



**NAVAL AIR TRAINING COMMAND**

**NAS CORPUS CHRISTI, TEXAS**

**CNATRA P-820 (New 12-94) PAT**

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## **RADAR THEORY**

### **GROUND MAPPING/INTERCEPT FUNDAMENTALS**



### **STRIKE/STRIKE FIGHTER**

**1994**



DEPARTMENT OF THE NAVY

CHIEF OF NAVAL AIR TRAINING  
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**20 DEC 1994**

1. CNATRA P-820 (New 12-94) PAT, "Radar Theory Ground Mapping/Intercept Fundamentals" is issued for information, standardization of instruction, and guidance of instructors and students in the Naval Air Training Command.
2. This Flight Training Instruction will be used to support the Strike Fighter and Strike, Theory and Scope Interpretation and Air Intercept Procedures.
3. Recommendations for changes shall be submitted to Chief of Naval Air Training via the appropriate CNATRA Stage Manager and Course Curriculum Model Manager. Recommended changes, not of an urgent nature, will be held until the next curriculum conference.
4. CNATRA P-819B, Radar Systems TN and OJN (08-92), P-819C Radar Theory and Scope Interpretation (11-91), and P-824 Air Intercept Radar (09-91) are hereby canceled and superseded.

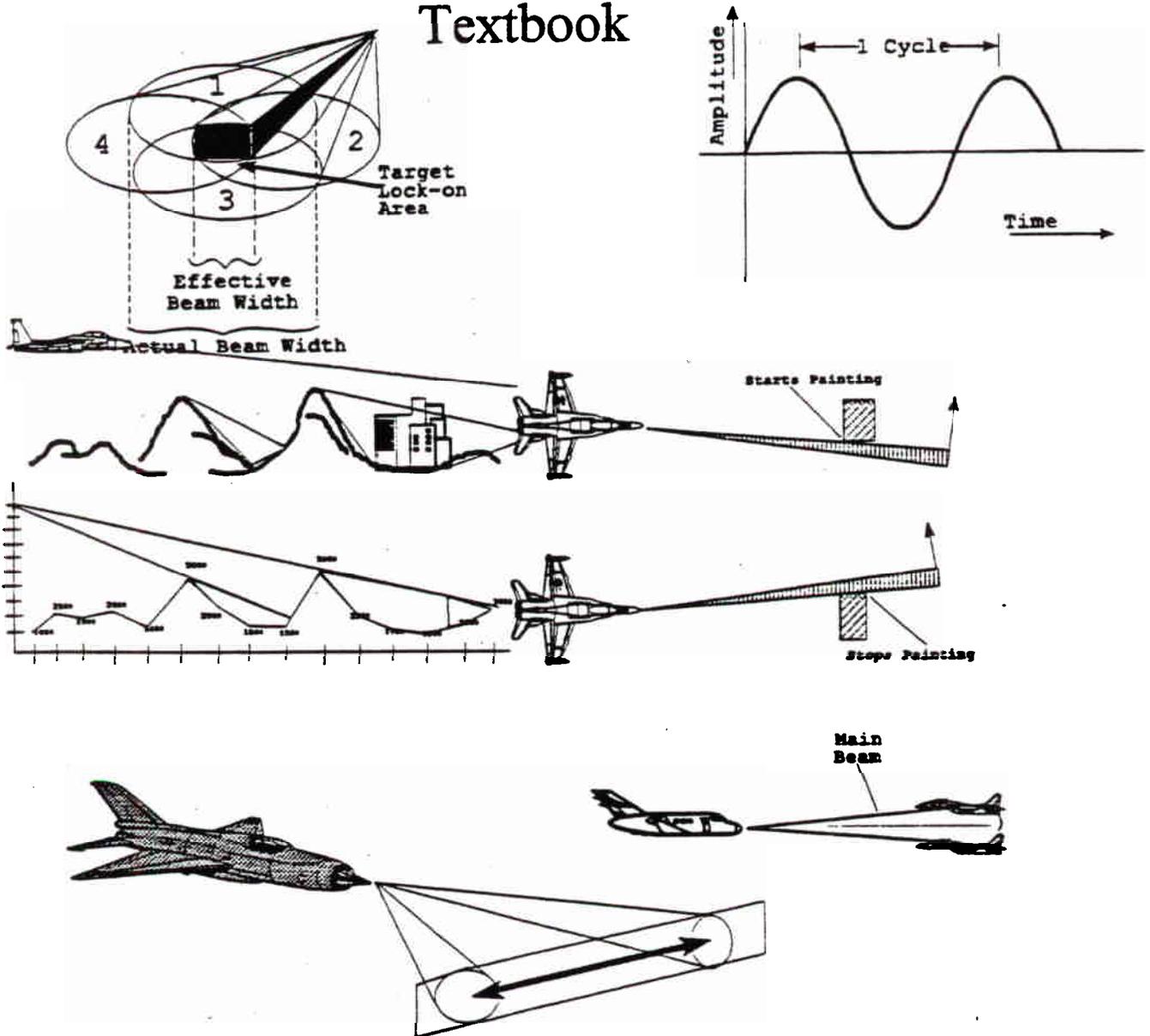
A handwritten signature in black ink, appearing to read "M. W. Smith", is positioned above the typed name.

M. W. SMITH  
Assistant Chief of Staff for  
Training and Operations

Distribution:  
CNATRA (10)  
COMTRAWING SIX (200)

# VT-86 Strike & Strike Fighter

## Radar Theory Ground Mapping/Intercept Fundamentals Textbook





## **TRAINEE UNIT GUIDE**

### **GROUND MAPPING/AIRBORNE INTERCEPT RADAR**

#### **OVERVIEW**

This course book is designed to guide you through Radar Theory and Operation training in a logical manner. It is divided into three main units of instruction that will prepare you to operate a tactical radar in ground mapping and air-to-air modes. Some of the learning objectives listed below will be accomplished in simulator and airborne environments, using this text for establishing the appropriate building blocks.

#### **SCOPE**

This course will familiarize you with the APG-66NT Ground Mapping and Air-to-Air Intercept Radars. The first unit presents the fundamentals of radar principles and theory -- instrumental for successful radar operation, calibration and scope interpretation. Proper manipulation and interpretation of the radar is necessary for completion of the curriculum at VT-86 and are essential to becoming a successful and competent NFO or WSO. After completion of this course you will be prepared to operate the APG-66NT radar during the synthetic and airborne training periods.

#### **TERMINAL LEARNING OBJECTIVES**

Operate a tactical radar weapons system effectively, manipulating the ground mapping and the air-to-air radar modes; standards are prescribed in learning objectives A.1 through A.10.

#### **LEARNING OBJECTIVES**

##### **Strike and Strike/Fighter Curriculum**

A.1 Explain the transmission characteristics affecting pulsed radar systems.

A.2 Interpret ground mapping radar display to obtain navigational information.

A.3 Explain the initialization of the Inertial Navigation Unit (INU) and warm-up of the radar without error.

A.4 Identify and state purposes of radar controls without error.

A.5 Adjust the radar controls in order to obtain best navigational display/information during trainer periods and flight evolutions 80% of the time.

A.6 Recognize and describe the imagery displayed in the ground mapping radar to 80% accuracy.

#### Strike/Fighter Curriculum Additional Objectives

A.7 Differentiate assigned bogey image from clutter, or the altitude line in search and track modes, during trainer periods and flight evolutions 80% of the time.

A.8 Explain and perform BIT tests on the radar and assess operational status of the system.

A.9 Maintain antenna beam centered on the radar image (proper spotlight) or initiate system lockup as required to maintain contact with the aircraft-radar image in an air-to-air intercept during trainer periods and flight evolutions 80% of the time.

A.10 Illustrate the usage of the radar display to ascertain the bogey's position relative to the interceptor aircraft during trainer periods and flight evolutions to the accuracy of +/- 2 degrees in azimuth, 1 degree in elevation, 50 knots of overtake, and 1/2 mile in range.

#### REFERENCES

1. T-39 NATOPS, Section VIII (Weapons System)
2. Radar Fundamentals, Weapons System Course, TPS, Naval Air Test Center, NAS Patuxent River, MD
3. Airborne Radars, Hughes Aircraft, Sunnydale, CA

#### MODE OF INSTRUCTION

All units will be presented in a lecture format. You are expected to have read the applicable material before the beginning of class. Space for note taking is provided at the end of each unit.

# RADAR PRINCIPLES & THEORY

## UNIT 1: RADAR THEORY

### Introduction

Radar is a primary active sensor used in operational warfighting units. It is incorporated in most tactical aircraft and tactical arenas. Radars vary considerably in size, composition, and performance depending upon their intended function and location, whether they are land based, shipboard, or airborne.

The mathematics and complex concepts of electromagnetic energy and circuitry are beyond the scope of this class. However, a basic understanding of the radar fundamentals, characteristics and limitations is essential to effectively operate the radar and analyze the displayed information.

### Uses of Radar

The term RADAR is an acronym for Radio Detection And Ranging. A radar is just what the name implies - a system that uses radio waves to detect and determine the range, bearing, and elevation of physical objects.

Radars have a myriad of uses available to the tactical aviator. Some of the more commonly used applications include:

- detecting and tracking of enemy ships
- detecting and tracking of enemy aircraft and missiles
- providing guidance for missiles
- allowing for navigation through adverse weather
- engaging airborne targets beyond visual range (BVR)
- providing aimpoint information for gunnery systems
- ensuring safe air travel via FAA control systems

The purpose of a radar system is to detect contacts of interest and determine their location and movement. Depending on how it is used, a radar system can be classified into one or more of the following six categories:

1) Early warning is used to detect enemy targets at long range, providing the greatest possible advanced warning. Such radar systems operate at relatively low frequencies to obtain these long range capabilities and require large power outputs. Positions reported by these systems are not exact, nor are they intended to be, since they are designed for early detection.

2) Surface search is used to scan the earth's surface for ships or ground targets. This type of radar system operates at higher frequencies than Early Warning systems and provides more accurate information. Ships also use surface search to aid in navigation, especially at night or in periods of reduced

visibility. Precise navigation is possible through the use of surface search radar with suitable reflective material placed in optimal positions (i.e. channel buoys with radar reflective materials).

3) Air Search is used to locate the position of aircraft and to determine their range, bearing and elevation. These radar systems are sometimes referred to as "3D radars" because of their three dimensional capability. They are used to direct fighter aircraft on an intercept course with enemy aircraft or to detect low flying aircraft intruding on airspace (e.g. drug runners in south Florida). This type of system operates at much higher frequencies and has shorter range than the previous two, but offers extremely accurate information about target location.

4) Airborne search radars are installed in numerous types of aircraft and must conform to stringent size and weight restrictions. These limitations result in limited range capabilities while still retaining high accuracy. Airborne search radar systems provide for air-to-air search, ground mapping, terrain avoidance, and radar navigation functions.

5) Fire control radar systems are primarily used to control the guidance of weapons. Such systems must provide very precise target location information for accurate guidance. They must also be capable of a very high degree of target resolution (i.e. distinguish two or more targets from one another at close proximity). These radar systems operate at frequencies higher than search radars because of the necessary precision guidance.

6) Identification radar is a special system used in conjunction with other types of radar systems. When activated, an identification pulse is transmitted to help identify a target. This is known as an "interrogation". If the target is equipped with a transponder, a reply is generated that is sent back to the originating system. Several codes are sent during this transmission. Modes 3 and C are used for traffic separation, modes 1, 2 and 4 are for military use. Mode 4 requires special encrypted equipment to identify a target's "IFF" (Identification Friend or Foe).

#### **Radar Terminology**

The following definitions are terms commonly used in radar discussions and operations. They should become part of your working vocabulary:

- a. Echo/Paint: an unmodified (i.e. "raw") radar return displayed on a scope.
- b. Contact: an echo on the scope thought to be the target's return signal.

- c. Clutter/Noise: unwanted echoes that are present on the scope. This could be from ground return, clouds, chaff, rain, etc.
- d. Beam: radar energy focused by an antenna that is transmitted out into space.
- e. Sidelobe: radar energy that is not part of the main beam; analogous to leakage from a water hose.
- f. Azimuth: angular distance from a reference point (usually the Aircraft Datum Line) in degrees.
- g. Signal to Noise ratio (S/N): a numeric measurement of contact return compared to clutter return. The higher the signal to noise ratio, the easier it is to see the contact in clutter and to track the contact.

### Radar Fundamentals

Radar energy is electromagnetic energy with the same properties as light: it travels at the speed of light, in straight line paths, and is reflected by physical objects. There is one important difference -- radar requires the existence of a radio source, light requires a light source. Radar equipment can readily determine the position of objects (targets) in space by transmitting this electromagnetic energy and processing the received energy reflected by those objects. Since metallic objects are the best reflectors of electromagnetic energy, ships, aircraft, and vertical structures provide strong echoes. Depending on the frequency used, rain storms and dense clouds also return echoes that can be readily detected by radar equipment. Lower frequencies are less apt to reflect echoes from weather and very high frequencies are absorbed by weather.

Several concepts must be mastered to understand the properties of radar. The relationships of wavelength, frequency, and their associated math must be understood.

### Speed of Electromagnetic Energy

Electromagnetic waves travel at the speed of light (C). They travel in a straight line path. The following velocities are equal to the speed of electromagnetic promulgation (the speed of light):

$$\begin{aligned}
 C &= 3 \times 10^8 \text{ meters per second} \\
 &= 162,000 \text{ nautical miles per second} \\
 &= 1 \text{ nautical mile per } 6.18 \text{ microseconds}
 \end{aligned}$$

## Radar Range Mile

From the above information, we know that electromagnetic energy travels at a rate of 162,000 NM per second, which gives us the equivalent of taking 6.18 microseconds to travel one nautical mile. Since the radar signal must travel to the target and return, it must take 12.36 microseconds to indicate one Radar Range Mile. In this way, the distance of any object may be measured simply by dividing the time of reflected energy in microseconds by 12.36.

## Frequency

Frequency is the measure of the periodic oscillations of the radar signal over time. It is the time it takes for one full cycle of the signal to complete itself. Frequency can be applied to electromagnetic waves, sound waves or even waves on the beach. The standard frequency unit is called Hertz or Hz, where one cycle per second is 1 Hz.

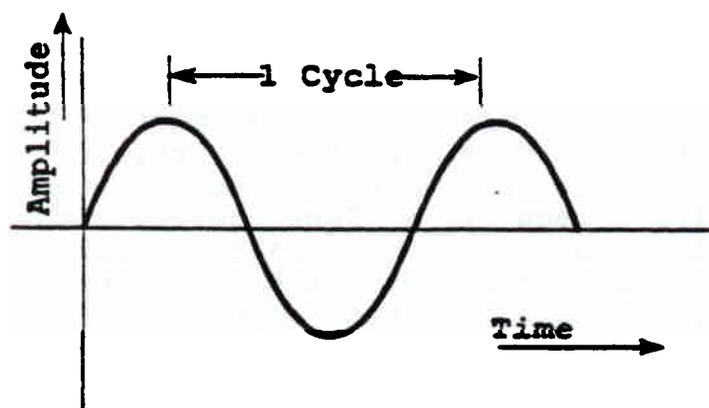


Figure 1

To determine the frequency of a wave, a measurement of time is taken between corresponding points on a wave. Applying the knowledge that frequency is the number of repetitions (or cycles) each second (i.e.  $f = 1/\text{Time}$ ), the frequency in hertz can be found. For example, if one cycle takes .25 seconds to complete, the frequency is:

$$f = 1 \text{ cycle}/.25 \text{ seconds}$$
$$f = 4 \text{ cycles per second or 4 Hertz}$$

The T-39's APG-66NT radar operates on four separate frequency channels, ranging from 9.7 to 9.9 GHz, or approximately 10 GHz (one Giga-Hertz is equivalent to  $10^9$  Hz). This means that the electromagnetic energy coming out of the antenna produces 10,000,000,000 cycles per second.

### Wavelength

Wavelength ( $\lambda$ ) refers to the physical distance between corresponding parts of the wave form. It is equal to the distance the energy wave will travel during the time required for one complete cycle. Therefore, the higher the frequency, the shorter the wavelength, and vice versa. We know that Distance = Rate x Time, and that the rate of travel is always C, the speed of light. Since frequency is inverse to time, then:

$$\begin{aligned}
 f &= 1/T \\
 T &= 1/f \\
 \text{distance} &= \text{wavelength} = \text{rate} \times \text{time} = C \times 1/f \\
 \text{wavelength } (\lambda) &= \frac{(3 \times 10^8 \text{ meters/second})}{(10 \times 10^9 \text{ seconds}^{-1})}
 \end{aligned}$$

$$\lambda = 3 \text{ cm}$$

If the wave being transmitted out by the APG-66NT could be seen and measured with a yardstick, 3 centimeters between the corresponding parts would result.

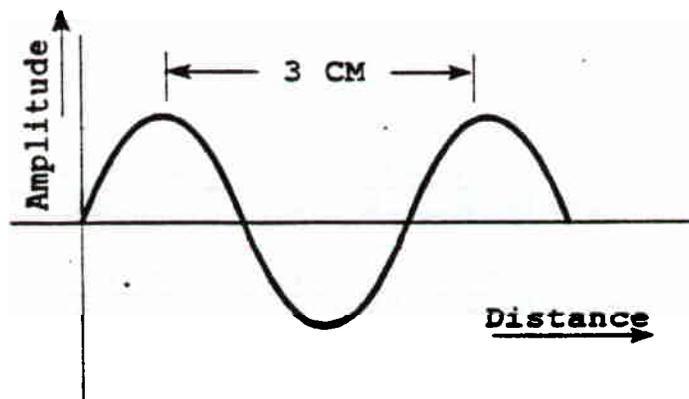


Figure 2

The higher the frequency, the shorter the wavelength, and vice versa. This is important because wavelength affects radar

horizon (how far the radar can see), radar precision (accuracy) and is related to the antenna size. Radar signals with longer wavelengths can effectively extend their horizon because of their ability to "bounce" off the atmosphere (remember: shorter wavelength implies a higher frequency, and absorption by atmospheric conditions), but radar ranging is inexact. Also, low frequency waves (with long wavelengths) require large and heavy antennae not conducive to weight critical aircraft.

### Frequency Selection

Ground mapping radars and fire control radars require accurate information for navigation, intercept, and weapon's guidance. Higher frequencies provide directional capabilities more suitable for these requirements. Higher frequencies will dissipate more rapidly and experience difficulty in a heavy weather environment.

It is important to be acquainted in the terms used to describe different frequencies and frequency bands. Two different scales are commonly used and can easily be confused. The original scale is that used today by most of the civilian population. During World War II, the military scale was invented to cloak radar use in secrecy. The following diagram shows the relative relationship between the two scales in terms of their range of frequencies (known as band width). Notice that the civilian X band and the military I band are approximately the same. These bands possess suitable properties for fire control operations and, as some know first hand, police traffic radars. As a result, the majority of air-to-air radars will operate in this band. The T-39 APG-66NT operates in this band.

