antennas in EW: Sidelobe Jamming
and Space Discrimination

3. Why is it important for an antenna to have a low sidelobe signal response?

4. Why is sidelobe noise jamming, as opposed to mainlobe noise jamming, the preferred electronic attack against weapon fire-control radars in the denial of target range and bearing data?

5. Briefly explain the difference between sidelobe cancellation and sidelobe blanking.
Sample Exercise

Extracted from

The Phased Array Antenna
Familiarization with the Phased Array Antenna

EXERCISE OBJECTIVE

When you have completed this exercise, you will be able to set up and operate the Phased Array Antenna and the Phased Array Antenna Controller. You will be able to observe the target echoes on the Radar Display of the LVRTS software.

DISCUSSION

A PAA uses electronically controlled phase shifts, rather than a mechanical scanning mechanism, to steer the radar beam. PAAs are therefore much simpler mechanically than conventional radar antennas. They are also lighter and require less maintenance. They can be used where it would be impractical to have a mechanically rotated antenna, as in aircraft or satellites. Since there are no moving parts, they perform agile and inertia-free beam steering, allowing target motion to be followed in near real time. In addition, PAAs can be designed to scan in both azimuth and elevation. They are not suitable for all applications, however, as the maximum scan angle is much less than that of a rotating antenna.

The Lab-Volt Phased Array Antenna is designed to be mounted on a support installed on the Rotating-Antenna Pedestal. This allows the PAA to be turned to the right or the left by hand (the motor in the Rotating-Antenna Pedestal is never used to turn the PAA). All connections and test points are available at the back of the PAA. There are no controls on the PAA itself. A plexiglass access door, located on top of the Phased Array Antenna case, provides access to the Rotman lens.

The PAA is controlled by the Phased Array Antenna Controller. This module has controls for SCAN MODE, BEAM SEQUENCE and DISPLAY MODE. The three-digit DISPLAY indicates the beam number, the beam position in degrees, or the scan speed, depending on the current DISPLAY MODE. The controller also has two POSITION/SPEED buttons (+ and −) that are used to change the active beam or the scan speed, depending on the SCAN MODE. The controls are explained in Table 1-1.

A PSEUDO-RANDOM beam sequence is sometimes used in military applications as it prevents pulse trains from being detected periodically by an opponent. The EVEN sequence is provided to allow visualizing the beam pattern on the PPI display.
**Table 1-1. Phased Array Antenna Controller controls.**

<table>
<thead>
<tr>
<th>SCAN MODE</th>
<th>MANUAL</th>
<th>CONTINUOUS</th>
<th>PRF LOCKED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No scanning is performed. Only one beam, selected using the POSITION/SPEED buttons, is active.</td>
<td>Beams are scanned according to selected BEAM SEQUENCE. Scan speed is selected using the POSITION/SPEED buttons.</td>
<td>Beams are scanned according to selected BEAM SEQUENCE. Scan speed is not variable as it is locked to the PRF.</td>
</tr>
<tr>
<td>BEAM SEQUENCE</td>
<td>INCREMENTAL</td>
<td>PSEUDO-RANDOM</td>
<td>EVEN</td>
</tr>
<tr>
<td></td>
<td>All beams are scanned consecutively.</td>
<td>All beams are scanned in pseudo-random order.</td>
<td>Only even-numbered beams are scanned.</td>
</tr>
<tr>
<td>DISPLAY MODE</td>
<td>BEAM NUMBER</td>
<td>POSITION</td>
<td>SPEED</td>
</tr>
<tr>
<td></td>
<td>DISPLAY shows active beam number.</td>
<td>DISPLAY shows beam position in degrees.</td>
<td>Display shows scan speed in SCAN/min.</td>
</tr>
</tbody>
</table>

**Procedure Summary**

First, you will set up the Radar Training System. Then you will make the necessary settings in order to clearly see the target reflections on the Radar Display. Using the Target Controller and the target table, you will set the targets in motion. On the Phased Array Antenna Controller, you will vary the scan speed and observe the results on the display. You will also use the other controls on the Phased Array Antenna Controller and observe their effect.

**PROCEDURE**

**Set-up and calibration**

1. Before beginning this exercise, the main elements of the Radar Training System (the antenna, the target table and the training modules) must be set up as shown in Appendix A.
   
   Turn on all modules and make sure the POWER ON LEDs are lit.