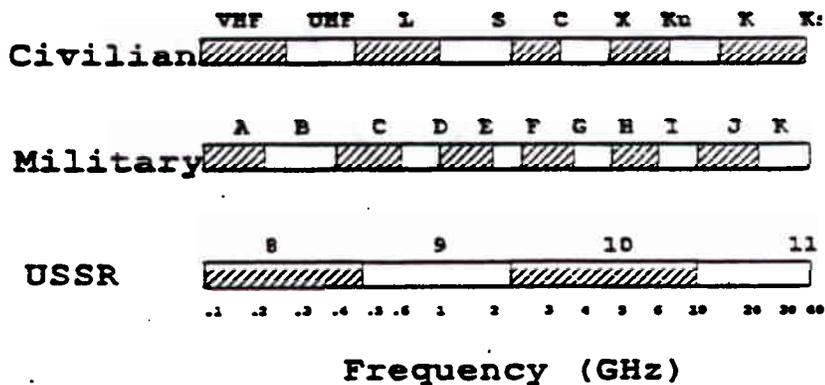


Figure 3

## **Radar Energy Transmittal Forms**

There are two forms in which radar energy can be transmitted: pulsed or continuous wave (CW). The basic principle of pulsed radar requires the transmitter to send out bursts of energy with a rest period between bursts while the energy travels out to search for targets. During the period in which the transmitter is at rest, the radar receiver is listening for echo signals which would indicate a reflecting source. This allows for just one antenna to be used, time-sharing duties with both transmitter and receiver. There are two categories of pulsed energy forms:

a. Pulse: a signal is sent out and the time is marked. When the reflected energy is received, the range is determined by the time it took for the energy to return.

b. Pulse Doppler: a signal is sent out in the same manner as above, but target parameters are determined by a frequency shift in the radar signal (more detail on this in the air-to-air section of this text).

Continuous wave (CW) transmissions require a steady broadcast of radar energy with a separate antenna to receive returning signals. Since the wave is not interrupted, CW provides a very accurate method to measure azimuth and elevation of a target. This form of energy is often used to guide missiles to impact via fire control radars. Another important use is a radar altimeter, which uses a CW signal that is frequency modulated (FM). The FM signal allows for a high level of accuracy in determining range.

## **Radar Performance Parameters**

Multiple factors can affect overall radar performance. A few of the most important ones to be explained are:

- (1) Pulse Characteristics
- (2) Power Output
- (3) Antenna Type
- (4) Radar Cross Section/Reflectivity

## **Pulse Characteristics**

Four basic terms that describe the components of pulsed radar are: pulse width (PW), pulse length (PL), pulse repetition frequency (PRF), and pulse repetition time (PRT).

Pulse width is the amount of time the radar uses to transmit its pulse. Different pulse widths are used to achieve different radar parameters, including minimum range and range resolution.

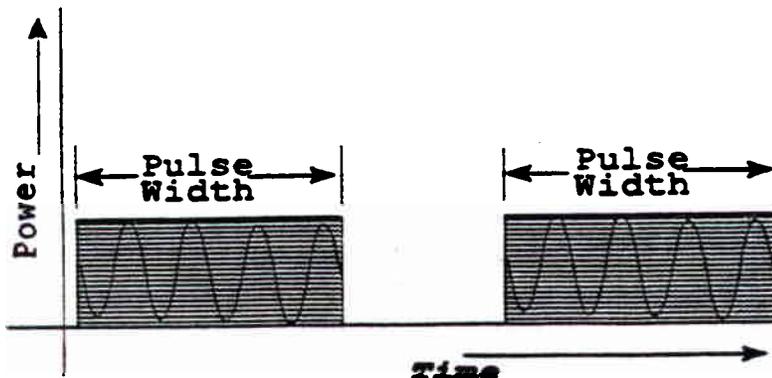


Figure 4

Pulse length refers to the physical distance of the transmitted pulse. Since pulse width is measured in time and pulse length is measured in distance, time must be converted to distance. Knowing how fast radar energy travels (the speed of light), the following equation can be used:

Distance	= Rate x Time
Pulse Length	= speed of light x pulse width
PL	= C x PW

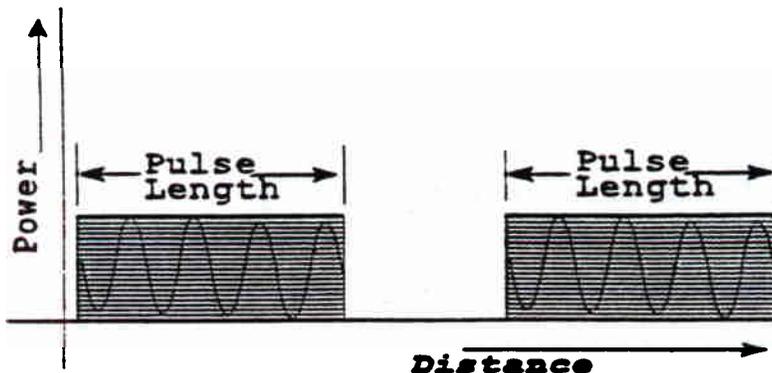


Figure 5

The pulse width of the APG-66NT will vary between .29 and 8 microseconds (depending on mode and usage of the radar). Since the smallest pulse width is .29 microseconds:

$$PL = (3 \times 10^8) \text{meters/second} \times (.29 \times 10^{-6}) \text{seconds}$$
$$PL = 87 \text{ meters}$$

This works out to be:  
PL = 284 feet

This means that when the T-39 transmits a pulse, the leading edge of the pulse is 284 feet away as the trailing edge leaves the antenna.

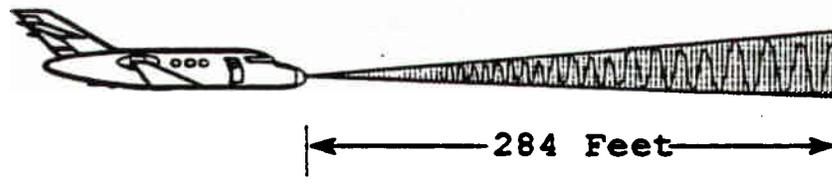


Figure 6

#### Minimum Range and Range Resolution

To detect a radar target, a pulse must travel from the transmitter to the target and return to the antenna. In order to detect a target at the closest distance in front of the aircraft (minimum range), the length of the pulse must be such that the transmitter is turned off just prior to the arrival of the echo. Since the antenna is shared by both transmitter and receiver, a target return will not be seen if a pulse is still being sent out because the receiver is at rest. Pulse length determines this minimum range and the range between separate targets at which each individual target can be detected (range resolution).

The minimum range of the radar corresponds to the minimum distance the receiver can see the target. To illustrate, imagine a yardstick representing the physical distance of the pulse, or pulse length, that has a tip which activates a transmitter and a

tail that shuts it off and turns on the receiver. If the yard stick were broken exactly in half, the tip and the tail would meet and the transmitter would be turned on and off at the same point. The remaining distance (1/2 the pulse length) would be the minimum range because it is the first opportunity for the receiver to be on.

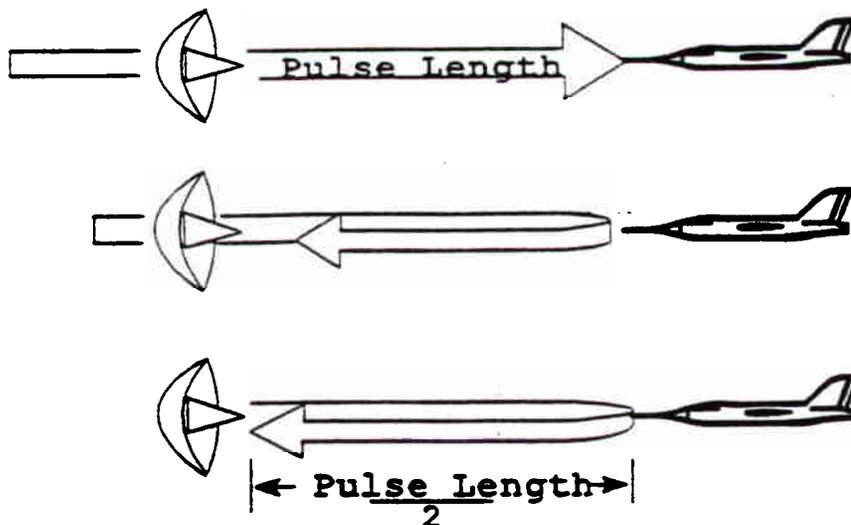


Figure 7

The same principles are involved in range resolution, also known as range discrimination. Range resolution is the ability of the radar to distinguish separate targets vice one large return. If two targets on the same bearing are separated by a distance equivalent to less than 1/2 the pulse length, the echoes of the two targets will appear as one larger echo. So range resolution is equivalent to minimum range, which is equal to 1/2 the pulse length. The T-39 radar pulse length is 284 feet.

Range Resolution =  $PL/2$   
 Range Resolution =  $284/2$   
 Range Resolution and Min Range = 142 feet

#### Pulse Repetition Frequency/ Pulse Repetition Time

The rate at which pulses are transmitted is referred to as pulse repetition frequency (PRF). The total time for a complete cycle of one pulse, rest time and the initiation of the next pulse is the pulse repetition time (PRT). Note that the PRF of the pulse and the frequency of the radar wave in the pulse are independent of each other (i.e. any frequency may operate with any PRF). Both the PRF and PRT are analogous to the relationship

of time and frequency. That is to say:

$$PRF = 1/PRT$$

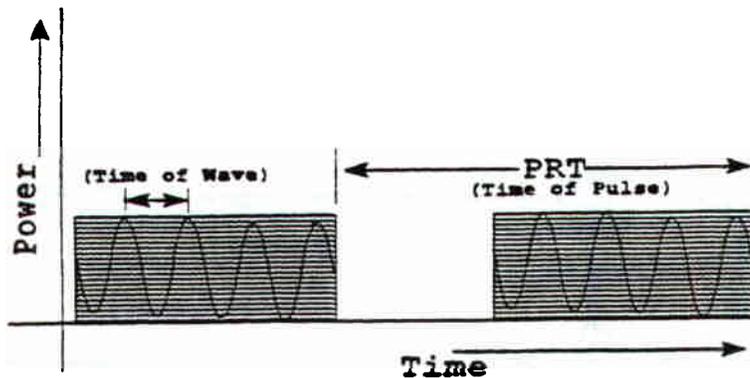


Figure 8

### Range Determination

Using a pulsed radar, range determination is a relatively simple process. If the time is measured from when a pulse is sent to when it returns, and knowing how fast it travels, then the range of a contact can be computed. Remembering that  $\text{Distance} = \text{Rate} \times \text{Time}$ , and using the speed of light and the measured time, the final distance is divided by 2 since the signal must travel from the aircraft to the target and back again.

### Maximum Range

The pulse repetition frequency (PRF) will determine the maximum theoretical range possible for the radar. The actual maximum range may be limited by factors such as power output, antenna gain, and target reflectivity. But examining the PRF will establish the maximum range that the pulse characteristics will allow.

The maximum time available to receive a target return is PRT since PRT equals the transmission time plus rest time (i.e. the time when the receiver is listening for returns). The target return must arrive at the antenna prior to the next pulse leaving the radar to be correctly displayed.

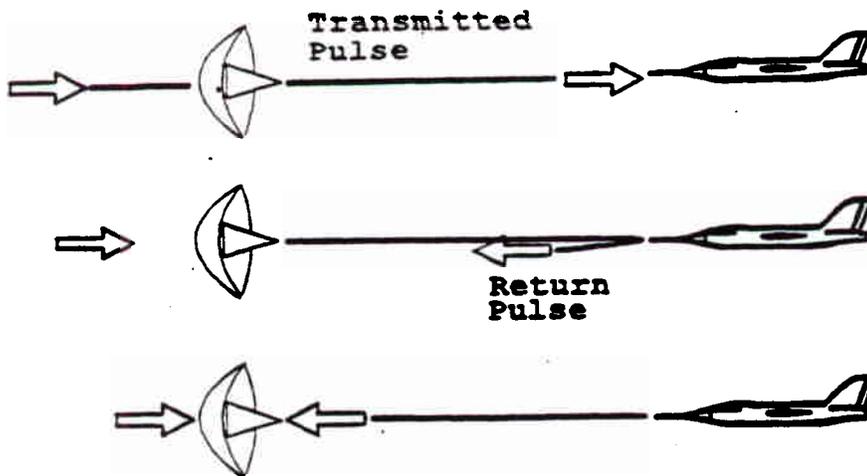


Figure 9

To determine  $R_{max}$ , the total distance the pulse must travel is twice the  $R_{max}$ . This is because the radar signal must travel to the target and return before the transmitter sends out another pulse in order for the first pulse to be received.

$$\begin{aligned}
 2 \times R_{max} &= \text{Rate} \times \text{Time} \\
 &= C \times \text{PRT} \\
 R_{max} &= (C \times \text{PRT})/2
 \end{aligned}$$

The APG-66NT utilizes several different PRF's depending on the range scale selected. The reason for that will be explained later, but right now let's say that with the 40 mile range scale selected the PRF is approximately 1360 Hz. If 20 mile range scale is selected the PRF switches to approximately 1740 Hz. This implies that the theoretical  $R_{max}$  will vary depending on the range scale selected.

If the 40 mile range scale is selected:

$$\begin{aligned}
 \text{PRT} &= 1/\text{PRF} \\
 \text{PRT} &= 1/1360 \text{ seconds}^{-1} \\
 R_{max} &= (C \times \text{PRT})/2 \\
 R_{max} &= 110,000 \text{ meters}
 \end{aligned}$$

Converting from meters to miles produces an  $R_{max}$  of approximately 60 miles. This means that if the radar puts out enough power and the display is extended to 60 miles, it is theoretically possible to see a target 60 miles away. Each

successive change in PRF for each range scale yields a theoretical range greater than the scale selected. The extra distance is a safety margin to allow for variations in transmitter power, target reflectivity, antenna positioning and many other factors that are present in the "real world" tactical environment.

### Power Output

The actual maximum range of the radar depends largely upon power output. Enough power must be radiated so that, at the desired maximum range, the received echo will have a power level sufficiently high enough to be "heard" over the noise and clutter.

Power output is usually referred to in one of two ways: peak power or average power. Peak power is the maximum power reached during the pulse width. Average power is the amount of power radiated, averaged over the entire PRT. From these definitions, it can be reasoned that as the pulse width increases, the average power decreases because the PRT will be longer. The fraction of the total cycle time that the transmitter is actually "firing" is defined as the duty cycle of the radar. The formula for duty cycle is:

$$\text{Duty Cycle} = \text{PW/PRT}$$

This is equivalent to defining Duty Cycle as:

$$\text{Duty Cycle} = \text{average power/peak power}$$

High peak power is desirable for producing strong echoes. Low average power is desirable for allowing smaller and lighter weight equipment (an important consideration for airborne systems). Therefore, it is advantageous to have a low duty cycle radar in an aircraft for both of these reasons.

As mentioned earlier, the PRF of the APG-66NT radar will change when we change range scales. This change in PRF also has an effect on the duty cycle to keep the system optimized for maximum performance at different ranges. For the example below, we'll keep the pulse width constant and assume peak power to be 100,000 watts (100 kilowatts) to simplify the computation.

40 mile range scale:

$$\begin{aligned} \text{PRT} &= 7.35 \times 10^{-4} \text{ seconds (as before; } 1/1360 \text{ Hz)} \\ \text{Duty Cycle} &= \text{PW/PRT} \\ &= (.29 \times 10^{-6}) / (7.35 \times 10^{-4}) \\ &= .00039 \end{aligned}$$

$$\begin{aligned}
\text{Duty Cycle} &= \text{Avg Power/Peak Power} \\
\text{Avg Power} &= \text{Duty Cycle} \times \text{Peak Power} \\
&= (.00039) \times (100,000) \\
&= 39 \text{ watts}
\end{aligned}$$

20 mile range scale:

$$\begin{aligned}
\text{PRT} &= 5.75 \times 10^{-4} \text{ seconds (as before; } 1/1740 \text{ Hz)} \\
\text{Duty Cycle} &= (.29 \times 10^{-6}) / (5.75 \times 10^{-4}) \\
&= .0005
\end{aligned}$$

$$\begin{aligned}
\text{Avg Power} &= (.0005) \times (100,000) \\
&= 50 \text{ watts}
\end{aligned}$$

This demonstrates for us that the switch to a smaller range scale increases the average power out of the radar. The greater the average power, the greater the chances of detecting a target. It also means that more pulses are being sent out for a given cycle time, or PRT. If we think about this intuitively, it makes sense: for longer range scales, we want fewer pulses being sent out for a constant PRT because we want the receiver to stay on longer to detect signals returning from targets further away. For shorter range scales, we would like more pulses being sent out for a constant PRT because we are only interested in returned signals from closer targets. The ideal situation would be to use a PRF that provides the theoretical Rmax of the scale selected and no greater, but real world limitations prevent that from happening.

#### Radar Beams

The radar system must have the ability to transmit and receive energy in a controlled manner. The radar antenna accomplishes this by forming the energy into a narrow beam called the main beam. This main beam illuminates only a small area; therefore, the beam must be moved horizontally and vertically in order to detect contacts in front of the aircraft. This is analogous to shining a flashlight back and forth in a dark room in an attempt to find an object.

The true shape of most radar beams is conical. The beam is smallest close to the antenna where the signal originates. As energy travels further and further away it occupies a larger volume but keeps it's original shape. Another reality is that concentrations of energy are built up around the radar beam. These are called sidelobes, with the strongest being perpendicular to the main beam (see figure 10). Generally, the more efficient the antenna, the smaller the sidelobes.

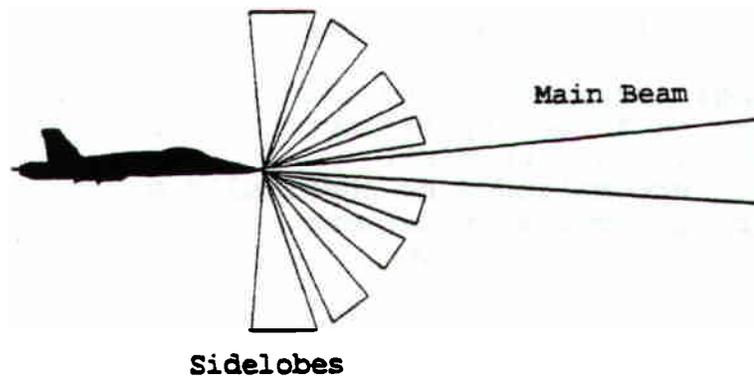


Figure 10

### Antenna Type

Once the electromagnetic pulse has been generated for the radar pulse, it is the purpose of the antenna to focus and concentrate this energy in one direction. Depending on the type, the antenna will attempt to direct the beam in a manner appropriate for it's intended useage.

There are four basic types of antennas: omnidirectional, parabolic, planar array, and phased array.

1) Omnidirectional antenna: No attempt is made to direct the energy as it travels or from where it is received. A CB antenna (figure 11) is an example of this type.

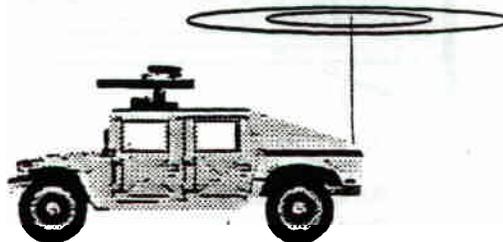


Figure 11

2) Parabolic dish antenna: Used in most early air-to-air and ground mapping radars because they are light, compact and provide good directability of the radar energy (fig 12).

- a) single antenna in the shape of a parabolic dish.
- b) beam is formed by reflecting energy off the interior of the dish.
- c) scan accomplished by physically moving the dish through some scan pattern.

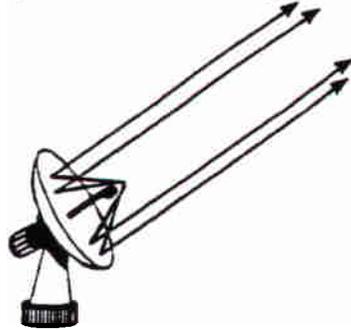
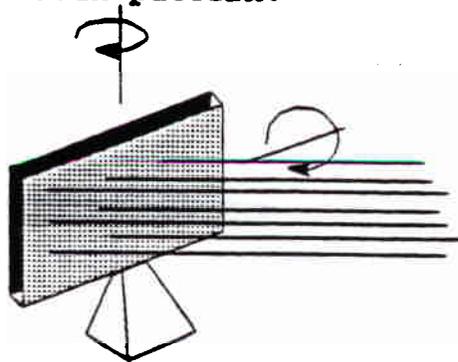


Figure 12

3) Planar array antenna: More advanced technique, used in the APG-66NT radar system (figure 13).

- a) multiple small antennas in the shape of a flat plane
- b) beam is formed by combining signals of the antennas.
- c) scan accomplished by physically moving the antenna through some scan pattern.

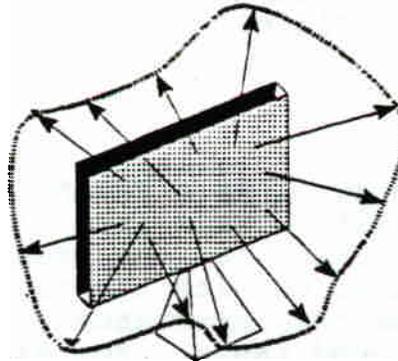


Mechanical  
Drive

Figure 13

4) Phased array antenna: The AEGIS Spy 1 radar is the classic example of a phased array radar (figure 14).

- a) multiple small antennas same as planar array.
- b) beam is formed same as planar array.
- c) electronic scan, no physical movement.



Electronic  
Scan Area

Figure 14

### Beam Shaping

There are several ways to shape the radar beam to optimize its use. Here at VT-86, we're concerned with two different uses: ground mapping navigation and air-to-air intercept. Because the T-39 radar system is not multi-functional like the F-16 system that it was originally designed for, we cannot use a single jet for each mission. As a result, your radar system will either be dedicated to ground mapping or air-to-air.

For effective ground mapping at high altitudes, the entire region to be mapped must be illuminated by the antenna's main lobe. It is best to shape the beam so the power received at equivalent patches on the ground is the same for all ranges, rather than diminishing with increased range. This is accomplished initially by illuminating the ground uniformly at all ranges.

Uniform illumination means that the amount of radar energy per unit of cross sectional area is the same at every point in range. The cross sectional area of the beam increases as the square of the slant range. At a constant altitude, this is proportional to that altitude (AGL). This proportion is the cosecant of the look down angle. Thus, this beam is called a cosecant squared beam.

In an air-to-air environment, the goal of the antenna is to shape the beam such that it is concentrated and sent in the direction to be searched, then provide accurate indications of target position. The more efficient the antenna in creating the beam, the more accurate the information available. In reality, the radar beam cannot be 100% effective: stray energy will always be present in the form of sidelobes. The beam is therefore defined by its half power points, or where the concentration of energy from the main axis falls off to 1/2 that value. This type of beam is known as a pencil beam.

#### Altitude Hole

An airborne radar system, like a TACAN, measures slant range vice ground range. The Altitude Hole is analogous to the "cone of confusion" of a TACAN station for the ground mapping radar. The AGL altitude, in combination with the distance to the target, will allow you to determine the importance of the difference between slant range and ground range. For example, at 10,000 AGL and 40 nm from a target, the difference is minimal; at 10,000 AGL and 5 nm, it is significant. At this altitude, you are just over 1.5 nm straight up in the air; therefore no returns can be seen on the scope at a distance less than this. Altitude hole has no effect in air-to-air radars.

#### Bar Scan

There are numerous methods used to scan radar beams to search for targets. The simplest and most common (and the only one you'll use here at VT-86) is a one bar scan. A one bar scan implies that the radar searches at a constant elevation with each sweep of the antenna. In order to change the elevation angle of the antenna, the operator has to manually move the antenna angle. Multibar scan implies that the radar searches at a constant elevation for one sweep; then changes elevation for the next sweep and eventually returns to its starting point (figure 15).

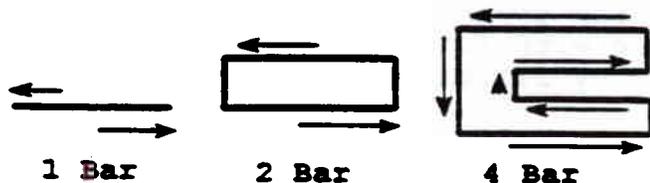


Figure 15

## Reflectivity

The radar cross section (RCS) is a characteristic of the target that is also critical to radar performance. This measurement is expressed in square meters ( $m^2$ ), and does not imply a simple relationship to the physical size of the object. However, as a general rule, the larger the target size, the larger the cross section is likely to be.

When an object is illuminated by an electromagnetic wave, a portion of the energy is absorbed as heat and the remainder is reradiated (scattered) in many directions. The percentage of energy directed back towards the source varies greatly as the aspect of the target varies. Major factors determining the RCS are target size, shape, skin material, aspect angle, and the actual radar frequency. There is no simple formula or rule of thumb that will give the cross section of an actual target such as a ship, aircraft, or building. Cross sectional data must be experimentally obtained and the results are valid only for the specified frequency.

Observe that the RCS of an aircraft varies as the angle at which that aircraft is viewed changes. Two factors are responsible for this:

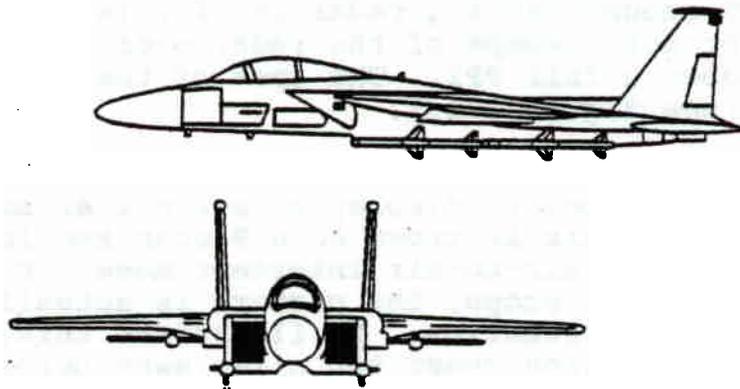


Figure 16

When viewed at 90 degrees:  
(1) the target appears physically larger,  
(2) the junction of the wings and the fuselage functions as a compilation of corner reflectors.

These effects combine to greatly enhance the radar echo. The current trends in tactical design incorporate "stealth" technology. Stealth technology reduces RCS to a minimum to avoid detection by enemy sensors. This is accomplished through a variety of methods including eliminating the sharp joints and the use of radar absorbent materials. The B-2 Stealth bomber and AEGIS destroyers are examples of this applied science.

## Radar Scope Displays

In use today are several different kinds of radar scope displays. Each display is designed to present the information required for the specialized requirements of the operator. Some of the most common scope displays are the Planned Position Indicator (PPI) and B-scan. The PPI is a scope with your own position in the center and a circular rotation. Most Early Warning radar systems use this type of indicator, normally scanned through 360 degrees. (see figure 17a.)

The sector PPI scans only through a selected portion of 360 degrees. This is used only when information from other sections is of no concern. As an example, an airborne ground mapping radar is not concerned with returns behind the wingline, so it would only scan through the forward-most 180 degrees (or less).

The APG-66NT ground mapping radar is of this type. Notice that it allows for more sweeps of the radar over a return in a given time than does a full PPI. The apex of the scope is the self-indication (see figure 17b.).

To allow for more detail in close, the sector PPI can be modified to widen the apex to display a return's azimuth in constant proportion. This is known as a B-scan and is the type used for the APG-66NT's air-to-air intercept mode. Unlike the display picture of a PPI scope, the picture is actually a distortion of the real situation. To illustrate this, imagine approaching a straight line coast ten miles away perpendicularly while looking at a B-scan scope. The coast directly in front of the aircraft will be displayed at a range of 10 miles. The coast to the left and the right of the nose will appear at a greater distance away since the slant range to these portions of the coast is further away. Note, however, that their relative azimuth is constant to the relative position left or right of the nose of the aircraft. The straight coast appears as a curved line on the B-scan scope. (see figure 17c.)

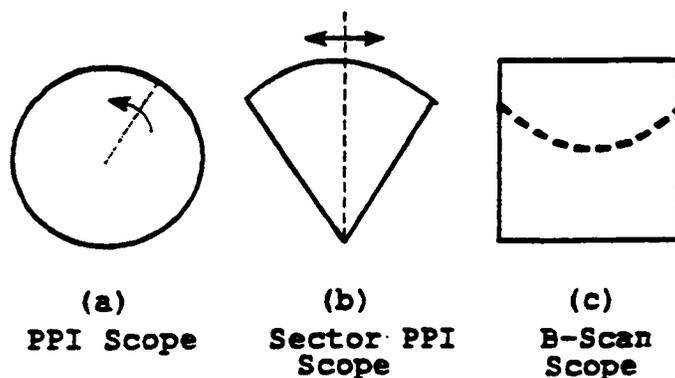


Figure 17

**Elements of a Pulsed Radar**

While radar sets in use today vary in complexity and function, there are areas of commonality worth understanding. Figure 18 shows the basic components of a typical pulsed system.

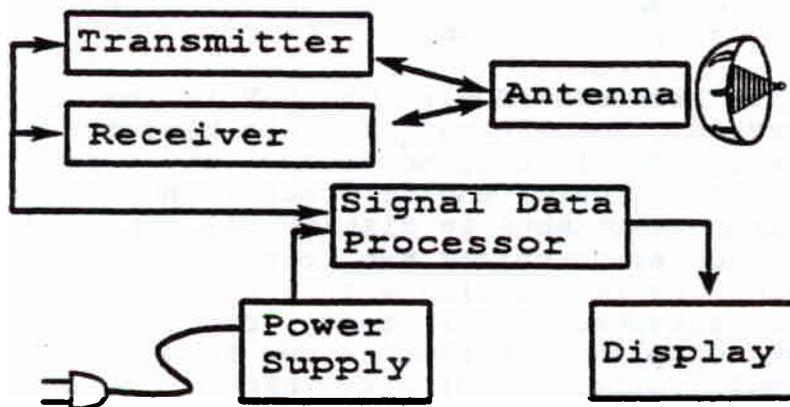


Figure 18

a) Power Supply: Power for the APG-66NT is provided by inverters separate from the main aircraft electrical system. They are activated when the Radar System Select switch, located

on the left pilot console, is placed in the ON position. Located on the aircraft's aft bulkhead are six circuit breakers, one for each inverter. Since AC power has three phases of power output, two inverters provide electrical distribution for each phase. If any single inverter fails, the appropriate mission inverter annunciator will illuminate. That specific phase will be reduced by 50%, but the radar will operate normally as the second inverter provides power as a corresponding backup. If a second inverter for that phase fails then the radar will automatically shutdown.

b) Antenna: The APG-66NT uses a planar array antenna located in the nose to transmit and receive radar signals. The antenna has two components: the main array and the spoiler array. The different antenna components are used depending on the mission; in ground mapping mode both arrays are utilized to provide uniform illumination of the surface, while the air-to-air mode uses the main array only.

c) Transmitter: Located in the aircraft nose compartment, the transmitter provides the pulsed energy at the proper frequency and pulse width. The portion of the transmitter that determines the pulse width to be used, based on range scale and mode selected, is known as the modulator.

d) Receiver: Also located in the nose compartment, the receiver is an extremely sensitive super heterodyne mechanism tuned to the radar carrier frequency. It accepts the returned radar energy (echoes) and sends signals to the signal data processor for conversion into display.

e) Signal Data Processor (SDP): The SDP is the brain of the aircraft radar system. The SDP contains the hardware and operational software that is used to control the overall operation of aircraft avionics and to process the digitized signals of the other components to display all required target information. The SDP synchronizes the transmitted and received signals, correlates the information with own aircraft measurements (i.e. airspeed and altitude), decides which signals are acceptable and displays the data in the form of video return on the aircraft Multifunctional Display (MFD). The SDP is the onboard computer that determines what information is and is not important to show the operator on the scope. It provides the link between each of the radar components and allows them to "speak" to one another.

f) Displays: Each aircraft carries three Multifunctional Displays (MFD) which present various target information. The MFD is a 5 inch cathode ray tube (CRT) with controls to adjust picture quality. The actual operation of the MFD will be discussed in later chapters.

This page reserved for notes

## UNIT 2: GROUND MAPPING RADAR SCOPE INTERPRETATION

### Preview

Many aircraft owe their night/IFR capabilities to radar. These radars provide ground mapping displays which enable air crews to successfully navigate to a target and return over any terrain and through almost any weather condition. It is most important for you to develop the basic skills necessary to interpret the radar display accurately and expeditiously. The ability to interpret the radar display is mastered through practice and experience, but the foundation of this skill is formulated by a thorough understanding of the factors which affect the display.

The radar display does not present an intuitively obvious display of the ground. Instead, it presents radar echoes by a specific intensity on the radar display. The presentation will indicate reflected Radio Frequency (RF) energy as lightened areas and the absence of RF energy as dark areas. The brightness directly corresponds to the intensity of the RF energy returned.

There are two general classifications that can be given to a radar echo: topographic (natural) and cultural (manmade). The intensity of echoes on the display will vary depending upon factors such as the inherent characteristics of the radar system and the controllable and uncontrollable aspects of the target (to be discussed later). These factors are all interrelated and dependent upon each other. In the following text, we will explain which of these factors are controllable and what causes these factors to vary.

### Echo Potential and Strength

Echo potential refers to the uncontrollable factors which affect the ability of an object to reflect RF energy, and thereby produce an echo on the radar display. Echo potential is dependent on four major factors: (1) object size, (2) object shape, (3) object composition, and (4) the object's environment.

Echo strength refers to the controllable factors affecting the operator's ability to determine targets on the radar scope. The most important of these particulars are: (1) transmitter power, (2) slant range, (3) run-in heading, (4) antenna tilt angle, (5) receiver gain, and (6) video gain.

### Uncontrollable Factors

Object size affects the potential that an object will be displayed on the radar display. Two similar objects of different size have different echo potentials because the larger object

will reflect more energy. Since more RF energy is reflected, the radar system will receive and process more energy.

Shape will affect the echo potential by the aspect, or angle, at which the RF energy strikes the target. This angle is referred to as the angle of incidence. The angle of reflected energy is also equal to the angle of incidence. Therefore, the echo strength is also affected by this reflection angle.

Consider the effects on echo potential in Figure 1(a). The energy that is hitting object A is being reflected back to the aircraft to be processed. A majority of the energy that is striking object B is being reflected away from the aircraft and will therefore not be processed.

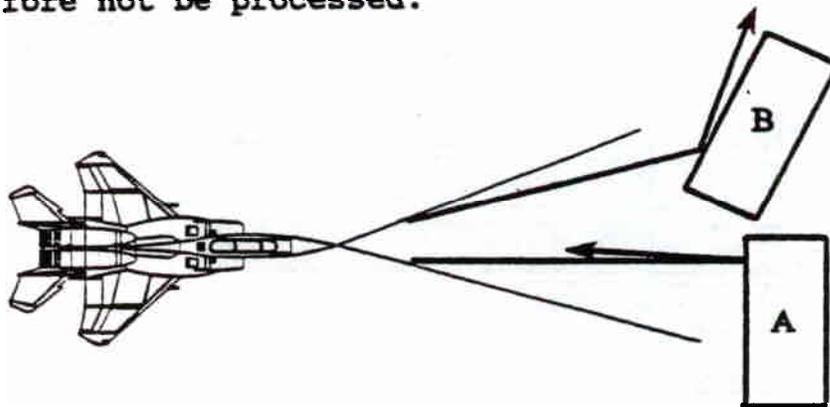


Figure 1(a)

From Figure 1(a), it is apparent that the best echo from an object will occur when the surface of the object is perpendicular to the radar beam. For example, a round object has low potential for producing an echo because it will have very little area that is perpendicular to the radar beam. The angles of reflectivity are maximized in the corner reflector as shown in Figure 1(b). Corner reflectors offer the greatest echo potential of all object shapes and can be utilized as effective checkpoints and aimpoints for radar navigation and targeting.

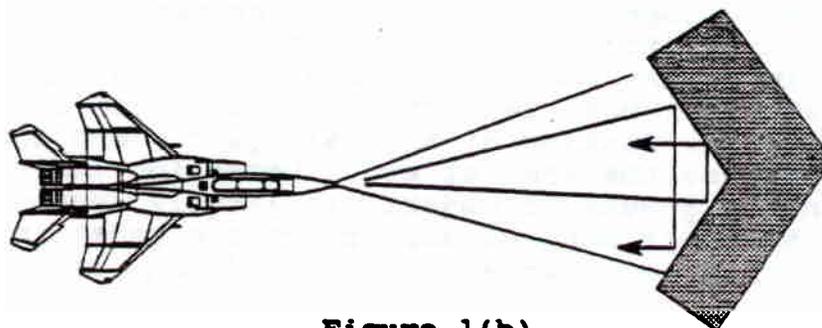


Figure 1(b)

Composition of an object greatly affects its echo potential. Table 1 gives a comparison of echo potentials for various materials. The table shows us that an object's echo potential depends on its surface material. Although a discussion of the electromagnetic properties of different materials is not within the scope of this course, an object's composition affects its ability to either reflect or absorb RF energy. This characteristic allows the radar to see the difference between land and water and many other different substances<sup>1</sup>.