2. Make sure that the LVRTS software has been started and that the Radar Training System has been connected, adjusted and calibrated according to the instructions in Appendix B. Then set the RF POWER switch on the Radar Transmitter to the STANDBY position.
   
   **Note:** DO NOT connect the power cable to the MOTOR POWER INPUT of the Rotating-Antenna Pedestal.

"Familiarization with the Phased Array Antenna"
Familiarization with the Phased Array Antenna

**Operation and adjustments**

3. Install the two-target adapter on the target table with two half-cylinder targets (see Figure 1-1). Make sure that distance \( D_y \) is close to 2 m. Distance \( D_x \) should be approximately 75 cm.

![Figure 1-1. Phased Array Antenna Setup.](image)
Familiarization with the Phased Array Antenna

4. On the Radar Transmitter, turn the RF POWER on.

5. On the Phased Array Antenna Controller, set the SCAN MODE to CONTINUOUS, the BEAM SEQUENCE to INCREMENTAL, and the DISPLAY MODE to SPEED. Use the POSITION/SPEED buttons to set the scan speed to 54 SCAN/min.

6. On the Target Controller, set the MODE to TRAJECTORY. Then select the circular trajectory. Adjust the speed as desired.

7. Adjust the Gain as necessary in the System Settings in order to produce a fairly clear image of the two targets on the Radar Display. Figure 1-2 shows an example of what you might observe.

   **Note:** Because of internal reflections in the PAA, spurious echoes always appear at the beginning of the range, near the PAA. Adjust the gain so that these are kept to a reasonable extent.

8. On the target Controller, set the TRAJECTORY SPEED to MAX. On the Phased Array Antenna Controller, gradually increase the scan speed by pressing the POSITION/SPEED + button while watching the display. As the scan speed is increased, target movements become smoother on the Radar Display and target motion can be followed in near real time.

   **Note:** When the scan speed is 1080 SCAN/min, the DISPLAY alternately displays “10” and “80”.

   **Note:** The azimuth indicator on the Radar Display (the small triangle touching the circumference of the display area) accurately shows the PAA beam position when the scan speed is low, however its movement becomes erratic at high scan speeds. This is simply because the update speed of the display is less than the higher scan speeds. When the PAA is used, the antenna Speed, indicated at the bottom left of the display is not accurate. If you find these distracting when using the PAA, you can hide them by setting the Azimuth/Speed setting to Hide.
9. On the Target Controller, set the MODE to POSITION.

Make sure that Azimuth Indicator is visible on the Radar Display. On the Phased Array Antenna Controller, set the SCAN MODE to MANUAL and the DISPLAY MODE to BEAM NUMBER. Use the POSITION/SPEED + and − buttons to cycle through the beams. Observe the displayed beam numbers and how the azimuth indicator moves on the Radar Display.
How many beams does the PAA have and how are they numbered?

Set the DISPLAY MODE to POSITION and use the POSITION/SPEED + and – buttons to cycle through the beams. Note that the beam position is displayed with a precision of 1°.

10. On the Phased Array Antenna Controller, set the BEAM SEQUENCE to PSEUDO-RANDOM and the DISPLAY MODE to BEAM NUMBER. Use the POSITION/SPEED + and – buttons to manually cycle through the beams. Observe the displayed beam numbers and the azimuth indicator on the Radar Display.

Set the SCAN MODE to CONTINUOUS, the DISPLAY MODE to SPEED and select the slowest speed. Then set the DISPLAY MODE to BEAM NUMBER. Observe the displayed beam numbers and the azimuth indicator on the Radar Display.

Describe how the beams are scanned in the PSEUDO-RANDOM mode.

11. Set the SCAN MODE to CONTINUOUS and the BEAM SEQUENCE to EVEN.

Increase the Gain in the System Settings to 10 so that the beam pattern is visible on the Radar Display. If necessary, right-click on the display and select Clear > Display in the context-sensitive menu to clean up the display. The background noise and the high gain should make the even-numbered beams clearly visible.

**Note:** When the BEAM SEQUENCE is set to EVEN, the even numbered beams are scanned in a pseudo-random order. This is done for technical reasons in order to facilitate visualization of the beam pattern on the Radar Display.

12. On the Phased Array Antenna Controller, set the SCAN MODE to PRF LOCKED, the BEAM SEQUENCE to INCREMENTAL and the DISPLAY MODE to SPEED.