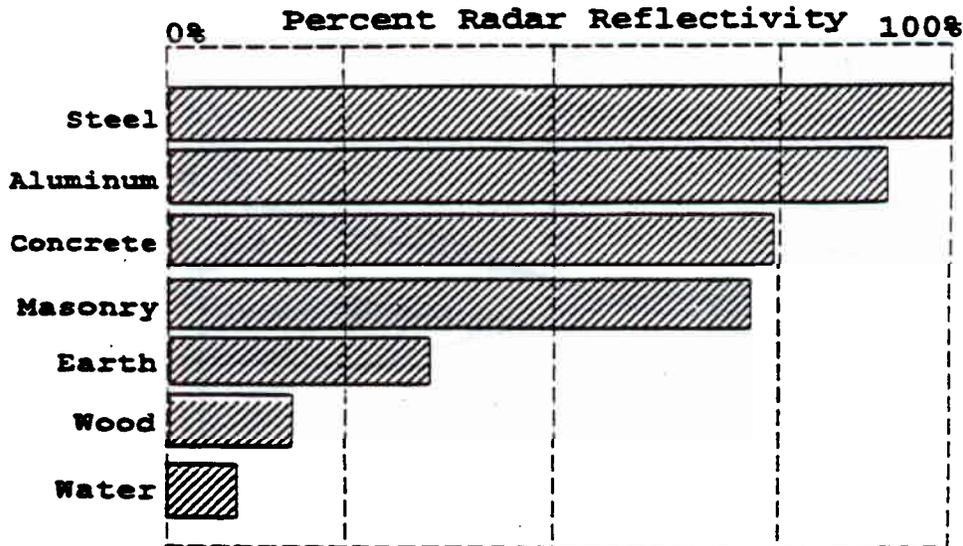


Table 1

The environment around objects is of significant importance to the ground mapping radar operator. Closely grouped buildings (see Figure 2) are sometimes displayed as a single echo. This situation is due to several factors. One factor is that buildings are normally made of material that provides excellent reflection properties. Another factor is that the buildings are grouped so closely together that they cause corner reflections among the buildings, forming one collective echo. A "corner reflector" is important because, regardless of the angle of incidence, the two or more reflections will return all energy back to the antenna. Parking areas, rail yards, and industrial complexes also cause the same effect. Detecting individual targets within the groups of objects is largely dependent upon the specs of the radar and the ability of the radar to discern these objects. This is known as Azimuth and Range Resolution.

<sup>1</sup>Water's actual reflective percentage is 100%, but the RF energy is always reflected away from the aircraft since it is in a horizontal plane.

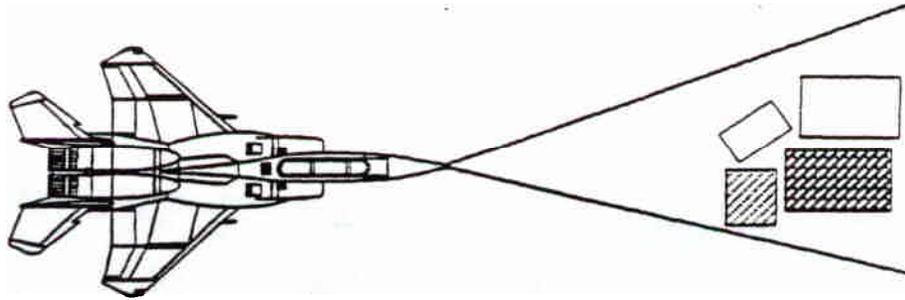


Figure 2

### Controllable Factors

#### Antenna Tilt

Proper control of the antenna tilt is needed to ensure that the maximum amount of energy is illuminating the target. This is analogous to shining a flashlight in a dark room. An object may only be seen if it is illuminated by electromagnetic energy (in this case, light).

Poor antenna elevation control can mean the difference between strong and weak signal strength. No amount of receiver gain can compensate for an improperly aimed antenna. Consider the affects of antenna tilt in Figure 3a. With antenna tilt set low, city B is not illuminated by the transmission.

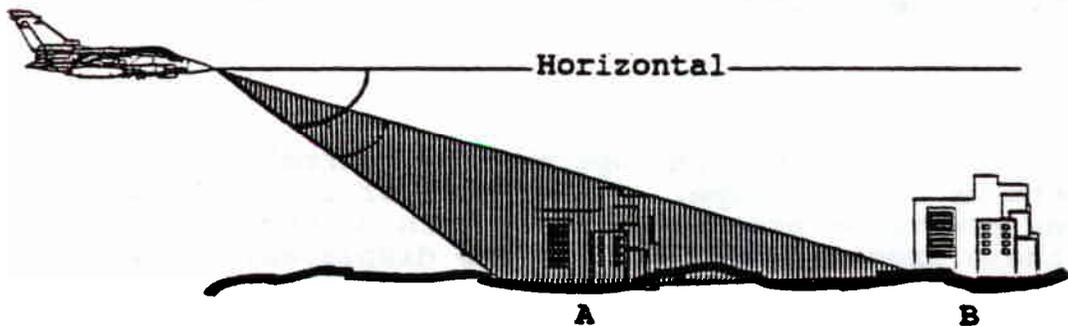


Figure 3a

With the antenna pointed too high, city A is not illuminated, as shown in Figure 3b.

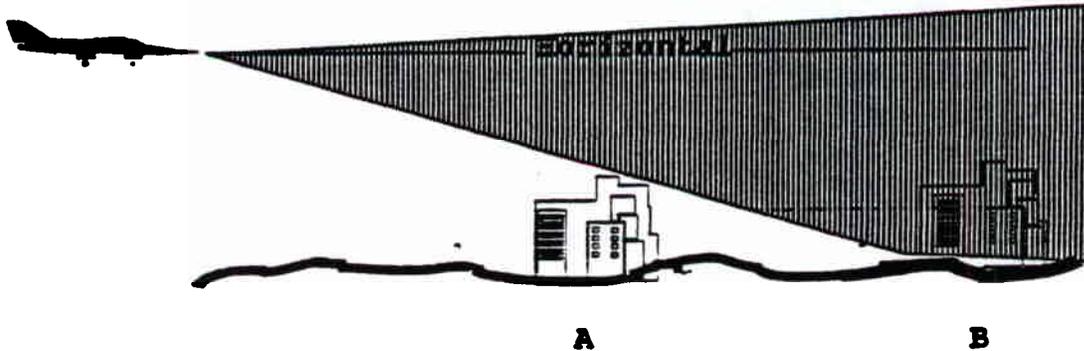


Figure 3(b)

### Receiver Gain

The receiver gain controls the amount of RF energy that the receiver will accept and process. In terms of operating the radar, this control will allow you to adjust the radar to accept or reject echoes. Generally, the receiver gain is initially set high and then turned down as range decreases. Properly adjusted receiver gain will allow you to display details of the terrain. An improperly adjusted receiver gain can washout the display or cause the radar to reject signals of interest. The squelch control on a radio is roughly analogous to receiver gain. It determines the strength of signals to be processed by the receiver.

### Video Gain

Video gain allows the operator to control the intensity of all returns on the scope. Where receiver gain controls which returns are to be processed, video gain determines the intensity that those processed returns will be displayed. Using the analogy of the radio again, this adjustment can be compared to the volume knob which determines the intensity of those signals allowed in by the squelch control. Video gain controls include the brightness and contrast knobs. Proper video gain is typically set during the initial setup and is not adjusted during the flight.

## **SCOPE PRESENTATIONS**

Returns on a radar scope are rectangular in shape, oriented perpendicular to the main beam. They vary in brightness depending on echo potential and strength. The terminology used to describe strength of returns are, listed from strongest to weakest: hard, medium, light, and (for an area absent of returns) no shows.

As you already know, a radar presentation is not an intuitive display of the information found on a Tactical Pilotage Chart (TPC). The topographical and cultural features found on a TPC will provide the information necessary for radar navigation. However, an ability to predict object presentation potential on a radar scope is vital to navigation success.

## **TOPOGRAPHICAL FEATURES**

### **Flat Terrain**

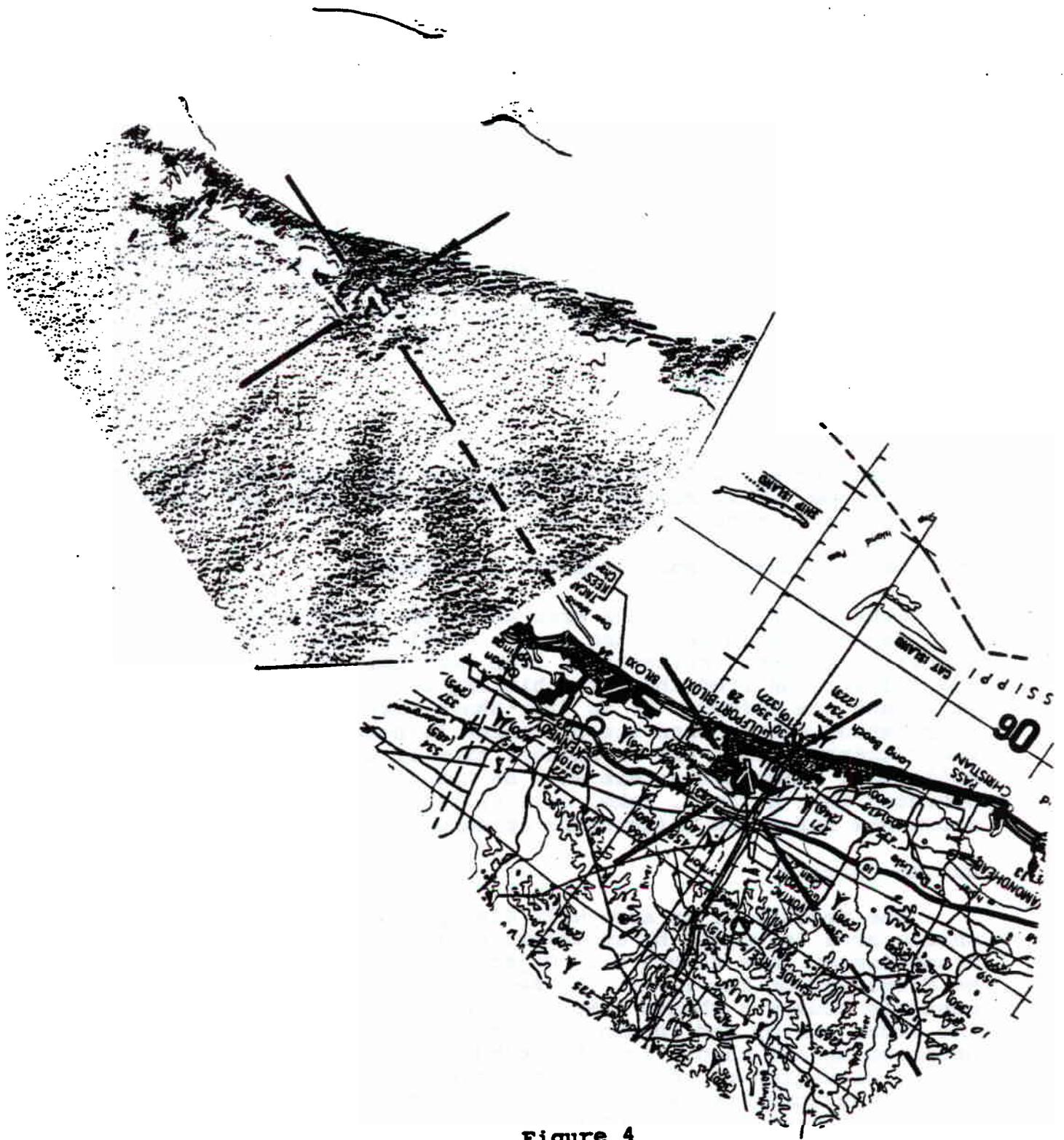
Flat terrain will be displayed as a light dusting of "snow" on the scope. This dusting is caused by the small reflections from the soil, rocks, trees, etc.

### **Land/Water Contrast and Far-Shore Brightening**

Consider Figure 4, the area where the water meets the land will cause a brightened echo on the display that represents the shoreline. Direct reflections from vertical rise in land mass and reflections from the water hitting the land mass are the cause and are referred to as "far-shore brightening". Far-shore brightening occurs when the shoreline is perpendicular to the radar transmission, and is another type of corner reflector. Many times this will be the first indication to the operator that a river, lake, or a shoreline lies ahead. Figure 4 shows how far-shore brightening appears on the scope.

### **Uneven Terrain**

The terrain of an area will also produce shadow areas. A shadow area is caused by an object masking out a radar transmission (see figure 5). Objects in the shadow area will not be displayed on the radar. As seen in Figure 5(a), a mountain causes a shadow area which keeps the town from receiving the radar energy and returning an echo. Factors affecting ridge brightening and shadow length include: aircraft altitude, slant range, elevation of the ridge and terrain elevation behind the ridge. An accurate radar prediction, considering all these factors, can be constructed using the shadow graph as seen in Figure 5(b).



**Figure 4**  
**Cultural Returns and**  
**Lines of Communication**

## Weather

A heavy thunderstorm can also affect the radar picture. Sometimes precipitation will be too light to return an echo, but at other times it will be dense enough to inhibit the radar transmission from traveling through it. If a return appears on the scope from weather, and it has a shadow behind it, then it means there is too much water in the cloud to fly through it. Normally, only convective activity (a Willy-Willy) will produce dense enough rainfall to be seen on the scope.

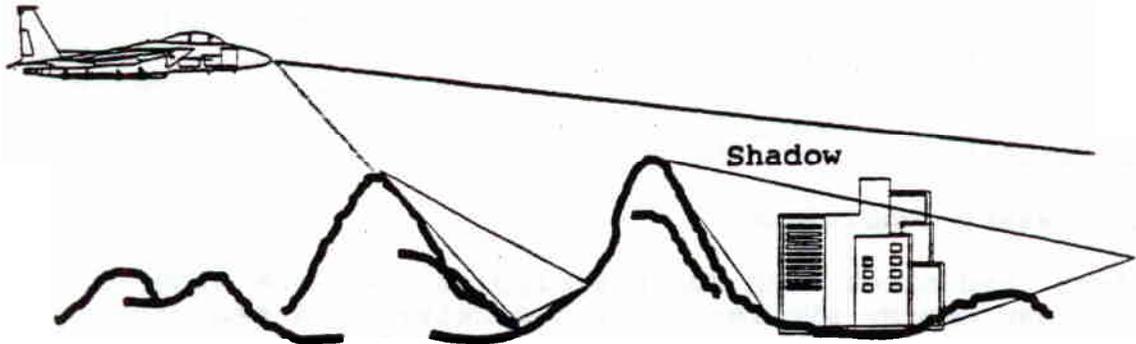


Figure 5(a)

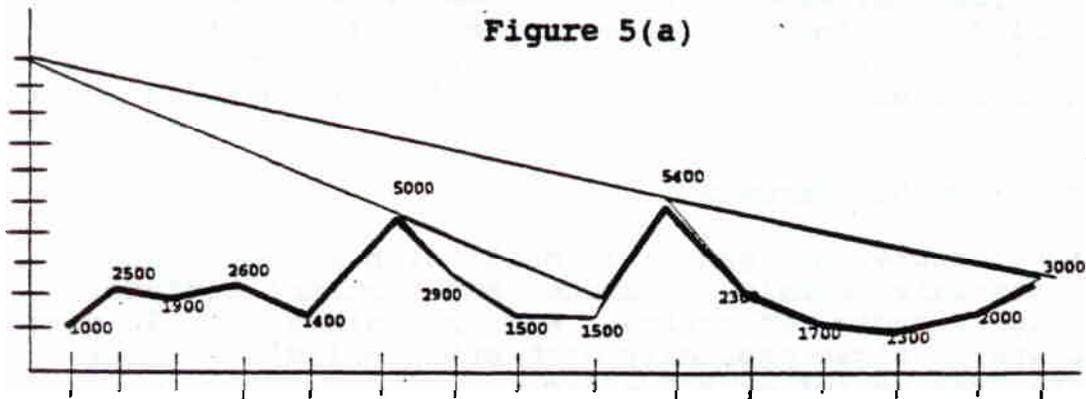


Figure 5(b)

## Causeways

Causeways are not natural topographic features, but because they are usually constructed of dirt or rock fill, and normally present land-water contrast, they are included here. Causeways have many of the return characteristics of shorelines. They may serve as excellent radar reference points, particularly in coastal cities. Piers, breakwaters, and even some bridges are also considered excellent checkpoints in land-water contrast areas.

## Ice and Snow

There are considerable global areas that are covered by ice and snow during the winter months. If a land area is covered by snow, the radar beam will reflect from the snow rather than from any of the features beneath it. The overall effect is to reduce the reflection from the object beneath, but not to change its general appearance. However, some specific features may be different. Very smooth ice or snow will appear the same as a water return -- a "no show". If the ice or snow is formed in irregular patterns, the returns created will be comparable to terrain features, the common being just ground return. In most cases, the rivers, lakes, and harbors that you will encounter will be "invisible" during the winter months, thereby reducing the availability of radar checkpoints.

## Sand and Desert Conditions

Large sand areas with surface ripples that are wind blown reflect radar energy similar to ground return. A seasonal lake in desert terrain may appear as a "no show" lake or ground return if it has dried up. However, large expanses of very flat beds (i.e. Bonneville Salt Flats in Utah) reflect radar energy the same as water and may appear as a "no show" when there is no water at all.

## CULTURAL AND MANMADE FEATURES

Manmade features are generally built with strong signal potential materials (metals, concrete) and vertical surfaces which are highly radar reflective. Most buildings have 90 degree angles and are in close proximity with other buildings which enhances the "corner reflector" effect.

Individual buildings, because of their shape as described above, appear as bright, solid, rectangular shaped returns on the scope. The rectangular shape is enhanced by errors caused from a delay in returned energy from both sides of the building. This error, known as "beam width error" will be covered later. But for now, realize that these returns have a rectangular shape and are brightly displayed. This is why cultural returns are displayed as hard returns.

1. Cities and Towns: At longer ranges, the radar presentation will consist of a few isolated returns generated by the tallest, largest, and most radar reflective structures. As range decreases, more returns will appear to supplement the previous ones, which remain dominant. Vertical development is important for strong cultural reflectivity at any range. However, at shorter ranges, large cultural build-ups tend to have overlapping returns due to close proximity of buildings and radar errors. It is important to realize, nonetheless, that the large

mass of radar returns is actually made of individual "blips". Cities often exhibit the "cardinal effect" as discussed in lines of communication below and as shown before in Figure 4.

An analysis of the city or town in reference to its industrial capability, terrain location, and lines of communication will help the operator determine the effective signal potential of that particular city or town. Small rural towns have predominately wooden and masonry structures, few lines of communication, and more trees than a larger city. Vertical development is decidedly absent in smaller towns and trees, which are often taller than the buildings in these towns, may deflect radar targets until the aircraft is at a closer range. Lastly, residential areas have a less intense return than downtown or in industrial areas.

2. Vegetation: This may also obscure small towns, rivers, and lakes by absorbing radar energy or reflecting it back as ground return. This is important when considering targets as they interface with the environment in which they occupy. Targets isolated in the desert will appear markedly different on the scope than similar ones in mountains or wooden terrain.

3. Airfields: These areas, especially large military airfields, are among the most prominent returns identifiable away from urban areas. Large hangars, parking lots, ramp areas, and other associated structures offer highly reflective targets. Small civil airfields normally do not provide good individual returns since they usually have few large structures. The actual airfield runways are considered "no show" areas because of their broad expanse of smooth concrete or asphalt. However, this is only discernible at extremely close ranges and relatively low altitudes. For VT-86 purposes, airfield runways will appear as ground return on radar predictions since grass or bare earth is the major ground cover surrounding airport areas.

4. Lines of Communication: A line of communication is the transportation access to a built up area. It may take the form of railroads, highways, rivers, and canals. None of these are visible on radar; however, associated bridges, embankments, levees, and railroad marshaling yards provide good radar reflectors. By far, the most important reason for considering lines of communication as an excellent radar significant target is the cultural returns located along these lines of communication. Businesses, warehouses, shopping centers, etc., are all located along major highways and railroads near cities and towns. In contrast, the highways, rivers, and railroads in the middle of farmland or desert will not normally exhibit cultural returns along lines of communication. Also, in cities and towns the lines of communication tend to merge in the downtown and/or industrial area where the strongest radar returns are expected.

So even if you have never been to that city, you can accurately predict areas of brightest and numerous returns by interpreting the lines of communication.

By design, streets in many cities are oriented to cardinal directions (i.e. north, south, east and west). Returns often appear persistent, bright, and oriented in the same direction as lines of communication. This is called "cardinal effect". A variant to this occurs in mountainous terrain as streets are oriented with valleys, not necessarily in cardinal directions.

5. Bridges: The metallic superstructures of bridges generally give excellent radar returns. Additionally, masking is not normally present in the immediate vicinity of these structures and any expanse of water in front of the bridge will enhance their radar reflective capabilities. Bridges oriented perpendicularly to the radar beam will generally paint a radar return depicting the entire length of the bridge on the scope. A bridge oriented parallel to the radar beam reflects less energy and displays a "ladder effect" return on the scope. At longer ranges, few blips in the "ladder" are observed, but this effect lessens as range decreases. Obviously, the radar return displayed on the scope will change with the type of construction, the overall size, the run-in heading, and the terrain of the bridge area.

6. Power lines and Towers: Steel electrical transmission towers, radio/microwave/water towers, fire watch towers, and oil wells are generally considered poor radar checkpoints. The use of these features as aids for navigation should be limited. They are usually only symbolized on charts rather than precisely located geographically and their returns may be buried in a mass of cultural returns in a town. Steel electrical transmission towers will occasionally present a surprise return for three or four sweeps when the radar beam is aimed parallel to a line of towers. This "surprise" is a long chain of evenly spaced, very regular blips that is displayed on the scope. This phenomenon should not be used as a radar checkpoint since its occurrence depends on several parameters coming together at a specific time.

#### **TPC CHART/RADAR SCOPE INTERPRETATION**

TPC charts depict both topographic and cultural features. As a summary of the previous material, the following chart lists some generalized radar returns by intensity. Your own radar interpretation will not always be as clear cut as this chart.

BRIGHT RETURNS	MEDIUM RETURNS	LIGHT RETURNS	NO SHOWS
Cities	Residential Areas	Ground Return	Lakes/ Rivers
Factories	Small Towns	Snow & Ice	Mountain Shadows
Bridges	Rain Showers		Dry Lake
Lines of Communication			Snow & Ice
Rail Yards w/ Rolling Stock			Runways
Thunderstorms			Valleys
Grain Elevators			
Near Side of Ridges			
Refineries			
Far Shore brightening			

#### GROUND MAPPING RADAR CHARACTERISTICS

The ground mapping radar is subject to certain limitations not applicable in the air-to-air modes. There are certain errors and distortions in the displayed returns which are a result of the physical characteristics of the radar set or the processing devices.

##### Beam Width Error

The radar beam width (BW) determines the azimuth resolution of the radar set. It also introduces an error into the scope presentation called "beam width error" (BWE). This BWE is produced as the radar beam scans the ground. The leading edge of the beam (see Figure 6) hits the object and the radar return is painted on the scope. It will continue to be painted until the trailing edge of the beam passes the target. This effectively adds the distance of one beam width to the painted echo by adding half the BW to each side. BWE, because it increases as range from an object increases, is considered the largest of all scope presentation errors.

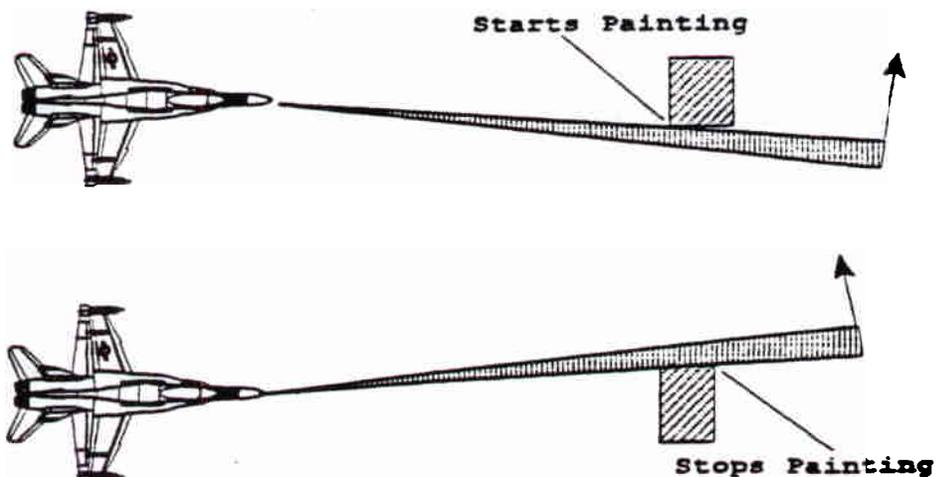


Figure 6

As you can deduce, if two objects are separated by less than one BW, the leading edge of the beam will cause returns from the second object before the trailing edge is finished with the first object. This causes the radar to paint the two objects as one.

The major effect this has on the operator is determining when and if two particular objects can be displayed separately by the radar (azimuth resolution). To determine the range at which a particular object can be discerned, simply divide the distance between objects by the beam width at one mile. For example, consider Figure 7 which shows a river that is 1/2 NM wide (3000 feet) and is oriented parallel to the antenna. With a beam width of 250 feet per NM, the radar will not be able to paint the shorelines until the river is within approximately 12 NM (3000 divided by 250 = 12.0). This is a result of BWE, which causes the radar to paint the two shorelines as one.

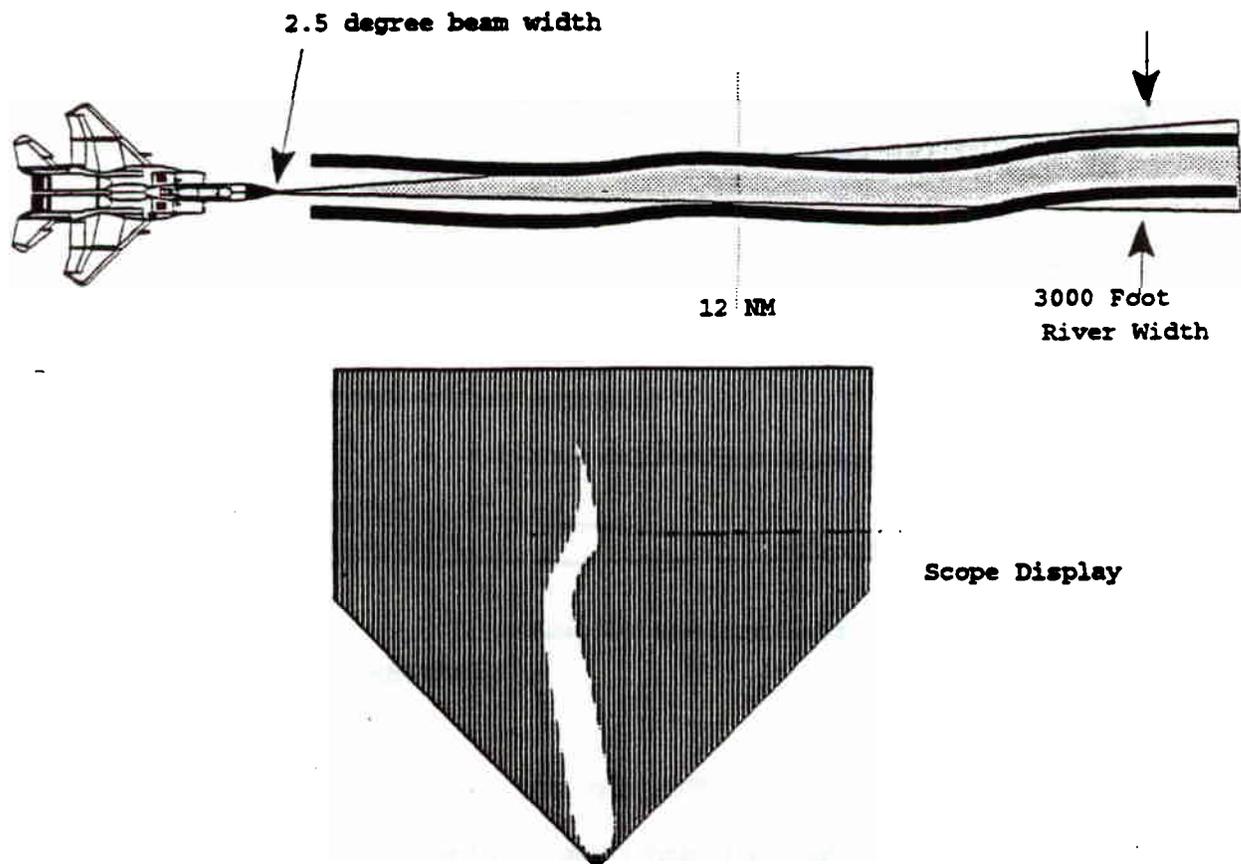


Figure 7

### Pulse Length Error

The pulse length of your radar determines its range resolution. As discussed in the radar principles unit, the range resolution is  $1/2$  the Pulse Length (PL/2). You must keep range resolution in mind when making predictions and selecting checkpoints because it affects what can and cannot be painted on the display.

Another error evident in the scope presentation is Pulse Length Error (PLE). In order to understand Pulse Length Error (PLE), consider the following occurrences: (1) The leading edge of the pulse hits the near side of the building B in Figure 8. During the time that the pulse was traveling to B, echoes from A were returning back to the radar.

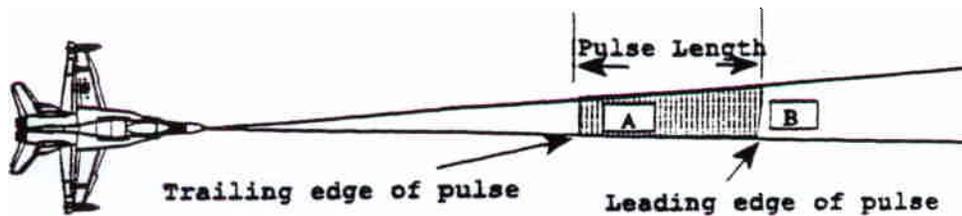


Figure 8

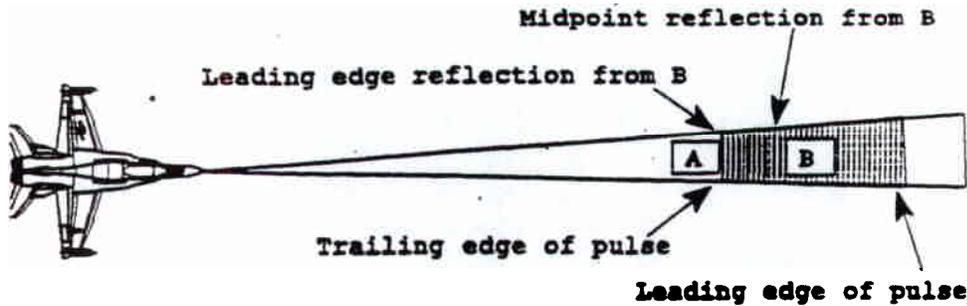


Figure 9

(2) In figure 9, as reflections caused by the leading edge hitting the near side of building B were traveling back to the radar, the trailing edge of the transmission was still traveling to the far edge of building A. The reflection from the leading edge of the pulse hitting the near side of B is now coinciding with the last reflection (due to the trailing edge) from building A.

This demonstrates for us that the reflections from the leading edge of the pulse will always be in synch (or parallel) with the reflections from the trailing edge of the pulse. For every foot that the transmission travels, the echo has to travel that same distance back to the radar. This characteristic effectively adds the distance of  $1/2$  PL to the target echo.

We can deduce that if two objects are on the same bearing, and the midpoint of the pulse hits the second object before the trailing edge finishes with the first object, both objects will be displayed as one. Therefore, two objects must be more than  $1/2$  PL apart for the radar to distinguish them as separate units. When operating a radar, you should not expect the radar to paint a river that is any less than  $1/2$  PL wide and perpendicular to the aircraft heading. Additionally, the operator should keep in mind that the radar will automatically add  $1/2$  PL to the depth of an object. One final note to remember: Pulse Length Error is independent of the range to the target.

## Spot Size Error

Spot Size Error (SSE) is an inherent error caused by scattering of electronic energy when electrons hit the inside face of the radar scope or CRT. The SSE produces a fringe (or halo effect) around the displayed target. The amount of SSE is determined by the individual pixel resolution of the Cathode Ray tube and can be controlled with proper receiver gain and video gain controls. This effect is usually ignored because, if controlled properly, it is small in comparison to BWE and PLE.

## Sum of Scope Errors

Because all of the errors have a cumulative effect on the scope display, the operator must sum all of these inherent errors:

- BWE adds 1/2 the beam width to each side of the return. It is the only error to decrease with decreasing range.
- PLE adds 1/2 the pulse length to the back of both the return and any beam width error.
- Spot size error adds to all sides of the return but varies with control inputs.

The cumulative effect of all errors is shown in Figure 10.

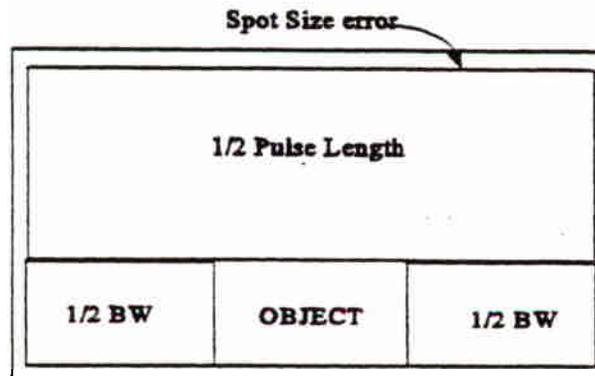


Figure 10

This page reserved for notes

## GROUND MAPPING RADAR CONTROLS

The T-39 has three student stations for utilizing the ground mapping radar. The radar on/off switch is located on the pilot's left console, which also houses a ground RADAR TRANSMIT OVERRIDE switch (for maintenance use only). Although there are Multi-functional Displays (MFD) on both sides of the aft cabin, only the right side station is fully functional with a HCU. Selection of the operating radar station is made using the RADAR SYSTEM SELECT switch at the two instructor stations. Regardless of who has control of the radar, all three stations are on as monitors.

There is a separate knob on the cockpit instrument panel, labeled RAD ANT, next to the HORIZ STAB TRIM gauge. This knob is used only to adjust the intensity of the INU cursor on the screen. At the rear radar station, this knob is located above the MFD. The knob is active only for the station which has control of the radar.

### Multifunction Displays

The 5" monochrome CRT MFD is the primary interface between operator and the radar system. Control for the radar is provided through the use of three "hard" keys (dedicated functions) and eight "soft" keys (non-dedicated functions). There are also 5 "soft" keys on the right side of the MFD used only for INU initialization. Figure 1 below shows these keys and their orientation.

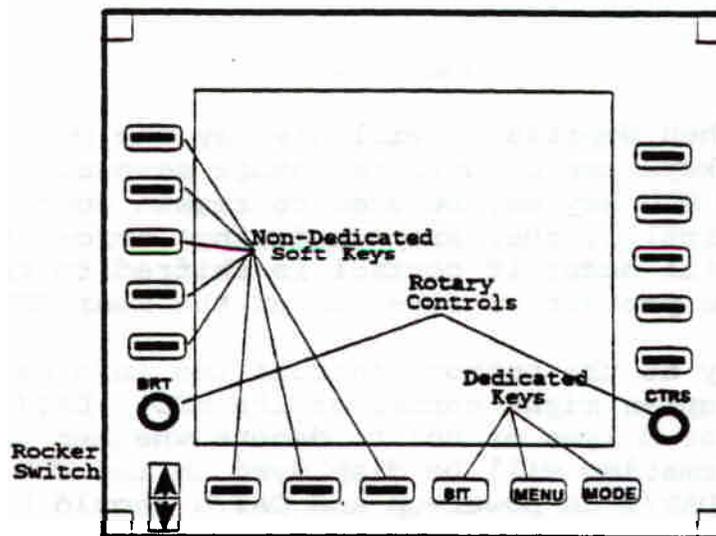


Figure 1

## Hard Keys

(1) Mode: When depressed, the MFD will display the mode functions, as shown in Figure 2. They are Ground Mapping (MAP) and Standby (SBY). To select a mode, depress the soft key next to the mode desired. If no change in mode is desired, press the MODE key a second time and the screen will revert to the mode previously in use. The mode in use will be displayed in the upper left corner of the MFD.

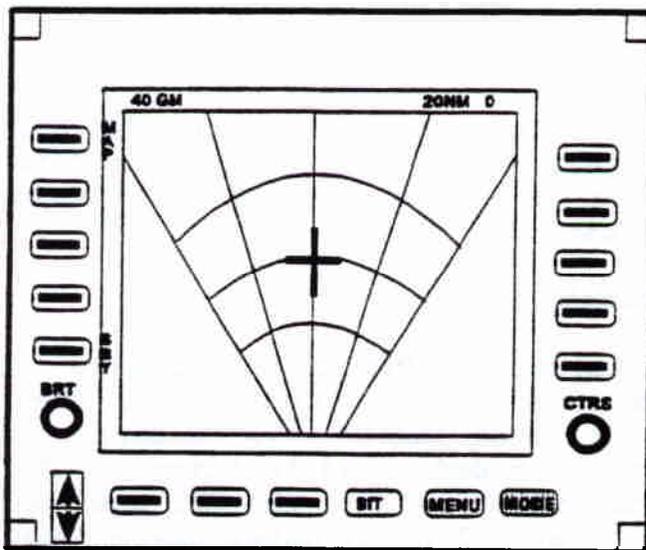


Figure 2

(2) Menu: When depressed, will display the menu selection page. The soft keys can be used to change several radar parameters. The HCU key may be used to regain control of the cursors (crosshairs) if they are "wandering" across the scope. This wandering will occur if control is shifted to the back station while the protective cover is on the rear HCU.

The DAT/ key at the bottom controls the information that is provided in the upper right corner of the MFD. DAT/ will be followed by a Y or N (yes or no) to denote whether cursor range and bearing information will be displayed on the MFD. The MFD will default to DAT/Y on power-up and DAT/N should be selected before flight.

The BLK/N key is not operational in ground mapping modes. Pressing the MENU key a second time returns the display to the current mode of operation.