On the Radar Synchronizer / Antenna Controller, select each PRF in Table 1-2 and record the scan speed displayed on the Phased Array Antenna Controller. Note that the POSITION/SPEED buttons have no effect in the PRF LOCKED mode.
Familiarization with the Phased Array Antenna

For each PRF in Table 1-2, use the scan speed to determine the number of PRF periods that elapse per scan and per beam. Enter your results in the table.

<table>
<thead>
<tr>
<th>PRF (Hz)</th>
<th>Scan Speed (SCAN/min)</th>
<th>PRF Periods per Scan (16 beams)</th>
<th>PRF Periods per Beam</th>
</tr>
</thead>
<tbody>
<tr>
<td>288</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>216</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>144</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1-2. Scanning in PRF LOCKED mode.

In the PRF LOCKED mode, is there always a whole number of PRF periods per beam?

☐ 13. On the Radar Transmitter, make sure that the RF POWER switch is in the STANDBY position. The RF POWER STANDBY LED should be lit. If no one else will be using the system, turn off all equipment.

CONCLUSION

In this exercise, you became familiar with the Phased Array Antenna and with the Phased Array Antenna Controller. You also observed the effect of the scan speed on the PPI display.

REVIEW QUESTIONS

1. What are some of the advantages and disadvantages of a PAA over a conventional radar antenna?

2. What is the advantage of using a pseudo-random scan sequence?
3. What is the effect of increasing the scan speed?
Other Sample
Extracted from
Principles of Radar Systems
1. In pulsed radar, the usual waveform of the transmitted radar signal is
   a. a pulsed sine wave.
   b. a continuous sine wave.
   c. a triangle wave.
   d. none of the above.

2. The position transducer in an antenna driving system
   a. sends a signal from the antenna to the rest of the radar system.
   b. indicates the direction the antenna is pointing.
   c. is required to correctly display targets according to their directions.
   d. all of the above.

3. The antenna driving system may keep the antenna speed proportional to the PRF
   a. by automatically adjusting the PRF according to the measured instantaneous antenna speed.
   b. using a servo system to maintain the antenna speed constant.
   c. by alternating the direction of antenna movement.
   d. either a or b.

4. The rotary joint in an antenna system
   a. couples the microwaves between the rotating antenna and the fixed waveguide or cable.
   b. prevents the transmitted signal from passing directly to the receiver.
   c. facilitates maintenance of the radar antenna.
   d. all of the above.

5. The bearing of a target
   a. is the vertical direction of the target, expressed as an angle in the vertical plane from a reference direction.
   b. is the horizontal direction of the target, expressed as an angle in the horizontal plane from a reference direction.
   c. determines the strength of the echo signal.
   d. depends on the reflecting characteristics of the target.

6. The target range is represented on the PPI display
   a. by the distance of the blip from the origin.
   b. by the angle of the blip from a reference angle on the screen.
   c. by the brightness of the blip.
   d. by the colour of the blip.
7. The target bearing is represented on the PPI display
   a. by the distance of the blip from the origin.
   b. by the angle of the blip from a reference angle on the screen.
   c. by the brightness of the blip.
   d. by the colour of the blip.

8. A radar receiver is said to be coherent when it
   a. detects both the power and frequency of the received signal.
   b. uses envelope detection to demodulate the received signal.
   c. detects both the amplitude and phase of the received signal.
   d. uses an RF amplifier in conjunction with an IF amplifier and a local oscillator.

9. The gain of the radar receiver
   a. does not affect the resolution of the PPI display.
   b. affects only the range resolution on the PPI display.
   c. affects only the angular resolution on the PPI display.
   d. must be adjusted for optimum range and angular resolution on the PPI display.

10. In a pulsed radar, increasing the width of the transmitted pulses of RF signal
    a. increases the transmitted peak power but decreases the range resolution.
    b. increases the transmitted average power but decreases the range resolution.
    c. has no effect on both the transmitted average and peak powers but decreases the range resolution.
    d. increases the transmitted average power but decreases the maximum detection range.
Instructor Guide Sample
Extracted from
Radar Training System
Unit 1  Fundamentals of Pulsed Radars

Introductory information

This unit presents the fundamentals of pulsed radar, such as the range-delay relationship and the radar equation, a simplified block diagram of a typical pulsed radar system, as well as safety rules applicable to all radar systems. Students are reminded of these safety rules by notes in the Procedure of each exercise in this manual.