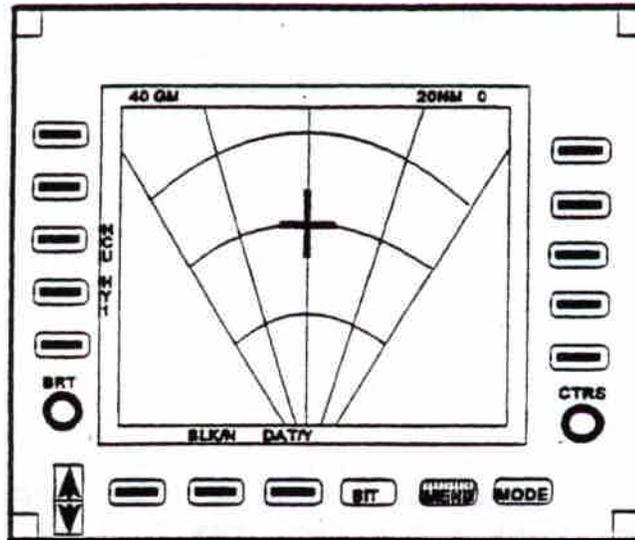


Figure 3

(3) BIT: when depressed, this key will show the Built-in-Test (BIT) page. The BIT enables a display of continuous BIT Line-Replaceable-Unit (LRU) status, and the ground mapping picture will not be displayed. Each LRU is listed with a corresponding status of either NORMAL, DEGRADED, or FAIL.

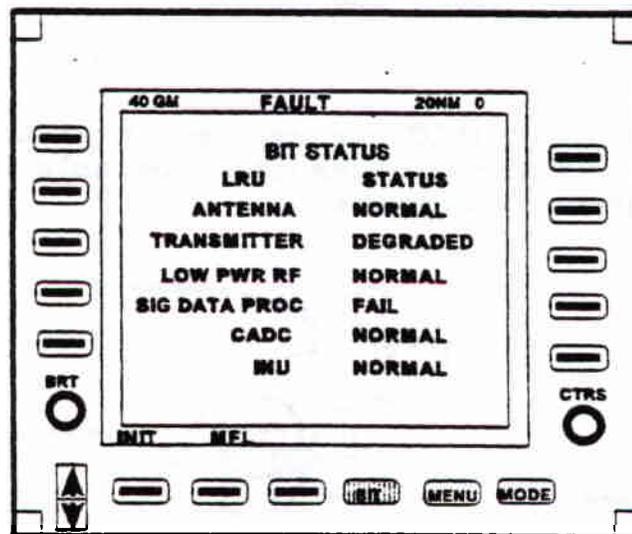


Figure 4

Two soft keys in the lower left corner of the BIT page allow either the Maintenance Fault List (MFL) or BIT Initialization (INIT) to display. The MFL gives further information on degraded or failed Line Replaceable Units (LRU). This information will stay in the MFL until engine shutdown with weight-on-wheels, as long as the fault condition continues to exist. The INIT soft key will initiate a 15 second test of the LRU's, after which time the display will return to the mode selected before running the BIT page. Also, depressing the BIT hardkey at any time will revert back to a previous mode of operation.

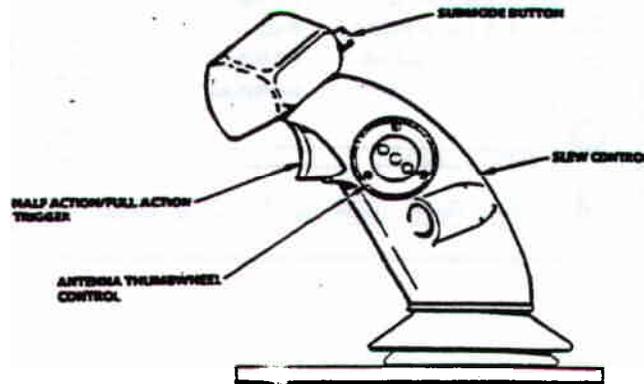
### Rotary Controls

There are two rotary control knobs on the MFD, the Brightness (BRT) control and the Contrast (CTRS) control. The proper positioning of these knobs requires that you select the STBY mode. A gradient scale will be displayed across the bottom of the MFD. The MFD will be blank if BRT is full counter-clockwise. Turn the CTRS knob full clockwise, then counter-clockwise a quarter turn. Brightness should then be adjusted so that the furthest left block of the gradient scale is barely distinguishable from the background.

A rocker switch, located in the lower left corner of the MFD, controls Receiver Gain (REC GAIN). It is adjusted by pushing the switch up or down to either increase or decrease the sensitivity of the radar display. A small indexer in the lower left corner of the screen shows the setting of the Receiver Gain.

### Hand Control Unit

The Hand Control Unit (HCU) is another interface. As shown below, the HCU has two control mechanisms operable in ground mapping: slew and antenna thumbwheel.



Hand Control Unit  
Figure 5

(1) Slew: The HCU is a self-centering, displacement-type control. When moved out of the center detent, the HCU will slew the cursors on the radar in both azimuth and range. A slight deflection results in slow movement, a full deflection gives quick movement. Once positioned, the cursors will be ground stabilized by the INU, tracking a given return.

(2) Antenna Thumbwheel: The thumbwheel is the antenna elevation control that is a thumb-operated, rotary knob. Rotating the thumbwheel away from you causes the antenna to move down in elevation, and vice versa as you move it towards you. This allows a full +/- 40° of elevation control. antenna elevation is displayed by an indexer and scale along the right side of the MFD. This indexer will dim when properly positioned for optimum coverage. The antenna should be left in the optimum position, with the indexer dimmed, until inside 10NM, where it will require manual adjustment.

Note: Keeping radar energy aimed at the target until marking on top will require "dumping" (manually tracking the target with the antenna) the antenna inside 5NM. The antenna can be dumped beyond the gimbal limits, at which point the antenna sweep indexer at the bottom of the MFD will freeze. To correct, simply raise the antenna slowly until sweep resumes.

#### Ground Mapping Operation

The GM mode provides the operator with an all-weather, drift stabilized map of the ground area ahead of the aircraft. A maximum azimuth of 45° to each side is provided in a Plan Position Indicator (PPI) format, with range selectable from 5 to 80 nautical miles. GM is selected by depressing the MAP soft key on the MODE selection page. Figure 6 shows the GM display.

(1) Azimuth: Used to select a radar scan of +/- 45°, +/- 30°, or +/- 10°. The respective scan width display will be "AZF", "AZ3", or "AZ1", and is selected by depressions of the key.

(2) Range Scale: Used to manually select the radar range of 80, 40, 20, 10, or 5 nautical miles. The respective display will be "R80", "R40", etc. The range selection will also be displayed in the upper left corner of the MFD.

(3) Center Cursor: Used to place cursors at the center of the MFD display. The cursor will then "snowplow" at a constant distance of one-half the range selected ahead of the aircraft until the HCU is out of detent. Softkey display will always be labeled "CTR".

(4) Marker Intensity: Used to increase intensity of range rings and strobes. Display will be "MK1", "MK2", etc., for preset intensities.

(5) Freeze: Used to "freeze" the displayed radar picture at the time selected. The antenna continues to move but does not change the MFD picture. Display will be "FRZ" with a frozen picture and "UNF" during normal operation. You must depress the key a second time to unfreeze the radar display.

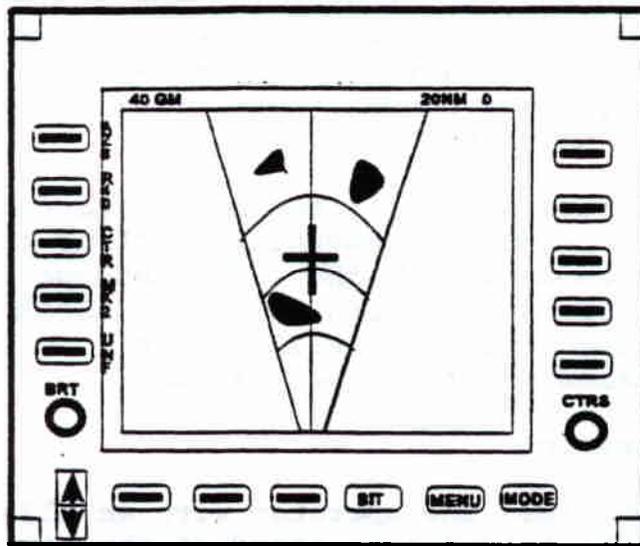


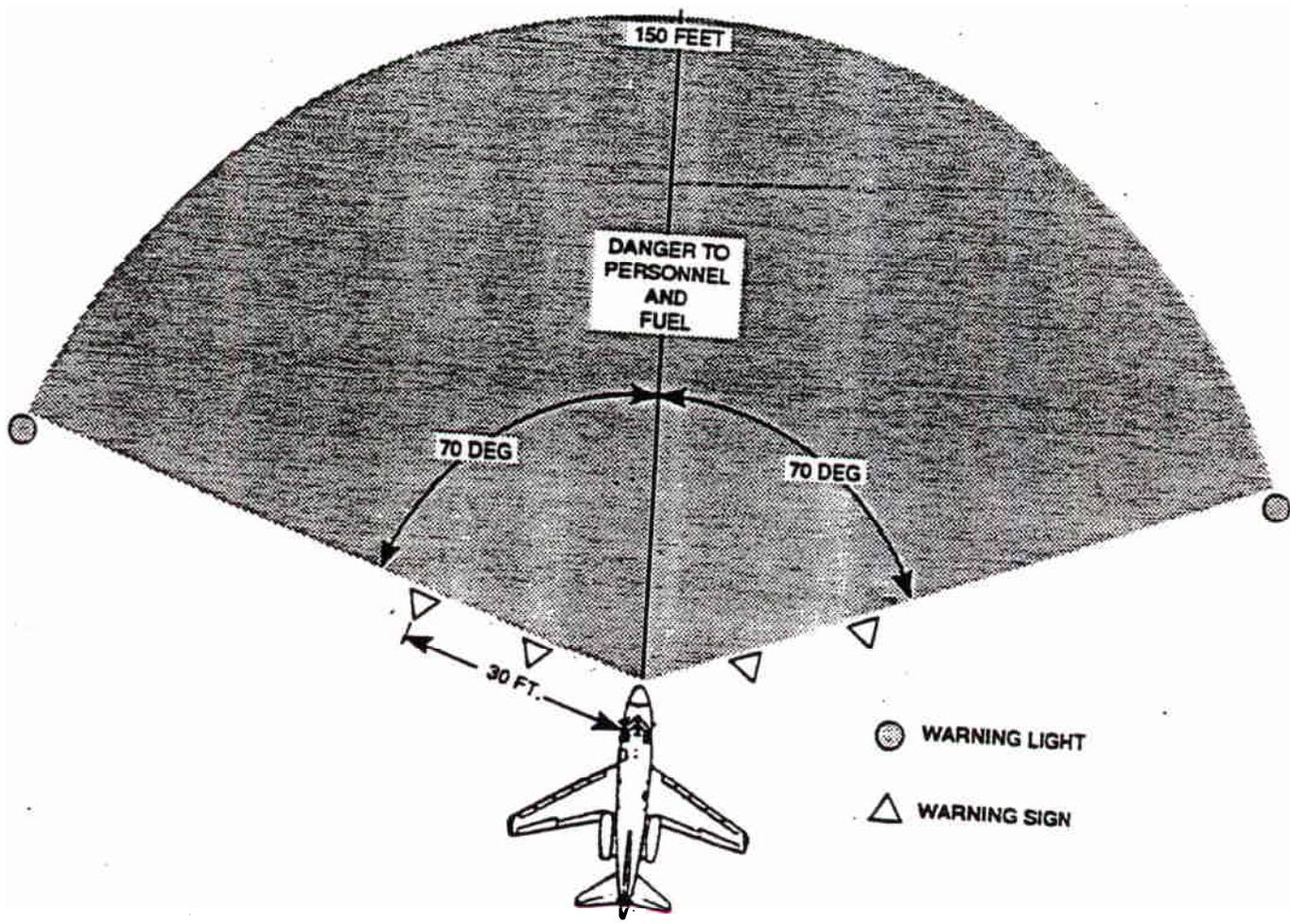
Figure 6

### Radar Ground Operation

The radar may be operated in a transmitting mode on the deck by placing the RADAR CONTROL switch to the ORIDE (override) position after lifting the red guard. This is not designed for aircrew use, but for maintenance purposes only.

If you experience a radar fault before takeoff and the maintenance personnel request you operate the radar on deck, you MUST abide by the WARNING on page 8-37 of the T-39N NATOPS. This WARNING precludes ground operation of the radar unless the aircrew ensure there are no personnel within the designated hazardous area of +/- 70° and with 150 feet of the nose of the aircraft. Figure 7 on the next page shows this danger area.

SAFE TO PERSONNEL  
SAFE TO FUEL



Radar Danger Area  
Figure 7

This page reserved for notes

## Unit 3: AIR INTERCEPT RADAR SCOPE INTERPRETATION

### Preview

The multi-mission capabilities of modern strike aircraft enable them to perform air intercept missions as lethally proficient as the air-to-ground missions. The key to this success is operator skill in manipulating the radar system for each different mission requirement.

Although the cockpit arrangement is identical, the controls and capabilities of the APG-66NT radar system differ vastly for each mission. Those components of the system that do not differ will not be addressed in this section.

### Antenna

The APG-66NT planar array antenna located in the nose is used for air intercept missions. The spoiler array, used to provide uniform illumination of the surface in the ground mapping mode, is inactive during these missions.

The antenna generates a 3.45° pencil beam which is mechanically scanned with an electric motor to create a search pattern. The antenna has the capability to move  $\pm 60^\circ$  of azimuth and  $\pm 60^\circ$  of elevation. Scan patterns and scan rates vary depending on the volume and range scale selected. Although in the fleet you will use the advantages of these different scan volumes, here at VT-86 you will use a one bar scan pattern for all air intercept work (Figure 1).

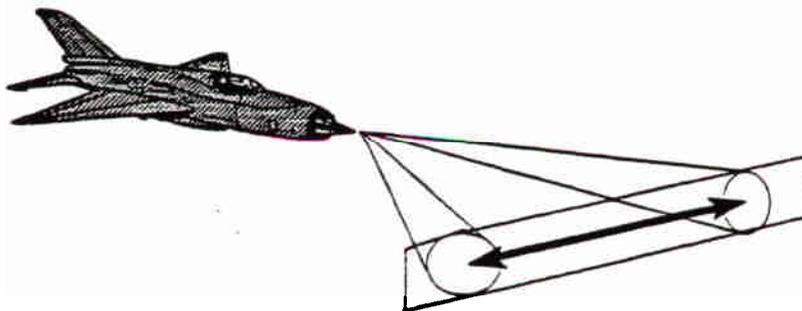


Figure 1

In the primary air-to-air mode of Pulse Search (PLS), the antenna can be scanned to 60° either side of the nose (total of 120°), or a smaller sector scan of 40° may be selected on the Multifunctional Display (MFD). There are two methods of using this sector scan: PLS Slewable and PLS Sector. In slewable mode, the 40° of scan will move relative to the Hand Control Unit's (HCU) acquisition symbol (also known as range gates). In sector, the 40° of scan is anchored wherever the acquisition (ACQ) symbol was last positioned when the submode button on the HCU was selected. This will be covered in more detail in a later discussion.

In all modes of the radar, the antenna is designed to sweep parallel to the horizon no matter what the aircraft attitude. This scan volume is said to be ground stabilized. This is accomplished via a gyro mechanism that is separate from the aircraft attitude reference. The result is a stable elevation platform of the antenna regardless of aircraft pitch attitudes (figure 2). This enables the operator to effectively determine target altitudes throughout the intercept.

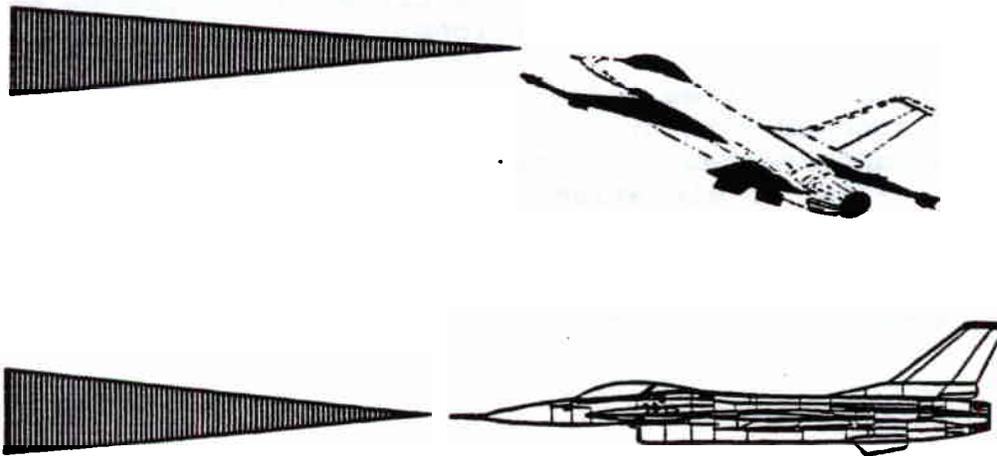


Figure 2

## Displays

As you begin the air intercept portion of your training through VT-86, you should be fairly adept at the displays and functions of your radar system. However, there are some differences in the air intercept modes that should be noted.

Located in the lower left corner of the MFD (figure 3), the Receiver Gain rocker switch which simulates control of the actual receiver threshold (in actuality, you are just controlling the sensitivity of your video display). For intercepts, you need to be continuously manipulating the displayed size of all radar contacts to keep them uniform at about 2-3° wide in azimuth. Any bigger will interfere with your ability to accurately determine contact parameters; any less may cause you to lose your contact amongst the clutter.

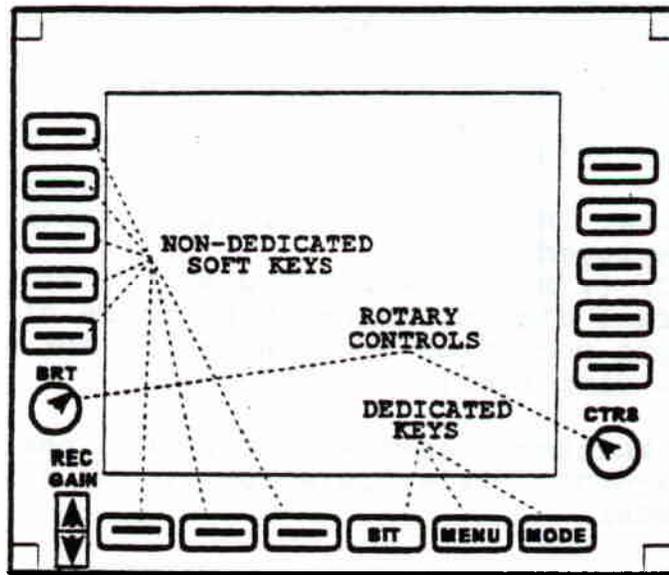


Figure 3

In the lower right row there are three permanently designated keys, the hardkeys: BIT, MENU, MODE.