Exercise 1-1 deals with the operation of pulsed radar at the system level, and introduces the A-scope display. The pulsed radar that can be obtained with the Radar Training System is then described, and the differences between this system and typical pulsed radar systems are pointed out. The role of the Dual-Channel Sampler, in particular, is explained. Various population protection standards for microwave radiation are presented, and students compare these to the radiation levels in the Radar Training System. Although the radiation levels in the Radar Training System are not dangerous, the safety rules used in working with microwave equipment are presented so that students will be acquainted with the working habits that must be followed in a full-scale radar environment.

For this first exercise, the Procedure provides very detailed descriptions of all manipulations. It also provides explanations on the role and operation of the various controls and displays of the Radar Training System used during this exercise. Fixed target blips, moving target blips, and the parasitic blips due to the system imperfections are observed on the A-scope display. The pulsed radar system is then used to detect various metallic objects in the laboratory classroom to increase the student's familiarity with the system. Appendix A in the student manual provides all the information required for setting up the Radar Training System.

The relationship between the target range and the round-trip transit time is explained in Exercise 1-2. This exercise also explains the concepts of range resolution and pulse length, and illustrates the relationship between them. The exercise shows that the range of targets and the round-trip transit time related to targets can be measured on the A-scope display. It also shows the effect of target separation and pulse width on the resolution of blips observed on the A-scope display.

As was the case for Exercise 1-1, the Procedure of this exercise provides explanations on the role and operation of the controls and displays of the Radar Training System that have not yet been used. The origin calibration of the A-scope display is carried out first, and then various observations on the range-delay relationship are performed using the A-scope display. The range resolution is measured and the effect of the pulse width on the range resolution is observed using the A-scope display. The origin calibration of the A-scope display could be introduced during a class period preceding the laboratory period for this exercise, since this subject is not dealt with in the discussion. Appendix B in the student manual provides a procedure for calibrating the A-scope display of the pulsed radar.
Exercise 1-3 presents the role of antennas in general, the role of the antenna in a pulsed radar system, and some types of radar antennas. It also presents antenna characteristics, such as the antenna fields, the radiation pattern, the directivity, the gain, and the angular resolution, and relates them to the antenna performance requirements of pulsed radar systems.

As was the case for the previous exercises, the Procedure of this exercise provides explanations on the role and operation of the controls and displays of the Radar Training System that have not yet been used. The radiation pattern, in the horizontal plane, is determined by receiving an FM-CW RF signal with the Radar Antenna. The angular resolution of the Radar Antenna is calculated using the 3-dB beamwidth determined from its radiation pattern. This result is then confirmed using the A-scope display of the pulsed radar. The FM-CW radar principles could be introduced in a class period preceding the laboratory period for this exercise since an FM-CW RF signal is used to determine the radiation pattern of the Radar Antenna. FM-CW radar is presented in Unit 3 of Volume 1.

The radar equation is derived in Exercise 1-4 to show the relationship between the various parameters which affect the operation of the radar. The relationship between the range and the power of the received echo signal is especially highlighted.

The exercise Procedure begins with the verification of the relationship between the maximum range and the transmitted power. The relationships between the power of the received echo signal and the target range, the target radar cross section, and the antenna parameters are then verified. The target radar cross section could be introduced more extensively than in the Discussion of this exercise, in a class period preceding the laboratory period for this exercise. Appendix C in the student manual provides details on the target radar cross section.
Exercise 1-1  Basic Principles of Pulsed Radars

Instructional plan

A. Explain the principle of operation of a pulsed radar system:

1. A pulsed RF signal is radiated by an antenna.

2. Part of the pulsed RF signal strikes a target, and is reflected back to the antenna which captures it.

3. The received pulsed RF echo signal is demodulated and converted into a video signal to be displayed.

B. Describe the role of each element in the simplified block diagram of a typical pulsed radar:

1. The transmitter produces a high-power pulsed RF signal. It may consist of a low-power RF oscillator, a modulator, and an RF amplifier connected in series. It may also consist of a modulator supplying high-power dc pulses to a high-power RF oscillator.

2. The pulse generator produces very short pulses that control the modulator in the transmitter.

3. The duplexer allows the transmitter and receiver to share the same antenna. In low-power radar systems, a circulator may act as a duplexer.

4. The antenna is the transition device between waveguides or transmission lines and free space. It is designed to radiate and receive RF signals within a narrow beam, thus allowing the direction of targets to be determined.