1) The MODE hardkey displays the different modes available to the operator. The primary air intercept selection will be PLS. In later portions of your training, you will be introduced to Up Look Search (ULS) and Down Look Search (DLS), also referred to as "advanced modes". Pressing the desired soft key will cause the radar to enter into that mode. Pressing the MODE key a second time without selecting any of the modes (PLS, ULS, or DLS) will return the radar to the previous mode of operation.

2) The MENU hardkey displays the different universal radar parameters. These parameters are the same regardless of the mode of operation:

- a) HCU: manually recalibrates the Hand Control Unit to a centered position. Only used if HCU does not center normally.
- b) HY: Target History, selects how many video returns will remain on the scope as the bogey is displayed. Normally set at "HY1".
- c) CH: Radar Channelization, selects the frequency the radar will operate on. To maintain the greatest possible separation with your wingman, odd numbered flights (i.e. Rocket 521) selects "CH1", and even numbered flights (i.e. Rocket 520) selects "CH4".
- d) SPM/N: Squint pair Mapping, not used in air intercept modes.
- e) BLK/ (Y/N): Attitude Blanker, allows the attitude line to be blanked from being displayed on the scope. Normally set at BLK/N (attitude line displayed).
- f) DAT/ (Y/N): Data Block display, allows displayed target digital information to be displayed in upper right corner of MFD. Normally set at DAT/N (data not displayed).

3) The BIT hardkey allows you to access the Built-in-Test modes of the APG-66NT. It's operation is the same as in the air-to-ground radar.

#### Hand Control Unit

The Hand Control Unit (HCU) consists of a hand control with a two detent trigger, an antenna elevation thumbwheel, and a submode button (figure 4). The HCU provides control for acquisition gate (also known as the cursor and range gates) movement and antenna control.

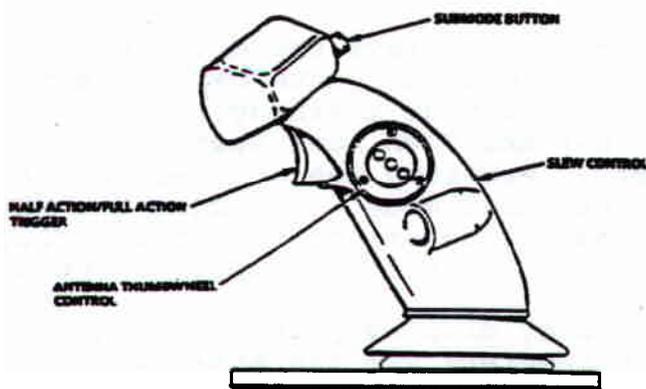


Figure 4

Movement of the HCU moves the position of the acquisition gates used for locking a target. The acquisition gates are two parallel lines approximately 6° apart that are normally in their default position, centered at the bottom of the MFD. Movement of the gates is via the HCU back and forth, left and right.

A rotary wheel is mounted on the inboard side of the HCU to adjust antenna elevation. In PLS, antenna elevation limits of +/- 20° are available via this thumbwheel. There is a Coarse Antenna Control knob located near each MFD that enables the operator to scan the full range of the antenna elevation limits (+/- 60°). Some manual dexterity is required to coordinate the use of both controls at the same time.

The readout of antenna elevation is on the right side of the MFD, displayed by a tic mark (or el strobe). The actual elevation must be interpolated using the scale displayed on the right side of the MFD. Once you have obtained a good radar return on your bogey, via a technique known as spotlighting, the bogey's relative elevation can be read off the el strobe. Scribe marks are displayed on the right side of the MFD, as well as an electronic zero degree reference mark.

The HCU has two trigger positions: half-action and full-action. The first position (half-action or detent) of the trigger collapses the radar sweep to +/- 5° at the azimuth set by the acquisition gates. This allows the operator to fine-tune the display to ensure the greatest possible radar return is received. The second position (full-action or detent) of the trigger collapses the sweep further to +/- 2 1/2° at the azimuth set. Once the trigger is released, any return found in the acquisition gates will be locked and auto track of that target will occur. If nothing is found the radar will default back to its original mode (PLS). Selecting half-action after a good lock is acquired will also return the radar back to the previous search mode. If the lock breaks for any other reason, the scan will return to a full sector search.

On the upper portion of the HCU is the Submode Button. A depression of this button in the PLS mode will cause the sector scan to be anchored +/- 20° about the acquisition gates position when the button was depressed. A second depression of the button will return the radar to full sweep.

### **Search Displays and Techniques**

The APG-66NT start up sequence is the same as you performed in the air-to-ground flights. The difference occurs after you have taken the NAV RDY alignment by selecting the MODE hardkey. In the aircraft designated as intercept, the default mode is PLS mode. There are now several softkeys available on the left side of the MFD (figure 5).

The following softkeys will be used by you during the intercept:

- AZ: Azimuth scan width selection. Either +/- 60° (AZF), or +/- 20° (AZ2) can be selected.
- R: Range scale selection. The numbers below the "R" signifies the range (either 80, 40, 20, 10, or 5 NM) that the entire scope represents, divided up into equal segments by the horizontal lines.
- BR: Shows selected bar scan. Either 1 bar, 2 bar, or 4 bar scan can be selected. You will use 1 bar.
- MK: Indicates the marker grid (horizontal & vertical lines) intensity level.

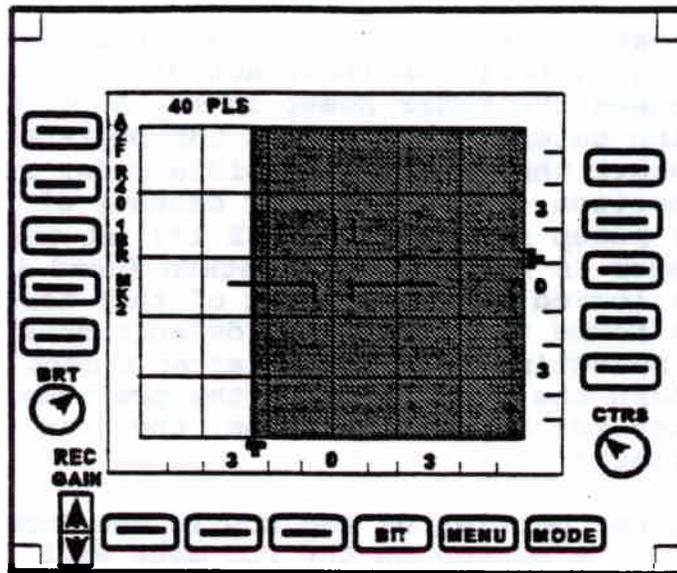


Figure 5

Several symbols are superimposed on the video display in the search mode and are always present:

**A-H Bar:** Artificial horizon bar, an aircraft attitude indicator superimposed on the screen. It's display is the same as a attitude gyro to show aircraft nose and wing position.

**El Strobe:** A scale is provided on the right edge of the MFD to aid in elevation determination. The screen will display two electronic tic marks: one is stationary at 0° elevation, the other represents where the center of the main lobe of your radar is actually pointing. If the thumbwheel on the HCU is rotated up, the tic moves up as the antenna is physically pointed up in elevation. Relative elevation is read off the MFD by comparing the actual elevation tic to the stationary 0° tic mark.

**ACQ gates:** Two parallel lines approximately 6° in width that are used to lock the target. It is normally located in the default position, centered at the bottom of the MFD. Pushing forward on the HCU moves the acquisition gates up the scope, lateral deflections of the HCU move the gates side to side.

### Search Techniques

To operate the radar effectively in the search mode, precise target range, azimuth, and elevation must be determined. A disciplined search technique must be used to quickly locate the target. Once radar contact is made, the range determination is a simple interpretation of the selected range scale. The analysis of target elevation can be deceptive unless the target is accurately "spotlighted" by the radar. Spotlighting is the technique of moving the antenna carefully in elevation to receive the greatest target energy return. Once an accurate elevation is determined, the target's altitude is made via simple math.

### Search Increments

The APG-66NT radar operates in the intercept mode with a beam width of 3.45°, with the shape of an ever expanding cone. As range increases, the area covered by the beam increases and the transmitted power is spread over a larger and larger volume. The figure below represents the true shape of a radar beam.

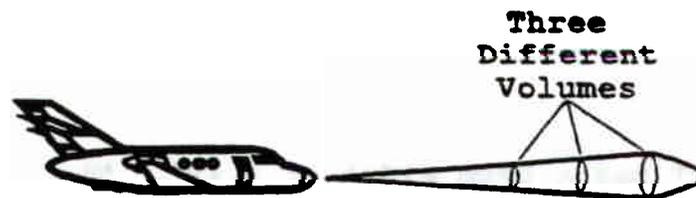


Figure 6

Because of the limited scan volume, the antenna must be deliberately moved to find the bogey in the fastest possible manner. Gouge numbers have been provided that must be committed to memory and put to use. It is only through a disciplined search technique that an operator will consistently have long range contacts.

Range	Search Limits	Increments
40 to 20	+/- 1°	1°
20 to 10	+/- 3°	3°
10 to 5	+/- 9°	3°
< 5	+/- 60°	3°

These numbers are valid for an altitude block of 10-20 thousand feet. A conscious decision must be made as to when the antenna should move during the search phase. Never move the antenna in the middle of a sweep. Instead, pick one side of the scope, allow the sweep to fully go from one side of the scope to the other, then move the antenna the prescribed increment.

#### Azimuth Determination

A secondary use of the acquisition gates symbol is as an aid in determining target angle off. For example, suppose a target appeared exactly 25° left of the nose. The operator notes that this position is not quite halfway between the 20° vertical scribe and the 40° scribe. Since the operator must interpolate to make an accurate azimuth determination, the acquisition gates can be useful. Since they are approximately 6° wide, the operator can slew the symbol so that one side is coincident with the 20° scribe. This now makes the other side of the acquisition symbol at about 26° left of the nose, which gives the operator a frame of reference from which to make a more accurate determination of angle off.

#### Spotlighting

The APG-66NT has a beam width of 3.45°. The antenna should be moved up or down in elevation to provide the strongest radar return on a target. This ensures that the beam is centered on the target and allows the correct elevation to be determined. A faint return occurs when the antenna is pointing too far above or too far below the target (figure 8). Although the target will still appear on the scope, it will be a weaker signal than if the main beam was centered. This would prevent the operator from incorrectly ascertaining the targets elevation because the el strobe position indicates the center of the main beam. This concept is known as spotlighting and requires constant attention of the operator to affect the best return signature on the target.

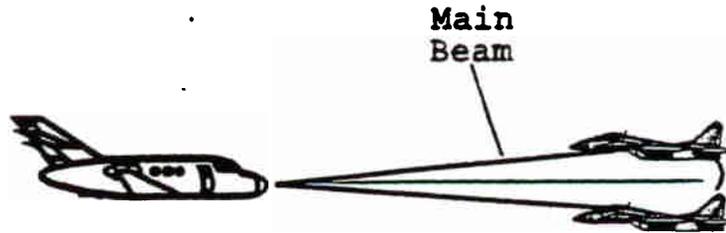


Figure 8

Using simple geometry will allow the operator to estimate target altitude. Given that our radar measures slant range, and the angle of elevation is angle A (figure 9), we can use trigonometry to determine the altitude differential between the fighter and the target:

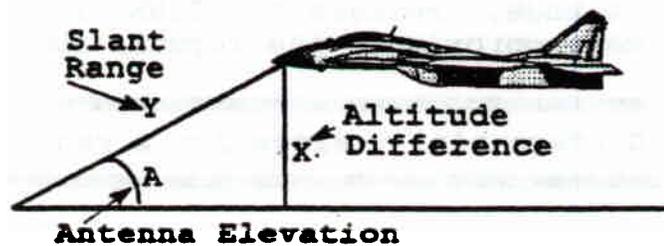


Figure 9

$$\text{SIN}(A) = X/Y$$

Y = Slant Range

A = Elevation

X = Altitude Difference between fighter and target

As an example: A target is spotlighted so that the target antenna elevation is 2° high at 20 miles. If the fighter altitude is 16,000 feet, what is the target altitude?

$$\text{SIN}(A) = X/Y$$

$$X = \text{SIN}(A) \times (Y)$$

$$X = \text{SIN}(2^\circ) \times (20 \text{ miles})$$

$$\text{converting } 20 \text{ miles} = 120,000 \text{ feet}$$

$$\text{converting } \text{SIN}(2^\circ) = .0349$$

$$X = (.0349) \times (120,000 \text{ feet})$$

$$X = 4,188 \text{ feet}$$

$$\text{Target alt.} = \text{fighter altitude} + \text{alt. difference}$$

$$\text{Target alt.} = 16,000 \text{ feet} + 4,188 \text{ feet}$$

$$= 20,188 \text{ feet}$$

There are two options to using this formula: 1) carry a programmable calculator in your tactical aircraft and hope that no one calls you a "geek", or 2) use a simpler gouge formula to determine target altitude. Because the SINE of a small number is close to zero, we can approximate the formula above with:

---

$$\text{Altitude Differential} = \text{elevation} \times \text{range} \times 100$$

---

In the example above, the calculations would be:

$$X = 2^\circ \times 20 \times 100$$

$$= 4,000$$

$$\text{Target altitude} = 16,000 + 4,000$$

$$= 20,000 \text{ feet}$$

#### Level Antenna

The APG-66NT radar, being a marvel of 20th century digital electronics, utilizes electronic antenna elevation that always levels the antenna at the zero tick mark on your scope. But to those fortunate warriors who will be F-14 RIO's, you will find that its 1960-era analog computer technology does not quite do all that this radar here can.

If your antenna level tic mark is in error by a few degrees, which it often is, your target altitude estimates will be off as well. There are two ways to verify the correct level antenna position. Each should be used if possible to provide the most educated guess of the actual level antenna position.

The first method is to use the altitude return of your own aircraft from the main beam. If the aircraft is in level flight at any altitude and the antenna is pointed 10° down, you will see ground return at the range (in miles) of the aircraft altitude. For example, if we are flying at 20,000 feet and point the antenna 10° down:

$$\text{Altitude difference} = \text{elevation} \times \text{range} \times 100$$

$$\text{Range} = \text{Altitude difference} / (\text{elevation} \times 100)$$

$$\text{Range} = 20,000 / (10^\circ \times 100)$$

$$\text{Range} = 20 \text{ miles}$$

The ground return will appear at 20 miles on the scope. Knowing this, we can check the antenna for level position. If the ground return appears at 20 miles with the antenna looking 8° low, we have a positive two degree difference. Level antenna will have to be 2° high in order correctly determine target altitude. We will also have to add two degrees to all elevations. Level antenna is termed "2° high".

The second method to verify level antenna is to find an airborne target with a known altitude. Here at VT-86, the fighter aircraft operates at 16,000 feet. During your runs as the bogey, you can check your antenna elevation against this known altitude. For example, if you are at 18,000 feet during one run, you know that the other aircraft will be 2° low at 10 miles (2,000 feet altitude difference divided by 10 miles and 100). If the elevation is different than what you calculated, use that difference the same way that was discussed in the earlier paragraph.

#### Pulse Modes

Further manipulation of the Pulse system is accomplished through five other submodes: 1) PLS Slewable, 2) PLS Sector, 3) PLS Acquisition, 4) PLS Track, and 5) PLS Track w/ missiles.

PLS Slewable mode: this is entered when you select the AZF softkey on the MFD. The softkey will change to AZ2 to signify a +/- 20° scan width. The scan will actually be 20° on either side of the range gates, and will follow the gates wherever they go.

This allows you to effectively bracket a scan around the bogey throughout the intercept no matter where it appears on the scope. As a default, the scan will go no further left or right on the scope than 20° to 60°, even if the range gates are placed all the way to the ends.

**PLS Sector mode:** this is entered in the same initial manner as PLS slewable mode, with the addition of depressing the submode button on the Hand Control Unit. Once activated, the +/- 20° becomes "anchored" where the range gates were at time of the depression. This allows movement of the range gates without moving the scan volume off of its anchored point. A second depression of the submode releases the scan from its position and it once again follows the range gates wherever they go.

**PLS Acquisition mode:** this is entered when the Hand Control Unit trigger is pressed to the half-action position. The scan collapses to a +/- 5° "super search" scan, centered on the position of the acquisition gates. This super search allows the operator to highlight the bogey more effectively.

**PLS Track (No Missiles) mode:** actual acquisition of the bogey does not occur until the Hand Control Unit trigger is depressed to the full-action position and then released. Once activated, the radar will now automatically perform bogey illumination functions. A 2.5 NM range gate brackets the target to maintain this illumination. The upper-most left softkey switches from AZ to MSL. All other scope clutter disappears and only the locked bogey is present.

**PLS Track (with Missiles) mode:** this mode is established when the operator selects the MSL softkey. Successive depression on the softkey cycles from AIM-7 Sparrow (A7), AIM-9 Sidewinder (A9), AIM-54 Phoenix (A54), and back to MSL. The scope also displays other information of importance when employing weapons (see Figure 10 on the next page):

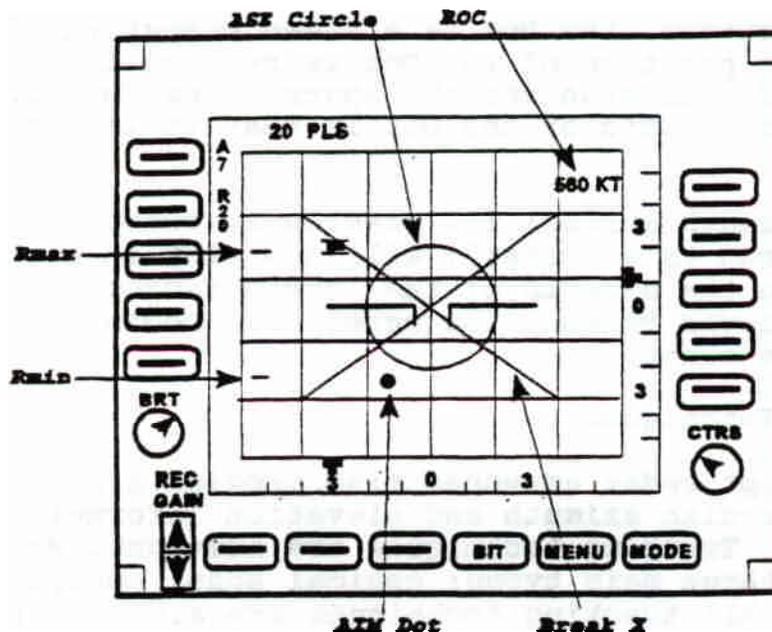


Figure 10

a) Rmax and Rmin: on the left side of the screen are two small horizontal tick marks which correspond to the maximum and minimum range of the selected missile.

b) Break X: this is displayed in the center of the scope to advise the operator that the aircraft is now beyond a safe envelope for firing a weapon. Either there is not enough time for the weapon to arm before impact or closure is too high to allow for a safe avoidance of explosive fragmentation patterns.

c) Rate of Closure (ROC): the relative rate of closure between the fighter and bogey aircraft will be displayed on the upper right side of scope. This occurs regardless of DAT Y/N position from the MENU hardkey.

d) Allowable Steering Error (ASE) Circle: displayed in the center, its purpose is to place the fighter aircraft in the correct attitude and approximate heading to launch a missile. It will change size depending on the missile selected and the range.

e) AIM Dot: an amplified display of the target's azimuth and elevation. The Dot's response is six times more sensitive than the target's actual position on the scope. Therefore, the Dot will only appear when the target is within 10° of azimuth and elevation. Another characteristic of the Dot is its function at different ranges. Outside of 12 NM, the Dot is an "angle off" Dot. This means that the position of the Dot will be at an angle off 6 times greater than the target's angle off.