5. The antenna driving system is used to orient the antenna. The movement of the antenna depends on the application for which the radar system is intended.

6. The receiver demodulates the received pulsed RF echo signal.

7. In many systems, the demodulated signal is passed through a signal processor to reduce the power of noise, interference, and unwanted echoes, and to provide various automatic detection functions.

8. The indicator of any radar system conveys target information to the operator. The indicator of most pulsed radar systems consists of a CRT display on which each target appears as a deflection or intensity modulation of the CRT beam (blip).

9. The synchronizer produces a train of pulses that are used to trigger the pulse generator and reset the indicator. The repetition frequency of these pulses is called the PRF.
C. Present a very common deflection-modulated display, the A-scope display:

1. In the A-scope display, the vertical deflection of the CRT beam is proportional to the target echo signal strength, and the horizontal deflection of the CRT beam is proportional to the target range.

2. A fixed target appears as a fixed amplitude deflection on the A-scope display. The amplitude and polarity of the deflection depend on the phase of the received echo signal.

3. A moving target appears as a varying amplitude deflection on the A-scope display since the phase of the received echo signal is varying in this case.

4. In pulsed radar, the target range is determined by the time elapsed between the transmission of an RF signal pulse and the reception of the echo signal (round-trip transit time).

5. Since the horizontal deflection of the CRT beam begins at the time an RF signal pulse is transmitted, the horizontal position of the beam is proportional to the round-trip transit time, and therefore to the target range.

D. Present the pulsed radar that can be obtained with the Radar Training System:

1. This pulsed radar system resembles typical pulsed radar systems, although some design differences can be noted.

2. First, the pulse generator is included in the Radar Transmitter. The radar transmitter has no RF amplifier since it operates at very low power.

3. The antenna driving system consists of the Antenna Controller, the Antenna Motor Driver, and the Rotating-Antenna Pedestal. A circulator in the Rotating-Antenna Pedestal acts as a duplexer.

4. The most noticeable difference between a typical pulsed radar system and the Radar Training System is the use of a sampler after the Radar Receiver.

5. The Dual-Channel Sampler allows the Radar Training System to operate over much shorter ranges than conventional pulsed radar systems.

6. The Dual-Channel Sampler is required to reduce the complexity and cost of the circuitry required to process the very short pulse signal from the receiver.

See Appendix D in the student manual for more details on the reasons for using a sampler in the Radar Training System.

E. Briefly explain the A-scope display that is obtained with the Dual-Channel Sampler:
1. The Dual-Channel Sampler samples only a part of the demodulated echo signal received after the transmission of each RF signal pulse.

2. The RANGE SPAN selector determines the length of the part of this signal that is sampled, and the ORIGIN control determines the instant at which sampling begins.

See Appendix D in the student manual for more details on the internal operation of the Dual-Channel Sampler.

F. Present the safety rules which apply to full-scale radar systems:

1. Microwaves can be dangerous at sufficiently high levels and for sufficiently long exposure times.

2. There are several safety standards intended to protect people working with microwaves. These are usually expressed in units of power density (Watt per unit area) at a given frequency.

3. The power density of a microwave beam is equal to the average power radiated, divided by the area of the beam.

4. The basic safety rule to be followed when working with full-scale radar systems is to avoid exposition to dangerous microwave radiation levels.
Exercise 1-2  The Range-Delay Relationship

Instructional plan

A. Explain the range formula:

1. The pulsed RF signal produced by the radar transmitter, like all EM waves, travels at the speed of light $c$.

2. The time the pulsed RF signal takes to travel from the radar to the target and back to the radar, is the round-trip transit time $T_R$.

3. The distance the pulsed RF signal travels from the radar to the target and back to the radar, is equal to twice the target range $R$.

4. Therefore,

$$ R = \frac{cT_R}{2} $$

B. Explain the range resolution and pulse length concepts:

1. The range resolution is the ability of a pulsed radar to resolve closely spaced targets along the same line of sight.

2. The range resolution is mostly determined by the duration, or pulse width $\tau$, of the RF signal pulses transmitted by the radar.

3. The distance related to the pulse width is called the pulse length

$$ L_p = \tau c $$

4. Theoretically, the range resolution is equal to one half the pulse length.

5. In practice, however, due to the performance limitations of various circuits and the presence of noise, the range separation required for resolving targets must be substantially greater than one half the pulse length.

6. The range resolution of a pulsed radar deteriorates as the pulse length increases.

C. Relate the range formula, the range resolution, and the pulse length to the A-scope display:

1. The A-scope display shows the amplitude of target echoes versus range for some fixed direction.

2. Since the target range is proportional to the round-trip transit time, the X axis of the A-scope display could be calibrated in either range or transit time.
3. As the range separation between targets decreases, the space between the corresponding blips on the A-scope display also decreases.

4. As the pulse length increases, the blips on the A-scope display become wider.

5. When the range separation between targets is smaller than one half the pulse length, the corresponding blips on the A-scope display merge to form a single blip.
Exercise 1-3  Radar Antennas

Instructional plan

A. Explain the role of antennas in general, and the role of the antenna in a pulsed radar system:

1. The role of any antenna is to radiate the signal which feeds it and/or capture the signal which strikes it.

2. In most pulsed radar systems, the antenna concentrates the pulsed RF signal into a narrow beam pointing in the desired direction, and captures echo signals from the desired direction only.

B. Describe some types of basic antennas:

1. The isotropic antenna is a hypothetical antenna which radiates equally in all directions.

2. The parabolic-reflector antenna consists of a parabola and a source of energy called the feed. The feed is located at the focus of the parabola, and illuminates the parabola.

3. Due to the characteristics of the parabola, any ray from the feed is reflected by the parabola in a direction parallel to its axis.

4. One disadvantage of the basic parabolic-reflector antenna is that the feed blocks some of the reflected signal. This can be remedied by using an offset feed.

5. There are other types of directional antennas, such as the Cassegrain and phased-array antennas.

C. Explain the antenna characteristics that are closely related to the performance of pulsed radar systems:

1. The area in front of the antenna is divided into three regions called the near field, the Fresnel field, and the Fraunhofer or far field.

2. Radar antennas usually operate in the far-field region where the antenna characteristics are independent of range.

3. The radiation pattern is a three-dimensional graph showing the energy radiated or received by the antenna as a function of direction.

4. A radiation pattern in one plane only is often sufficient to characterize an antenna. For this reason, it usually consists of a two-dimensional graph.
5. The radiation pattern is usually determined by measuring the received signal level from another source when the antenna is pointing in various directions.

6. This measurement is usually carried out in an anechoic chamber to prevent undesired reflections from disturbing the result.

7. The radiation pattern of an isotropic antenna shows that the radiation is uniform in all directions, whereas that of a directional antenna shows that the radiation is concentrated in a main lobe pointing in one direction.

8. The radiation pattern of a directional antenna also contains sideno ws, which represents the radiation in other directions.

9. Sideno ws are undesired since the role of the antenna in a pulsed radar is to radiate and receive signal in one direction at a time.

10. The 3-dB beamwidth of the antenna is a measure of the antenna directivity.

11. The directivity $G_D$ is the capability of a directional antenna to concentrate energy in one particular direction. It is calculated by dividing the maximum radiation intensity by the average radiation intensity.

12. The power gain $G$ of a directional antenna is equal to the directivity $G_D$ multiplied by the efficiency factor of the antenna.

13. The effective aperture $A_e$ of a directional antenna is the size of the antenna's frontal area expressed in terms of the wavelength. It is related to the power gain by the following equation:

$$ G = \frac{4\pi \cdot A_e}{\lambda^2} $$

14. The angular resolution is the ability of a directional antenna to distinguish between targets located in different directions. It is usually 1 to 1.5 times the 3-dB beamwidth of the antenna.
Exercise 1-4  The Radar Equation

Instructional plan

A. Present the most important factors affecting the power of the received echo signal:

1. One of the most important characteristic of a radar system is the maximum detection range. It is ultimately determined by the S/N ratio required by the receiver.

2. The received echo signal power is proportional to the average power of the transmitter.

3. The received echo signal power decreases rapidly as the target range increases. This is mainly due to the reduction of the power density of the transmitted EM waves as they spread.

4. The received echo signal power is proportional to the antenna gain and antenna effective aperture.

5. The radar cross section is a measure of the size of a target as seen by the radar. The greater this size, the greater the transmitted power intercepted by the target, and the greater the received echo signal power.

B. Derive the radar equation:

1. The power density at a distance $R$ from an isotropic antenna is equal to the transmitted power $P_t$ divided by the surface area of a sphere of radius $R$ (equation (1-8) in the student manual).