Inside 12 NM, however, the Dot is a "lead computing" Dot. This implies that the position of the Dot is related to the computed position of lead collision for the Sparrow and Phoenix missiles. The final characteristic of the Dot is that it is aircraft stabilized.

f) Azimuth Strobe: The previously sweeping azimuth strobe (also known as a "caret") will now stay in a position corresponding to the azimuth of the locked target. If lock is broken, for whatever reason, the caret will begin sweeping again in a full sector sweep.

### Track and Lock Techniques

Air intercept radar antennas also provide a method to automatically furnish azimuth and elevation information with no operator input. Tracking techniques are numerous, so we'll just concentrate on three main types: conical scan, monopulse, and silent lobing. All tracking techniques are similar in that the radar compares returning radar signals to make a correlation of the highest level of signal strength.

1) Conical Scan: Shown in figure 11 below, it is one of the original tracking techniques. When a radar lock is obtained, the radar beam is nutated (rotated) around the target. The radar keeps track of which antenna position provides the greatest signal return and moves the antenna in that direction. This corrects for movements and error in target azimuth and elevation. Although this method has proven extremely reliable it is also easily jammed by enemy systems.

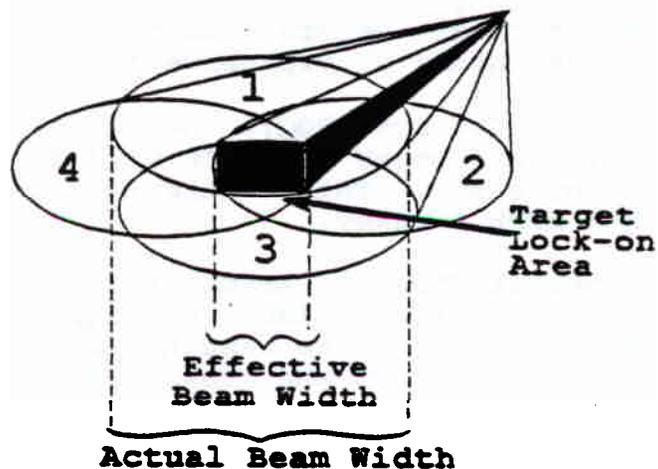
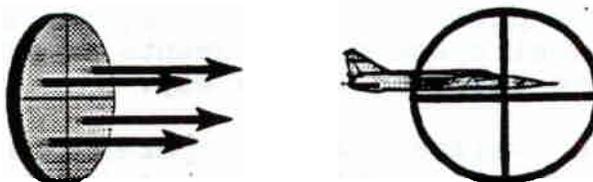


Figure 11

2) **Monopulse:** Shown in Figure 12, this is a newer technique that is less susceptible to deception by electronic means. The antenna face is divided into four quadrants for target return sampling. When a target is locked, the radar continues to transmit pulses. The four quadrants return four separate signals which are received and compared to each other. The antenna is moved in the direction of the quadrant with the highest signal strength. Because all four samples are taken at the same time with no delay between comparisons, this method has proven to be more jam resistant than the conical scan method.



**Monopulse**

**Figure 12**

3) **Silent Lobing:** This technique works in a similar fashion to the monopulse tracker. The antenna is split into two halves at a time, alternating between top & bottom and left & right. When a lock is initiated, the radar samples returns from the top and bottom of the antenna. The antenna then moves up or down depending on which half receives a greater return. The radar then compares signals from the left and right sides to make a correction for azimuth. Through continual correcting of elevation and azimuth the antenna automatically points to the target. This is the tracking technique employed by the APG-66NT radar in the T-39.

Regardless of the automatic tracking technique utilized by the radar system, the operator must first acquire a target via disciplined search increments and good spotlighting. As mentioned before, lock is activated when the trigger is released on the HCU, so care must be exercised when attempting lock to not move the HCU prematurely. If the lock attempt does fail the radar will always default to a PLS mode. This default is not instantaneous, however. While the radar returns to PLS, valuable

time is wasted as the bogey continues to travel downrange. Some good techniques include not attempting lock while in a turn, keeping a steady hand until releasing the HCU trigger, and ensuring a good spotlight is established so that the radar can acquire the target quickly. Once locked, interpolation of range, azimuth, and elevation is made easier because of less antenna movement on the operator's part.

### **Built in Tests**

The complexity of radar systems has significantly increased since their first inception. Along with their increased capability to detect targets, they also possess an increased capability to determine what's wrong with them when they do not operate properly. This is the purpose of the Built-in-Test (BIT) system. The APG-66NT has BITs available to the operator to check system performance prior to use. The system also continuously conducts an internal check of components to advise the operator if components have degraded in any way.

The BITs are available to the operator and are selectable via the BIT hardkey on the MFD. On the initial power up of the aircraft, a 3 minute Auto BIT sequence will occur and the results will be displayed. If there are any problems in this initial phase it may mean the aircraft is not mission capable for your event. Although this auto BIT is running, it will not be displayed on the MFD while the INS alignment is occurring.

The APG-66NT uses its continuous monitoring system during all phases of operation. If there is a fault detected, the system will display the FAULT at the top of the screen. If the operator selects the BIT hardkey, the BIT page will display. A second depression of the BIT will return the system to the previous mode. Selecting either the MFL (Maintenance Fault List) or INIT (Initialize) softkeys will perform those functions as appropriate.

### **ADVANCED MODES OF THE RADAR**

#### **Pulse Doppler Radar**

The APG-66NT also incorporates a Pulse Doppler (PD) radar system. Although the basic characteristics are similar to a Pulsed system, there are some significant differences. From a practical point of view, the radar is still transmitting a pulsed signal of a certain frequency, pulse width, and pulse length. The difference is that a PD radar measures the change in the returned signal frequency from a target in motion.

A simple demonstration of pulse doppler theory is an approaching train. As the train comes toward you, the sound that you hear appears to be of a higher frequency than the sound you

hear as it leaves. This is because the total signal of the sound is the addition of the motion of the train towards you as well as the motion of the sound waves. Figures 13a and b below shows graphically how the total frequency that you receive is affected by motion towards you and motion away.

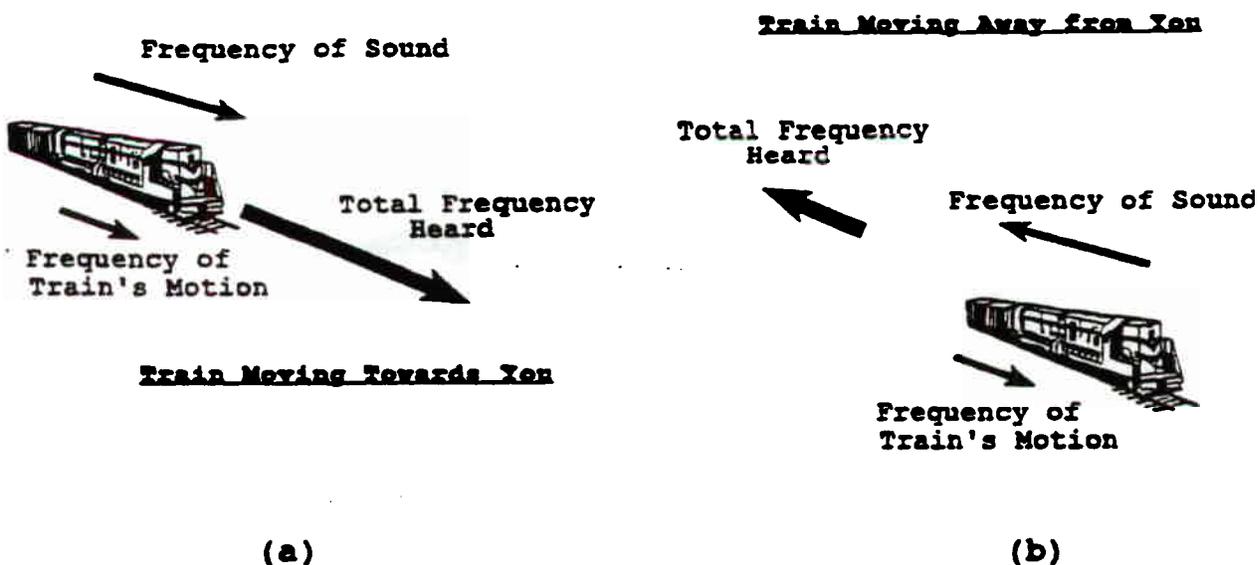


Figure 13

Although the figures are a bit exaggerated, we know from our own experiences that objects moving towards us appear to have a higher frequency than those moving away. That is because our ears pick up the total relative frequency of the noise made by the object. A PD radar system works the same way. It measures the shift in the total frequency that it receives and compares it to the frequency of the signal it originally sent out.

Airborne PD radar systems work on the same principle, with the radar looking for a change in the transmitted signal caused by a change in the frequency. Figure 14 on the next page shows an outgoing radar signal that is slightly different as it returns because it is the combination of the original frequency plus the frequency due to the motion of the target aircraft.

This method of determining target information has advantages and disadvantages. The biggest advantage is that the radar filters out unwanted returns easier because the things that make up clutter (i.e. clouds, ground return, vertical development, etc) have no real motion. Therefore, the frequency of the returning radar signal will be unaffected by these things and the radar displays won't show them. From a tactical point of view, it also means that simple jamming methods (i.e. chaff, pulse jammers, etc) will be ineffective against a PD radar system.

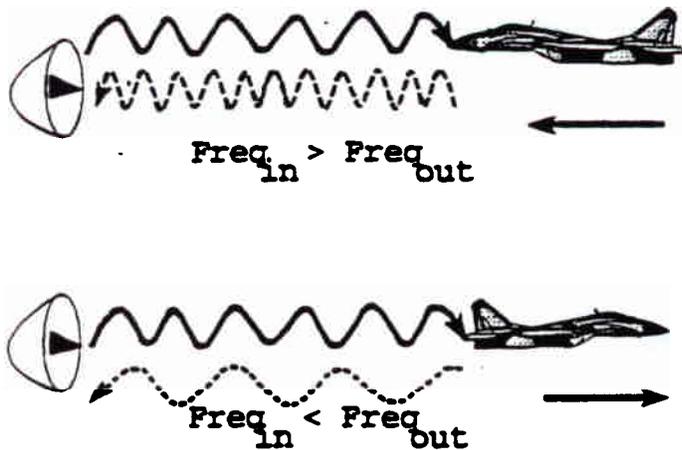


Figure 14

The system is not infallible, however, and the operator must be aware of its disadvantages. In order for a target to be detected, it must have relative motion with the radar signal. The figure below shows two instances when aircraft will not have any relative motion (and thus won't be displayed): 1) moving away at the same speed, and 2) in the beam, or 90 degrees crossing angle position.

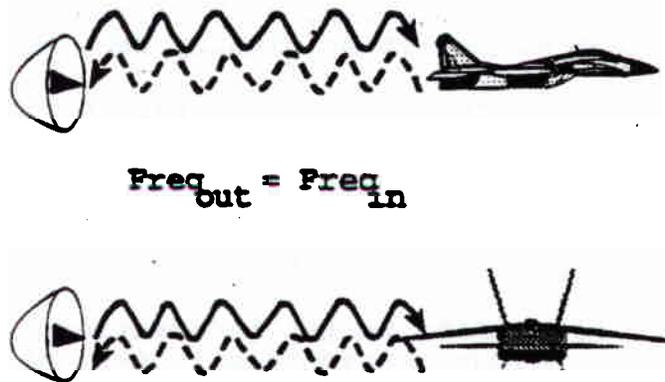


Figure 15

## Down Look Search Mode (DLS)

DLS is the primary search mode which provides target detection in the presence of clutter. The airborne targets are presented in a clutter free, heading stabilized, B Scan display. Instead of operator-intensive spotlighting to obtain the best radar display, the APG-66NT synthetically produces a radar display of the same size for each radar contact. This doesn't eliminate the need for good search increment discipline and antenna placement awareness, but it does allow for better intercept control with occasional hands-free operation.

DLS places the main beam from a level position to a low position. The antenna elevation tic mark indicates where the top of the main beam is at. The rest of the main beam is below this reference mark. To enter a DLS mode, select MODE hardkey and DLS softkey. The screen display is shown below in figure 16.

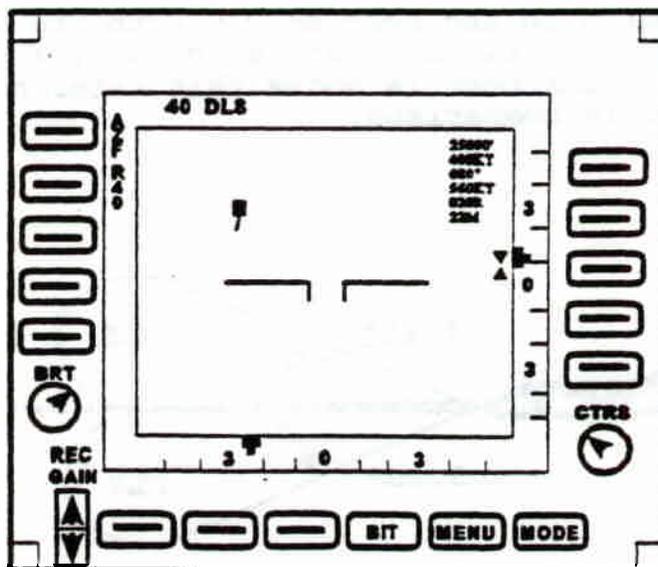


Figure 16

The radar will still sweep back and forth in the same manner as PLS. However, the sector scans are slightly different with +/- 60°, +/- 30°, and +/- 10° selectable. Range scales can be selected manually, as before, or automatically when a locked target moves closer than 40% of the current scale selected.

There are two automatic tracking options in DLS: *Single Target Track (STT)* and *Situational Awareness Mode (SAM)*. To enter STT, position the acquisition symbol over the target and squeeze the HCU trigger to full action (half-action does nothing). The radar will enter STT upon release of the trigger. If lockon does not occur, the system will try an automatic reacquisition mode (called REAC) for 2 seconds to attempt a lock. If that fails, the system defaults to the DLS mode. Selecting half action once in STT will break lock and put the system back in DLS.

SAM is a PD mode that allows you to have the automatic tracking capability of a STT plus the advantage of searching for all other targets like in DLS. It does this by keeping the antenna locked on to the target for 2 seconds, then does 3 sweeps of the antenna in the previously selected azimuth setting. It continues this cycle until you exit the SAM mode. SAM can only be entered from a STT by selecting full action rapidly. SAM is exited back to STT by selecting full action again.

### Up Look Search Mode (ULS)

Up Look Search is the same as DLS with the exception that the antenna elevation tic mark shows the bottom of the main beam. The rest of the radar beam is above this reference mark. Figure 17 shows the two in comparison.

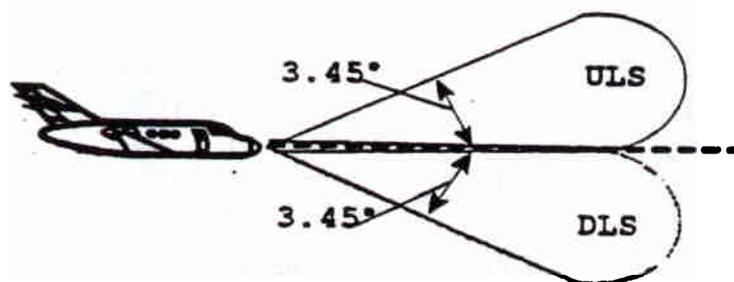


Figure 17

### ACM Modes

Air Combat Maneuvering modes (ACM) are rapid acquisition, auto search and track, hands-off modes of both DLS and ULS. Also known as "hot boxes", these modes allow the operator a completely hands-off ability to acquire a target directly into an STT if within 10NM and in their established box of azimuth and

elevation. There are four boxes selectable in order: 1) ACM Forward, 2) ACM Up, 3) ACM Boresight, and 4) ACM slewable. Any target within these boxes will automatically be locked inside a range of 10 NM. The parameters for each are:

- 1) ACM Forward (ACM):
  - a box +/- 10° in azimuth and from 0° in elevation down to 15° low.
- 2) ACM Up (ACM-Up):
  - a box +/- 5° in azimuth and from 0° in elevation up to 40° high.
- 3) ACM Boresight (ACM-B):
  - a pencil-beam cone boresighting out of the aircraft datum line.
- 4) ACM Slewable (ACM-S):
  - a moveable (via HCU) box +/- 30° in azimuth and +/- 10° in elevation.

Each box is selected by depressing the ACM softkey on the MFD and then cycling through the sub-mode button on the HCU. Figure 18 below shows each.

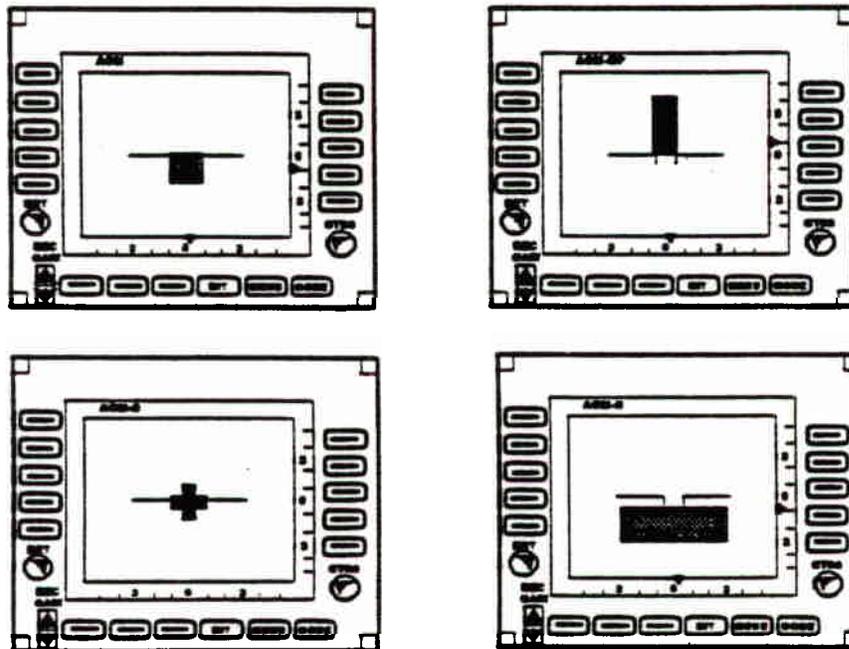


Figure 18

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