2. The power density at a distance $R$ from a directive antenna is equal to the product of the transmitted power $P_t$ and antenna power gain $G$, divided by the surface area of a sphere of radius $R$ (equation (1-9) in the student manual).

3. The power reflected back towards the radar by a target located at a distance $R$ from the antenna is equal to the power density at the target times the radar cross section $\sigma$ of the target (equation (1-10) in the student manual).

4. The power density of the signal reaching the radar antenna is equal to the power reflected back towards the radar by the target divided by $4\pi R^2$ (equation (1-11) in the student manual).

5. The power $P_r$ of the signal received by the radar antenna is equal to the power density at the antenna times its effective area $A_e$ (equation (1-12) in the student manual).

6. This form of the radar equation shows that the power of the received echo signal is inversely proportional to the fourth power of the range $R$. 


7. The substitution of $P_t$ by $S_{\text{min}}$ and $R$ by $R_{\text{max}}$ in equation (1-12), and a rearrangement of terms, allows the classical form of the radar equation to be obtained (equation (1-13) in the student manual).

C. Explain the use of the radar equation:

1. The classical form of the radar equation can be used to estimate the maximum range at which a target can be detected, although it neglects many losses such as atmospheric absorption, system degradation in the field, etc.

2. The radar equation shows the relationship between the various parameters which affect the operation of the radar.

3. When the same antenna is used for both transmission and reception, it is convenient to express the antenna effective aperture in terms of gain using equation (1-14) in the student manual.

Demonstrations

- Observation of the output signals of the Dual-Channel Sampler

1. Set up and calibrate the pulsed radar with the A-scope display, and then place the target at a range of approximately 1 m.

2. Make the appropriate settings on the oscilloscope to simultaneously observe the I- or Q-CHANNEL SAMPLED OUTPUT and the A-SCOPE TIME BASE OUTPUT signals.

3. Observe that the SAMPLED OUTPUT signals are repetitive pulse signals, and that the A-SCOPE TIME BASE OUTPUT signal is a ramp signal.

4. Select various PRFs on the Radar Synchronizer. Observe that the repetition frequency of the SAMPLED OUTPUT signals and A-SCOPE TIME BASE OUTPUT signal is equal to the PRF selected.

5. Vary the origin of the observation range. Observe that the pulses in the SAMPLED OUTPUT signals move left when the origin is moved away from the Radar Antenna (ORIGIN control turned clockwise) and vice versa.

6. Select the 7.2-m range span and set the origin of the observation range so that the parasitic blips affecting the pulsed radar are near the origin.

7. Successively select the 3.6- and 1.8-m range spans. Observe that the SAMPLED OUTPUT signals represent a smaller portion of the radar echo signal as the range span decreases.
• Observation of the reciprocity of antenna characteristics

1. Install the horn on the target table mast and orient it so that it points towards the Radar Antenna.

2. Connect the modules as shown in Figure 3-18 of the student manual. This figure shows an FM-CW radar system in which the Radar Antenna is used in transmission and the horn in reception.

3. Set the modulating frequency \( f_m \) and frequency deviation \( \Delta f \) to 600 Hz and 150 MHz, respectively (1.2-V p-p, 600-Hz triangular-wave signal at the CONTROL VOLTAGE MONITOR OUTPUT of the Radar Transmitter).

4. Set the RF power on, and then vary the position of the Radar Antenna so that it scans the horn. Observe that the signal at the FM-CW OUTPUT is maximal when the Radar Antenna is aligned with the horn because the Radar Antenna directs energy in one direction only.

5. Using the same set-up, perform a similar observation with the Radar Antenna used in reception and the horn in transmission. In this case, observe that the signal at the FM-CW OUTPUT is maximal when the Radar Antenna is aligned with the horn because the Radar Antenna receives energy from one direction only. This shows the reciprocity of antenna characteristics.

**Presentation Aids**

1. Review the New Terms after the unit DISCUSSION OF FUNDAMENTALS.

2. Explain that the microwaves used in radar are similar to those used in microwave ovens. To protect the microwave oven users against exposition to dangerous levels of radiation, all such ovens are provided with a security mechanism that automatically turns off the microwave source when the oven door is opened. This highlights the need to observe the basic safety rules that apply when working in a radar environment.

3. Compare the radar echo signal to the echo you hear when shouting in a vast closed area, such as a valley encircled by mountains.

4. Review the properties of parabolas.